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Original Article

Rainfall trend analysis in the Mae Klong River Basin, Thailand

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Abstract

This paper examined seasonal and annual rainfall trends of the Mae Klong River Basin in Thailand. Monthly rainfall data of eight stations were used for the period 1971–2015. The non-parametric Mann-Kendall test was used to detect trends whereas the slope of the trends was determined by Sen's slope method. Datasets with significant serial correlation were corrected by the pre-whitening approach. For the dry season, 5 out of 8 stations showed increasing rainfall trends while for the wet season, 50% of the stations showed increasing trends. On an annual scale, 75% of the stations exhibited increasing rainfall trends. The upper region of the basin which contributes inflows to the Srinagarind and Vajiralongkorn Dams had increasing annual rainfall trends. For the entire basin, the trend analysis found increasing rainfall on both seasonal and annual scales. The results of this study can help water resource managers prepare better assessments and planning of water resources in the basin.

Keywords: rainfall, trend analysis, Mann-Kendall test, Sen's slope test, Mae Klong River Basin

1. Introduction

Climate and hydro-meteorological studies are mainly influenced by rainfall. Changes in the pattern of rainfall and its effects on water resources are among the major problems faced by water resource planners. Rainfall is the primary source for agricultural food production and regulates our ecosystems. The availability of an ample quantity of freshwater resources is critical for life on earth. Climate change, economic growth, and the increase in population have increased the challenges of decision makers to properly allocate water among different water use sectors. Accurate knowledge of the rainfall regime is a prerequisite for effective water resources planning and management.

The availability of freshwater resources in Southeast Asia is projected to decrease, especially in the large river basins due to climate change. The factors responsible are population increase and a rise in demand due to higher living standards (Intergovernmental Panel on Climate Change [IPCC], 2007). Extreme weather conditions in the form of heavy rainfall hit Thailand in December 2016 which pointed to the challenges posed by climate change. The Asian Development Bank reported climate change to be one of the main hurdles for the development of Southeast Asia. Thailand is a major exporter of rice and agriculture output is 10% of GDP. Thailand faced four years of drought prior to heavy rainfall in December 2016 which largely affected its agricultural sector. The livelihood of the people associated with agriculture was also significantly affected. The heavy rainfalls at the end of 2016 on one side ended the drought effects but this extreme event resulted in flooding of 2387.64 km^2 (590, 000 acres) of farmland (Hinteregger, 2017). The impacts of climate change on Thailand such as violent flooding, prolonged droughts, decreased yields of agriculture and fisheries, and the rise in sea levels are already serious and will contribute to additional problems such as challenges in water management and in the tourism industry in the next few decades. These could have serious implications for the economic growth of Thailand. The government of Thailand has begun efforts to mitigate and adapt to the effects of climate change but these are limited due to the lower level of institutional capacity (Marks, 2011).

Thailand has twenty-five major river basins among which the Mae Klong River Basin has plentiful water resources which are vital for the economy of Thailand.

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Shrestha (2014) reported rainfall anomalies for the Mae Klong River Basin using data from a Regional Climate Model (PRECIS) for two SRES (Special Report on Emission Scenarios) scenarios A2 and B2. Results showed that rainfall anomalies are projected to increase in the wet season and decrease in the dry season in the near future of the 2020s (2011-2040). As a result, water availability is expected to increase under both scenarios for the wet season in the Mae Klong River Basin. Sharma and Babel (2018) analyzed the effects of climate change on streamflow using improved daily precipitation data from the ECHAM4/OPYC climate model. Results indicated that climate change will not significantly impact water resources or water availability in the coming decades in the Mae Klong River Basin. Furthermore, there could be a chance for monsoons to arrive before the start of the regular period. It is also expected that the streamflow will increase in the dry season and decrease in the wet season in the Basin. Rojrungtavee (2009) studied water supply and demands under future climate change in the Mae Klong River Basin using data from the PRECIS climate model. Results showed increased magnitude in peak rainfall with shorter durations of rainy seasons. A significant reduction in crop water requirement was estimated for the irrigation demand in the future due to the effects of climate change in the wet season. Simulation of reservoir operations in the basin showed small shortages for the irrigation demands during both the dry and wet seasons. Manee, Tachikawa, and Yorozu (2015) studied changes in the hydrological variables for selected basins in Thailand using the Mann-Kendall (MK) test for the period 1980–2011. For the Mae Klong River Basin, three weather stations were considered, namely Umphang (Thai Meteorological Department [TMD] 376401), Thong Pha Phum (Royal Irrigation Department [RID] 130053), and Kanchanaburi (RID 130013). The results showed an increasing trend in rainfall for the Umphang and Thong Pha Phum stations on a seasonal scale (both dry and wet seasons) as well as on an annual scale. However, a decreasing rainfall trend was observed for the Kanchanaburi station. The trends in inflows to the two main dams in the Mae Klong River Basin (Srinagarind and Vajiralongkorn Dams) were found to be increasing on seasonal and annual scales. Limsakul and Singhruck (2016) analyzed long term trends and variability of total and extreme precipitation in Thailand for 1955–2014. Results indicated that precipitation events have been less frequent but more intense for most of Thailand.

Planning and development of water resource projects are primarily based on the past climate as a reliable guide under the assumption of stationarity, that is, the climate will remain stable (or stationary) for the next multiple decades irrespective of the variations in climate variables such as rainfall and temperature. However, climate change is altering the hydrological system as it brings non-stationarity into the systems (Hayhoe, 2015). Trends detection in the hydro-meteorological variables has received increasing attention and has been studied by many researchers globally. The aim of this research study was to analyze the temporal and spatial trends in rainfall for the Mae Klong River basin which could be useful for better assessment and planning of water resources.

2. Study Area

The Mae Klong River Basin lies between 13º8′-16º23′N in latitude and 98º11′-100º13′E in longitude in the west of Thailand with a total area of 30,167 km^2 (Figure 1). There are two main storage dams which are the Srinagarind Dam and Vajiralongkorn Dam, and two diversion dams which are the Tha Thung Na Dam and Mae Klong Dam. Two small tributaries of the Lam Taphoen River discharge into the Khwae Yai River and the Lampachi River drains into the Khwae Noi River. Water inside the basin is available for domestic and industrial demands, hydroelectric power, and salinity control. Outside the basin, water is supplied to the neighboring Tha Chin Basin in the dry season and to the Metropolitan Waterworks Authority in Bangkok. The Greater Mae Klong Irrigation Project (GMKIP), which is the second largest irrigation project in Thailand, is located in the lower part of the basin. The GMKIP is composed of 10 sub-irrigation projects, two of which are located on the right side while eight are situated on the left side of the Mae Klong River (Khalil, Rittima, & Phankamolsil, 2018).

3. Materials and Methods

3.1 Data

The monthly rainfall data of eight stations were obtained from the TMD and RID for 1971–2015 (Figure 2a). Owing to the variation of rainfall, the basin was divided into 3 sub-regions, namely the Upper Region, the Middle Region, and the Lower Region. Annual rainfall data for the eight stations are shown in Figure 3 while the statistical analysis (maximum, minimum, and coefficient of variation [CV]) of the annual data is given in Table 1. The mean annual rainfall varied from 840.73 mm (Station 130042) in the lower part of the basin to 1767.93 mm (Station 130053) in the upper area of the basin. The CV varied from 17% (Station 130053) to 36% (Station 130042) for the eight stations. The mean annual rainfall of the stations was interpolated using the inverse distance weighting technique in TeREsA software. The spatial distribution of the mean annual rainfall in the basin is shown in Figure 2b. Average annual rainfall totals in the basin point to higher rainfall in the upper part of the basin and lower rainfall in the lower part of the basin where the most extensive water demands including GMKIP are located.

3.2 Methods

3.2.1 Rainfall data homogeneity tests

Homogeneity tests are used to assess the effects of non-climatic factors such as changes in instruments, observa-tion practices, station relocations, and station environments on climate time series data (Toreti *et al.*, 2011). The homogeneity of the rainfall data for the eight stations was assessed by two commonly used tests: the Standard Normal Homogeneity Test (SNHT) proposed by Alexandersson (1986) and the Buishand Test proposed by Buishand (1982). These tests were conducted at 5% significance level using the ‘trend’ R-

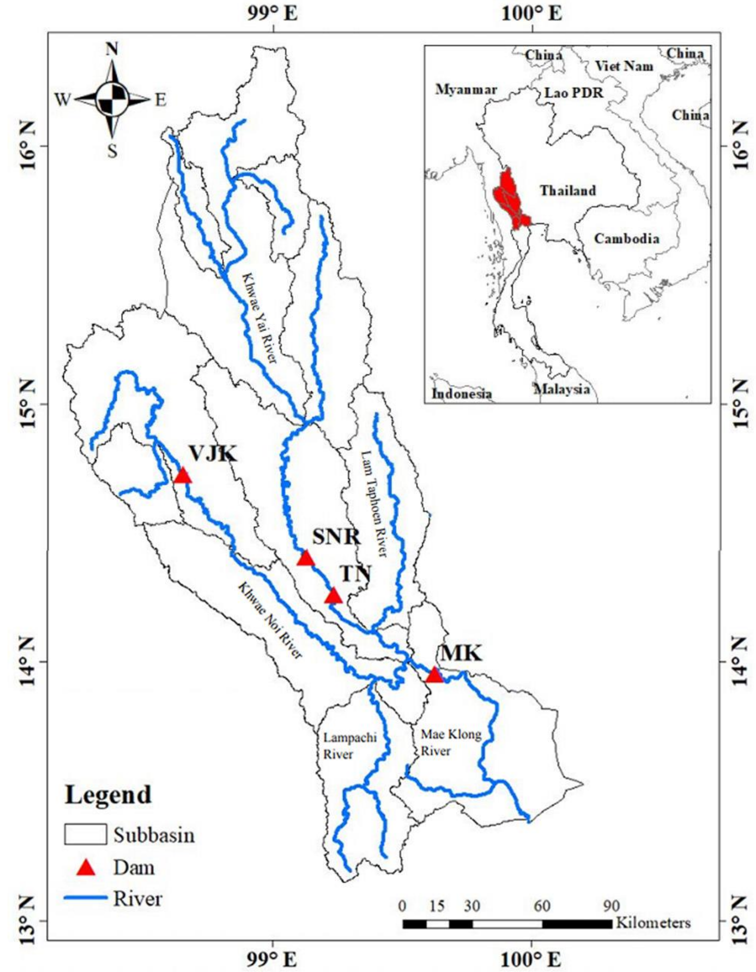

Figure 1. The Mae Klong River Basin.
VJK=Vajiralongkorn Dam, SNR=Srinagarind Dam, TN=Tha Thung Na Dam, MK=Mae Klong Dam.

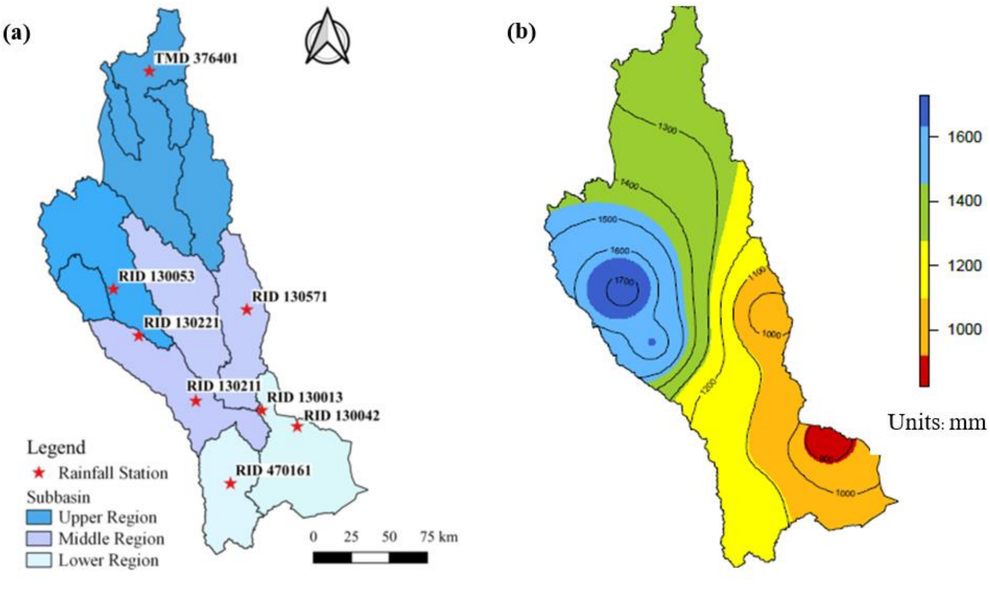

Figure 2. Spatial distribution of rainfall stations and mean annual rainfall in the Mae Klong River Basin for 1971–2015.

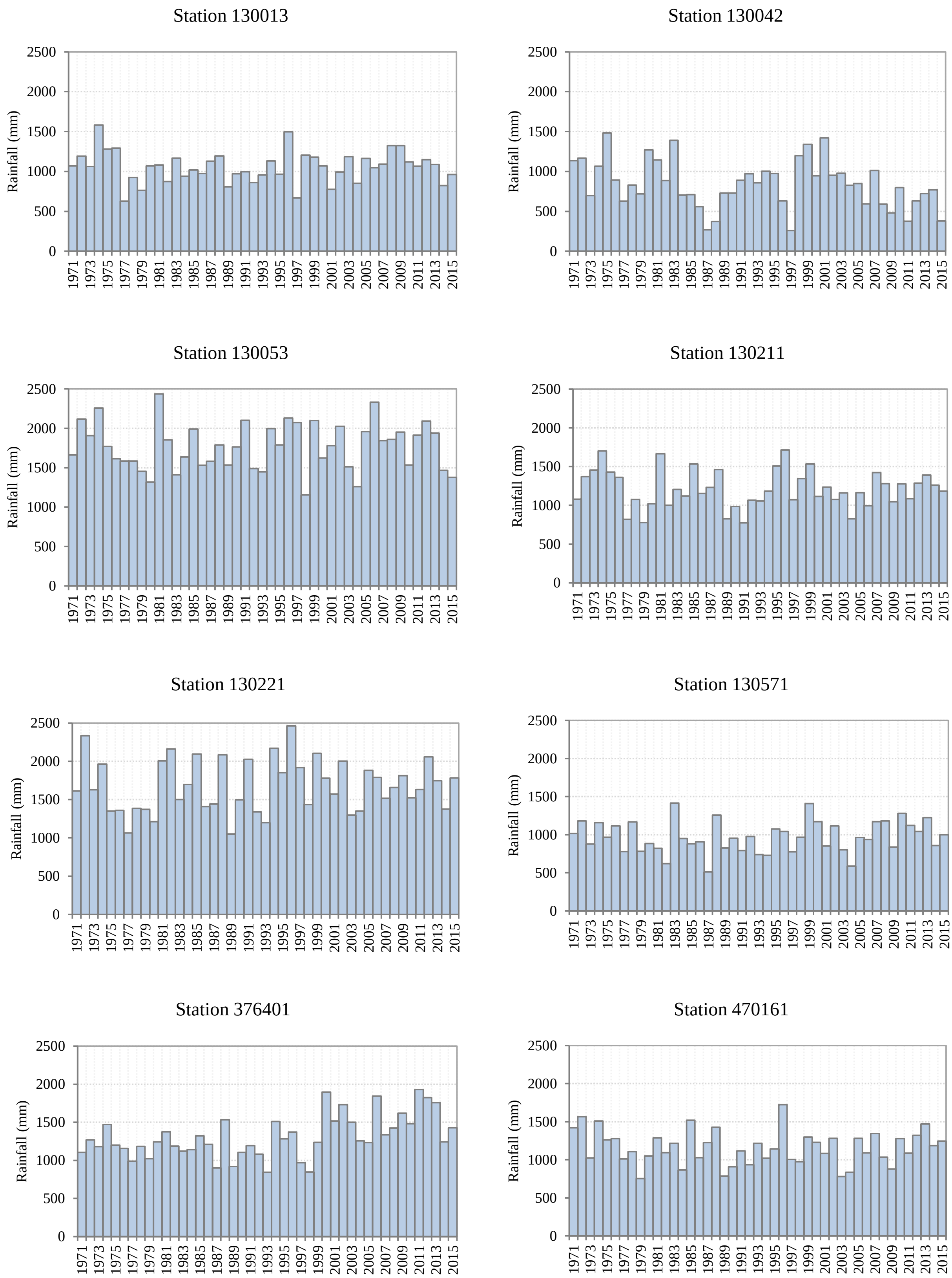

Figure 3. Annual rainfall of 8 stations in the Mae Klong River Basin during 1971–2015.

Table 1. Statistical properties of annual rainfall data from 1971 to 2015.

Rainfall Stations		Min. Rainfall (mm)	Max. Rainfall (mm)	Avg. Rainfall (mm)	CV
Name	Code				
A. Mueang, Kanchanaburi	Station 130013	627.70	1581.70	1055.87	0.18
A. Tha Maka, Kanchanaburi	Station 130042	260.30	1481.20	840.73	0.36
A. Thong Pha Phum, Kanchanaburi	Station 130053	1155	2438.70	1767.93	0.17
Ban Lum Sum, Kanchanaburi	Station 130211	774.20	1713.50	1207.41	0.20
Huai Mae Nam Noi, Kanchanaburi	Station 130221	1049.80	2462.10	1677.58	0.20
Ban Thong Pong, Kanchanaburi	Station 130571	508.88	1414.41	970.49	0.21
Umphang, Tak	Station 376401	844.57	1928.90	1310.84	0.21
Ban Bo, Ratchaburi	Station 470161	754.00	1722.20	1159.71	0.19

package (Pohlert, 2018). The rainfall data were considered homogeneous if the values of the SNHT test statistic (To) were less than 8.33 (Alexandersson, 1986) and values of the Buishand test statistic ($R/\sqrt{n}$) were less than 1.55 (Buishand, 1982) for a data sample of 45. Results of the two tests for the mean annual rainfall data of the stations are given in Table 2. The results of the test statistics for both tests were less than the critical values which showed that the rainfall data were homogenous.

3.2.2 Serial correlation effect

The MK test requires the rainfall time series (x_1, x_2, x_3, ……, x_n) to be serially independent. If the data have a serial correlation (also called autocorrelation) then the significance level of the MK test will be either underestimated or overestimated depending upon the serial correlation to be negative or positive. If the lag-1 correlation coefficient (denoted by r_1) is not significant at the 95% confidence level then the MK test is applied to the original data series. If the lag-1 correlation coefficient is significant, then the original series is 'pre-whitened' before application of the MK test. The pre-whitened series can be obtained as (x_2-r_1x_1, x_3-r_1x_2,….., x_n-r_1x_{n-1}) (Luo *et al.*, 2008).

3.2.3 Mann–Kendall (MK) trend test

The MK test statistic S is calculated as (Kendall, 1975; Mann, 1945)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{Sgn}(x_j - x_k) \quad (1)$$

where

$$\mathrm{Sgn}(x_j-x_k) = \begin{bmatrix} 1 & \text{if } (x_j-x_k) > 0 \\ 0 & \text{if } (x_j-x_k) = 0 \\ -1 & \text{if } (x_j-x_k) < 0 \end{bmatrix}, \quad (2)$$

x_j and x_k are sequential values of the time series data, and n is the length of the dataset. A positive value of S indicates increasing trend and a negative value indicates decreasing trend. If the dataset length is more than 10, then the test is done using the normal distribution with expectation (E) and variance (var). The expectation describes the average value and the variance describes the spread (amount of variability) around the expectation.

Table 2. Homogeneity tests statistics for mean annual rainfall data (For homogeneous series, To < 8.33, and $R/\sqrt{n} < 1.55$).

Station	SNHT statistic (To)	Buishand test statistic ($R/\sqrt{n}$)
Station 130013	6.65	1.29
Station 130042	6.78	1.18
Station 130053	2.82	0.85
Station 130211	4.45	1.10
Station 130221	2.46	1.14
Station 130571	3.10	1.11
Station 376401	2.51	1.26
Station 470161	4.69	1.15

$$\mathrm{var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \quad (3)$$

In Equation 3, q is the number of tied groups, and t_p denotes the number of ties of extent p. A tied group is a set of sample data having the same value. The standard test statistic (Z_{MK}) is given by

$$Z_{MK} = \begin{bmatrix} \frac{S-1}{\sqrt{\mathrm{var}(S)}} & \text{if } S>0 \\ \frac{S+1}{\sqrt{\mathrm{var}(S)}} & \text{if } S<0 \\ 0 & \text{if } S=0 \end{bmatrix}. \quad (4)$$

The value of Z_{MK} is the MK test statistic that follows a normal distribution having a mean of 0 and a variance of 1. The trend test can be done at a selected significance level denoted by α. The null hypothesis of no trend is rejected when $|Z_{MK}| > Z_{1-\alpha/2}$, and the time series has a statistically significant trend. The value of $Z_{1-\alpha/2}$ can be obtained from the standard normal distribution table. In this study, the MK test was applied for detection of rainfall trends that were statistically significant at α=0.001 (99.9% confidence intervals), α=0.01 (99% confidence intervals), α=0.05 (95% confidence intervals), and α=0.1 (90% confidence intervals). At the 0.1%, 1%, 5%, and 10% significance levels, the null hypothesis (no trend) is rejected if $|Z_{MK}|>3.29$, $|Z_{MK}|>2.576$, $|Z_{MK}|>1.96$, and $|Z_{MK}|>1.64$, respectively.

3.2.4 Sen's slope method

This non-parametric method (Sen, 1968) is used to determine the magnitude (or slope) of a trend in hydro-meteorological data. The technique involves calculating slopes for all of the pairs of ordinal time points and then using the median of these slopes as the estimate of the overall slope. This technique can be effectively used for quantification of a trend in time series data since it is not sensitive to outliers. The magnitude of the trend slope Q is computed as

$$Q = \text{median}\left[\frac{x_j - x_k}{j - k}\right] \qquad \forall \; k < j \qquad (5)$$

where for i = 1, 2, ..., N, x_j is the data value at time j, x_k is the data value at time k and j is the time after k (j>k) and N is a number of all pairs x_j and x_k.

The excel template MAKESENS 1.0 (MK test for trend and Sen's slope estimates), which is a free and easy-to-use tool developed by Finnish Meteorological Institute, Finland, was used to detect and estimate the trends in the monthly, seasonal, and annual time series of rainfall data. In MAKESENS, the two-tailed test is used for four different significance levels of α: 0.001; 0.01; 0.05; and 0.1 (Salmi, Maatta, Anttila, Ruoho-Airola, & Amnell, 2002). TeREsA sofwater (Travaglini, Fluixá-Sanmartín, Alesina, Foehn, & García Hernández, 2016), which is a toolbox in R for environmental analysis, was used to plot the spatial distribution of rainfall trends in the Mae Klong River Basin.

4. Results and Discussion

4.1 Calculation of autocorrelation coefficient

R is a programming language and free software environment for statistical computing and graphics. In R, the fundamental unit of shareable code is the package. A package bundles together code, data, documentation, and tests, and is easy to share with others. The R package 'forecast' provides methods and tools for displaying and analyzing univariate time series forecasts including exponential smoothing via state space models and automatic ARIMA modelling. The lag-1 autocorrelation coefficient for the monthly, seasonal, and annual rainfall data for all the stations was calculated using 'forecast' R package (Hyndman, O'Hara-Wild, Bergmeir, Razbash, & Wang, 2017). The lag-1 autocorrelation coefficient values for the monthly, seasonal, and annual time series are given in Table 3. The rainfall series for which the autocorrelation coefficient was significant at 95% confidence level were 'pre-whitened' using the method suggested by Yue, Pilon, Phinney, and Cavadias (2002) before application of the non-parametric tests using 'modifiedmk' R package (Patakamuri, 2018). The R package 'modifiedmk' is useful in implementing modified versions of non-parametric MK trend tests and Spearman's rank correlation coefficient tests.

4.2 Rainfall station-based trend analysis

The trend analysis was carried out on monthly, seasonal, and annual scales for a 45-year period from 1971 to 2015. The seasons in Thailand are generally classified into the dry season from May to October and the wet season from November to April in the central and northern basins. In the western basins due to delayed climate, the dry season is considered from January to June and the wet season from July to December. Therefore, due to location of the Mae Klong River Basin in the western region of Thailand, the dry season was considered from January to June and the wet season from July to December due to climate characteristics (Biltonen, Kwanyuen, Kositsakulchai, & Pattani, 2003; Manee *et al.*, 2015). The spatial distributions of the trend analysis for the monthly, seasonal, and annual time series of rainfall data during 1971–2015 are shown in Figures 4 and 5. The MK test statistic (Z_{MK}) and Sen's slope (Q) for the monthly, seasonal, and annual series of rainfall are given in Table 4. No trends for rainfall were detected for the month of January at any of the stations. In April, six out of eight stations showed increasing trends. The increasing trend for Station 376401 was significant at 99% confidence level with a slope of 1.277 mm/year. The increasing trend at station 130211 was significant at 95% confidence level with a slope of 1.857 mm/year. The months of May and June, which are in the dry season, 5 out of 8 stations showed a decreasing trend. The months of August, September, and October showed similar trends with rainfall trends increasing at 50% (4/8) of stations

Table 3. Lag-1 autocorrelation coefficient for rainfall data.

Month/Season	Autocorrelation Coefficient							
	Station 130013	Station 130042	Station 130053	Station 130211	Station 130221	Station 130571	Station 376401	Station 470161
January	-0.127	-0.015	-0.146	0.131	-0.053	-0.052	-0.208	-0.078
February	-0.127	0.118	-0.006	-0.111	0.028	0.037	-0.043	-0.204
March	0.067	0.191	-0.263	0.071	0.039	-0.188	0.032	-0.128
April	0.128	0.109	-0.184	0.062	0.024	**0.324***	-0.019	-0.039
May	-0.224	0.238	0.193	0.109	-0.225	**-0.321***	-0.173	0.035
June	-0.178	-0.016	0.172	0.143	0.173	0.113	-0.025	0.164
July	-0.095	0.032	0.152	-0.291	-0.017	-0.053	0.209	0.140
August	-0.020	0.022	0.013	-0.120	-0.125	0.082	0.067	0.184
September	0.094	**0.432***	-0.098	0.093	0.104	-0.308	**0.326***	0.005
October	0.122	0.232	**0.352***	0.127	**0.332***	-0.064	0.120	-0.030
November	-0.120	-0.008	0.115	-0.020	-0.106	-0.006	-0.103	0.002
December	0.013	0.065	-0.106	-0.020	-0.149	-0.118	-0.037	-0.114
Dry Season	0.161	**0.372***	-0.023	0.239	-0.173	0.250	0.164	-0.115
Wet Season	-0.078	0.112	-0.009	-0.061	0.048	**-0.376***	**0.323***	-0.069
Annual	-0.013	**0.318***	-0.023	0.170	0.007	-0.122	**0.372***	-0.067

Note: *Statistically significant at 95% confidence level

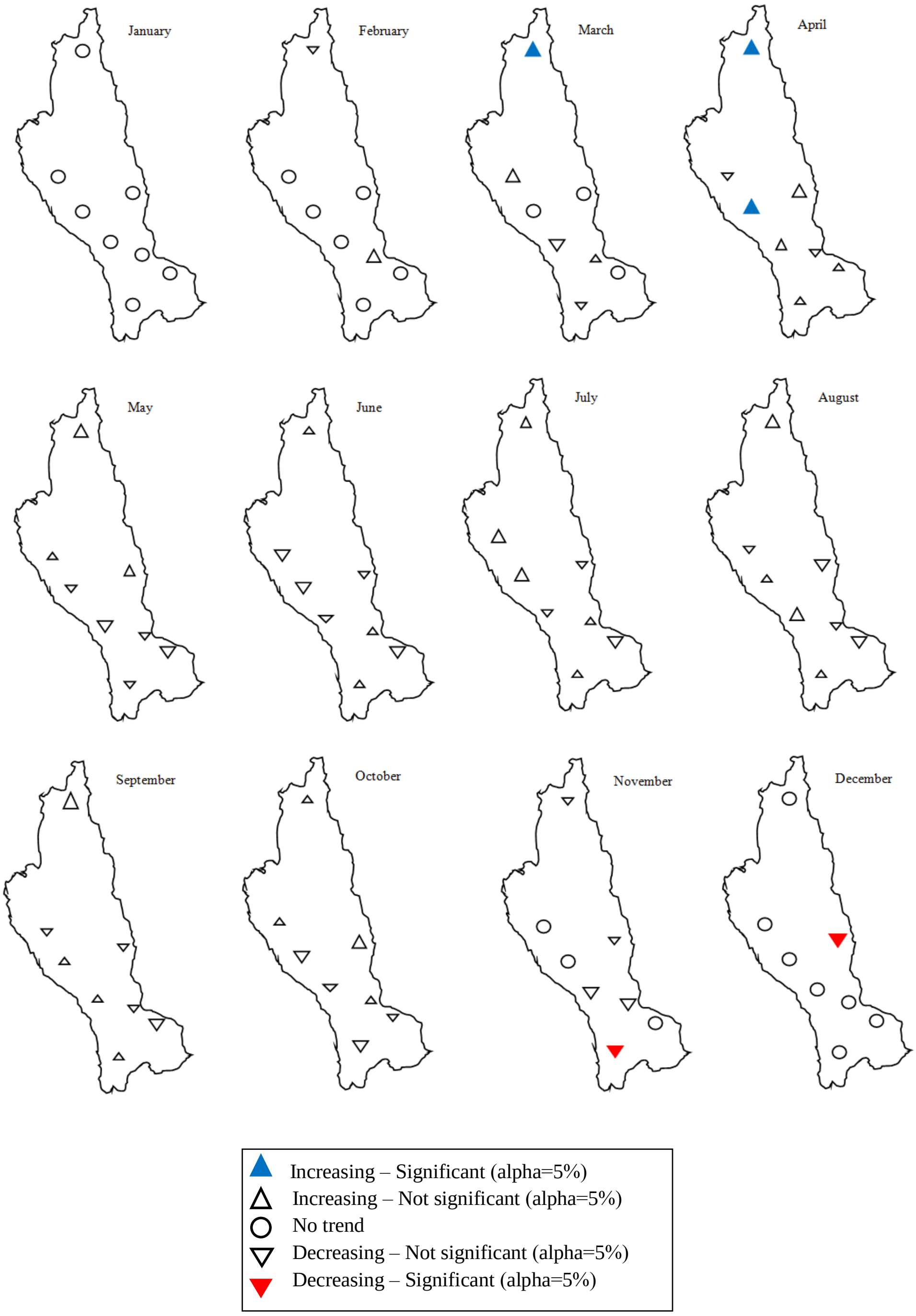

Figure 4. Spatial distribution of trends in monthly rainfall.

while decreasing trends were observed for the other 50% of stations. The rainfall trends for 5 stations were decreasing in November. Station 470161 had a statistically significant decreasing slope of 0.845 mm/year at 95% confidence level. No trends were detected for December except for station 130571, which had a statistically significant decreasing trend at 95% confidence level with a slope of 0.006 mm/year. The variation in the rainfall trends could be due to locations (latitude and longitude) of the rainfall stations and topography of the study area.

For the dry season, 5 out of 8 stations showed increasing rainfall trends. The increasing trend at Station 376401 was significant at 95% confidence level with an increasing slope of 4.277 mm/year in the dry season. For the wet season, 50% of the stations (4/8) showed an increasing trend while 50% showed decreasing rainfall trends. The increasing trend at Station 376401 was significant at 90% confidence level with a slope of 4.220 mm/yr, in the wet season. The upper region of Mae Klong River Basin showed increasing trends while the middle and lower regions had

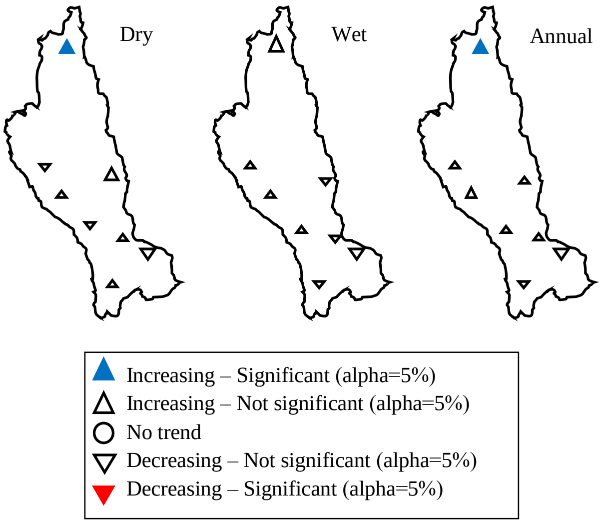

Figure 5. Spatial distribution of trends in seasonal and annual rainfall.

mixed seasonal rainfall trends. Station 376401 and station 130053 located in the upper region showed increasing rainfall trends in the wet season. On an annual scale, 75% of the stations (6/8) showed increasing trends while two stations showed decreasing trends (Figure 5). The increasing trend at Station 376401 was statistically significant at 95% confidence level with an increasing slope of 6.475 mm/year. From the spatial distribution of the stations, it was observed that the annual rainfall trends were increasing in the upper and middle regions of the Mae Klong River Basin while decreasing for the lower region of the basin. The increased rainfall trends in the wet season and on an annual scale in the upper region of the basin could have implications for inflows to the two main dams, i.e. Srinagarind and Vajiralongkorn. It could signify that the dams should be operated in a manner to optimize the hydropower production and downstream release of water during the dry season to meet the water demands. The RID has recently planned water supply to Uthai Thani Province from the Srinagarind Dam at 1892 million cubic meters (MCM)/year (Khalil *et al.*, 2018). Station 130571 located in the Lam Taphoen River Basin (Figure 1) has an increasing rainfall trend on an annual scale. Lam Taphoen River drains to Khwae Yai River downstream of the Tha Thung Na Dam. A greater portion of the area of Lam Taphoen is dependent on rain-fed agriculture. Station 470161 located in the Lampachi River Basin showed decreasing rainfall trends in the wet season and on annual scale. Lampachi River Basin has a serious problem of soil erosion due to no medium or large scale irrigation projects (Biltonen *et al.*, 2003).

4.3 Rainfall trend analysis for the entire Mae Klong River Basin

The arithmetic mean method was used to average the rainfall data of the eight stations for the whole Mae Klong River Basin. A rainfall trend analysis was carried out for the monthly, seasonal, and annual time series. The results of the trend analysis are given in Table 5. For the month of January, a statistically significant increasing trend was observed at 95% confidence level with a slope of 0.052 mm/year. February had an increasing trend with 90% confidence level with a slope of 0.206 mm/year. The seasonal and annual scales showed that the rainfall trends were increasing for the basin. The dry season had a rainfall trend that was increasing compared to the wet season with a slope of 0.708 mm/year. On an annual scale, the rainfall had an increasing trend with a slope of 0.843 mm/year. The upper region of the basin had a greater mean annual rainfall that contributed to runoff into the two main reservoirs, i.e. Srinagarind and Vajiralongkorn dams (Figure 2b). The downstream release from both dams was re-regulated by two diversion dams, i.e. the Tha Thung Na and Mae Klong Dams, because the lower region of the basin with a relatively lower mean annual precipitation had no potential droughts. Water was supplied to the GMKIP from the Mae Klong Dam. This irrigation demand was 6,219 MCM/year during 2000–2015. The increasing rainfall trends in the basin have pointed to an ample availability of water resources in the basin to meet inside water demands as well as outer basin transfer to the Metropolitan Waterworks Authority in Bangkok and to the Tha Chin Basin during the dry season. For 2000–2015, the amounts of diverted water to the Tha Chin Basin and Metropolitan Waterworks Authority were 849 and 352 MCM/year, respectively (Khalil *et al.*, 2018).

5. Conclusions

Any increase or decrease of rainfall in any region will affect the quantity of runoff generated and can impact water resources planning and water allocation to different water-use sectors. The present study evaluated the trends in monthly, seasonal, and annual rainfall for the Mae Klong River Basin located in the western region of Thailand. The MK test was used to detect the trend and the Sen's slope method was used to determine the magnitude of the trend. The pre-whitening approach was used to correct for the autocorrelation in the time series. For station-based trend analysis, in the dry season, 5 out of 8 stations showed increasing rainfall trends while for the wet season, 50% of the stations (4/8) showed increasing trends**.** Station 376401 located in the upper region of the Mae Klong River Basin showed a statistically significant upward trend at 95% confidence level with a slope of 4.277 mm/year in the dry season while a significant upward trend at 90% confidence level with a slope of 4.22 mm/year in the wet season. On an annual scale, 75% of the stations exhibited increasing rainfall trends. The trend analysis for the entire Mae Klong River Basin showed increasing rainfall trends in both seasonal and annual data. The Sen's slope estimates for the dry and wet season were 0.708 mm/year and 0**.**292 mm/year, respectively, while the slope was 0.843 mm/year for the annual data**.** Since water in the basin supplies both inside and outside water demands, the dams need suitable reservoir operating policies for efficient water resources management**.** Increasing rainfall trends, both on seasonal and annual scales, have supported the fact of outer basin water transfer to neighboring Tha Chin Basin during the dry season and to Metropolitan Waterworks Authority for water supply in the Bangkok area.

Acknowledgements

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Table 4. MK test statistic (Z_{MK}) and Sen's slope (Q) for monthly, seasonal and annual rainfall in the Mae Klong River Basin.

Month/ Season	Station 130013		Station 130042		Station 130053		Station 130211		Station 130221		Station 130571		Station 376401		Station 470161	
	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q	Z_{MK}	Q
January	0.920	0	1.135	0	1.272	0	0.303	0	1.409	0	0.176	0	0.235	0	0.695	0
February	1.164	0.008	0.773	0	0.039	0	0.920	0	0.929	0	-0.646	0	-0.166	-0.004	-0.518	0
March	0.548	0.099	1.086	0	**1.790**$^+$	0.718	-1.360	-0.438	0.137	0	0.108	0	**3.042******	0.941	-0.382	-0.135
April	-0.088	-0.044	0.470	0.072	-0.010	-0.054	1.174	0.870	**2.221***	1.857	1.588	0.933	**2.710******	1.277	1.096	0.515
May	-0.518	-0.492	-1.135	-0.887	0.245	0.368	-1.418	-1.290	-0.225	-0.163	0.831	0.433	0.479	0.557	-0.518	-0.472
June	0.998	0.418	-1.624	-1.130	-1.428	-1.689	-0.871	-0.722	-1.105	-1.762	-0.518	-0.301	0.010	0.002	0.714	0.575
July	0.088	0.136	-1.516	-1.217	1.184	1.886	-0.313	-0.107	**1.800**$^+$	2.493	-1.634	-1.201	**1.927**$^+$	1.546	0.812	0.580
August	-0.929	-0.460	-1.360	-0.968	-0.108	-0.106	1.086	0.794	0.499	0.448	**-1.927**$^+$	-1.063	**1.927**$^+$	0.971	0.792	0.434
September	-0.421	-0.490	-0.819	-0.841	-0.440	-0.378	0.147	0.125	0.205	0.187	-0.734	-0.579	1.244	1.081	0.225	0.262
October	0.127	0.226	-0.362	-0.317	0.068	0.021	-0.479	-0.548	-1.281	-1.427	0.968	1.088	0.284	0.232	-0.910	-1.291
November	-1.105	-0.294	-0.714	0	0.039	0	-1.379	-0.382	-0.470	0	-1.321	-0.106	-0.841	-0.142	**-2.054***	-0.845
December	-1.115	0	0.509	0	0.587	0	-0.900	0	-0.293	0	**-2.534***	-0.006	0.039	0	-1.145	0
Dry Season	0.401	0.710	-1.399	-1.928	-0.460	-1.247	-0.284	-0.520	0.421	1.163	**1.947**$^+$	2.387	**2.397***	4.277	0.714	0.898
Wet Season	-0.812	-1.574	**-1.908**$^+$	-5.560	0.695	1.963	0.225	0.599	0.695	1.902	-0.753	-1.218	**1.851**$^+$	4.220	-0.518	-1.231
Annual	0.127	0.274	-1.143	-4.306	0.010	0.126	0.029	0.267	0.636	3.175	0.812	1.819	**2.114***	6.475	-0.088	-0.296

Note: *** if trend at $\alpha = 0.001$ level of significance, ** if trend at $\alpha = 0.01$ level of significance, * if trend at $\alpha = 0.05$ level of significance, + if trend at $\alpha = 0.1$ level of significance. Z_{MK} is MK test statistic and Q is Sen's slope estimate in mm/year.

Table 5. Rainfall trend analysis for the whole Mae Klong River Basin.

Time series	First year	Last year	No. of years	Z_{MK}	significance	Q (mm/yr)
Jan	1971	2015	45	2.015	*	0.052
Feb	1971	2015	45	1.712	+	0.206
Mar	1971	2015	45	0.831		0.208
Apr	1971	2015	45	1.438		0.678
May	1971	2015	45	-0.577		-0.309
Jun	1971	2015	45	-1.203		-0.676
Jul	1971	2015	45	0.675		0.419
Aug	1971	2015	45	-0.068		-0.033
Sep	1971	2015	45	-0.029		-0.023
Oct	1971	2015	45	-0.479		-0.365
Nov	1971	2015	45	-1.360		-0.376
Dec	1971	2015	45	-0.362		-0.001
Dry Season	1971	2015	45	0.655		0.708
Wet Season	1971	2015	45	0.225		0.292
Annual	1971	2015	45	0.479		0.843

Note: * if trend at α=0.05 level of significance, + if trend at α=0.1 level of significance.

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