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Seasonal and Annual Trends of Rainfall and Streamflow in the Mae Klong Basin, Thailand

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Abstract

This study examined seasonal and annual trends of rainfall and streamflow data in the Mae Klong Basin, Thailand. Monthly data of eight key rainfall stations and ten streamflow stations were analyzed to detect trends using the non-parametric Mann-Kendall test, whilst the magnitude of the trends was determined by Sen's slope method for the period 2000-2015. For 75 % of the analyzed stations, rainfall was found to increase in the wet season and decrease in the dry season. Station 130013 situated in the lower region showed a statistically significant increasing trend with a trend slope of 16.02 mm a^{-1} in the wet season, while station 130042- also located in the lower region of the basin- showed a statistically significant decreasing trend, with a trend slope of 23.60 mm a^{-1} in the dry season. On an annual basis, 63 % of the analyzed stations showed increasing rainfall trends, particularly in the central and lower regions of the Mae Klong Basin; however, rainfall trends in the upper region were found to be decreasing, which reflected water contributions to two main reservoirs in the upper part. The trends of naturalized inflow of Srinagarind and Vajiralongkorn Reservoirs were found to be decreasing on both seasonal and annual bases, while two naturalized streamflow stations located in Lam Taphoen and Lampachi sub-basins in the central and lower regions, respectively, showed increasing trends in both dry and wet seasons. The trends of regulated streamflow stations downstream of 4 main dams which were a result of reservoir operation were found to mostly decrease on an annual scale. Results of this study can help water resources managers enhance accuracy of assessment and effective planning of water resources management in the basin.

Keywords: Rainfall and streamflow trends analysis; Mann-Kendall's Test; Sen's Slope Test; Mae Klong Basin

Introduction

Planning and design of water resources projects are primarily based on historical and observational time series of hydro-meteorological variables under an implicit assumption of stationarity i.e. time invariant, for the statistical characteristics of the data. However, due to global climate change, this assumption can no longer be held valid [1]. It is crucial to understand the potential shifts in future projections for rainfall, as a fundamental determinant of the hydrological cycle, and because changes in rainfall patterns can result in droughts, floods and adverse impacts on agricultural production and biodiversity [2]. Changes in streamflow are also important and accurate information on streamflow is vital for effective water resource management, e.g. planning of dams and water treatment plants, flood forecasting, and assessing in-stream flow requirements. To deal effectively with the impacts of climate change, hydro-meteorological information in the region must be well understood.

Trend detection for hydro-meteorological variables has been studied frequently by many researchers. Zeleňáková [3] studied long term precipitation trends in eastern Slovakia using the Mann-Kendall (MK) test. Results showed positive trends for monthly and annual rainfall for all gauging stations. Longobardi & Villani [4] analyzed trends in seasonal and annual time series of rainfall stations in the Mediterranean region. Results showed predominantly negative trends at both seasonal and annual scales except for the summer period. Yeh et al. [5] studied spatial and temporal trends of streamflow for 12 gauging stations in northern Taiwan. Only one station showed a significant downward trend for average annual streamflow. Results for monthly and seasonal analysis showed that 72.2 % of the stations showed increasing trends. Kahya & Kalaycı [1] studied streamflow trends for 26 basins in Turkey. These researchers reported negative trends for basins in western Turkey, while no clear trends were identified for basins situated in the east of the country.

Trend detection in the time series data can be approached using either parametric or non-parametric statistical techniques, though in general. Non-parametric techniques are preferred. The MK test, a non-parametric test, has been frequently used for detection of trends in the time series data of precipitation and streamflow [2]. One benefit of the MK-test is that the data do not need to conform to any specific distribution.

The Mae Klong Basin is one of Thailand’s major river basins, with plentiful water resources. The Greater Mae Klong Irrigation Project (GMKIP), the basin’s most water intensive use sector, is located in the lower portion of the basin. The main focus of this study was to analyze trends in rainfall and streamflow in the basin, including naturalized and regulated flows, in order to support better assessment and management of water resources.

Study area

The Mae Klong Basin lies in the west of Thailand, occupying an area of 30,167 km^2 as shown in Figure 1. It is close to the Tanaosri mountain ranges which form the border between Thailand and Myanmar, and it is a headwater of the Mae Klong River in Tak and Kanchanaburi Provinces. Two tributaries originate in this mountain range, the Khwae Yai (or Khwae Srisawat) in Tak Province, and the Khwae Noi (or Sai Yok Noi) in Kanchanaburi Province [6]. The Mae Klong Basin has abundant water resources which are crucial to the national economy especially in the west of the country. There are 2 main storage dams, Srinagarind (SNR) and Vajiralongkorn (VJK), built across the two main rivers, the Khwae Yai and Khwae Noi. Additionally, two main diversion dams, the Tha Thung Na (TN) and Mae Klong (MK) serve to regulate flow on the downstream sides of the Khwae Yai and Mae Klong Rivers. There are also two small tributaries- the Lam Taphoen River, discharging into the Khwae Yai River, and the Lampachi River, draining to the Khwae Noi River.

Land use in the basin can be divided into forest, agriculture, urban, miscellaneous areas, and water bodies. Forest covers 68.13 %, followed by agriculture (22.90 %), urban areas (3.40 %), miscellaneous areas (2.47 %), and water bodies (3.10 %). Water usage in the lower basin is quantitatively intensive. The water is pre-dominantly used to irrigate more than 4,800 km^2 of agricultural land in the GMKIP, and also supplies domestic and industrial demand, hydropower, and salinity control measures towards the Gulf of Thailand [7].

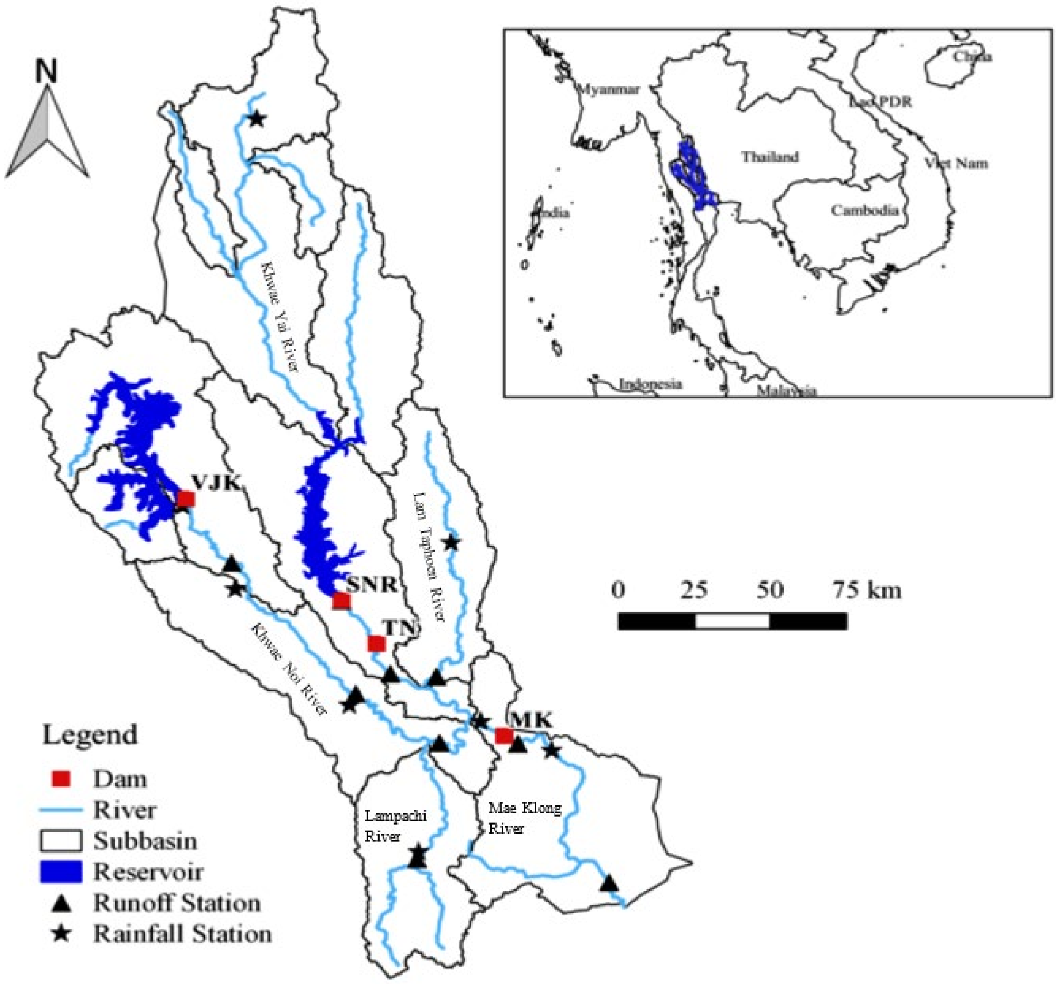

Figure 1 Mae Klong Basin.

Materials and methods

1) Data

Monthly rainfall data for 8 key stations (Stn. 130013, 130042, 130053, 130211, 130221, 130571, 376401, and 470161) were obtained from the Royal Irrigation Department (RID) and the Thai Meteorological Department (TMD) for the period 2000-2015. Monthly streamflow data were obtained for 10 gauging stations; 4 naturalized flow stations at SNR and VJK dams, and K.12, K.17 in Lam Taphoen (LTP) and Lampachi (LPC) sub-basins and 6 regulated flow stations; K.36, K.54, K.10, K.37, and K.57 from the Royal Irrigation Department for 2000-2015. The general description and basic statistics of the rainfall and streamflow stations are given in Table 1, while the spatial distribution of rainfall stations and streamflow gauging stations are shown in Figure 2. Owing to the variability of rainfall, the basin was divided into 3 sub-regions (upper, middle and lower regions) as shown in Figure 2. Missing rainfall measurements were obtained from nearby stations based on their correlations. Consistency of the rainfall data was checked using double-mass analysis. The annual rainfall data from the eight stations (as shown in Figure 3) varied in the range of 771-1,780 mm a^{-1} on average; annual streamflow for the ten gauging stations in the Mae Klong Basin is shown in Figure 4. The average inflow of SNR and VJK were found to be 157.44 and 183.20 m^3 s^{-1} a^{-1}, equivalent to 4,964.98 and 5,777.46 MCM a^{-1}, while the naturalized flow of K.12 and K.17 stations are 6.57 and 7.04 m^3 s^{-1} a^{-1}, respectively. The average regulated flow of all the gauging stations ranges between 139.42-973.45 m^3 s^{-1} a^{-1}.

Table 1 General description and basic statistics for the rainfall and streamflow stations

Rainfall stations					
Station code	**Latitude**	**Longitude**	**Mean annual rainfall (mm)**	**Minimum rainfall (mm)**	**Maximum rainfall (mm)**
130013	14.00° N	99.55° E	1,064.76	777.6	1,324.80
130042	13.91° N	99.77° E	770.30	377.30	1,420.30
130053	14.74° N	98.64° E	1,779.29	1,258.70	2,333.30
130211	14.09° N	99.18° E	1,106.81	84.30	1,423.30
130221	14.45° N	98.80° E	1,575.74	221	2,059.90
130571	14.60° N	99.46° E	949.49	64.50	1,278.40
376401	16.02° N	98.87° E	1,563.07	1,232.60	1,928.90
470161	13.54° N	99.36° E	1,084.72	171.90	1,469.60
Streamflow stations					
Station code	**Latitude**	**Longitude**	**Mean annual streamflow (m^3 s^{-1})**	**Minimum flow (m^3 s^{-1})**	**Maximum flow (m^3 s^{-1})**
K.10	14.09° N	99.17° E	220.17	100.88	308.85
K.11A	13.95° N	99.65° E	200.45	82.33	343.05
K.12	14.15° N	99.42° E	6.57	1.33	15.22
K.17	13.54° N	99.36° E	7.04	2.52	10.51
K.36	14.16° N	99.28° E	139.42	68.08	182.77
K.37	13.93° N	99.43° E	244.03	130.01	346.13
K.54	14.53° N	98.79° E	196.32	93.19	284.63
K.57	13.47° N	99.94° E	973.45	755.30	1,247.20
SNR	14.41° N	99.13° E	157.44	76.97	240.38
VJK	14.73° N	98.60° E	183.20	77.59	252.29

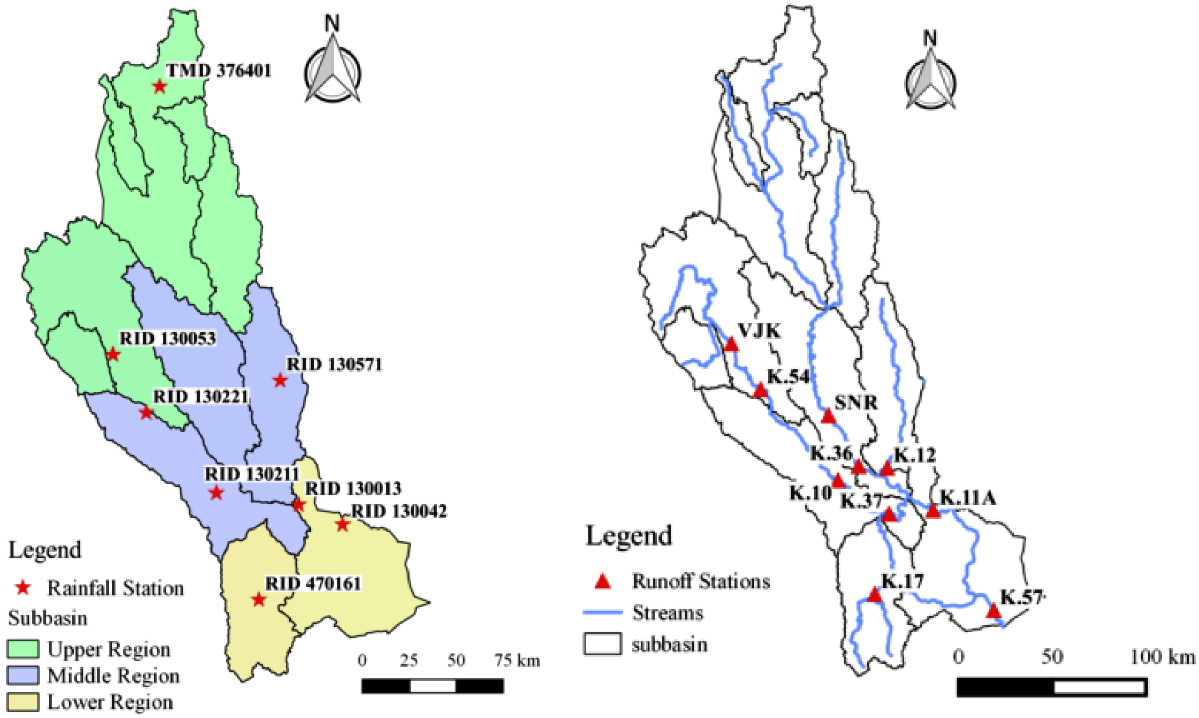

Figure 2 Location of rainfall and streamflow stations in the Mae Klong Basin.

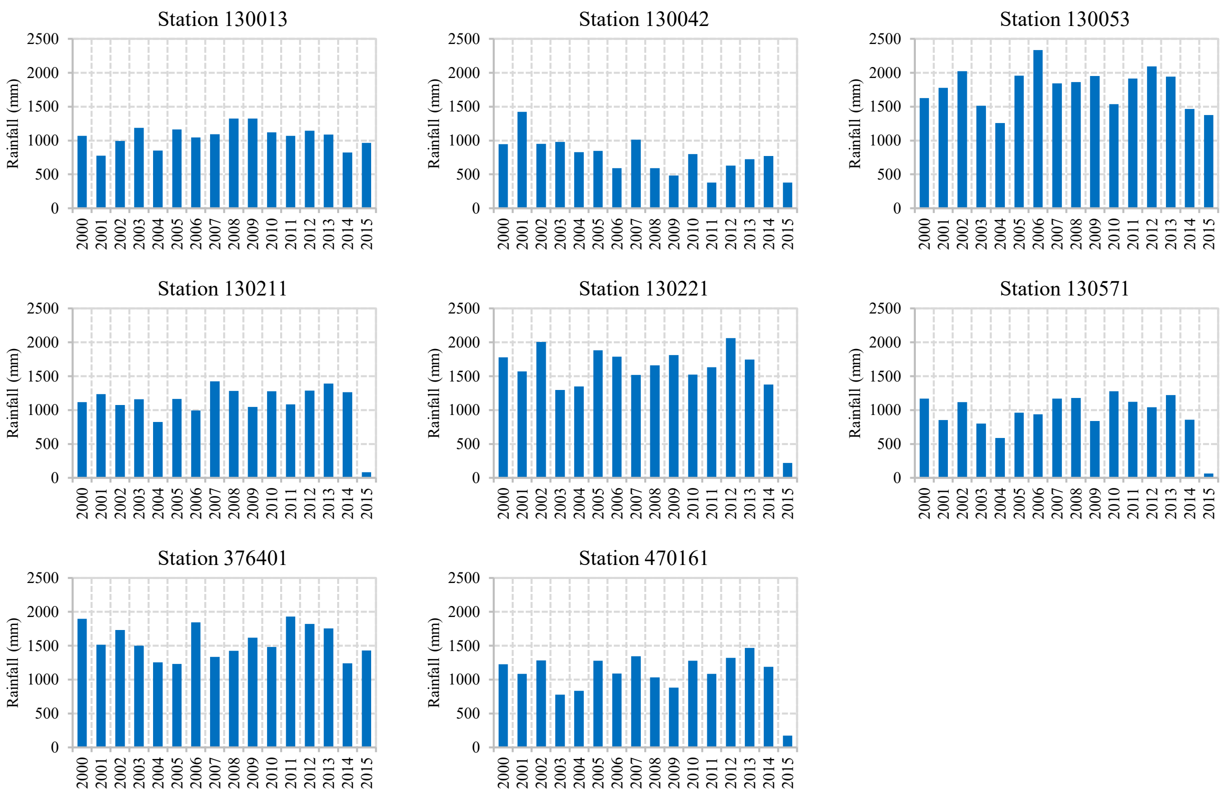

Figure 3 Annual rainfall of 8 stations in the Mae Klong Basin during 2000-2015.

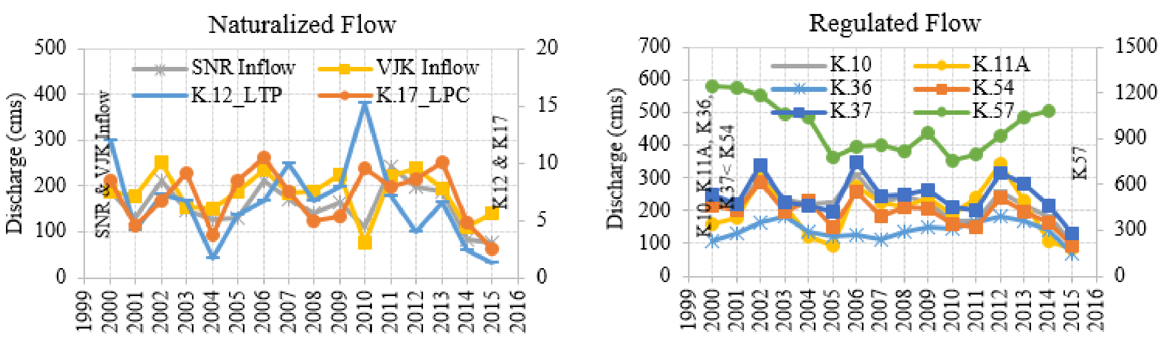

Figure 4 Average annual streamflow of 10 gauging stations in the Mae Klong Basin.

Methods

1) Mann–Kendall (MK) trend test

The MK test statistic S [8-9] is calculated as;

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

where

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

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 an increasing trend, and a negative value indicates a 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);

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

Where 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;

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

The value of Z_{MK} is the Mann-Kendall test statistic that follows a normal distribution with mean 0 and variance 1. Testing trend is done at the specific α significance level. When $|Z_{MK}| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this analysis, the MK test is applied to detect if a trend in the rainfall and streamflow time series is statistically significant at significance levels, α = 0.001 (or 99.9 % confidence intervals), α = 0.01 (or 99 % confidence intervals), α = 0.05 (or 95 % confidence intervals) and α = 0.1 (or 90 % confidence intervals). At the 0.1 %, 1 %, 5 %, and 10% significance levels, the null hypothesis of no trend is rejected if $|Z_{MK}| > 3.29$, $|Z_{MK}| > 2.576$, $|Z_{MK}| > 1.96$, and $|Z_{MK}| > 1.64$, respectively.

2) Sen's slope method

This non-parametric method [10] is used to determine the magnitude of trend in hydro-meteorological data. The method involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as the estimate of the overall slope. This method is not sensitive to outliers and can be effectively used for quantification of trend in a time series data. The estimate of the trend slope Q is given by;

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

Where 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 for detecting and estimating trends in the seasonal and annual times series of rainfall and streamflow data. The MAKESENS procedure is based on the nonparametric MK test for trend analysis and the non-parametric Sen's method for detection of trends in magnitude. The MAKESENS template was created using Microsoft Excel 97 and the macros were coded with Microsoft Visual Basic. In MAKESENS, the two-tailed test was used for four different significance levels α: 0.001, 0.01, 0.05, and 0.1. This tool has been used by many researchers for trend analysis of hydro-meteorological variables [11-21].

Results and discussion

Trend analysis of rainfall and streamflow data was carried out on seasonal and annual bases for the period 2000-2015. The seasons in Thailand are generally defined as: (1) dry season (November to April) and (2) wet season (from May to October) for the central and northern regions of the country. However, in the western region, the dry season begins later, lasting from January until June, while the wet season continues from July until December due to a delay in seasonal climate transition. The seasonal trend analysis of rainfall and streamflow in the Mae Klong Basin was therefore based on this local seasonality [22-23].

1) Trend analysis of rainfall data

The spatial distribution of trend analysis for seasonal and annual time series of rainfall data for the period 2000-2015 is shown in Figure 5. The results of the MK-test statistic (Z_{MK}) and Sen's slope (Q) tests for the seasonal and annual scales of rainfall are shown in Table 2. The data indicate that six of the eight stations showed a decreasing rainfall trend in the dry season, while two stations in the central region of the basin (Stn. 130221 and Stn. 130571) showed an increasing rainfall trend. The decreasing trend for Stn. 130042 situated in the lower region of basin is statistically significant at 99 % confidence level with a slope of 23.60 mm a^{-1}. For the wet season, two stations (Stn. 130221 and Stn. 130042) showed a decreasing trend while all the remaining stations showed an increasing trend. The increasing trend for Stn. 130013 is significant at 90 % confidence level with a slope of 16.02 mm a^{-1}. On an annual basis, 63 % of the analyzed stations (5 stations) showed increasing rainfall trends in the central and lower regions of the Mae Klong Basin while three stations showed decreasing trends and two stations situated in the upper region were found to be predominantly decreasing. Stn. 130042 showed a statistically significant decreasing trend at 99 % confidence level with a slope of 37.64 mm a^{-1}. The variation in the rainfall trends could be due to location of the rainfall stations and topography of the study area.

As shown in Figure 5(a), in the dry season, a decreasing trend is observed in the upper and lower regions of the Mae Klong Basin, whilst an increasing rainfall trend was found in the wet season in the central region of the basin (Figure 5b). On an annual scale (Figure 5c), an increasing trend was observed in the central and lower regions of the basin and a decreasing trend in rainfall in the upper region. Rainfall in the upper region of the basin contributes water to two main reservoirs: Srinagarind and Vajiralongkorn Dams (Figure 1).

The decrease in annual rainfall in the upper region of the basin is reflected in the declining trends in annual streamflow to these two dams.

Shrestha [24] reported rainfall anomalies for the Mae Klong Basin using data from the Regional Climate Model (PRECIS) for two SRES (Special Report on Emission Scenarios) scenarios A2 and B2. The A2 scenario represents moderate economic growth, a very high population increase, together with a focus on self-reliance and local identity. The B2 scenario represents slow economic growth, low population increase, a focus on environmental sustainability and regional solutions to environmental issues. Results showed that rainfall anomalies in the Mae Klong Basin were projected to increase in the wet season and decrease in the dry season. This study also found that rainfall trends are mostly decreasing in dry seasons for 75 % (6 out of 8) of the stations and increasing in wet seasons. In addition, this study has also shown that the Mae Klong Basin has been experiencing the effects of climate change in both dry and wet seasons.

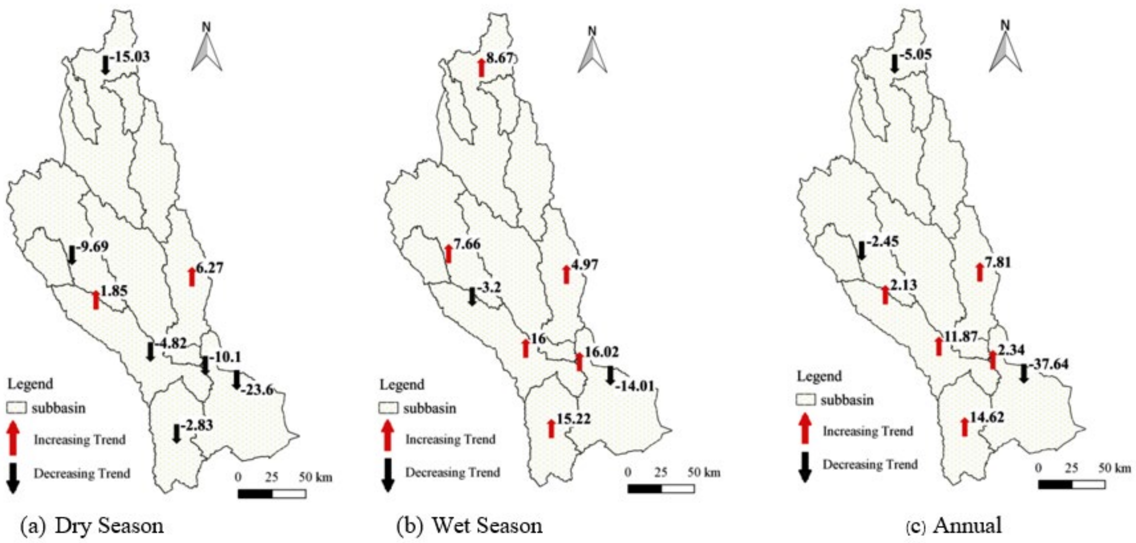

Figure 5 Spatial distribution of rainfall stations with increasing and decreasing magnitude of trends in millimeters per year in the Mae Klong Basin.

2) Trend analysis of streamflow data

The streamflow stations can be categorized into two groups by flow characteristics, the first group where naturalized flow occurs comprising SNR, VJK, K.12, and K.17. SNR and VJK represent reservoir inflow to two main dams, Srinagarind and Vajiralongkorn Dams which can be managed by reservoir operations. K.12 and K.17 stations are situated on Lam Taphoen and Lampachi River in the lower east and west of the basin, respectively. The flows at these four gauging stations could be influenced by both climate and land use changes. For the second group, the flows are considered as regulated flows comprising K.54, K.10, and K.37 stations established downstream of the Vajiralongkorn Dam, K.36 station to measure the flow downstream of the Tha Thung Na Dam, and K.11A and K.57 stations situated downstream of the Mae Klong Dam. Since flows at these six stations are regulated and subject to reservoir operation policy, water demand factors inside (water supplied for domestic and industries, agriculture, and salinity control) and outside of the basin (water supplied to MWA and Tha Chin Basin), as well as the underlying natural factors influencing local flows.

Table 2 MK-test statistic (Z_{MK}) and Sen's slope (Q) for seasonal and annual scales of the rainfall in the Mae Klong Basin

Month/Season	Stn. 130013		Stn. 130042		Stn. 130053		Stn. 130211		Stn. 130221		Stn. 130571		Stn. 376401		Stn. 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	0	-1.00	0	1.35	0	**1.67+**	0	0.95	0	1.21	0	0.57	0	0.75	0
February	0.23	0.01	0.10	0	**-1.95+**	**-1.13**	0	0	0.41	0.10	-0.57	0	0	0	-0.15	0
March	-0.41	-0.43	-0.93	-0.78	0.95	1.92	0.59	0.58	1.14	3.41	-0.14	0	0.05	0.30	-0.41	-0.46
April	-1.49	-5.29	0.86	1.28	-0.23	-1.14	-0.95	-2.80	0.05	0.89	-0.14	-0.29	-0.50	-2.25	0.50	1.51
May	-1.13	-4.55	**-3.56*** **	**-14.71**	**-2.39***	**-14.67**	-0.68	-2.79	**-1.67+**	**-9.82**	-0.14	-1.00	**-1.85+**	**-9.67**	-0.77	-2.60
June	0.41	2.22	-0.86	-2.76	1.49	5.90	-0.05	-0.23	1.31	5.92	**1.67+**	**6.27**	-0.59	-3.96	0.59	3.17
July	1.13	2.78	-0.41	-0.93	0.68	7.23	0.50	3.37	0.14	2.54	1.58	5.84	0.50	1.56	**1.85+**	**6.51**
August	0.59	1.41	-1.22	-3.80	-1.13	-7.44	1.22	3.98	-0.86	-3.58	1.49	3.76	0.23	2.00	0.41	0.93
September	0.68	3.81	**-1.94+**	**-7.95**	0.05	0.31	0.86	5.61	-0.32	-1.41	-0.41	-2.16	0	0.26	0.14	3.19
October	0.95	3.36	-0.41	-2.43	0	-0.13	0.05	0.31	0.05	0.41	-0.36	-1.53	0.05	0.09	0.14	1.32
November	0.63	0.84	0.50	0.20	0	0	1.51	2.13	1.60	1.88	1.21	0	0.54	0.64	1.21	2.91
December	-0.11	0	**-1.66+**	0	1.05	0	0.77	0	0.42	0	**1.93+**	0	0.37	0	1.04	0
Wet Season	**1.85+**	**16.02**	-1.58	-14.01	0.41	7.66	1.49	16.00	-0.68	-3.20	0.68	4.97	0.95	8.67	1.58	15.22
Dry Season	-1.31	-10.10	**-3.20** **	**-23.60**	-1.49	-9.69	-0.50	-4.82	0.59	1.85	0.68	6.27	-1.58	-15.03	-0.50	-2.83
Annual	0.05	2.34	**-2.66** **	**-37.64**	-0.14	-2.45	1.40	11.87	0.23	2.13	0.77	7.81	-0.32	-5.05	1.13	14.62

Note: *** if trend at $\alpha = 0.001$ level of significance ($|Z_{MK}| > 3.29$),
** if trend at $\alpha = 0.01$ level of significance ($|Z_{MK}| > 2.576$),
* if trend at $\alpha = 0.05$ level of significance ($|Z_{MK}| > 1.96$),
+ if trend at $\alpha = 0.1$ level of significance ($|Z_{MK}| > 1.64$).
Z_{MK} is MK-test statistic and Q is Sen's slope estimate in mm/year.

The spatial distribution of trend analysis for seasonal and annual time series of streamflow for 10 gauging stations for the period 2000-2015 is shown in Figure 6. The MK-test statistic (Z_{MK}) and Sen's slope (Q) data for the seasonal and annual scales of streamflow are given in Table 3. The results indicate that for the dry season, Stn. K.57 and SNR showed a statistically significant decreasing trend at 95 % confidence level, with trend slopes of 30.47 and 2.96 m^3 s^{-1} a^{-1}, respectively (Figure 6a). An increasing trend was shown at 50 % of the streamflow stations (5 stations) while 4 stations showed a decreasing trend. Stn. K.12 showed no discernible trend in the dry season. For the wet season (Figure 6b), 70 % of the stations (7 stations) showed statistically insignificant decreasing trends while the remaining 3 stations showed an increasing trend. On an annual basis (Figure 6c), Stn. K.57 showed a significant decreasing trend at the 90 % confidence level, with a trend slope of 16.94 m^3 s^{-1} a^{-1}. All remaining stations showed a decreasing trend except Stn. K.36, which showed an increasing trend in streamflows.

Water in the Mae Klong Basin is used to meet a range of user demand, including domestic, industrial, irrigation, and hydropower. The most intensive water demand is from the GMKIP, located in the basin's lower region. Also, water is diverted to the Tha Chin Basin during the dry season and also to the Metropolitan Waterworks Authority (MWA). The results of trend analysis for streamflow in the basin showed more decreasing trends in dry seasons than in wet seasons. This could be attributed to out-of-basin supply to meet increasing demands during the dry season. For the period 2000-2015, this diverted water to the Tha Chin Basin and Metropolitan Waterworks Authority amounted to 849 and 352 MCM a^{-1}, respectively [7].

However, the trends of naturalized inflow of Srinagarind and Vajiralongkorn Reservoirs were also found to be decreasing on a seasonal and annual basis due to decreasing rainfall in the upper region. Meanwhile, naturalized streamflows at K.12 and K.17 stations showed increasing trends in both dry and wet seasons. The regulated flows at most stations; K.10, K.37, K.36, and K.11A continue to show an increasing trend in the dry season, indicating release of increasing volumes of water from the dams to meet downstream demand. However, on the annual scale, the trends in regulated streamflows for K.36, K.54, K.10, K.37, and K.57 stations (which result from reservoir operations) were found mostly to show a decreasing trend.

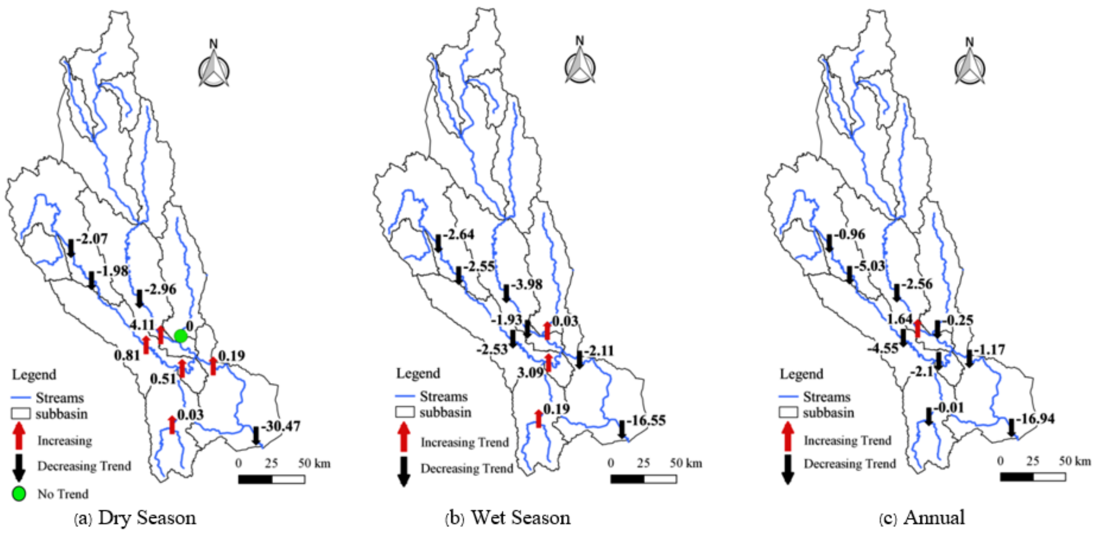

Figure 6 Spatial distribution of streamflow stations with increasing and decreasing magnitude of trends in cubic meter per second per year in the Mae Klong Basin.

Table 3 MK-test statistic (Z_{MK}) and Sen's slope (Q) for seasonal and annual scales of the streamflow in Mae Klong Basin

Month/ Season	SNR		VJK		K.12		K.17		K.10		K.11A		K.36		K.37		K.54		K.57	
	Z_{MK}	Q	Z_{MK}	Q	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	-0.77	-0.30	0.77	0.20	0.14	0	1.04	0.05	-0.36	0	0.23	0.72	1.04	2.17	-0.05	-0.17	-1.49	-1.88	**-1.68**$^{+}$	**-26.81**
February	-0.50	-0.21	0.77	0.21	-0.23	0	1.04	0.04	1.27	2.39	1.31	3.65	1.04	3.20	0.59	1.29	0.32	0.71	**-2.08***	**-23.19**
March	-0.32	-0.19	0.95	0.49	0.23	0.02	-0.14	-0.01	0.45	0.56	0.23	0.59	**1.67**$^{+}$	**4.14**	0.05	0.16	**-1.67**$^{+}$	**-3.04**	**-2.18***	**-14.92**
April	-1.22	-0.98	0.23	0.04	-0.14	-0.02	0.32	0.03	1.04	2.81	0.50	1.41	1.13	2.90	1.13	3.39	0.32	1.42	**-1.98***	**-24.74**
May	**-2.48***	**-5.69**	**-2.30***	**-7.54**	-0.23	-0.08	-0.86	-0.15	-0.23	-0.07	-0.68	-2.62	0.50	1.03	-0.41	-1.23	-0.77	-1.59	**-1.78**$^{+}$	**-26.93**
June	-1.40	-5.23	-0.59	-3.18	-0.32	-0.03	0.23	0.03	-1.22	-2.97	-0.77	-4.42	0.86	3.10	-1.31	-3.10	**-1.76**$^{+}$	**-6.26**	-0.79	-20.62
July	-1.04	-8.95	-0.14	-2.23	-0.86	-0.13	0.86	0.17	-0.59	-1.27	-0.86	-4.48	0.32	1.24	-0.32	-1.21	-0.59	-2.31	-0.79	-26.45
August	0.05	1.02	-0.68	-12.25	0.14	0.01	0.68	0.11	0	0.23	0	0.20	-0.14	-0.75	0.68	7.36	-0.23	-1.16	-1.39	-28.92
September	-0.50	-8.20	-0.14	-1.57	1.13	0.36	0.00	0.01	**-2.93****	**-23.47**	-0.77	-7.83	-0.86	-3.91	0.05	0.67	-0.59	-3.79	-0.59	-7.09
October	-0.32	-1.31	0.50	2.17	0.77	0.49	0.59	0.72	0.14	1.05	0.32	2.68	-0.14	-2.12	0.86	4.64	0.23	0.65	-0.49	-9.99
November	-0.23	-0.52	0.50	0.59	-0.23	-0.21	0.41	0.26	0.05	0.01	0.05	1.12	-1.04	-3.82	1.13	3.42	-1.13	-2.58	-0.79	-9.69
December	-0.50	-0.44	0.50	0.33	0.00	0.00	1.04	0.13	-0.45	-0.69	-0.86	-3.98	-0.86	-2.04	-0.77	-1.43	-1.40	-1.73	-1.29	-16.29
Wet Season	-0.59	-3.98	-0.23	-2.64	0.05	0.03	0.50	0.19	-0.68	-2.53	-0.05	-2.11	-0.95	-1.93	0.32	3.09	-0.77	-2.55	-1.09	-16.55
Dry Season	**-2.03***	**-2.96**	-1.13	-2.07	0	0	0.32	0.03	0.68	0.81	0.05	0.19	1.40	4.11	0.14	0.51	-1.22	-1.98	**-2.38***	**-30.47**
Annual	-0.86	-2.56	-0.23	-0.96	-1.31	-0.25	-0.05	-0.01	-1.85	-4.55	-0.05	-1.17	1.04	1.64	-0.77	-2.10	-2.03	-5.03	**-1.68**$^{+}$	**-16.94**

Note: *** if trend at $\alpha = 0.001$ level of significance ($|Z_{MK}| > 3.29$),
** if trend at $\alpha = 0.01$ level of significance ($|Z_{MK}| > 2.576$),
* if trend at $\alpha = 0.05$ level of significance ($|Z_{MK}| > 1.96$),
+ if trend at $\alpha = 0.1$ level of significance ($|Z_{MK}| > 1.64$).

Z_{MK} is MK-test statistic and Q is Sen's slope estimate in m^3/s/year. SNR and VJK represent inflows to Srinagarind and Vajiralongkorn Dams, respectively.

A summary of MK-test statistic (Z_{MK}) for rainfall and streamflow stations in dry and wet seasons and on an annual basis is shown in Figure 7.

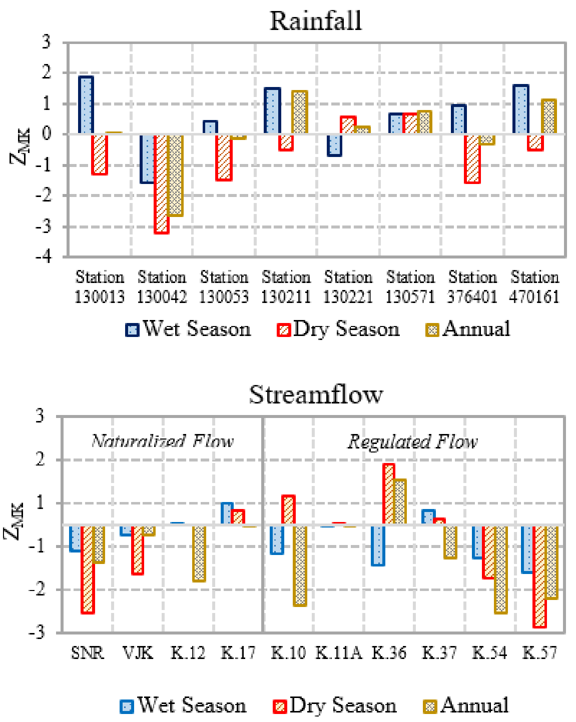

Figure 7 Summary of MK-test statistic (Z_{MK}).

Conclusions

This study evaluated seasonal and annual trends in rainfall and streamflows for the Mae Klong Basin. The Mann-Kendall test was used to detect the trend itself, while the Sen's slope method was used to determine the magnitude of the trend. For 75 % of analyzed stations, rainfall trends were found to be increasing in wet seasons and decreasing in dry seasons. Station 130013 situated in the lower region showed a statistically significantly increasing trend with a trend slope of 16.02 mm a^{-1} in the wet season, while station 130042 also situated in the lower region of basin showed significantly decreasing trend with a trend slope of 23.60 mm a^{-1} in the dry season. The increasing trends found for wet season rainfall, and the decreasing trends in dry season rainfall suggest that climate change is already impacting the basin. On an annual basis, 63 % of the analyzed stations showed increasing rainfall trends. The existing dams in the basin needs to be operated to allow greater storage capacity in the wet season, as safeguard against increasing risks dry season droughts. The result of trend analysis of reservoir inflows predominantly highlighted the decreasing water availability of Srinagarind and Vajiralongkorn Dams on both seasonal and annual bases; this is reflected in the reduced capability of the two dams to allocate water to fully satisfy down-stream demands. In the dry season, Stn. K.57 located downstream of Mae Klong Dam and SNR (inflow to the Srinagarind Dam) showed a statistically significant decreasing trends at 95 % confidence level, with trend slopes of 30.47 $m^3 s^{-1} a^{-1}$ and 2.96 $m^3 s^{-1} a^{-1}$, respectively. In addition, the decreasing trend in the regulated streamflow could be attributed to increased water demand both inside and outside of the basin. These results are expected to help managers, planners and policy makers to enhance accuracy of assessment of water resources and predictions, and enable effective planning decisions in the Mae Klong Basin.

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