Characteristic of extreme rainfall in Makassar, Province of South Sulawesi

A Rahim¹*, B Bakri², Anisa¹, A Mutholib³ and A Haerunnisa¹

¹Departement of Mathematics, University of Hasanuddin, Makassar, Indonesia
²Departement of Civil Engineering, University of Hasanuddin, Makassar, Indonesia
³Meteorology, Climatology and Geophysics Agency of Province of South Sulawesi

*amran@science.unhas.ac.id

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.

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 Marocoo 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. Schroer 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.](image)

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:
3

There is no trend in data series

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:

\[ \text{Var}(S) = \frac{(n-1)(2n+5) - \sum_{p=1}^{q} \left[ (t_p - 1)(2t_p + 5) \right]}{18} \]

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 \( Z_{\text{value}} \).

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

If \( |Z_{\text{value}}| > Z_{\alpha/2} \) 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 \([15]\):

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

where

\[ 1 + \frac{x - \mu}{\sigma \xi} > 0; \quad -\infty < \mu < \infty; \quad \sigma > 0; \quad \text{and} \quad -\infty < \xi < \infty \]

\( \mu, \sigma, \) and \( \xi \) 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:
where \( \mu, \sigma, \) and \( \xi \) 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 \( X_1, X_2, \ldots, X_n \) be independent variables of GEV distribution. The log-likelihood function of GEV parameter denoted as follows [15]:

(*) For \( \xi \neq 0 \)

\[
I(\mu, \sigma, \xi) = -n \log(\sigma) - \left(1 + \frac{1}{\xi}\right) \sum_{i=1}^{n} \log \left[1 + \xi \left(\frac{X_i - \mu}{\sigma}\right)\right] - \sum_{i=1}^{n} \left[1 + \xi \left(\frac{X_i - \mu}{\sigma}\right)\right]^{-1/\xi}
\]

where

\[1 + \xi \left(\frac{X_i - \mu}{\sigma}\right) > 0 \quad 1 + \xi\]

\( i = 1, 2, \ldots, n. \)

(**) For \( \xi = 0 \)

\[
I(\mu, \sigma, \xi) = -n \log(\sigma) - \sum_{i=1}^{n} \frac{X_i - \mu}{\sigma} - \sum_{i=1}^{n} \exp \left[-\left(\frac{X_i - \mu}{\sigma}\right)\right]
\]

If an analytical solution cannot be obtained for equation (2) then a numerical solution would be employed to obtained estimated value of \( \mu, \sigma, \) and \( \xi \) 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

\[
AIC = 2k - 2\log(L)
\]

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:
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 shows that heavy rainfall occurs almost every year in 1983 - 2015 except in 1994. Although, heavy rainfall occur 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 showed 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 $\mu$, $\sigma$, and $\xi$ are constant for stationary processes and $\mu$ and $\sigma$ 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.

| $Z_{value}$ | $Z_{0.0.475}$ | Level of Significance | Result |
|------------|---------------|-----------------------|--------|
| -2.72      | 1.96          | 0.05                  | $H_0$ 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 is mean 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 Côte’d’Ivoire, Khomzy et al. [17] in some stations rain gauge of Marocco 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 ($\mu$), scale parameter ($\sigma$) and shape parameter ($\xi$). Parameters $\mu$ and $\sigma$ assumed to vary with time in the non-stationary model and constant for the stationary model. The shape parameter ($\xi$) 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: $\mu(t) = \mu_0 + \mu_1 t + \mu_2 t^2$, $\sigma(t) = \exp(\sigma + \sigma_1 t)$
Model 7: $\mu(t) = \mu_0 + \mu_1 t + \mu_2 t^2$, $\sigma(t) = \exp(\sigma + \sigma_1 t + \sigma_2 t^2)$
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:

| Model  | Location  | Scale  | Shape |
|--------|-----------|--------|-------|
| Model 1| $\hat{\mu}_0$ | $\hat{\mu}_1$ | $\hat{\mu}_2$ | $\sigma_0$ | $\sigma_1$ | $\sigma_2$ | $\xi$ |
| Model 2| 134.80    | -      | -     | 34.86   | -      | -      | 0.12 |
| Model 3| 128.31    | -      | -     | 4.08    | -0.04  | -      | 0.19 |
| Model 4| 126.76    | -      | -     | 3.77    | 0.02   | -0.002 | 0.14 |
| Model 5| 151.43    | -0.82  | -     | 35.61   | -      | -      | 0.17 |
| Model 6| 161.26    | -1.35  | -     | 4.31    | -0.05  | -      | 0.14 |
| Model 7| 165.48    | -1.52  | -     | 3.52    | 0.07   | -0.003 | 0.12 |
| Model 8| 161.68    | -2.74  | 0.06  | 34.36   | -      | -      | 0.22 |
| Model 9| 171.62    | -2.66  | 0.03  | 4.29    | -0.05  | -      | 0.16 |
| Model 10| 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 $\mu$ are varying for all models as well as for $\sigma$. Estimation values of $\xi$ 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:

| 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:
\[ \hat{\mu}(t) = 165.48 - 1.52t \]
\[ \hat{\sigma}(t) = \exp(3.52 + 0.07t - 0.003t^2) \]
\[ \hat{\xi} = 0.12 \]

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

\[ \hat{\mu}(t) = 165.48 - 1.52t \]
\[ \hat{\sigma}(t) = \exp(3.52 + 0.07t - 0.003t^2) \]
\[ \hat{\xi} = 0.12 \]

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

Acknowledgement

The author would like to say thank you to RISTEKDIKTI for funding this research. We would like to thank for Meteorology, Climatology and Geophysics Agency of Province of South Sulawesi, Indonesia for providing daily rainfall data.

References

[1] Lei Wang, Zhengfang Wu, Hongshi He, Fuxue Wang, Haibo Du and Shengwei Zong. 2017. Changes in summer extreme precipitation in Northeast Asia and their relationships with the East Asian summer monsoon during 1961–2009. International Journal Of Climatology. 37: 25–35. DOI: 10.1002/joc.4683.

[2] IPCC Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation; Field, C.B., Barros, V., Stocker, T.F., Dahe, Q., Eds.; Cambridge University Press: Cambridge, UK, 2012.

[3] Villafuerte Ii MQ, Matsumoto J, Kubota H. 2015. Changes in extreme rainfall in the Philippines (1911–2010) linked to global mean temperature and ENSO. Int. J. Climatol. 35(8): 2033–2044, doi:10.1002/joc.4105.

[4] Fu X, Kuo CC, Gan TY. 2015. Change point analysis of precipitation indices of Western Canada. Int. J. Climatol. 35(9): 2592–2607, doi: 10.1002/joc.4144.

[5] Powell, E.J.; Keim, B.D. (2015). Trends in daily temperature and precipitation extremes for the Southeastern United States: 1948–2012. J. Clim., 28, 1592–1612.

[6] Eden J. M., Sarah F. Kew, Omar Bellprat, Geert Lenderink, Iris Manola, Hiba Omrani, Geert Jan van Oldenborgh. 2018. Extreme precipitation in the Netherlands: An event attribution case study. Weather and Climate Extremes, 21 (2018) 90–101. Doi:10.1016/j.wace.2018.07.003.

[7] Mishra, V., J. M. Wallace, and D. P. Lettenmaier 28 (2012), Relationship between hourly extreme precipitation and 29 local air temperature in the United States, Geophys. Res. Lett., 39, 30 LXXXXX, doi:10.1029/2012GL052790.

[8] Khomzy K, Mahe G, Tramblay Y, Sinan M, Snoussi M. 2015. Trends in Rainfall and Temperature Extremes in Morocco. Natural Hazard and Earth System Science Discussion, 3, 1175-1201. Doi:10.5194/nhessd-3-1175-2015
[9] Zhang D, Yan D, Wang Y, Lu F, Wu D. 2015. Changes in extreme precipitation in the Huang-Huai-Hai River basin of China during 1960-2010. *Theoretical and Applied Climatology*, **120**, 195–209, doi: 10.1007/s00704-014-1159-2.

[10] Martinkova M and Hanel M. 2016. Evaluation of Relations between Extreme Precipitation and Temperature in Observational Time Series from the Czech Republic. *Hindawi Publishing Corporation Advances in Meteorology*. Volume **2016**, pages:1-9. doi.org/10.1155/2016/2975380.

[11] Wang, G., Wang, D., Trenberth, K.E., Erfanian, A., Yu, M., Bosilovich, M.G., Parr, D.T., 2017. The peak structure and future changes of the relationships between extreme precipitation and temperature. *Nat. Clim. Change* 7, 268–274. doi.org/10.1038/nclimate3239.

[12] Schroer K., Kirchengast G. 2017. Sensitivity of extreme precipitation to temperature: the variability of scaling factors from a regional to local perspective. *Climate Dynamics* pp 1–21, doi:10.1007/s00382-017-3857-9

[13] Chu P-S, Zhang H, Chang H-L, Chen T-L, Toffe K. 2018. Trends in return levels of 24-hr precipitation extremes during the typhoon season in Taiwan. *Int J Climatol*. 38, 5107–5124, https://doi.org/10.1002/joc.5715

[14] Hirsch RM., Slack JR. Smith RA. 1982. Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Research*. 18(1): 107-121.

[15] Coles S. 2001, *An Introduction to Statistical Modeling of Extreme Values*. Springer Series in Statistics. Springer-Verlag: London.

[16] Gneneyougo Emile Soro, Dabissi Noufé, Tié Albert Goula Bi and Bernard Shorohou. 2016. Trend Analysis for Extreme Rainfall at Sub-Daily and Daily Timescales in Côte d’Ivoire. *Climate* 2016, 4(3), 37; doi.org/10.3390/cli4030037.

[17] Kenza Khomzy, Gil Mahe, Yves Tramblay, Mohamed Sinan, and Maria Snoussi. 2016. Regional impacts of global change: seasonal trends in extreme rainfall, run-off and temperature in two contrasting regions of Morocco. *Natural Hazards Earth System Sci.*, **16**, 1079–1090, doi:10.5194/nheess-16-1079-2016

[18] Vahid Rahimpour Golroudary, Yijian Zeng, Chris M. Mannaerts, Zhongbo (Bob) Su. 2016. Attributing seasonal variation of daily extreme precipitation events across the Netherlands. *Weather and Climate Extremes* **14** 56–66. http://dx.doi.org/10.1016/j.wace.2016.11.003.