Investigation of Trends in Multiday Extreme Rainfall

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Abstract— *Detecting trends in both hydrological and hydrometeorological data series is important in the context of climate change. Although multiday rainfall has caused disastrous consequences for Sri Lanka in the past, little attention has been paid to analyse multiday extreme rainfall data for trends. This paper analyses past extreme rainfall data in the Kelani River basin of a period of 57 years from 1960 to 2016 using both parametric and non-parametric tests to detect trends in a multiday scale. The daily rainfall data was assessed for homogeneity using the RhtestsV4 and extreme rainfall data was extracted using the Block Maxima method. Modified Mann-Kendall test, Mann-Kendall test, Sen's slope estimator, Linear regression method and the Innovative Trend Analysis method was used in detecting trends in the extreme rainfall data. It was found that Norton and Maussakelle shows significant positive trend for 1-day and Maussakelle for 2-day, and Wewalthalawa shows a significant negative trend for 4-day. The study will also help in assessing the suitability of using the Innovative Trend Analysis method for detecting rainfall trends in Sri Lanka. By determining trends in extreme rainfall data from the Kelani River basin, predictions can be made about the future direction of rainfall, which can aid in preparing for future hazards and risks.***

Keywords— **extreme rainfall, multiday rainfall analysis, trend detection**

I. INTRODUCTION

In recent history, climate patterns have been dynamic and are expected to change even more in the future. Due to these shifts in weather patterns, many parts of the world are being affected. Uchiyama, Ismail, and Stevenson (2021), stated that the Asia-Pacific region, the region where Sri Lanka is located, is one of the regions that are extremely weak against climate hazards due to the increase in population and its geological characteristics, among other factors. These changes in climate in terms of magnitude and frequency cause floods, droughts, heatwaves, etc. which affect the economy, the environment, and the society of a country (Wu and Qian, 2017). According to the Intergovernmental Panel on Climate Change (IPCC), global warming will pass 1.5 ° C in the next two decades, drastically affecting ~~the~~ global climate, especially by increasing extreme rainfall events (Allen *et al.*, 2021).

The World Meteorological Organisation (WMO) had defined extreme rainfall as an incident where the mean rainfall is higher than a specified threshold for a certain period (Kuleshov Y *et al.*, 2020). The impact of an extreme rainfall event could be enhanced if the rainfall is persistent. Sri Lankan rainfall is mostly due to the country being in the tropical region with a monsoonal system. Furthermore, convectional rain and depressional rain during inter-monsoonal periods also bring rainfall to the country (Statistical Abstract 2019, 2019). Thus, Sri Lanka is exposed to frequent extreme rainfall events which can result in flooding and other disasters. Previous studies have concluded that the brunt of extreme rainfall events is focused on the South-West part of Sri Lanka, mainly influencing the western province (Sanjeewani and Manawadu, 2017) and that higher intensity rainfall tends to cause frequent flash floods in urban areas.

Intense rainfall over a short period of time can result in flooding, as well as continuous rainfall over a longer period, and the outcome can end up being worse if the rainfall is intense and persistent at the same time (Acero, Gallego and García, 2012). Although Sri Lanka is a country that receives a considerable amount of rainfall every year, extreme or otherwise, most studies have been focused on analysing daily rainfall for annual rainfall trends or seasonal variations (Jayawardene, Sonnadara, and Jayewardene, 2005). For Sri Lanka a notable number of floods were the result of multiday rainfall (Hettiarachchi, 2016).

It is essential for a data series to be homogeneous when investigating for trends. Many methods exist to test for homogeneity of a data series such as Standard Normal Homogeneity Test (SNHT), Rhtests, Penalized Maximal t-test (PMT), Penalized Maximal F-test (POF), Multiple Analysis of Series for Homogenization (MASH), Pettit test (Ming Kang and Yusof, 2012). Out of these, the MASH method and the Rhtests were developed specially to test for homogeneity of data series in month or day scales (Shen *et al.*, 2018). Rhtests were developed by the Climate Research Centre of the Environment Ministry of Canada and are based on a two-phase regression model, and it has the ability to investigate the data and correct them on a daily, weekly, or yearly scale (Kuleshov Y *et al.*, 2020). It was found that the MASH method is more likely to detect break points in data series if a reference data set is available and is preferable for large scale climate difference studies, whereas Rhtests tend to retain more of the original data of observations available (Li *et al.*, 2016).

Block Maxima (BM) method and the Peak Over Threshold (POT) method are two widely used methods for extracting extreme rainfall data. For the BM method, whatever the maximum rainfall value is for a predetermined period, usually a year, is extracted as the extreme value, and for the POT method, every value that exceeds a certain level is extracted as extreme rainfall data (Coles, 2001). The literature mentioned that there is no standard practise or clarification in choosing between the BM method and the POT method, and that both methods have been used frequently in the process of extracting extreme rainfall data (Zakaria, Ahmad Radi, and Satari, 2017).

There are many methods available for trend detection, they can be simply divided into two subgroups, parametric methods, and non-parametric methods, either statistical or graphical. The biggest attraction of non-parametric tests is the absence of the requirement of a normal distribution in the data series. The most widespread non-parametric tests are the Mann-Kendall test, Sen's slope estimator, Spearman's Rho test, and the Innovative Trend Analysis (ITA) method (Wang *et al.*, 2020). Hamed and Rao (1998) suggested that for both MK and Spearman's Rho tests disregarding the existence of autocorrelation in the data set can affect the results and introduced the Modified Mann-Kendall test (MMK test) to counter the effect. Sa'adi *et al.*, (2019). have stated that the MMK test is preferable over the MK test as it helps to reduce overestimation in trends of rainfall. Yet, for MMK test, the existence of autocorrelation for more than one lag would again affect the results or fail to provide results. Furthermore, because both the MK and MMK tests can only detect the existence of a trend, a slope estimator method such as the Sen's Slope test must be paired to calculate the magnitude of the trend.

A relatively new non-parametric graphical trend detection method introduced by Sen is the Innovative Trend Analysis method (ITA). This method is a graphical method that makes it easier to comprehend the result of the test, and it has a wider range of applications because it is not limited by the length of the data series, assumptions of distribution and serial correlation (Wu and Qian, 2017). The literature also stated that the ITA method is more powerful, helping to recognize more hidden trends in precipitation data that cannot be obtained through the usual classical methods (Abeysingha, 2022).

The simplest methods of parametric tests for trend detection are the linear regression method and students t-test. The negative side of parametric tests is that it assumes that the variance of the data to be normal and homogeneous which rainfall data might not be (Sarailidis and Tsiougkos, 2018).

Therefore, for this research, as non-parametric tests, Mann-Kendall test, Modified Mann-Kendall test paired with Sen's slope were used along with the ITA method. As parametric tests, linear regression was used to detect for rainfall trends.

II. Methodology and Data

- Step 1: Obtain daily rainfall data

Daily rainfall data from 15 hydrometric stations were taken from the Department of Meteorology, Sri Lanka, so that the Kelani River basin can be covered spatially to obtain the best results. The details of the selected stations are given in Table 1.

- Step 2: Quality control of data

The quality control of the rainfall data was done using the RClimDex software, based on R Software. For all the rainfall stations used for this research, there were no missing values or unreasonable values. An issue that was identified was that for the entire year at Maliboda station, the rainfall data was recorded as zero, while nearby stations had rainfall data.

- Step 3: Assessing data homogeneity

RHtestsV4, an R based software; was utilized to assess the homogeneity of each rainfall data series for all rain gauge stations. The software is based on both penalized maximal F test (PMF) and the penalized maximal T test, out of which for this research, PMF was used.

After conducting this test, it was determined that the Maliboda station rainfall data shows seven change points, shifts in the mean of the dataset, which are significant at a nominal level of 95%. Since such change points can affect the results obtained from trend analysis methods, the Maliboda station was omitted from the analysis.

- Step 4: Extraction of extreme rainfall data

The BM method was used to extract the extreme values for a series of 1 – 7 days of multiday rainfall. The R package extRemes was utilized on RStudio for this task.

- Step 5: Preparation of data

From the extracted extreme values, 1 – 7 multiday extreme rainfall data series were prepared for all fourteen selected rainfall gauge stations to conduct the trend detection tests.

- Step 6: Analysis of rainfall trends

The prepared series were analysed using the following tests.

1. Modified Mann-Kendall test

The analysis of all rainfall data series was done using RStudio. The package modifiedmk (Hamed and Ramachandra Rao, 1998) was used to conduct both MK and MMK and the results were obtained. For the research, 5% significance level was considered. Thus, the critical value of the trend was calculated to be ±1.96 for both the MK and MMK tests.

2. Innovative Trend Analysis

The results for this test were gained through the RStudio package - trendchange (Şen, 2012).

3. Sen's slope test

To detect the magnitude of the trend for the MK test, the non-parametric method proposed by Sen was employed using the modifiedmk package on RStudio.

4. Linear Regression method

The magnitude of a trend in a data series can be detected through this test, and to identify whether the trend is significant or not, the t-test was paired with the linear regression. The critical t value was calculated to be 2.00. Both tests were again performed on RStudio, and the results were obtained.

III. Results and Discussion

A. Trends in 1-day to 7-day rainfall data series

For the 14 rainfall gauge stations, MMK test, MK test, Sen's slope, Linear regression, and t-test for slope as well as the ITA test were performed to 1-day to 7-day maximum rainfall data series.

The results obtained from MK and MMK tests as well as the results of the Sen's slope, Linear regression, t-test, and ITA for 1-day series are given in Table 1.

Table 1. Results for 1-day maximum series (Significant in bold)

Station	MK	MMK	Sen's	LR	t-test	ITA
Avissawella Hospital	0.43	0.43	0.17	0.30	0.84	0.36
Bopatthalawa	-0.98	-1.75	-0.23	-0.37	-1.30	-0.35
Campion Estate	0.26	0.26	0.06	-0.02	-0.09	-0.12
Castlereigh	1.21	1.21	0.42	0.51	1.09	0.52
Colombo	-1.14	-1.14	-0.60	0.06	0.10	0.19
Digalla Estate	0.22	0.29	0.06	0.15	0.44	0.42
Dunedin Estate	0.73	0.73	0.28	0.44	1.32	-0.05
Hanwella Group	0.47	0.58	0.16	0.23	0.63	0.49
Labugama Tank	-0.53	-0.53	-0.14	0.08	0.19	0.07
Laxapana	1.16	1.40	0.60	0.54	1.04	0.94
Maussakelle	**2.76**	**2.76**	**0.88**	**1.14**	**2.97**	**1.36**
Norton	1.63	**2.02**	**0.82**	**1.06**	**2.08**	**1.38**
Pasyala	1.28	1.21	0.44	0.40	1.29	0.32
Wewalthalawa	-0.85	-1.37	-0.29	-0.20	-0.48	-0.65

Figure 1 shows the graphical representations of ITA method for 1-day maximum rainfall series of 4 rainfall stations.

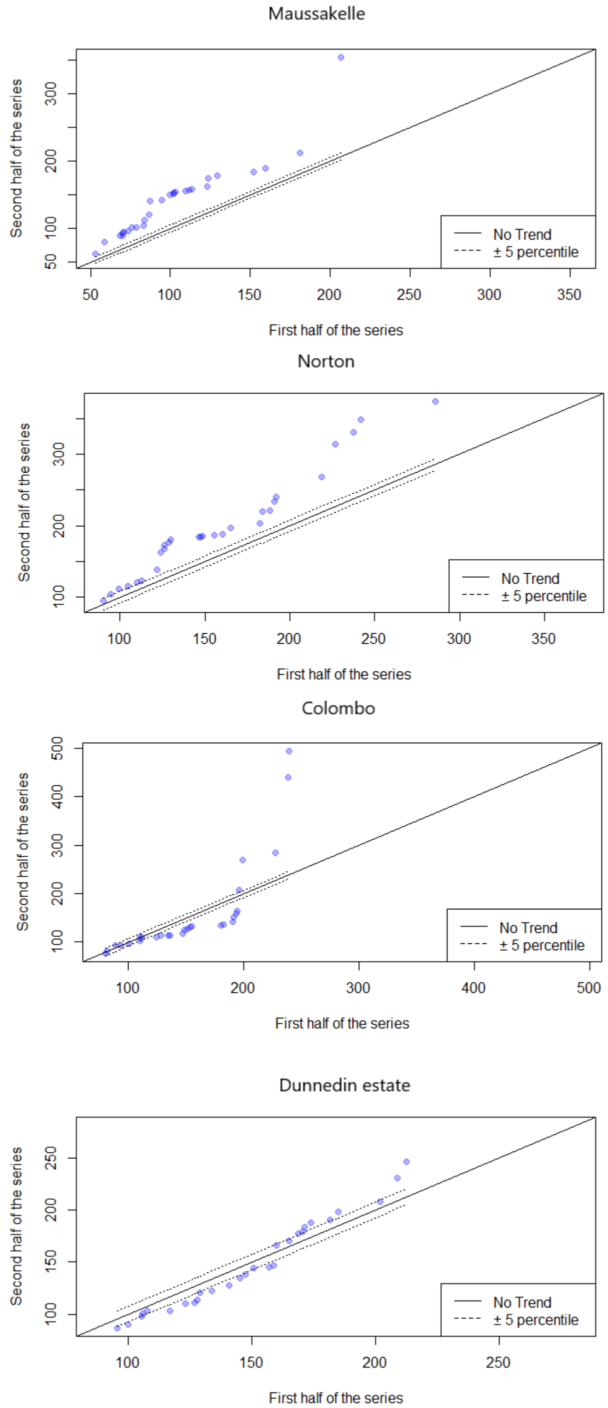

Figure 1: Selected ITA results for 1-day maximum series

Referring to Table 1, from the results obtained through MMK test, it was identified that Maussakelle and Norton show a significant positive trend in 1-day maximum rainfall, while Bopaththalawa shows a notable negative trend, even though the trend is not significant at 95%. For MK test, it shows a significant positive trend only for Maussakelle and a notable positive trend for Norton. In the case of linear regression, it shows significant positive trends for both Maussakelle and Norton, coinciding with MMK test results. For the remaining stations, most of them have a positive trend (Avissawella hospital, Campion estate, Castlereigh, Digalla estate, Dunedin estate, Hanwella group, Laxapana and Pasyala) while only a few stations (Colombo, Labugama tank, and Wealthalawa) show a negative trend, even though none of them significant for both MMK and MK tests. Most of the time, the results of MMK and MK tests are in agreement with linear regression, except for two stations.

Considering the ITA method, a very clear positive trend can be seen in the graphs on Figure 1 for both Maussakelle and Norton, as the data almost completely lie on the upper triangle. The points on Castlereigh and Laxapana graphs mostly lie on the upper triangle but is positioned very close to the 1:1 solid line.

It is also possible for graphs to show non-monotonic trends and for the points to be on both sides of the 1:1 line. Such points can be divided into clusters and can help identify hidden trends in rainfall series.

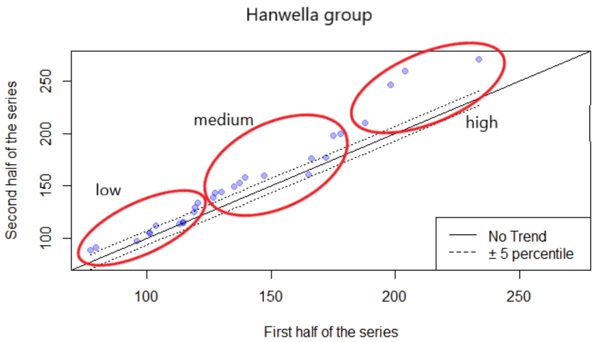

Figure 2: Clusters of Hanwella group

For Hanwella and Pasyala while the low cluster is mainly on the no trend line, both medium and high clusters are located on the upper triangle, again resulting in a positive trend. For Avissawella hospital, Digalla estate and Labugama tank the points are mostly on the no trend line for both low and medium clusters, a positive trend can be observed on the high cluster, resulting in an overall positive trend. The opposite can be said for the Campion estate and Wewalthalawa graphs. For Bopaththalawa, the low cluster is located on the no trend line but for both medium and high clusters the points lie within the lower triangle, resulting in a negative trend. Dunedin estate shows negative trends for both low and medium cluster, while it shows a positive trend for the high cluster, but all points are located close to the no trend line indicating a very low trend. For Colombo, the lower cluster is within the no trend while the medium cluster shows a negative trend, and the higher cluster shows a positive trend. The combination of all three trend patterns finally showed as a positive trend. This can be interpreted as, the medium rainfall values are comparatively lower for the second half of the data set compared to the first half, however, the high rainfall values are significantly higher in the second half of the data series. This indicates a rise in 1-day extreme rainfall events for Colombo.

Comparing the results between ITA and linear regression for all 14 stations, both tests generate similar results for trend.

Investigating the results of 2-day maximum rainfall series for all rainfall stations, Maussakelle is the only station that shows a significantly positive trend for MK, MMK and linear regression test. It also shows a clear positive trend in the ITA graphical output, and though not as significant as Maussakelle, Norton also shows a clear positive trend.

Avissawella hospital, Castlereigh, Hanwella, Labugama Tank, Laxapana, and Norton show rising trends while Bopaththalawa, Colombo, and Wewalthalawa show decreasing trends from MK, MMK, and linear regression test results for 2-day extreme rainfall series. Campion estate, Digalla estate, Dunedin and Pasyala show very low trends, which can be taken as no trend.

Hanwella, Labugama tank and Laxapana all have the points on the upper triangle resulting in a positive trend, but the points are located close to the no trend line. Both Avissawella and Dunedin stations show no trend at low and medium clusters, but the higher cluster is in the upper triangle resulting in a positive trend. Bopaththalawa, Wewalthalawa and campion estate mostly shows a decreasing trend. Meanwhile, Castlereigh, Digalla, and Pasyala points are located mainly around the no trend line resulting in no trend. The Colombo graph shows no trend on the lower cluster, a negative trend on the medium cluster and a positive trend on the high cluster.

For 3-day maximum rainfall, no significant trends were detected through any method. Maussakelle shows a positive trend which even though not significant, is very close to being significant. Wewalthalawa on the contrary shows an almost significant negative trend. Avissawella hospital, Castlereigh and Norton all shows a positive trend for MK, MMK and linear regression and Bopaththalawa, Colombo, Digalla estate, Dunedin estate, and Pasyala shows a negative trend. Campion estate shows a low positive trend for MK and MMK while showing a low negative for linear regression. Labugama tank, Hawella group and Laxapana resulted in low trend values and can be assumed to have close to no trend.

The results from ITA, Maussakelle shows a clear positive trend with almost all points on the upper triangle. Norton also shows a positive trend with most points located close to the no trend line in the low cluster. On the contrary, Wewalthalawa shows a clear negative trend in the data with most values on the lower triangle. The remaining stations mostly show a close to no trend overall, even though smaller trends in low, medium, and high clusters could be observed.

In investigating for trends in 4-day maximum rainfall series, a significant negative trend was observed from both MMK and linear regression for Wewalthalawa, while MK showed a result very close to being significant. Maussakelle showed a trend close to being significantly positive. Bopaththalawa and Colombo gives a negative trend while Norton shows a positive trend. The remaining stations all show trends that either they are very close to no trend or have no trend.

Observing the results of the ITA method, Wewalthalawa clearly portrays a negative trend while Maussakelle shows a positive trend located comparatively closer to the no trend line. Norton shows a low cluster positive trend, medium cluster negative trend and a high cluster positive trend which overall results in a positive trend. Bopaththalawa also shows the points in the 1:1 area for the low cluster and for medium and high cluster, a negative trend. All other stations have an overall trend that is close to being no trend.

For the results of 5-day, 6-day and 7-day, no significant discoveries were identified.

For 5-day, Bopaththalawa, Colombo, Hanwella group, Labugama tank, and Wewalthalawa shows decreasing trends while Maussakelle and Norton displays positive trends. The remaining stations all have trend values close to zero and can be categorized to have no trend. The results obtained from MK, MMK and Linear regression are comparable to each other and no disparity can be observed. The results obtained from the ITA method are in line with the results obtained from the traditional methods. The graph of Wewalthalawa displays a clear negative trend whereas Maussakelle displays a positive trend, though located closer to the 1:1 line compared to the former station. The remaining stations all show points very near the 1:1 line resulting in no trends.

For 6-day maximum rainfall series, for MK, MMK and linear regression tests, Bopaththalawa, Colombo, Digalla estate, Hanwella group, Laxapana, Pasyala and Wewalthalawa gives negative trends while Maussakelle and Norton have positive trends. The remaining stations all shows trend values closer to being no trend. ITA method results show a clear negative trend for Wewalthalawa. The remaining stations all display the points mainly around the 1:1 line, concluding no trend.

While for 7-day maximum rainfall series, no significant trend is detected, it can be observed that Wewalthalawa has a negative trend that is close to being significant. Bopaththalawa, Colombo, Digalla estate, Hanwella group, Laxapana, and Pasyala gives a negative trend while Maussakelle and Norton gives a positive trend. Castlereigh shows no trend, and Avissawella hospital, Dunedin estate and Labugama tank have trend values that are very close to zero trend.

Observing the graphical output of ITA method, a negative trend can be clearly observed for Wewalthalawa station. For the remaining stations either positive or negative trends can be identified, yet the points on the graphs are generally located close to the 1:1 line making it so that the trends are not very high. For most part, the result obtained from ITA is compliant to results obtained through linear regression and does not show a large variation.

B. Parametric approach and non-parametric approach

Comparing the results obtained from parametric methods to the results obtained from non-parametric method, it shows that the results are approximately 90% comparable. In the case of significant trend detection, linear regression, which is a parametric test, always detected any trend that MMK or MK detected. On the contrary, MK failed to identify 2 significant trends, that were identified by MMK and Linear regression.

MMK test considers the correlation among the rank order of the data the order that they display according to time (Hamed and Ramachandra Rao, 1998). This is considered as the better option compared to MK due to this reason, as most of the time data has serial correlation. To conduct MK test, the autocorrelation effects must be removed from the data series, and this can lead to the removal of a portion of data that may affect the trend. This can be named as the reason why MK test failed to identify 2 significant trends in the data series.

But an issue identified regarding the MMK test was that when the data is independent, it can lead to identifying false trends with the assumption that the data is autocorrelated. This was also observed in a few instances (i.e..6-day and 7-day for Campion estate).

Linear regression and t-test for slope are the two parametric tests used in the research. For parametric tests, the downside is that to analyse data, there needs to be a normal distribution among the data (Kocsis, Kovács-Székely and Anda, 2020).

ITA method was also utilized in the analysis and this method is also a non-parametric method. The plus side of the ITA method is that it gives a graphical representation of the analysis, and this can be used to identify the smaller trends within the series that add up to give the final trend result. While some disparity in a few stations exist between the classical methods and the graphical method of analysis (i.e., Dunedin 1-day maximum rainfall) for most part, the results are in harmony. The ITA graphical representation is also helpful in finding out about whether the trend in monotonic or not.

IV. CONCLUSION

To identify trends in multiday extreme rainfall for the Kelani River Catchment, MK test, MMK test, Sen's slope estimator, Linear regression paired with t-test for slope and ITA method were utilized. For most part, the results obtained from each method bore similar results to each other except for a very few instances. The relatively recent method of trend analysis, ITA proved to be commendable in identifying smaller trends within the data series and the ability to visually observe the variations within the trend. The only issue with this method is that it gives no numerical value to identify whether the trend is significant or not. Thus, the ITA method can be used as a qualitative method of analysing rainfall data rather that a quantitative method.

From the results obtained, significant positive trends were observed for Maussakelle for 1-day and 2-day, and for Norton 1-day. Significant negative trends were present for Wewalthalawa 4-day. While not significant at 95%, Maussakelle showed considerably high trends for 3-day and 4-day while Bopaththalawa showed a close to significant negative trend for 1-day. Wewalthalawa 3-day and 7-day also displayed considerably high negative trends.

From these results, the lower catchment has both positive and negative trends, though none are significant. Comparing results from 1-day to 7-day a clear pattern cannot be identified, though positive or negative trends both seem to diminish as series go from 1-day to 7-day. The upper catchment on the other hand has positive trends, except for Bopaththalawa and Wewalthalawa. All significant trends are also located on the upper catchment of the river for both positive and negative trends.

REFERENCES

Abeysingha, N.S. (2022) 'A Review of Recent Changes in Rainfall Trend in Sri Lanka', *Tropical Agricultural Research and Extension*, 25(1), p. 1. Available at: https://doi.org/10.4038/tare.v25i1.5584.

Acero, F.J., Gallego, M.C. and García, J.A. (2012) 'Multi-day rainfall trends over the Iberian Peninsula', *Theoretical and Applied Climatology*, 108(3–4), pp. 411–423. Available at: https://doi.org/10.1007/s00704-011-0534-5.

Allen, M.R. *et al.* (2021) *SPECIAL REPORT: GLOBAL WARMING OF 1.5 ^{o}C*. Australia.

Coles, S. (2001) *An Introduction to Statistical Modeling of Extreme Values*. London: Springer London. Available at: https://doi.org/10.1007/978-1-4471-3675-0.

Hamed, K.H. and Ramachandra Rao, A. (1998) 'A modified Mann-Kendall trend test for autocorrelated data', *Journal of Hydrology*, 204(1–4). Available at: https://doi.org/10.1016/S0022-1694(97)00125-X.

Hettiarachchi, P. (2016) *Intigrated Approach for Riverine Management in Sri Lanka View project Climate Resilience Improvement Project (CRIP) View project*. Available at: https://www.researchgate.net/publication/342865359.

Jayawardene, H., Sonnadara, D. and Jayewardene, D. (2005) 'Trends of Rainfall in Sri Lanka over the Last Century', *Sri Lankan Journal of Physics*, 6(0), p. 7. Available at: https://doi.org/10.4038/sljp.v6i0.197.

Kocsis, T., Kovács-Székely, I. and Anda, A. (2020) 'Homogeneity tests and non-parametric analyses of tendencies in precipitation time series in Keszthely, Western Hungary', *Theoretical and Applied Climatology*, 139(3–4), pp. 849–859. Available at: https://doi.org/10.1007/s00704-019-03014-4.

Kuleshov Y *et al.* (2020) *WMO Space-based Weather and Climate Extremes Monitoring Demonstration Project for East Asia and Western Pacific, World Meteorologocal Organization*.

Li, Z. *et al.* (2016) 'Comparison of two homogenized datasets of daily maximum/mean/minimum temperature in China during 1960–2013', *Journal of Meteorological Research*, 30(1). Available at: https://doi.org/10.1007/s13351-016-5054-x.

Ming Kang, H. and Yusof, F. (2012) *Homogeneity Tests on Daily Rainfall Series in Peninsular Malaysia, Int. J. Contemp. Math. Sciences*.

Sa'adi, Z. *et al.* (2019) 'Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test', *Meteorology and Atmospheric Physics*, 131(3), pp. 263–277. Available at: https://doi.org/10.1007/s00703-017-0564-3.

Sanjeewani, R.M.S.S. and Manawadu, L. (2017) *Proceedings of the International Symposium on ICT for Environmental Sustainability DYNAMIC TRENDS OF RAINFALL EXTREMES IN SRI LANKA*.

Sarailidis, G. and Tsiougkos, S. (2018) *Rainfall frequency analysis using block maxima and peaks over threshold approaches*.

Şen, Z. (2012) 'Innovative Trend Analysis Methodology', *Journal of Hydrologic Engineering*, 17(9), pp. 1042–1046. Available at: https://doi.org/10.1061/(asce)he.1943-5584.0000556.

Shen, L. *et al.* (2018) 'Homogeneity Test and Correction of Daily Temperature and Precipitation Data (1978–2015) in North China', *Advances in Meteorology*, 2018. Available at: https://doi.org/10.1155/2018/4712538.

Statistical Abstract 2019 (2019) *Department of Census and Statistics*.

Uchiyama, C., Ismail, N. and Stevenson, L.A. (2021) 'Assessing contribution to the Sendai Framework: Case study of climate adaptation and disaster risk reduction projects across sectors in Asia-Pacific (2015–2020)', *Progress in Disaster Science*, 12, p. 100195. Available at: https://doi.org/10.1016/j.pdisas.2021.100195.

Wang, Y. *et al.* (2020) 'Innovative trend analysis of annual and seasonal rainfall in the Yangtze River Delta, eastern China', *Atmospheric Research*, 231. Available at: https://doi.org/10.1016/j.atmosres.2019.104673.

Wu, H. and Qian, H. (2017) 'Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s', *International Journal of Climatology*, 37(5), pp. 2582–2592. Available at: https://doi.org/10.1002/joc.4866.

Zakaria, R., Ahmad Radi, N.F. and Satari, S.Z. (2017) 'Extraction method of extreme rainfall data', in *Journal of Physics: Conference Series*. Institute of Physics Publishing. Available at: https://doi.org/10.1088/1742-6596/890/1/012154.

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