
CHARACTERISTIC OF EXTREME RAINFALL IN PROVINCE OF SOUTH SULAWESI

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Abstract. The effect of climate change on extreme rainfall is important to note due to its damaging impact on the environment and humanity. This study aims to analyze the characteristics of extreme rainfall in the Province of South Sulawesi. The characteristics investigated are trends and models of extreme rainfall distribution. Trend analysis of extreme rainfall used the Mann-Kendall Test. Modeling of extreme rainfall distribution used the Annual Maximum approach with Generalized Extreme Value (GEV) distribution. The extreme rainfall distribution model is approached with non-stationary models. The method of parameter estimation used the maximum likelihood method coupled with the BFGS Quasi-Newton methods. Model selection performed based on the smallest Akaike's Information Criterion (AIC) value. Using rainfall data in Makassar rain gauge for a period from 1983 to 2015, the results show that there is a decreasing trend of extreme rainfall in Makassar Municipality and the appropriate distribution model for extreme rainfall data is a non-stationary model.

Keywords: Extreme rainfall, Mann-Kendall Test, GEV distribution, non-stationary model, BFGS Quasi Newton

1. Introduction

In recent years, some research suggests that climate change has influenced the pattern of extreme rainfall in various regions. The climate change can cause the differences in extreme rainfall pattern over time. Usually, analysis of flooding used an assumption that extreme rainfall pattern is constant over time or known as a stationary pattern. The stationary assumption is not appropriated again if extreme rainfall pattern was influenced by climate change due to changes in the temporal pattern of extreme rainfall.

The effect of climate change on extreme rainfall is important to note due to its damaging impact on the environment and humanity [1]. Climate extreme can cause a huge impact on human life, environment, economy, and society [2]. Losses from flood have reached tens of billions of dollars and thousands of people were killed every year [3]. Thus, an assessment of changes in natural hazards is a major problem of extreme rainfall [4, 5, 6].

Some researchers have shown that extreme precipitation has related to climate change. Mishra et al. [7] examine the relationship between extreme precipitation and temperature across the Contiguous United States (CONUS). Khomzy et al. [8] reported that extreme event in the southern region of Marocco was affected by the change of temperature. Zhang et al. [9] exhibited temporal changes of extreme precipitation with a downward trend for frequency and an increasing trend for intensity in the Huai River Basin. Martinkova and Hanel [10] evaluated the relations between Extreme Precipitation and Temperature in the Czech Republic. Wang et al. [11] investigated the peak structure and future changes in the relationships between extreme precipitation and temperature. Schroeer and Kirchengast, [12] investigated the relationship between extreme rainfall and temperature in south-eastern Austria. Eden et al., [6] identify changes of extreme precipitation as a result of anthropogenic climate change in the Netherland. Chu et al. [13] showed that extreme precipitation has a positive trend during the typhoon season in Taiwan. Chu et al. [13] also showed that extreme rainfall distribution is more suitable with the non-stationer model due to the effect of climate change.

Makassar Municipality is one of the big cities in Indonesia. Makassar is located in the middle of the Indonesia region. The Tropical Climate in Makassar is characterized by notable dry and wet seasons. Most of the annual rainfall is recorded during the wet season from November to March. Extreme rainfall in Makassar Municipality cause some problems such as flood, traffic, and health problems. However, investigation of extreme rainfall and the relationship with climate change has not been done yet. The investigation of trends and extreme rainfall patterns is needed to arrange the mitigation effort.

In this study, we analyzed the characteristics of extreme rainfall patterns in Makassar Municipality to arrange mitigation planning. The characteristics investigated are a trend and GEV distribution models of extreme rainfall. The trend analysis of extreme rainfall was investigated by using the Mann-Kendall Test. Modeling of extreme rainfall distribution was constructed using Annual Maximum approaches with Generalized Extreme Value (GEV) distribution. The extreme rainfall distribution model investigated, considering stationary and non-stationary processes.

Analysis of characteristics of extreme rainfall is essential for understanding extreme rainfall patterns to manage water. This analysis can help resilience infrastructure and reducing the impact of floods. The result of analysis also used to manage water supply, especially in the dry season. This study looks for providing more awareness on the evolution of extreme rainfall at daily time scales in Makassar Municipality.

2. Methodology

2.1. Data

Daily precipitation data set from 1983 to 2015 were collected from Hasanuddin Rain Gauge Station in Makassar Municipality. The validity of the data was checked by the Meteorology, Climatology and Geophysics Agency of Province of South Sulawesi. Makassar Municipality is located in (5.05 - 5.18S) and (119.21 - 119.62E). The area of Makassar Municipality is around 199.26 km².

In this study, the day with less than 5 mm of rain was denoted as no-rain days. The days which have maximum rainfall values in a year were defined as extreme rainfall. The set of extreme rainfall data were employed to identify the trend pattern and GEV distribution model of extreme rainfall.

Monthly mean rainfall in Makassar municipality for a period of 1983-2015 is described in Figure 1.

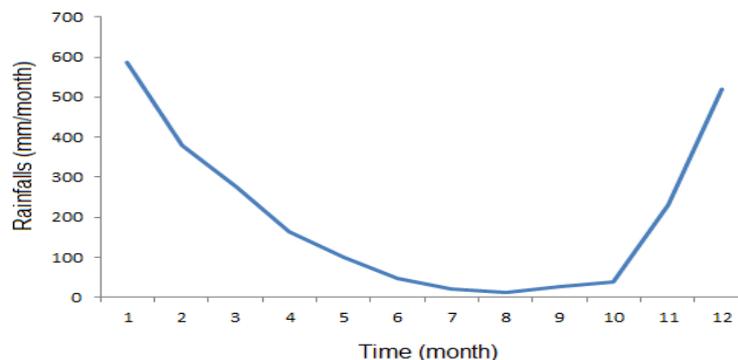


Figure 1 Plot of Monthly mean rainfalls in Makassar Municipality.

Figure 1 revealed that the high monthly mean rainfalls appeared in November, December, January, February, and March. Other months showed lower monthly mean rainfall periods. Most of the extreme rainfall data are obtained from November to March for every year. According to this rainfall pattern, as shown in Figure 1, rainfall pattern in Makassar municipality is dominated by the monsoonal rainfall pattern.

2.2. Mann-Kendall Test

The Mann-Kendall Test is a non-parametric test used to find out trends in a series data set. The hypothesis of the Mann-Kendall test as follows:

H_0 : There is no *trend* in data series
 H_1 : There is a *trend* in data series

S statistics of the Mann-Kendall test is defined as [14]:

$$S = \sum_{i=1}^{k-1} \sum_{j=i+1}^k \text{sign}(x_j - x_i)$$

where

$$\text{sign}(x_j - x_i) = \begin{cases} 1 & , x_j - x_i > 0 \\ 0 & , x_j - x_i = 0 \\ -1 & , x_j - x_i < 0 \end{cases}$$

There is no trend if $S = 0$. If $S > 0$ the data series tends to increase, otherwise the data series tends to decrease. The variance of S can be calculated by:

$$\text{Var}(S) = [(n-1)(2n+5) - \sum_{p=1}^q [(t_p(t_p-1)(2t_p+5))]] / 18 \quad (1)$$

where:

n is the number of data, $\text{Var}(S)$ is a variance of S , t_p is the number of data at group- p , and q is the number of groups. The result of equation (1) would be used to calculate Z_{value} .

$$Z_{value} = \begin{cases} \frac{(S-1)}{(\text{Var}(S))^{1/2}} & , S > 0 \\ 0 & , S = 0 \\ \frac{(S+1)}{(\text{Var}(S))^{1/2}} & , S < 0 \end{cases}$$

If $|Z_{value}| > Z_{\alpha/2}$ then H_0 is rejected, otherwise H_0 is accepted.

2.3. Distribution of GEV

Extreme rainfall data used in this study were fitted as GEV Distribution. Standard GEV distribution denotes in equation (2) as follows [15]:

$$G(x) = \text{GEV}(\mu, \sigma, \xi) = \begin{cases} \exp\left\{-\left[1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}, & \xi \neq 0 \\ \exp\left\{-\exp\left[-\left(\frac{x-\mu}{\sigma}\right)\right]\right\}, & \xi = 0 \end{cases} \quad (2)$$

where

$$1 + \xi\left(\frac{x-\mu}{\sigma}\right) > 0; \quad -\infty < \mu < \infty; \quad \sigma > 0; \quad \text{and} \quad -\infty < \xi < \infty$$

μ , σ , and ξ denoted location, scale, and shape parameters respectively.

The distribution in equation (2) is known as a stationary process due to all parameters distribution does not change over time [15]. However, the extreme rainfall patterns often vary with time [9, 13]. Coles [15] showed that the non-stationary process is more suitable than a stationary process if extreme data series changed systematically through time. Non-stationary processes assumed that the parameters of the GEV distribution change over time. GEV model for non-stationary processes denoted in equation (3) as follows:

$$GEV(\mu(t), \sigma(t), \xi(t)) \quad (3)$$

where

μ , σ , and ξ depend on t (time).

There are some approaches can be used for parameter estimation in extreme value models. These include graphical approaches, moment-based approaches, and likelihood-based approaches. In this study, we used likelihood-based approaches coupled with BFGS Quasi-Newton.

2.4. Likelihood function of GEV Distribution

Let X_1, X_2, \dots, X_n be independent variables of GEV distribution. The log-likelihood function of GEV parameter denoted as follows [15]:

(*) For $\xi \neq 0$

$$l(\mu, \sigma, \xi) = -n \log(\sigma) - \left(1 + \frac{1}{\xi}\right) \sum_{i=1}^n \log \left[1 + \xi \left(\frac{x_i - \mu}{\sigma}\right)\right] - \sum_{i=1}^m \left[1 + \xi \left(\frac{x_i - \mu}{\sigma}\right)\right]^{-1/\xi} \quad (4)$$

where

$$1 + \xi \left(\frac{x_i - \mu}{\sigma}\right) > 0 \quad 1 + \xi$$

$i = 1, 2, \dots, n.$

(**) For $\xi = 0$

$$l(\mu, \sigma, \xi) = -n \log(\sigma) - \sum_{i=1}^n \left(\frac{x_i - \mu}{\sigma}\right) - \sum_{i=1}^m \exp \left[-\left(\frac{x_i - \mu}{\sigma}\right)\right] \quad (5)$$

If an analytical solution cannot be obtained for equation (2) then a numerical solution would be employed to obtained estimated value of μ , σ , and ξ that maximized log-likelihood function in equation (4) or (5).

2.5. Model Selection

Akaike's Information Criterion (AIC) commonly used in the model selection. Let k is the number of parameters in (4) or (5) and L is the maximum value of likelihood function, AIC value of model (4) or (5) is

$$AIC = 2k - 2 \log(L) \quad (6)$$

Based on equation (6), the best candidate model for the data is the one with minimum AIC value. The AIC rewards goodness of fit and also includes a penalty that is an increasing function of the number of estimated parameters.

3. Result and Discussion

Rainfall data used in this research is daily rainfall data in Makassar Municipality at a period of 1983 - 2015. A plot of daily rainfall data in Makassar was shown in Figure 3 as follows:

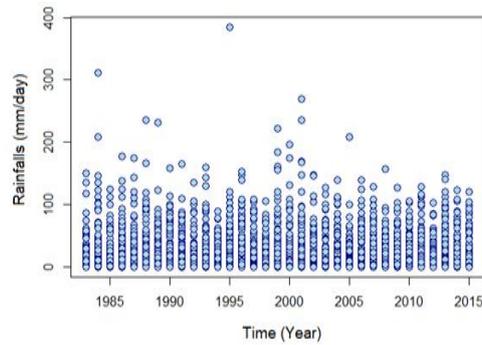


Figure 3 The plot of daily rainfalls in Makassar Municipality, 1985-2015

Meteorology, Climatology and Geophysics Agency of Indonesia classified that rainfall with magnitude is greater than 100 mm/day as heavy rainfall. Generally, heavy rainfall occurred more than one time every year in Makassar Municipality as shown in Figure 3. In the period of 1994, 1997, and 1998, El-Nino became higher than other periods of observation. Strong El-Nino periods especially in 1994, 1997, and 1998 related to the lower rainfall periods in Makassar municipality. In these periods, the magnitude of rainfall is less than 100 mm/day. There are not high rainfalls as seen in the other periods. Meanwhile, the highest rainfall was reached in 1995. The highest rainfall in Makassar municipality in 1995 related to Severe Tropical Cyclone Bobby which appeared in Northern Australia. The Tropical Cyclone Bobby caused more water vapor in the atmosphere to move to the Indonesia region and also in Makassar municipality. Overall, heavy rainfalls series in Makassar municipality tend to decrease over observation periods.

Table 1: Description of Extreme Rainfall in Makassar Municipality for a period of 1983-2015.

Time (year)	Number of rainy days in a year (day)	Percentage of rainy day in a year (%)	Maximum Rainfalls (mm/day/year)
1983	136	37.26	151
1984	190	51.91	312
1985	149	40.82	125
1986	149	40.82	178
1987	135	36.98	175
1988	168	45.90	235
1989	157	43.01	231
1990	134	36.71	158
1991	108	29.58	165
1992	136	37.16	135
1993	143	39.18	160
1994	124	33.97	90
1995	164	44.93	385
1996	159	43.44	153
1997	98	26.85	109
1998	176	48.22	106
1999	168	46.03	222
2000	164	44.81	197
2001	158	43.29	270
2002	130	35.62	148
2003	116	31.78	128
2004	132	36.05	139
2005	142	38.90	208
2006	136	37.26	139
2007	150	41.09	129
2008	154	42.08	157
2009	140	38.36	128
2010	223	61.09	106
2011	152	41.64	129
2012	149	40.71	103
2013	167	45.75	148
2014	145	39.73	124
2015	90	32.97	121

The AM approach defines the maximum value each year as an extreme value. The extreme value of daily rainfall data in Makassar is obtained by taking maximum rainfall every year. The period of rainfall data is from 1983 to 2015 thus there are 33 of extreme rainfall values over the observation period.

Results of extreme data plots are shown in Figure 3 as follows:

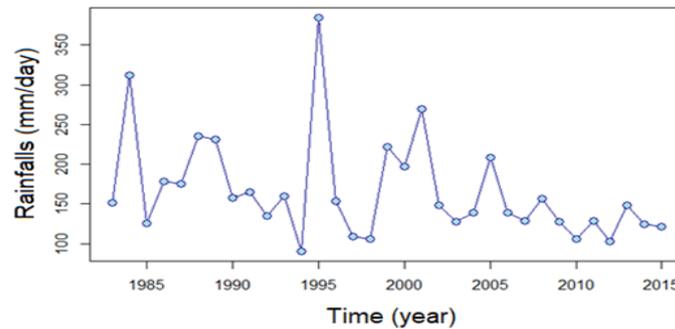


Figure 3 Extreme rainfall series data in Makassar Municipality using AM Approaches.

Figure 3 shows that heavy rainfall occurs almost every year in 1983 - 2015 except in 1994. Although, heavy rainfall occurs almost every year the magnitude of heavy rainfall tends to decrease systematically. There is no clear seasonal pattern in extreme rainfall series. Based on the phenomenon shown in Figure 3, in this study we investigate the model of GEV distribution for extreme rainfall in Makassar Municipality in linear and quadratic forms. According to Coles [15], we set μ , σ , and ξ are constant for stationary processes and μ and σ are denoted as a function of time for non-stationary processes.

3.1. The Trend in Extreme Rainfalls Series

Figure 3 showed a plot of extreme rainfall series in the Makassar Municipality. Generally, extreme rainfall series tend to decrease over observation periods. The result of the trend analysis of Extreme rainfall in Makassar Municipality using the Mann-Kendall Test at a 5% level of significance is revealed in Table 2.

Table 2. The result of Mann Kendall Test of Extreme rainfall in Makassar Municipality.

Z_{value}	$Z_{0.475}$	Level of Significance	Result
-2.72	1.96	0.05	H₀ is rejected

Table 2 showed that the absolute value of the Mann-Kendall Test of extreme rainfall in Makassar Municipality is 2.72 which is greater than 1.96. It means that there is a trend in the extreme rainfall series in Makassar Municipality. Negative Z_{value} indicated that there was a negative trend or decreasing trend in extreme rainfall series in Makassar Municipality. The decreasing trend was consistent with the extreme rainfalls graph in Figure 3. The decreasing trend found in this study is similar to that of Soro et al. [16] in Côté d'Ivoire, Khomzy et al. [17] in some stations rain gauge of Morocco and Chu et al. [13] in Taiwan.

3.2. Modeling of GEV distribution

The model of GEV distribution can represent stationary or non-stationary processes. A model with stationary processes would be employed if all parameter models are invariant over time. Otherwise, the model with non-stationary processes would be used if the parameter model is varying over time. The GEV distribution parameters in non-stationary models can vary over time in the form of linear and or non-linear functions, whereas in the stationary model the GEV distribution parameters are constant and time-dependent. The parameters of the GEV Distribution model consist of location parameter (μ), scale parameter (σ) and shape parameter (ξ). Parameters μ and σ assumed to vary with time in the non-stationary model and constant for the stationary model. The shape parameter (ξ) is generally assumed to be constant i.e. $\xi(t) = \xi$. In this study, we consider a linear and quadratic form of the parameter model. Based on the description then the model used is selected from the following nine models:

Model 1:	$\mu(t) = \mu,$	$\sigma(t) = \exp(\sigma)$
Model 2:	$\mu(t) = \mu,$	$\sigma(t) = \exp(\sigma + \sigma_1 t)$
Model 3:	$\mu(t) = \mu,$	$\sigma(t) = \exp(\sigma + \sigma_1 t + \sigma_2 t^2)$
Model 4:	$\mu(t) = \mu_0 + \mu_1 t,$	$\sigma(t) = \exp(\sigma)$
Model 5:	$\mu(t) = \mu_0 + \mu_1 t,$	$\sigma(t) = \exp(\sigma + \sigma_1 t)$
Model 6:	$\mu(t) = \mu_0 + \mu_1 t,$	$\sigma(t) = \exp(\sigma + \sigma_1 t + \sigma_2 t^2)$
Model 7:	$\mu(t) = \mu_0 + \mu_1 t + \mu_2 t^2,$	$\sigma(t) = \exp(\sigma)$
Model 8:	$\mu(t) = \mu_0 + \mu_1 t + \mu_2 t^2,$	$\sigma(t) = \exp(\sigma + \sigma_1 t)$
Model 9:	$\mu(t) = \mu_0 + \mu_1 t + \mu_2 t^2,$	$\sigma(t) = \exp(\sigma + \sigma_1 t + \sigma_2 t^2)$

3.3. Parameter Estimation of GEV Distribution

Estimate value parameters of GEV distribution are obtained such that the estimated parameter value would be maximizing the log-likelihood function in equation (4) or (5). However, analytic solution for (4) or (5) is intractable thus we employed a numerical method.

The result value of the parameter estimation is obtained by using the likelihood maximum method and iteratively proceeded using the Quasi-Newton BFGS method. The result of parameter estimation for extreme rainfall data in Makassar is shown in Table 3 as follows:

Table 3:Parameter estimation values of GEV Distribution

Model	Location			Scale			Shape
	$\hat{\mu}_0$	$\hat{\mu}_1$	$\hat{\mu}_2$	$\hat{\sigma}_0$	$\hat{\sigma}_1$	$\hat{\sigma}_2$	$\hat{\xi}$
Model 1	134.80	-	-	34.86	-	-	0.25
Model 2	128.31	-	-	4.08	-0.04	-	0.19
Model 3	126.76	-	-	3.77	0.02	-0.002	0.14
Model 4	151.43	-0.82	-	35.61	-	-	0.17
Model 5	161.26	-1.35	-	4.31	-0.05	-	0.14
Model 6	165.48	-1.52	-	3.52	0.07	-0.003	0.12
Model 7	161.68	-2.74	0.06	34.36	-	-	0.22
Model 8	171.62	-2.66	0.03	4.29	-0.05	-	0.16
Model 9	167.32	-1.80	0.007	3.53	0.07	-0.003	0.12

Table 3 shows the parameter estimation of GEV distribution for all models. Estimation values of μ are varying for all models as well as for σ . Estimation values of ξ in [0.12, 0.25].

3.4. Model Selection of GEV Distribution

Model selection using AIC values obtained from equation (6) after the estimation of GEV distribution parameters. Model selection was performed to determine the appropriate model for extreme rainfall data in Makassar. The model chosen is the model that has the smallest AIC value. The AIC values obtained for each model are listed in Table 4 as follows:

Table 4. AIC Values for GEV Distribution Models

Model	AIC Values
Model 1	354.11
Model 2	352.68
Model 3	354.14
Model 4	354.71
Model 5	350.09
Model 6	348.72
Model 7	356.11
Model 8	351.94
Model 9	350.70

Table 4 showed that model 6 has the smallest AIC value of 348.72. Based on these results, the model chosen for extreme rainfall data in Makassar Municipality is model 6 that is:

$$\begin{aligned}\hat{\mu}(t) &= 165.48 - 1.52t \\ \hat{\sigma}(t) &= \exp(3.52 + 0.07t - 0.003t^2) \\ \hat{\xi} &= 0.12\end{aligned}$$

where location parameter and scale parameter varying over time in the form of linear functions and quadratic functions while the shape parameter is constant. The location parameter tends to decrease in linear form and scale parameter in quadratic form. The similar model found in Chu et al. [13] and Golroudbary et al. [18].

4. Conclusion

Based on daily rainfall data in Makassar Municipality from 1983 to 2015, we investigated the trend and model of GEV distribution. There is a trend in extreme rainfall data series. Mann-Kendall test value is -2.72, indicating that extreme rainfall tends to decrease over the observation period. Meanwhile, the model of GEV distribution of extreme rainfall data is suitable for non-stationary processes. Model of GEV distribution of extreme rainfalls in Makassar denoted as

$$\begin{aligned}\hat{\mu}(t) &= 165.48 - 1.52t \\ \hat{\sigma}(t) &= \exp(3.52 + 0.07t - 0.003t^2) \\ \hat{\xi} &= 0.12\end{aligned}$$

We recommended a model with non-stationary process in order to investigated behavior of extreme rainfalls in Makassar Municipality accurately.

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