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Research Article

Comparison of Statistical Methods to Graphical Methods in Rainfall Trend Analysis: Case Studies from Tropical Catchments

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Time series analyses for climatic factors are important in climate predictions. Rainfall is being one of the most important climatic factors in today's concern for future predictions; thus, many researchers analyze the data series for identifying potential rainfall trends. The literature shows several methods in identifying rainfall trends. However, statistical trend analysis using Mann–Kendall equation and graphical trend analysis are the two widely used and simplest tests in trend analysis. Nevertheless, there are few studies in comparing various methods in the trend analysis to suggest the simplest methods in analyzing rainfall trends. Therefore, this paper presents a comparison analysis of statistical and graphical trend analysis techniques for two tropical catchments in Sri Lanka. Results reveal that, in general, both trend analysis techniques produce comparable results in identifying rainfall trends for different time steps including annual, seasonal, and monthly rainfalls.

1. Introduction

Trend analysis is one of the technical ways of predicting the future movement of any measurement. The trend analysis usually uses time series observations over a significant period to predict the future behavior of that observation. Application of the trend analysis can be found in many disciplines in meteorology, including identifying precipitation trends [1, 2] and temperature trends [3, 4], stream flow predictions [5], identifying evaporation trends [6], wind speed trends [7], etc. However, the trend analysis was used in many other areas for identifying future behavior of those observations. Identifying the malaria prevalence trends in Ethiopia [8], identifying the trends of human immunodeficiency virus in the United States [9], economic recession in the United Kingdom, and the trends of suicidal rates [10] and determination of recent trends in hospitalization, mortality and fatality due to sepsis in the United States [11] are the other examples of the trend analysis. Nevertheless, the trend analysis against the meteorology and climate issues takes much attention due to the dominant behavior of human feelings.

Climate change or climate variability has made a significant influence on the whole world. Most of the economic, social, and political decisions are now bound to the climate change or climate variability. Therefore, many policies and treaties have been introduced by most of the countries to reduce the adverse impact, which leads to climate change or climate variability. Some countries even introduced new policies to minimize the usage of fossil-fuel-powered vehicles in their countries to reduce the emission of pollutants leading to various adverse environmental issues including global warming. On the other hand, significant amount of research is being carried out to mitigate the impact of climate change and global warming.

Climate prediction is a highly researched area in today's world. Various models including computer models, statistical models, and graphical models are used by many researchers. Among many other models, including artificial neural networks (ANN), fuzzy logic techniques, and stable linear Langevin equations, statistical methods are famous among the researchers because of the simplicity of the method. Therefore, as it was stated in the first paragraph, nonparametric-test-based models in identifying climatic trends are very popular among many researchers. In addition, graphical methods in identifying the climatic trends are another technique used by researchers. They are simple and less complicated in usage. More details on the widely used graphical method are given in the following sections.

Among these prediction models and tests, it is interesting to see their comparison for the same dataset. Toth et al. [12] have compared the results of short-term rainfall prediction for real-time flood forecasting using linear stochastic autoregressive moving average models (commonly known as ARMA), ANN models, and nonparametric nearest-neighbors methods. The research shows some interesting findings among the compared models. In addition, Azamathulla et al. [13] presented a comparison study for atmospheric temperature in Tabuk, Saudi Arabia using gene expression programming and ANN. They concluded that the gene expression programming has merits over the ANN in atmospheric temperature prediction for Tabuk, Saudi Arabia.

However, there is little research on the climatic trends in the context of Sri Lanka. In addition, there is no comparison study on various techniques and methods in obtaining the climate predictions in the Sri Lankan context. Most of the rainfall trend analyses carried for Sri Lanka was based on nonparametric statistical tests. In addition, literature does not provide any information about the usage of graphical methods in rainfall trend identification for Sri Lanka. Therefore, it would be interesting to have a detailed comparison on the available methods in climate prediction and then to have a clear idea on the accuracy of each method to a tropical climate. Thus, this paper presents a comparing study of two methods (statistical method and graphical method) in obtaining rainfall trends to two catchments in tropical climate of Sri Lanka (naming Uma Oya catchment and Denawaka Ganga catchment). Therefore, this research would be helpful for further research in comparing more computational methods in climate prediction in the context of tropical climates.

2. Statistical Methods in Rainfall Trend

Statistical parametric and nonparametric tests detect the trends in climatic data. The parametric t-tests have a less potential compared to the nonparametric Mann–Kendall test when the probability distribution of the dataset is skew [14]. Therefore, nonparametric tests were only considered for this comparison study. Mann–Kendall test is a widely adopted nonparametric test for the trend analysis in the literature.

2.1. Mann–Kendall Test. The Mann–Kendall test determines the monotonic upward and downward trend of the dataset over the time [15, 16]. Hirsch et al. [17] added the seasonality assessment to the test and it is used to analyze the trends in climatic data. This trend may or may not be linear. Therefore, the Mann–Kendall test is a replacement for the linear regression models in the trend analysis. In addition, it does not require the residuals from the fitted regression line to be normally distributed. Therefore, the test is nonparametric, in other words, a distribution-free test.

The Mann–Kendall test can be best viewed as an exploratory analysis test; therefore, this is an important nonparametric test in weather data predictions [17]. The test is widely used all over the world as a statistical test to determine the climatic trends. Khaniya et al. [18] have studied the trend analysis in Uma Oya catchment using the Mann–Kendall test and concluded that there is no water scarcity to the catchment in recent future. In addition, Wickramagamage [19] has observed the trends in Sri Lanka but in a macro way using the Mann–Kendall test.

The Mann–Kendall statistic S is given by the following formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right), \qquad (1)$$

where x_j and x_i are time series and n is the number of data points in the time series. The "sgn" sign function can be expressed as

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} +1, & >\left(x_j - x_i\right), \\ 0, & =\left(x_j - x_i\right), \\ -1, & <\left(x_j - x_i\right). \end{cases} \qquad (2)$$

The variance of the Mann–Kendall test is given by

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}, \qquad (3)$$

where t_i is the number of ties up to sample i. Then, the Mann–Kendall statistics Z_c is given by

$$Z_c = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}}, & S > 0, \\ 0, & S = 0, \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}}, & S < 0. \end{cases} \qquad (4)$$

Z_c follows the standard normal distribution. A positive Z_c value shows an upward trend, whereas negative Z_c gives a downward trend for the data period. The Mann–Kendall test is based on several assumptions as listed below.

(i) It assumes the data obtained are time independent (not serially correlated over the time) and identically distributed.

(ii) The data obtained over the time represent the true conditions at the data observation times.

(iii) The data collection and handling were carried out without any biased situation.

2.2. Sen's Slope Estimator Test. Sen's slope estimator test is usually combined with the Mann–Kendall test and can be used to identify the magnitude of the trend in univariate time series. The test has a significant resistance to the outliers of the data series, in other words to the extremely high or low data values [20]. Theil [21] first presented this method and later it was expanded by Sen [22]. Therefore, in some literature, this test can be found as "Theil-Sen estimator." It is in the category of nonparametric tests and does not follow any particular probability distribution. Sen [22] proposed it as an alternative to the least-square regression line where it uses weighted mean to find the slope. Sen's slope uses the median to find its slope for the trends. Since 1968, the test is widely used in assessing the trend magnitude for rainfall series over the time. Slope for all data pairs can be calculated as follows:

$$T_i = \frac{x_j - x_k}{j - k}, \quad \text{for } i = 1, 2, 3, \ldots, n, \ j > k, \tag{5}$$

where T_i is the slope and x_j and x_k are data values at time j and k, respectively. The median of the n values of T_i is symbolized as Sen's slope estimator (Q_i) and given in the following equation:

$$Q_i = \begin{cases} T_{(n+1)/2}, & n \text{ is odd,} \\ \frac{1}{2}\left(T_{n/2} + T_{(n+2)/2}\right), & n \text{ is even.} \end{cases} \tag{6}$$

3. Graphical Methods in Rainfall Trend Analysis

Most of the data series used in statistical analysis for trend identification are assumed as serially independent (for example in Mann–Kendall test). However, it is a well-known fact that some of the hydrological data (water quality series, stream flow data, antecedent rainfalls, etc.) are not serially independent at least during some time periods. These hydrological data, therefore, statistically show significant serial correlation [23]. von Storch [24] showed that even moderate correlation in the data series produces some errors in the trends. In addition, these issues were clearly presented by von Storch [24] and Blain [25]. Blain [25] stated that the limitations of the statistical trend tests are mostly based on its null hypothesis. Based on the issues in statistical analysis, several researchers have tried prewhitening of data series to reduce the serial correlation [26].

Şen [27] has presented an innovative graphical method to identify the positive and negative trends in climatic data. The innovative method was used for several other areas by Şen [28, 29] and Öztopal and Şen [30]. The method is simple and straightforward. The following steps illustrate this innovative graphical method.

(i) First, the data series is divided into two or more equal subseries.

(ii) Next, the subdata series are arranged to the ascending order.

(iii) Then, plot two antecedent series in the Cartesian coordinate system (the older one in the X axis and the recent one in the Y axis).

(iv) After that, draw a 45° line and two other lines at +5% and −5% at the same coordinate system.

(v) If the time series are in between +5% and −5%, it can be said that there is no trend. However, if the data scatter is placed above +5%, a positive trend in the recent data compared to the older data can be predicted and vice versa.

Even these ±5% lines can be extended to ±10% lines for no trends and also the scatters can be grouped in identifying the partial trends [30]. Gedefaw et al. [31] have also carried out innovative technique in identifying the rainfall trends in Ethiopia.

4. Case Study Applications

Two catchments were selected as the case studies for the comparison studies of the rainfall trend analysis. They are Uma Oya catchment in the Uva province of Sri Lanka and the Denawaka Ganga catchment in the Sabaragamuwa province of Sri Lanka. These two catchments are shown in Figure 1 (Uma Oya catchment in blue rectangle with blue arrow and Denawaka Ganga catchment in red rectangle with red arrow). The analyzed rain gauges in these two catchments are also given in Figure 1.

4.1. Uma Oya Catchment. Uma Oya catchment covers about 720 km^2 of area in both wet and intermediate zones of Sri Lanka. Therefore, it has a rich biodiversity. The catchment feeds Mahaweli River, the longest river in Sri Lanka through Uma Oya. It starts from Pidurutalagala mountain range (highest mountain in Sri Lanka at 2500 m from mean sea level) and reaches Rantembe reservoir (one of the hydropower development reservoirs in Sri Lanka at 152 m from mean sea level). There is an ongoing development project called Uma Oya development made this catchment interesting among the developers and environmentalists not only in Sri Lanka but also in some other countries [32]. More information about the catchment and its ongoing development project can be found in Khaniya et al. [33].

Uma Oya catchment is well known as a green catchment due to its high rainfall throughout the year. Specifically, it gets its maximum rainfall during the north-eastern monsoon period (December to February); however, it has average rainfalls during the south-western monsoon period (May to September) and the second intermediate season (October to November). The selected rain gauging stations in Uma Oya catchments are shown by U_1 to U_5 in the catchment figure. The coordinates of these rain gauging stations are given in Table 1. Rainfall data for 26 consecutive years (1992–2017) were obtained from Meteorological Department, Sri Lanka for this comparison study.

4.2. Denawaka Ganga Catchment. Denawaka Ganga catchment is an interesting catchment as it has a leading run-of the-river hydropower plant in Sri Lanka. The catchment is in Ratnapura district of Sri Lanka. This is one of the catchments in the wet zone of the Sri Lanka and receives

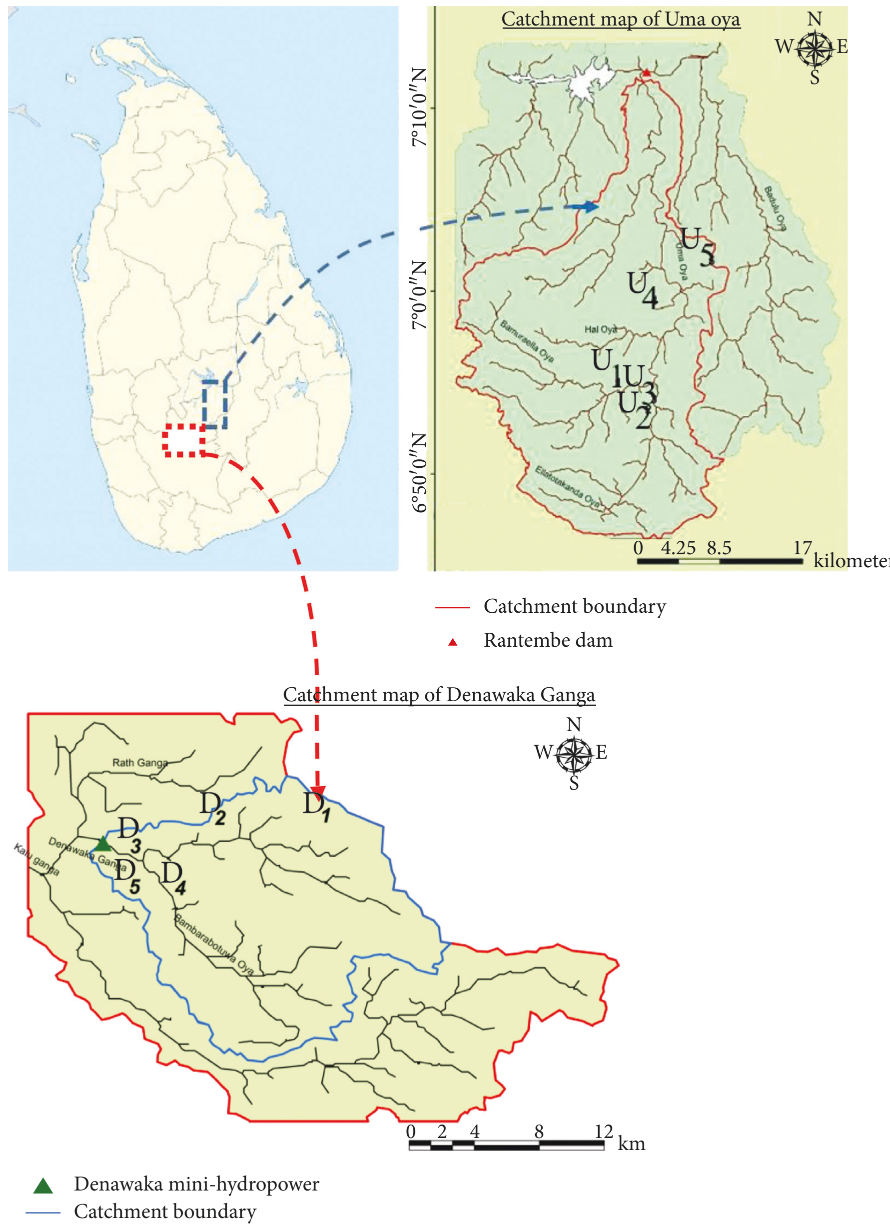


Figure 1: Uma Oya and Denawaka Ganga catchments.

Table 1: Selected rain gauges in two catchments.

Catchment	Rain gauge	Latitudes and longitudes
Uma Oya	U_1—Welimada group	6.90°, 80.90°
	U_2—Hilpankandura estate	6.88°, 80.94°
	U_3–Dyrabba estate	6.89°, 80.94°
	U_4—Kirklees estate	6.99°, 80.94°
	U_5—Ledgerwatte estate	7.03°, 81.01°
Denawaka Ganga	D_1—Alupolla estate	6.72°, 80.58°
	D_2—Hapugastenna estate	6.72°, 80.52°
	D_3—Galaboda estate	6.70°, 80.47°
	D_4—Lellopitiya estate	6.68°, 80.50°
	D_5—Landsdown middle division estate	6.67°, 80.47°

heavy rainfall volumes. Therefore, flooding is frequent in the region and its surroundings [34]. The catchment receives its maximum rainfall during the southwest monsoon season (May to September of the year); however, the past rainfall records in the catchment show a significant rainfall throughout the year. The catchment is rather a smaller in area (172.58 km^2) compared to Uma Oya catchment and covered mostly by a natural forest but with few villages. Five rain gauges are selected for the Denawaka Ganga catchment to carry out the rainfall trend comparison study. These gauging station locations are given in Table 1 and shown in Figure 1 (D_1 to D_5). A total of 30-year monthly rainfall data (1988–2017) were collected from Meteorological Department, Sri Lanka.

Sri Lanka experiences four rainfall seasons: northeast monsoon (December–February), first intermediate season (March–April), southwest monsoon (May–September), and second intermediate season (October–November). Therefore, rainfall data were processed as the seasonal rainfalls other than the monthly rainfalls and annual rainfalls. Then, the statistical trend analysis and graphical trend analysis were carried out.

5. Results and Discussion

Figures 2(a)–2(e) show the obtained graphical trends for the annual rainfalls in the rain gauges in Uma Oya catchment. The straight lines in the figures are the 45° lines (1 : 1 lines). The two dashed lines above and below the straight line are the 10% variance lines from the 45° line. Scattered data show the potential trends in the second half of the time series compared to the first half of the time series. It was assumed herein that the trend is not predicted if the data scatter is in between or much closer to the variances of the 45° line. Therefore, Figures 2(a)–2(e) suggest that there are upward trends in Kirkless estate and Ledgerwatte estate rain gauges. Dyrabba estate too shows a bit upward trend; however, the data scatter is inconclusive for a sound conclusion. Therefore, it is kept at no trend status. However, other two rain gauge stations (Hilpankandura estate and Welimada group) clearly show no possible trends in rainfall for the annual rainfall data.

The graphical trend findings are confirmed from the statistical trend analysis. The comparison results are shown in Table 2. As it can be seen from the Table 2, similar findings were illustrated in the statistical analysis for the annual rainfall for the Uma Oya catchment. Therefore, for the annual rainfall analysis, both tests generate similar rainfall trends.

Table 3 shows the graphical and statistical trend analysis results for the seasonal rainfalls in Uma Oya catchment. Trend analysis figures are not included in this paper due to length limitations. Highlighted (in grey) sections show the comparable results for the statistical and graphical trend analysis. Hilpankandura estate in first intermediate season and Ledgerwatte estate in south-western monsoon show incomparable results for the two methods in trend analysis. However, as stated earlier, the majority of the seasons in the rain gauging stations provide comparable results.

Table 4 extends the analysis for the monthly basis over the years. Even though the table shows few in-comparisons, the majority of the months show the comparable trend results from the two methods. Dyrabba estate and Hilpankandura estate have four incomparable months in each. All other gauging stations have less than those of. Therefore, in general, the two tests in trends analysis produce acceptable and comparable results.

Results for extended comparisons of trend analysis for the second catchment are given in the following figure (Figure 3) and tables (Tables 5–7). Figure 3(a) gives the graphical trend analysis results for Alupolla estate for annual rainfall. A section of data points are above the +10% of the 45° degree line. However, the other section is inside the +10% and −10%; therefore, it was considered a "no trend" situation. However, Figures 3(b) and 3(c) show majority of their data points under the −10% line to the 45° line. Therefore, they show negative trends. Similarly, Figure 3(d) visualizes a no-trend situation while Figure 3(e) represents a positive trend.

Table 5 presents the statistical and graphical trend analysis results for the annual rainfall values. Comparable results show that it has only 60% acceptability. Alupolla estate and Galaboda estate trend analysis results are incomparable. However, other three rain gauges show acceptable comparable results.

The extended analysis results in seasonal basis are shown in the Table 6. Despite few incomparable cases in between statistical trend and graphical trend analyses, the majority of the seasons for five rain gauges have comparable trends. Similar results can be seen in the Table 7 where it gives the trend analysis in higher resolutions in months. Therefore, in general, Uma Oya catchment and Denawaka Ganga catchment produce comparable trend analysis results.

6. Conclusions

Two tests in trend analysis, statistical trend analysis, and graphical trend analysis results produced for two catchments in the tropical climate in Sri Lanka show that the both tests are in generally produces comparable trends in rainfall. Trend analyses for annual time series data, seasonal time series, and monthly time series have clearly shown that the innovative trend analysis technique has a merit similar to the statistical trend analysis techniques. The following table (Table 8) concludes the above stated observation. In conclusion, the two catchments have 81.2% (Uma Oya catchment) and 75.3% (Denawaka Ganga catchment) comparable results in trend analysis.

The innovative method is easy to conduct and the cost of the computation is lower compared to others. Therefore, the technique can be widely used in identifying the trends. However, this technique does not provide any numerical value of the trend. Therefore, the innovative method is a qualitative analysis rather than a quantitative analysis. Therefore, this can be well used to identify the possible trends at a resource less environment. If the trend is quantitatively important, at least a statistical trend analysis has to be carried out.

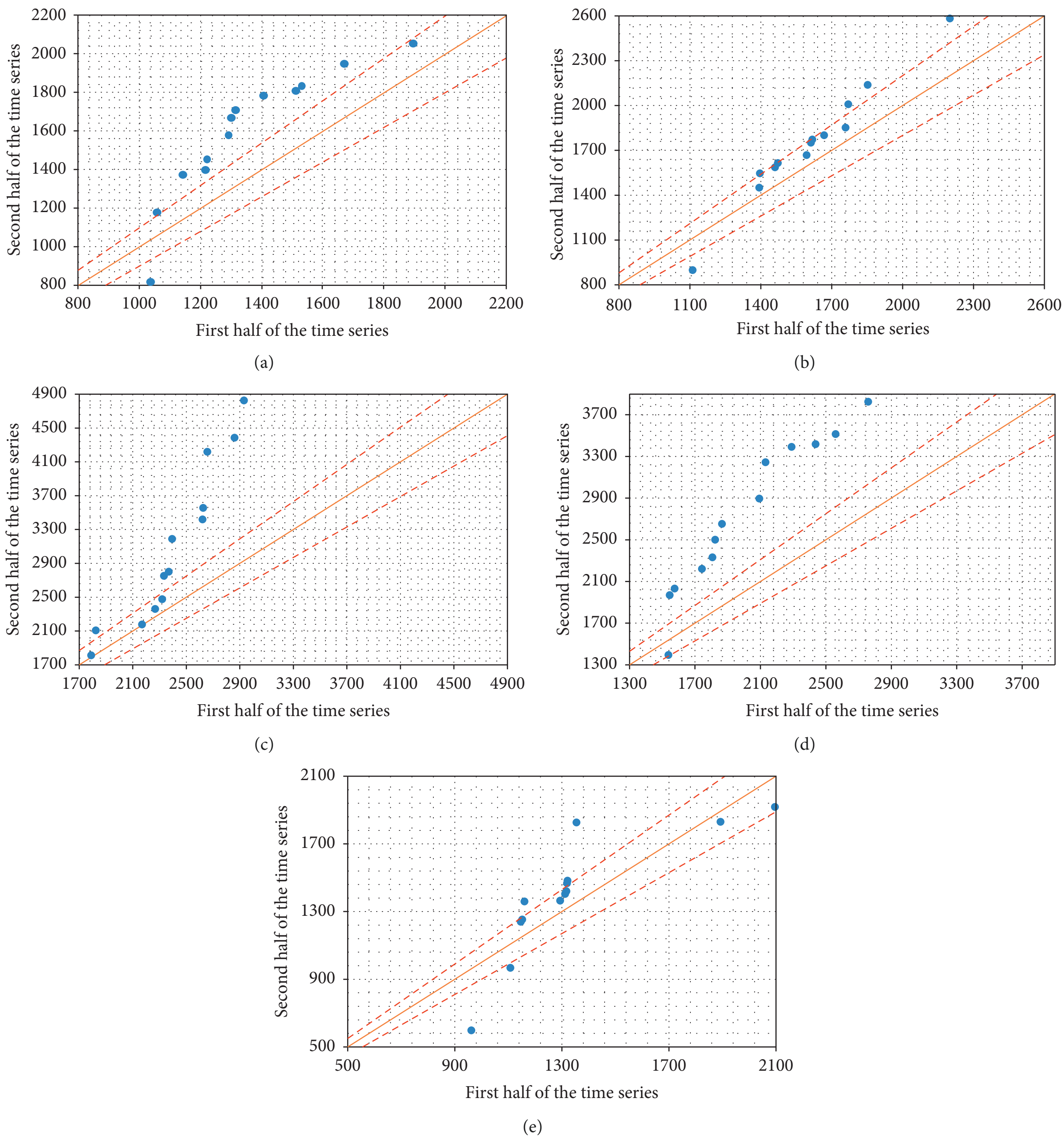


Figure 2: Graphical trends for annual rainfalls for Uma Oya catchment. (a) For Dyrabba estate. (b) For Hilpankandura estate. (c) For Kirklees estate. (d) For Ledgerwatte estate. (e) For Welimada group.

Table 2: Comparison results for annual rainfalls for Uma Oya catchment.

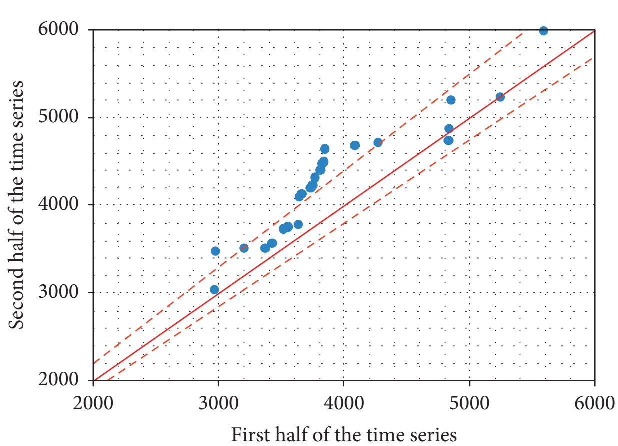
Raingauge station	Statistical trend analysis [32]	Graphical trend analysis
Dyrabba estate	No trend	No trend
Hilpankandura estate	No trend	No trend
Kirklees estate	Yes—upward (48 mm)	Yes—upward
Ledgerwatte estate	Yes—upward (59.3 mm)	Yes—upward
Welimada group	No trend	No trend

Table 3: Comparison results for seasonal rainfalls for Uma Oya catchment.

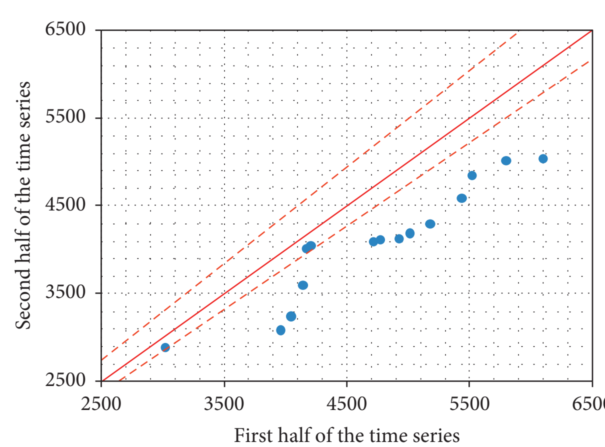
Raingauge station	Season	Statistical trend analysis [32]	Graphical trend analysis
Dyrabba estate	1^{st}	No trend	No trend
	NE	No trend	No trend
	2^{nd}	No trend	No trend
	SW	No trend	No trend
Hilpankandura estate	1^{st}	No	Yes—upward
	NE	No trend	No trend
	2^{nd}	No trend	No trend
	SW	No trend	No trend
Kirklees estate	1^{st}	Yes—upward	Yes—upward
	NE	No trend	No trend
	2^{nd}	No trend	No trend
	SW	No trend	No trend
Ledgerwatte estate	1^{st}	Yes—upward	Yes—upward
	NE	No trend	No trend
	2^{nd}	No trend	No trend
	SW	No	Yes—upward
Welimada group	1^{st}	Yes—upward	Yes—slightly upward
	NE	No trend	No trend
	2^{nd}	No trend	No trend
	SW	No trend	No trend

Table 4: Comparison results for monthly rainfalls for Uma Oya catchment.

Month	Trends									
	Dyrabba		Hilpankandura		Kirklees		Ledgerwatte		Welimada	
	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical
Jan	No	No	No	No	No	No	No	No	No	No
Feb	No	No	No	No	No	No	No	No	No	No
Mar	No	Yes—up	No	Yes—up	Yes—up	Yes—up	Yes—up	Yes—up	Yes—up	Yes—up
Apr	No	No	No	No	No	No	No	No	No	No
May	No	Yes—up	No	No	No	No	No	Yes—up	No	No
Jun	No	No	Yes—down	No	No	No	No	No	No	Yes—down
Jul	No	Yes—down	No	Yes—down	No	No	No	No	No	No
Aug	No	No	No	No	No	No	No	No	No	No
Sep	No	No	No	Yes—down	No	No	No	No	No	No
Oct	No	No	No	No	No	Yes—up	No	Yes—up	No	No
Nov	No	No	No	No	No	No	No	No	No	No
Dec	No	Yes—up	No	No	No	Yes—up	No	Yes—up	No	No

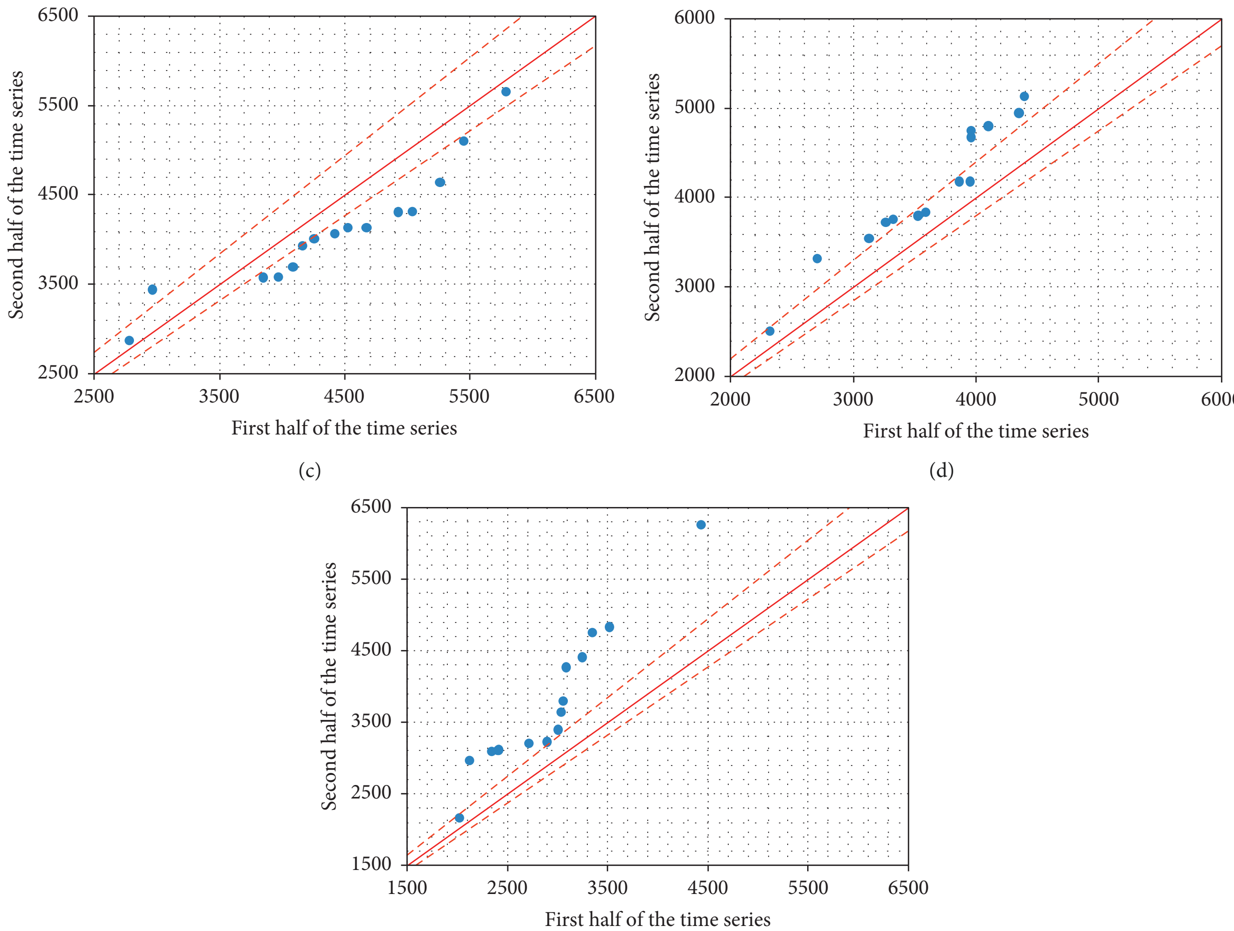


(a)



(b)

Figure 3: Continued.



(c) (d) (e)

Figure 3: Graphical trends for annual rainfalls for Denawaka Ganga catchment. (a) Allupola estate, (b) Hapugastenna estate, (c) Galaboda estate, (d) Lellopitiya estate, and (e) Landsdown middle division estate.

Table 5: Comparison results for annual rainfalls for Denawaka Ganga catchment.

Raingauge station	Statistical trend analysis [18]	Graphical trend analysis
Allupola estate	Yes—upward (15.5 mm)	No
Hapugastenna estate	Yes—downward (32 mm)	Yes—downward
Galaboda estate	No	Yes—downward
Lellopitiya estate	No	No
Landsdown middle division estate	Yes—upward (56.5 mm)	Yes—upward

Table 6: Comparison results for seasonal rainfalls for Denawaka Ganga catchment.

Raingauge station	Season	Statistical trend analysis	Graphical trend analysis
Allupola estate	1^{st}	No	No
	NE	No	No
	2^{nd}	Yes—upward	No
	SW	No	No
Hapugastenna estate	1^{st}	No	No
	NE	No	Yes—downward
	2^{nd}	No	No
	SW	No	Yes—downward

Table 6: Continued.

Raingauge station	Season	Statistical trend analysis	Graphical trend analysis
Galaboda estate	1st	No	No
	NE	No	No
	2nd	No	No
	SW	No	No
Lellopitiya estate	1st	No	Yes—upward
	NE	No	No
	2nd	No	No
	SW	No	No
Landsdown middle division estate	1st	Yes—upward	Yes—upward
	NE	Yes—upward	Yes—upward
	2nd	Yes—upward	No
	SW	No	No

Table 7: Comparison results for monthly rainfalls for Denawaka Ganga catchment.

Month	Trends									
	Allupola estate		Hapugastenna estate		Galaboda estate		Lellopitiya estate		Landsdown middle division estate	
	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical	Statistical	Graphical
Jan	No	Yes—up	No	No	No	No	No	No	No	No
Feb	No	No	No	Yes—down	No	No	No	No	No	No
Mar	No	No	No	No	Yes—up	Yes—up	No	Yes - up	No	No
Apr	No	No	No	No	Yes—up	No	No	No	No	No
May	No	No	No	No	Yes—up	No	No	No	No	Yes—up
Jun	No	No	No	No	No	No	No	No	No	Yes—up
Jul	No	No	No	Yes—down	No	No	No	No	Yes—down	No
Aug	No	No	No	No	Yes—up	No	No	No	No	Yes—up
Sep	No	No	No	No	No	No	No	No	No	No
Oct	No	No	No	Yes—down	No	No	No	No	No	No
Nov	No	No	No	No	Yes—up	No	No	No	No	No
Dec	No	No	No	No	No	No	No	No	No	No

Table 8: Comparison percentages for two catchments in different rainfall periods.

Catchment	Rainfall periods		
	Annual (%)	Seasonal (%)	Monthly (%)
Uma Oya	100	90	76.7
Denawaka Ganga	60	75	78.3

However, it is important to carry out more trend analysis for many catchments and get sound conclusions. In general, it can be concluded herein that the graphical analysis can be easily adopted for the rainfall trend analysis for the qualitative analysis; however, for a quantitative analysis, a statistical trend analysis is recommended.

Data Availability

The climatic data and the analysis data are available from the corresponding author upon request.

Disclosure

The research was carried out in the Sri Lanka Institute of Information Technology, Sri Lanka.

Conflicts of Interest

The author declares that there are no conflicts of interest.

References

[1] G. Naveendrakumar, M. Vithanage, H.-H. Kwon, M. C. M. Iqbal, S. Pathmarajah, and J. Obeysekera, "Five decadal trends in averages and extremes of rainfall and temperature in Sri Lanka," *Advances in Meteorology*, vol. 2018, Article ID 4217917, 13 pages, 2018.

[2] P. Shi, X. Ma, X. Chen, S. Qu, and Z. Zhang, "Analysis of variation trends in precipitation in an upstream catchment of Huai river," *Mathematical Problems in Engineering*, vol. 2013, Article ID 929383, 11 pages, 2013.

[3] M. Amirabadizadeh, Y. F. Huang, and T. S. Lee, "Recent trends in temperature and precipitation in the Langat river basin, Malaysia," *Advances in Meteorology*, vol. 2015, Article ID 579437, 16 pages, 2015.

[4] D. R. Easterling, "Maximum and minimum temperature trends for the globe," *Science*, vol. 277, no. 5324, pp. 364–367, 1997.

[5] E. Kahya and S. Kalaycı, "Trend analysis of streamflow in Turkey," *Journal of Hydrology*, vol. 289, no. 1–4, pp. 128–144, 2004.

[6] G. Fu, S. P. Charles, and J. Yu, “A critical overview of pan evaporation trends over the last 50 years,” *Climatic Change*, vol. 97, no. 1-2, pp. 193–214, 2009.

[7] S. Rehman, “Long-term wind speed analysis and detection of its trends using Mann-Kendall test and linear regression method,” *Arabian Journal for Science and Engineering*, vol. 38, no. 2, pp. 421–437, 2012.

[8] K. Tesfay, M. Yohannes, and S. Bayisa, “Trend analysis of malaria prevalence in Raya Azebo district, Northern Ethiopia: a retrospective study,” *BMC Research Notes*, vol. 11, no. 1, p. 900, 2018.

[9] S. Greenland, “Dose-response and trend analysis in epidemiology,” *Epidemiology*, vol. 6, no. 4, pp. 356–365, 1995.

[10] B. Barr, D. Taylor-Robinson, A. Scott-Samuel, M. McKee, and D. Stuckler, “Suicides associated with the 2008-10 economic recession in England: time trend analysis,” *BMJ*, vol. 345, p. e5142, 2012.

[11] V. Y. Dombrovskiy, A. A. Martin, J. Sunderram, and H. L. Paz, “Rapid increase in hospitalization and mortality rates for severe sepsis in the United States: a trend analysis from 1993 to 2003,” *Critical Care Medicine*, vol. 35, no. 5, pp. 1244–1250, 2007.

[12] E. Toth, A. Brath, and A. Montanari, “Comparison of short-term rainfall prediction models for real-time flood forecasting,” *Journal of Hydrology*, vol. 239, no. 1–4, pp. 132–147, 2000.

[13] H. Azamathulla, U. Rathnayake, and A. Shatnawi, “Gene expression programming and artificial neural network to estimate atmospheric temperature in Tabuk, Saudi Arabia,” *Applied Water Science*, vol. 8, no. 6, pp. 184–190, 2018.

[14] B. Onoz and M. Bayazit, “The power of statistical tests for trend detection,” *Turkish Journal of Engineering and Environmental Sciences*, vol. 27, pp. 247–251, 2003.

[15] H. B. Mann, “Nonparametric tests against trend,” *Econometrica*, vol. 13, no. 3, pp. 245–259, 1945.

[16] M. Kendall, *Rank Correlation Methods*, Charles Griffin, London, UK, 4th edition, 1975.

[17] R. M. Hirsch, J. R. Slack, and R. A. Smith, “Techniques of trend analysis for monthly water quality data,” *Water Resources Research*, vol. 18, no. 1, pp. 107–121, 1982.

[18] B. Khaniya, H. G. Priyantha, N. Baduge, H. M. Azamathulla, and U. Rathnayake, “Impact of climate variability on hydropower generation: a case study from Sri Lanka,” *ISH Journal of Hydraulic Engineering*, pp. 1–9, 2018.

[19] P. Wickramagamage, “Spatial and temporal variation of rainfall trends of Sri Lanka,” *Theoretical and Applied Climatology*, vol. 125, no. 3-4, pp. 427–438, 2016.

[20] R. Wilcox, *Fundamentals of Modern Statistical Methods*, Springer, New York, NY, USA, 1st edition, 2001.

[21] H. Theil, “A rank-invariant method of linear and polynomial regression analysis. I, II, III,” *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, vol. 53, pp. 386–1412, 1950.

[22] P. K. Sen, “Estimates of the regression coefficient based on Kendall’s Tau,” *Journal of the American Statistical Association*, vol. 63, no. 324, pp. 1379–1389, 1968.

[23] S. Yue and C. Y. Wang, “Applicability of prewhitening to eliminate the influence of serial correlation on the Mann-Kendall test,” *Water Resources Research*, vol. 38, no. 6, pp. 4-1–4-7, 2002.

[24] H. von Storch, “Misuses of statistical analysis in climate research,” in *Analysis of Climate Variability: Applications of Statistical Techniques*, H. von Storch and A. Nawarra, Eds., pp. 11–26, Springer-Verlag, Berlin, Germany, 1995.

[25] G. C. Blain, “The Mann-Kendall test: the need to consider the interaction between serial correlation and trend,” *ActaScientiarum. Agronomy*, vol. 35, no. 4, pp. 393–402, 2013.

[26] S. Razavi and R. Vogel, “Prewhitening of hydroclimatic time series? Implications for inferred change and variability across time scales,” *Journal of Hydrology*, vol. 557, pp. 109–115, 2018.

[27] Z. Şen, “Innovative trend analysis methodology,” *Journal of Hydrologic Engineering*, vol. 17, no. 9, pp. 1042–1046, 2012.

[28] Z. Şen, “Innovative trend significance test and applications,” *Theoretical and Applied Climatology*, vol. 127, no. 3-4, pp. 939–947, 2017.

[29] Z. Şen, “Hydrological trend analysis with innovative and over-whitening procedures,” *Hydrological Sciences Journal*, vol. 62, no. 2, pp. 294–305, 2016.

[30] A. Öztopal and Z. Şan, “Innovative trend methodology applications to precipitation records in Turkey,” *Water Resources Management*, vol. 31, no. 3, pp. 727–737, 2016.

[31] M. Gedefaw, D. Yan, H. Wang et al., “Innovative trend analysis of annual and seasonal rainfall variability in Amhara regional state, Ethiopia,” *Atmosphere*, vol. 9, no. 9, pp. 326–335, 2018.

[32] H. Barghamadi, P. Nater, and P. Huwyler, “Hydraulic fracturing stress measurements and their implication for the design of the first concrete lined pressure shaft in Sri Lanka,” *Journal of Hydraulic Engineering*, vol. 2, no. 1, pp. 60–66, 2016.

[33] B. Khaniya, I. Jayanayaka, P. Jayasanka, and U. Rathnayake, “Rainfall trend analysis in Uma Oya basin, Sri Lanka, and future water scarcity problems in perspective of climate variability,” *Advances in Meteorology*, vol. 2019, Article ID 3636158, 10 pages, 2019.

[34] H. K. Nandalal and U. R. Ratnayake, “Flood risk analysis using fuzzy models,” *Journal of Flood Risk Management*, vol. 4, no. 2, pp. 128–139, 2011.