2023 April EER5-14030684

by I Wayan Yasa

Submission date: 11-Apr-2023 09:09AM (UTC-0500)

Submission ID: 2061568670

File name: 2023_April_EER5-14030684.pdf (903.53K)

Word count: 4641

Character count: 21865

Environment and Ecology Research 11(2): 284-294, 2023 http://www.hrpub.org
DOI: 10.13189/eer.2023.110205

Impact of Climate Change and the El Niño – Southern Oscillation on Extreme Rainfall

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Received January 9, 2023; Revised February 9, 2023; Accepted March 19, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Heri Sulistiyono, I Wayan Yasa, Humairo Saidah, I Dewa Gede Jaya Negara, Ery Setiawan , "Impact of Climate Change and the El Niño – Southern Oscillation on Extreme Rainfall," Environment and Ecology Research, Vol. 11, No. 2, pp. 284 - 294, 2023. DOI: 10.13189/eer.2023.110205.*

(b): *Heri Sulistiyono, I Wayan Yasa, Humairo Saidah, I Dewa Gede Jaya Negara, Ery Setiawan (2023). Impact of Climate Change and the El Niño – Southern Oscillation on Extreme Rainfall. Environment and Ecology Research, 11(2), 284 - 294. DOI: 10.13189/eer.2023.110205.*

Abstract Some information states that the world is currently experiencing climate change. Many scientists have researched the relationship between climate change and various natural events. Still, there has been no research on the relationship between climate change and extreme rainfall events. The relationship between climate change and extreme rainfall events needs to be clearly understood, as extreme wet events can cause losses such as landslides in hilly areas, submerged agricultural areas, and damaged residential facilities due to flooding. Meanwhile, extreme dry events can lead to droughts and forest fires. The authors have proposed a procedure to utilize the upper and lower threshold values to determine the extreme rainfall. The proposed procedure uses correlation coefficient and regression modeling. The authors hope that engineers can estimate the extreme rainfall after understanding the relationship between climate change variables and the El-Nino Southern Oscillation (ENSO) on local rainfall. This study applied monthly rainfall data from the Alas Rainfall Station in Indonesia, climate change data, and ENSO from 1992 to 2021 to demonstrate the proposed procedure. The results showed that climate change affects the occurrence of Extreme Rainfall at the Alas Rainfall Station. The predicted extreme wet was 118.11%, and the predicted extreme dry was 72.12%. Extreme wet events are becoming more frequent, while extreme dry events are decreasing. The ENSO has no significant relationship to the extreme rainfall at several stations.

Keywords Climate Change, El Nino-Southern Oscillation, Extreme Rainfall, Correlation, Regression

1. Introduction

Climate change and the El-Nino Southern Oscillation (ENSO) are becoming hot discussions among the international community. Climate change and the ENSO affect many countries around the world. Problems caused by extreme weather and climate change, such as disease outbreaks, health problems, and high waves, to farmers who fail to harvest, and other social vulnerabilities are becoming more serious [1-7]. The high rainfall intensity causes the area to be vulnerable to flooding. Hillside areas that experience extreme rains are very detrimental. The high rainfall intensity can cause landslides around the hillside areas. Up to now, there is not any research on the impacts of climate change and ENSO on extreme rain. Therefore, the authors are challenged to research the Impact of Climate Change and the ENSO on Extreme Rainfall.

This research aims

1) To identify the relationship between climate change variables and ENSO on the monthly local rainfall;
2) To develop the mathematical model of the relationship between climate change variables and ENSO on monthly local rainfall; and
3) To determine the impacts of climate change and ENSO (El Nino Southern Oscillation) on extreme local rainfall.

The authors hope that the results of this study can be an early warning against the negative impacts caused by extreme weather and changing climates, such as floods and droughts.

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2. Materials and Methods

2.1. Research Procedure

This study uses three kinds of data, namely local monthly rainfall data, climate change data, and the ENSO data. The authors propose a research procedure as shown in Figure 1.

Figure 1 shows the three steps in the procedure. Step 1 is collecting data for research. Step 2 is the data analysis stage, starting with finding the relationship between climate change data and ENSO with local monthly rainfall data. The second analysis in step 2 is the development of local monthly rainfall models based on climate change and ENSO variables. Based on the definition and interpretation of the correlation coefficient [7], the authors consider only variables with a correlation coefficient of at least 60% with the local monthly rainfall. Next in step 3 is the interpretation and discussion of the impacts based on the regression model obtained in step 2.

The authors used correlation analysis to find and ensure that the variables involved in the later modeling had a correlation coefficient of at least 60% to local monthly rainfall. The authors used the Pearson correlation equation [9]. The author uses a minimum standard of acceptance for the correlation coefficient of at least 60%. A correlation coefficient of 60% means a moderate correlation [10]. The authors used multiple linear regression to develop the equation of extreme rainfall based on the variables of climate change and the El Niño–Southern Oscillation. Many articles have explained the Pearson Correlation Coefficient and Multiple Linear Regression, so the authors do not repeat the explanation of the Pearson Correlation Coefficient and Multiple Linear Regression in this article.

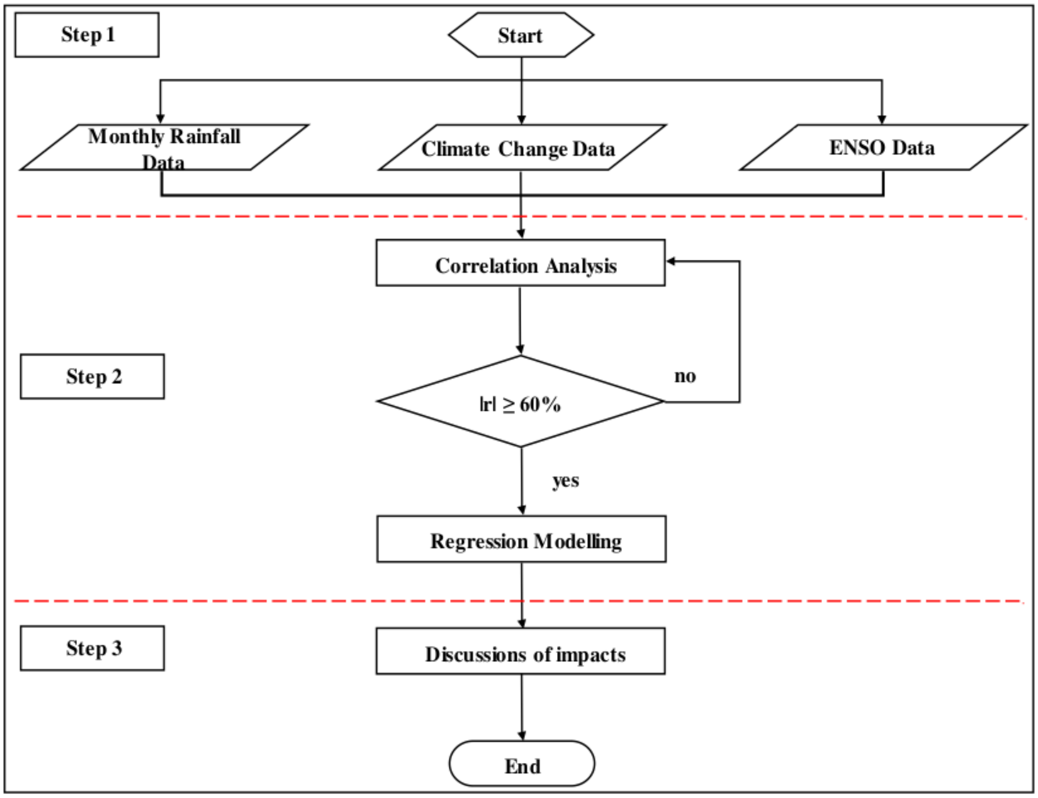

Figure 1. The Research Procedure

2.2. Correlation

The authors use the Pearson Correlation Coefficient in this study to determine the relationship between local rainfall variables with climate change and ENSO variables. The equation of the Pearson Correlation Coefficient is

$$r_{xy} = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y^2)]}} \quad (1)$$

with: r_{XY} is the Pearson's Correlation Coefficient, n is the number of data, and X and Y are variables.

2.3. Modelling

The author uses the regression method to model local rainfall based on climate change and ENSO variables. The general formula for regression [11] is as

$$Y = C + B_1X_1 + B_2X_2 + \ldots + B_nX_n + E \quad (2)$$

with: Y is the response variable, C is the constant, B_1, B_2, and B_n are the coefficients, X_1, X_2, and X_n are the independent variables, and E is a normal-random number.

Many textbooks and articles have explained the Pearson Correlation Coefficient and Regression Modelling in detail. Therefore, the authors do not re-explain them in this paper.

2.4. Goodness of Fit Test

The author uses three fit test parameters, namely the Root Mean Square Error (RMSE), the Determination Coefficient (R^2), and the Nash-Sutcliffe Efficiency (NSE).

2.4.1. Root Mean Square Error (RMSE)

The RMSE is to measure the accuracy of a model to predict the future. RMSE has a minimum value of 0. A small value of the RMSE indicates a small difference between observation and simulation. The best model has a smallest RMSE value [12]. The equation of RMSE is as follows [13].

$$\text{RMSE} = \sqrt{\Sigma(Y_s - Y_o)^2 / n} \quad (3)$$

with: RMSE is the Root Mean Square Error, Y_s is the simulation results, Y_o is the observation data, n is the amount data.

2.4.2. The Coefficient of Determination

The coefficient of determination is a value to indicate how well the model fits the data [14]. The equation of the coefficient of determination is as follows:

$$R^2 = 1 - (\Sigma(Y_i - \mu_Y)/\Sigma(Y_i - yi)) \quad (4)$$

Where: R^2 is the coefficient of determination, Y_i is the observation data, μ_Y is the mean of observation data, yi is the point at the regression line.

2.4.3. The Nash-Sutcliffe Efficiency

The author uses the Nash-Sutcliffe Efficiency in this study to measure the accuracy of model to predict the observation. The Equation of Nash-Sutcliffe Efficiency is as follows [15].

$$\text{NSE} = 1 - [\ \Sigma\ (Y_s - Y_o)^2 / \Sigma\ (Yo - \mu_o)^2\ ] \quad (5)$$

with: NSE is the Nash-Sutcliffe Efficiency, Y_s is the simulation results, Y_o is the observation data, μ_o is the average of observation data.

2.5. Extreme Bounds

In this paper, the authors define extreme bounds as the maximum and the minimum bounds of data that can go. Extreme (outer) data means data that lies beyond those bounds [16]. After having some information about the acceptance data for the normal distribution [17], the authors apply a 10% probability of extreme events, which is a 5% upper bound and a 5% lower bound. The authors use the table of standard normal area to obtain upper and lower bounds. The authors do not provide the table of standard normal area as many reference books provide the table. According to the standard normal area table, the upper bound value is 1.64 and the lower bound is -1.64, so the upper and lower bounds of the data are as follows.

$$UB = \mu + (1.64*\sigma) \quad (6)$$

And

$$LB = \mu - (1.64*\sigma) \quad (7)$$

with: UB is the Upper Bound, LB is the Lower Bound, μ is the average of data, σ is the standard deviation of data.

In this paper, the authors define the status of extremely wet if the amount of rainfall is larger than the upper bound. The definition of extremely dry status is when the amount of rainfall is zero or less than the lower bound.

2.6. Application

The author demonstrates the research procedure at the Alas rain station on Sumbawa Island, Indonesia. Figure 2 shows the location of Alas Station on Sumbawa Island, Indonesia.

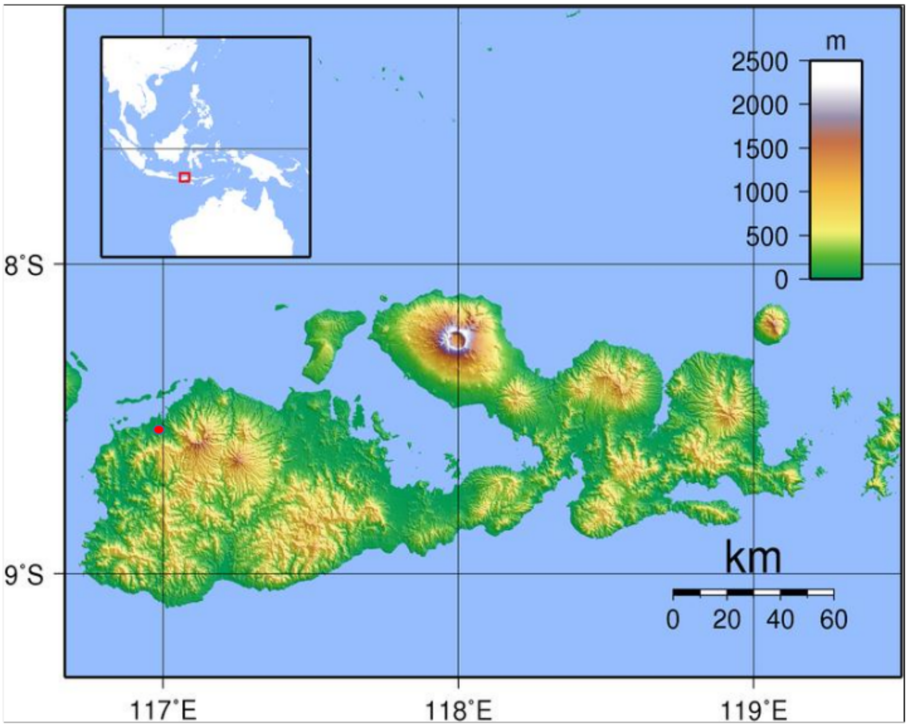

Figure 2. The Alas Station on Sumbawa Island

The authors used Global Scale Climate Change data from the GCM (Global Circulation Model) CMIP5 with the period of 1978 to 2007 with a scale of 1.875° x 1.875° or 225 km x 225 km.

The climate change data [18] used include:

- Air Temperature (output variable name: ta, unit: Kelvin).
- Relative Humidity (output variable name: hur, unit: %).
- Near-Surface Wind Speed (output variable name: sfcWind, unit: m.s-1).
- Eastward Wind (output variable name: ua, unit: m.s-1).
- Specific humidity (output variable name: hus, unit: 1).
- Evaporation (output variable name:evspsbl, unit: kg.m-2.s-1).
- Sea Level Pressure (output variable name: psl, unit: Pascal).
- Cloud Area Fraction (output variable name:clt, unit: %).
- Leaf Area Index (output variable name: lai, unit: 1).
- ENSO Moisture Content (output variable name: mrso, unit: kg.m-2).
- Temperature of ENSO (output variable name: tsl, unit: Kelvin).
- Surface Air Pressure (output variable name: ps, unit: Pascal).
- Surface Temperature (output variable name: ts, unit: Kelvin)

Table 1 shows the correlation coefficient between rainfall data from each rain station with the variables of climate change and the ENSO.

Table 1. The Correlation Coefficient between rainfall data from each rain station with the variables of climate change and the ENSO

Variables	r
ua	-0.70
ta	-0.09
hur	0.11
hus	0.03
evspsbl	-0.04
psl	-0.03
clt	0.09
lai	-0.03
mrso	-0.01
ps	-0.03
ts	-0.03
sfcWin	0.07
tsl	0.02

Table 2. The Regression Analysis

Station:	**Alas**				
Equation:	R = 163.8 + 25.29 ua				
Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	162.28	5.82	27.87	0.000	
ua	25.54	1.54	16.62	0.000	1.00
RMSEP (mm)	**R² (%)**	**NSE**			
81,88	71,50	0,83			

Table 1 shows that Eastward Wind has a correlation coefficient higher than 60%. The authors consider this variable in developing the local monthly rainfall model using regression analysis. Table 2 shows the regression analysis.

The statistical equation of rainfall (R) at the Alas Station is 163.8 + 25.29 u. The Variance Inflation Factor of the ua variable is 1. A value of 1 indicates that no other variable is correlated with the ua variable. Indeed, it is the only variable involved in the model. The P value of the ua variable is 0. The P-value of less than 5% indicates the ua variable has a statistically significant role in the model.

The goodness of fit test shows RMSE 81.88 mm, R^2 71.50%, and NSE 0.83%. These results indicate that the equation can predict rain at Alas Station very well based on the East Wind. The author conducted a rainfall prediction simulation using the equation in Table 2. Figure 3 shows the simulation results.

Figure 3 shows that the rain pattern of predicted rainfall is similar to the rain pattern of observations. However, some observation peaks are higher than the prediction peaks. Figure 4 shows the rainfall prediction until 2100.

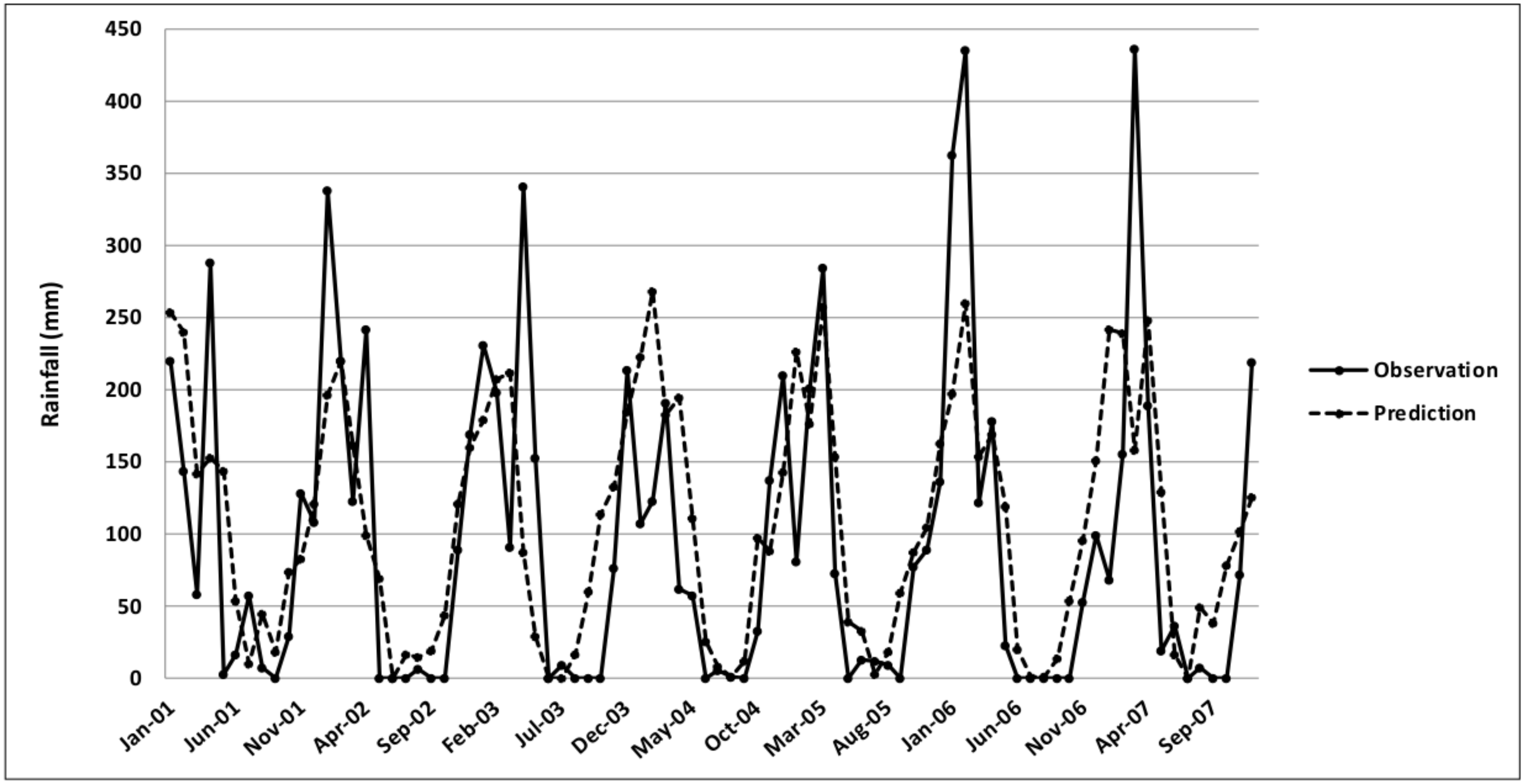

Figure 3. Results of the regression equation in the calibration process

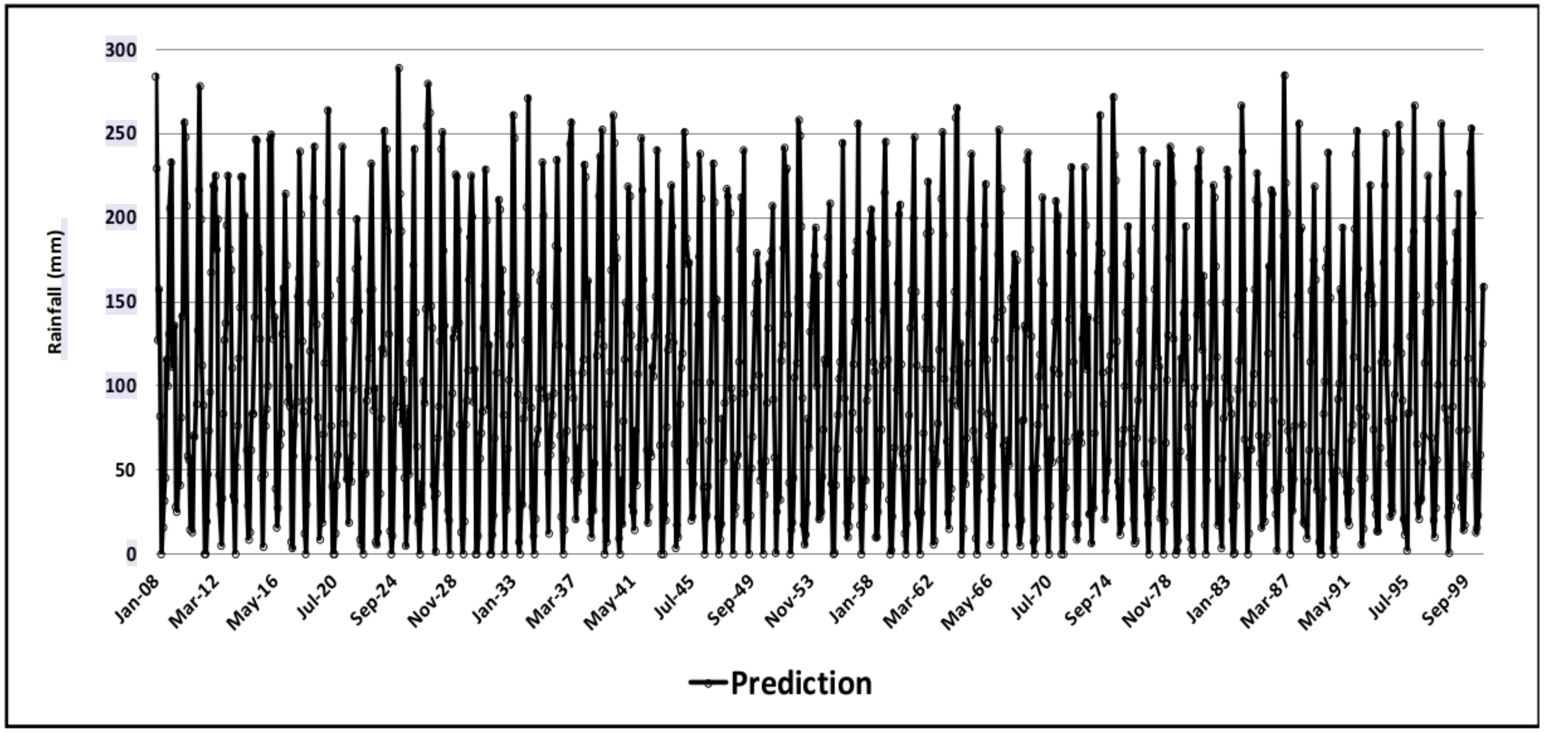

Figure 4. Rainfall Simulation Results of the regression equation

2.7. The Calculation of Upper Bounds and Lower Bounds

The authors calculate upper bounds and lower bounds using equations (5) and (6); Table 3 shows the results of calculation.

Table 3 shows the upper and lower bounds for every month. The maximum upper bound is 462.41 and the minimum lower bound is zero. Rainfall data above the upper limit indicates an extremely wet event. Rainfall data below the lower limit indicates an extremely dry event. Table 4 shows observations of extremely wet events from 1978 to 2007. Table 5 shows predictions of extremely wet events from 2008 to 2100.

Table 4 shows the 27 events of extremely wet from 1978 to 2007. The maximum extremely wet is 701 mm, and the maximum excess rainfall is 238.59 mm over the monthly upper bound. The probability of extreme events is 90% every year. The average from the excessive rain over the monthly upper bound is 49.32 mm.

Table 3. Upper Bound, Lower Bound, and Average

No	Month	Upper Bound (mm)	Lower Bound (mm)
1	January	418.53	70.47
2	February	462.41	0
3	March	359.22	40.25
4	April	267.96	0
5	Mei	135.81	0
6	June	26.43	0
7	July	45.11	0
8	August	23.42	0
9	September	62	0
10	October	133.46	0
11	November	335.77	0
12	December	339.96	26.24

Table 4. The Prediction of extremely wet event from 1978 to 2007

No	Year	Rainfall (mm)	Upper Bound (mm)	Excess (mm)	No	Year	Rainfall (mm)	Upper Bound (mm)	Excess (mm)
1	Oct-78	158	133.46	24.54	14	May-90	180	135.81	44.19
2	Nov-78	395	335.77	59.23	15	Aug-90	32	23.42	8.58
3	Sep-79	80	62	18	16	Feb-92	701	462.41	238.59
4	Nov-79	469	335.77	133.23	17	Jul-93	55	45.11	9.89
5	Dec-79	566	339.96	226.04	18	Jul-96	77	45.11	31.89
6	Jan-81	454	418.53	35.47	19	Nov-96	432	335.77	96.23
7	Aug-81	44	23.42	20.58	20	Jun-98	54	26.43	27.57
8	Sep-81	63	62	1	21	Jan-99	427	418.53	8.47
9	Sep-84	83	62	21	22	Apr-01	288	267.96	20.04
10	Sep-88	76	62	14	23	Jul-01	57	45.11	11.89
11	Oct-88	216	133.46	82.54	24	Apr-03	341	267.96	73.04
12	Jul-89	47	45.11	1.89	25	May-03	153	135.81	17.19
13	Aug-89	27	23.42	3.58	26	Mar-07	437	359.22	77.78
					27	Jun-07	36	26.43	9.57

Table 5. The Prediction of extremely wet event from 2008 to 2100

No	Year	Rainfall (mm)	Upper Bound (mm)	Excess (mm)	No	Year	Rainfall (mm)	Upper Bound (mm)	Excess (mm)
1	Jan-08	284.50	270.28	14.23	36	Apr-43	209.76	176.74	33.02
2	Oct-08	115.71	109.71	6.00	37	Sep-44	89.50	82.04	7.47
3	May-09	136.11	132.05	4.06	38	Oct-44	110.79	109.71	1.07
4	Nov-09	142.10	139.29	2.81	39	May-45	173.65	132.05	41.60
5	Jul-10	47.41	34.05	13.36	40	Jun-45	55.73	45.23	10.50
6	Feb-11	278.43	268.06	10.37	41	Mar-49	240.31	233.67	6.64
7	Apr-12	181.23	176.74	4.49	42	Jun-50	54.92	45.23	9.69
8	May-12	199.57	132.05	67.52	43	Oct-51	115.03	109.71	5.32
9	Jun-12	47.10	45.23	1.87	44	May-54	165.93	132.05	33.88
10	Apr-14	201.69	176.74	24.95	45	Mar-57	256.73	233.67	23.06
11	Apr-15	179.49	176.74	2.75	46	Oct-66	127.86	109.71	18.15
12	Jun-15	45.56	45.23	0.33	47	Nov-66	141.15	139.29	1.86
13	May-16	141.11	132.05	9.06	48	Aug-67	54.81	53.44	1.37
14	Jun-17	88.22	45.23	42.99	49	Nov-73	139.94	139.29	0.65
15	Jun-19	56.82	45.23	11.59	50	Jul-74	37.50	34.05	3.45
16	Jun-21	56.72	45.23	11.48	51	Jan-75	272.56	270.28	2.29
17	Aug-21	53.94	53.44	0.49	52	Oct-79	117.11	109.71	7.40
18	Mar-24	241.59	233.67	7.91	53	Sep-80	89.42	82.04	7.39
19	Apr-24	192.27	176.74	15.53	54	Nov-80	142.47	139.29	3.18
20	Jan-25	**289.32**	270.28	19.04	55	Dec-80	230.12	183.65	46.46
21	Jun-25	45.53	45.23	0.30	56	May-81	165.78	132.05	33.73
22	Sep-25	86.31	82.04	4.27	57	Sep-81	88.82	82.04	6.78
23	Feb-27	280.15	268.06	12.09	58	Aug-84	62.31	53.44	8.87
24	Mar-27	262.66	233.67	28.99	59	Jul-85	34.66	34.05	0.60
25	May-27	134.95	132.05	2.90	60	Nov-86	142.79	139.29	3.50
26	Jul-32	36.19	34.05	2.14	61	Dec-86	189.68	183.65	6.03
27	Feb-34	271.61	268.06	3.55	62	Jan-87	285.39	270.28	15.12
28	Jun-35	48.07	45.23	2.84	63	Jul-87	44.37	34.05	10.32
29	Aug-35	58.92	53.44	5.47	64	Dec-91	193.92	183.65	10.27
30	Jul-37	63.16	34.05	29.11	65	Oct-92	110.44	109.71	0.73
31	Aug-38	54.18	53.44	0.73	66	Nov-92	154.20	139.29	14.90
32	Apr-39	252.52	176.74	**75.78**	67	Oct-93	114.58	109.71	4.86
33	Aug-41	73.93	53.44	20.49	68	Sep-95	83.49	82.04	1.45
34	Aug-42	60.76	53.44	7.32	69	Nov-97	160.18	139.29	20.88
35	Oct-42	111.42	109.71	1.70	70	Dec-97	200.16	183.65	16.51

Table 6. The observations of extremely dry events from 1978 to 2007

No	Year	Rainfall (mm)	Lower Bound (mm)	Deficit (mm)
1	Jan-85	58	70.47	(12.47)
2	Jan-07	68	70.47	(2.47)

Table 7. The predicted extremely dry event from 2008 to 2100

No	Year	Rainfall (mm)	Lower Bound (mm)	Deficit (mm)	No	Year	Rainfall (mm)	Lower Bound (mm)	Deficit (mm)
1	Mar-09	111.47	114.94	(3.47)	19	Feb-51	181.06	184.65	(3.59)
2	Aug-13	0.00	0.25	(0.25)	20	Feb-54	177.80	184.65	(6.85)
3	Nov-14	83.91	87.63	(3.71)	21	Dec-54	112.92	117.82	(4.90)
4	Jan-17	148.90	149.54	(0.63)	22	Apr-55	41.93	43.92	(1.99)
5	Sep-19	18.99	25.82	(6.83)	23	Dec-55	114.29	117.82	(3.53)
6	Dec-22	116.76	117.82	(1.05)	24	Mar-60	113.15	114.94	(1.79)
7	Oct-25	47.83	55.73	(7.90)	25	Mar-64	88.44	114.94	(26.5)
8	Aug-28	**0.00**	0.25	(0.25)	26	Oct-67	53.68	55.73	(2.05)
9	Nov-30	85.23	87.63	(2.40)	27	Feb-68	178.83	184.65	(5.82)
10	Sep-31	22.93	25.82	(2.88)	28	Oct-70	54.73	55.73	(1.00)
11	Mar-37	107.86	114.94	(7.08)	29	Mar-73	110.63	114.94	(4.31)
12	Dec-37	116.39	117.82	(1.42)	30	Aug-80	0.00	0.25	(0.25)
13	Oct-38	53.86	55.73	(1.87)	31	Mar-83	92.00	114.94	(22.94)
14	Sep-40	18.03	25.82	(7.79)	32	Apr-89	38.66	43.92	(5.26)
15	Jan-41	137.68	149.54	(11.86)	33	Aug-89	0.00	0.25	(0.25)
16	Sep-43	20.30	25.82	(5.52)	34	Feb-93	159.81	184.65	(24.84)
17	Feb-49	150.90	184.65	**(33.75)**	35	Mar-94	113.68	114.94	(1.26)
18	Feb-50	179.13	184.65	(5.52)	36	Feb-99	175.26	184.65	(9.39)

Table 5 shows the 70 events of extremely wet. The maximum extremely wet is 289.32 mm, and the maximum excess rainfall is 75.78 mm over the monthly upper bound. The probability of extremely wet is 75.27% every year. The average of excess rainfall over the monthly upper bound is 12.68 mm with a standard deviation is 15.07 mm. Table 6 shows the observations of the extremely dry event from 1978 to 2007.

Table 7 shows the 36 events of the predicted extremely dry from 2008 to 2100. The minimum extremely dry is zero mm, and the maximum deficit rainfall is 33.75 mm below the monthly lower bound.

3. Conclusions

Based on the research results, the authors found that the correlation coefficient of the Eastward Wind to the monthly local rainfall is negative 70%. This value means that about 70% of the Eastward Wind data correlate oppositely to the monthly local rainfall.

The authors have developed a regression model of the monthly local rainfall based on the Eastward Wind to predict the monthly local rainfall until 2100.

The authors determined that the impacts of climate change and ENSO (El Nino Southern Oscillation) on extreme local rainfall include the events of 70 wet extremes and 36 dry extremes until 2100.

The maximum extremely wet is 289.32 mm, and the maximum excess rainfall is 75.78 mm over the monthly upper bound. The minimum extremely dry is zero mm, and the maximum deficit rainfall is 33.75 mm below the monthly lower bound.

Acknowledgements

The authors are very thankful for the financial support for this research from the University of Mataram. The authors are also grateful to the River Basin Organization

for Nusa Tenggara I and the World Meteorology Organization for providing data.

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