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Trend Analysis of Rainfall in Tonle Sap Lake Region of the Lower Mekong Basin

Ty SOK*, Chantha OEURNG, Layheang SONG

Faculty of Water Resources and Hydrology, Institute of Technology of Cambodia, Russian Ferderation Blvd., P.O. Box 86, Phnom Penh, Cambodia.

Abstract: *The study aimed to analyze rainfall trend in Tonle Sap Lake regions of the Lower Mekong Basin and to determine if these time series belonged to a similar regime, have had any significant trends. To reveal the behaviors of annual and monthly rainfall for trends, historical data series of available 6 stations in more than 30 years from the 1980s to 2012 were used in this study. From the basic daily rainfall data, total and means of monthly and annual rainfall are formed for each individual station together with other basic statistics. These statistic results were used to investigate the spatial pattern of the inter-annual variability of annual rainfall totals over the study area. To detect the change, the annual rainfall data were subjected to process the intervention analysis (using Cumulative Summation technique) and step change analysis (using rank-sum test) and subsequently the trend in individual rainfall station were determined using Mann Kendall (MK) test. The applied methods presented similar results for annual rainfall trend. It emphasizes that the time-series of the annual rainfall variation in Tonle Sap Lake region presented no significant trend (statistically significant at $p<0.05$) for all stations. The result of the monthly trend shows the presence of increasing in the monthly rainfall amounts from January to May (mid of dry season to start of rainy season) in the investigated period.*

Keywords: rainfall trend; intervention analysis, step change analysis;Mann Kendall (MK) test

1. INTRODUCTION

Information about the trends of rainfall is considered as of important since it is closely related to the water resource management and planning and other water relates issues in Mekong River basin, particularly the Tonle Sap basin region which associated with flood related problems. Understanding of the regional level of rainfall behavior is also important for the agriculture sector. In the rained condition success or failure of crops, it is closely linked with rainfall pattern (Holvoet et al., 2008). Thus it becomes increasingly important to study the trends in rainfall and their statistic explanation.

Rainfall trend analyses which cover both the temporal and spatial dimensions have been of great concern during the past century because of the attention given to global climate change from the scientific community: they indicate a small positive global trend, even though large areas are instead characterized by negative trends (Houghton et al., 1996). Spatial differences in trends can occur as a result of spatial differences in the changes in rainfall and temperature and spatial differences in the catchment characteristics that translate meteorological inputs into the hydrological response (Seitzinger et al., 2010). Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Obviously, different researchers have used different methodologies for trend detection (Lee et al., 2013). Intervention analysis has been carried using the Cumulative Summation (CUSUM) technique to determine inconsistencies in rainfall data which might have resulted from climate changes and/or anthropogenic activities which include observational errors in monitoring and change of recording methodology and equipment among others (Kampata et al., 2008). Inter-annual variability is better (than mean value) and one of the most important indicators of the reliability of rainfall (Beaujouan et al., 2002; Styczen et al., 1993). Alternatively, the Mann–Kendall (MK) test has been widely used to evaluate the presence of a statistically significant trend in hydrological and climatological time-series including rainfall (Galloway et al., 2002).

It is, therefore, becoming clearer that analysis of rainfall trends is important in studying in Tonle Sap Lake regions, Lower Mekong River basin to assist in water resources planning and management in this region. This study aimed

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* Coresponding authors:
E-mail:sokty_itc@yahoo.com; Tel: +855-11-980-698;
Fax: +855-23-880-369

to (1) investigate the rainfall characteristic of the long-term rainfall and (2) to analyze the longterm rainfall trend (annual and monthly scale) in Tonle Lake regions of the Lower Mekong Basin.

2. METHODOLOGY

2.1 Study area

Tonle Sap basin covers the whole catchment of the Tonle Sap Lake (TSL), with a total area of 81,663 km^2, which consists of the Great Lake, the Tonle Sap River and each of its tributary catchments (Figure 1). TLS basin is bordered by the Elephant and Cardamom Mountains in the west and south-west shielding the basin from the Gulf of Thailand, and the Dangrek mountains in the north, which separates the basin from the Korat Plateau. The alternating monsoon system controls the climate in Cambodia. In the wet season (called raining season), the southwest monsoon is from May to November when about 90% of the rainfall occurs. The remaining months, the northeast monsoon, are hot and less humid (called dry season) with particularly high potential transpiration demands in March and April. The annual average temperature is 28 °C, with an average maximum temperature of 38 °C in April and an average minimum temperature of 17 °C in January (Neitsch et al., 2011).

2.2 Rain-gauge database

In this research due to the short period of recorded at more than 40 stations meteorological station in the TSL basin, six stations were used. The records of a number of stations started in the mid-nineties, and almost all have data for a few years from 2000. Only 6 stations have longer data series starting in the 1980s up to present. Another 39 stations have available data for more than 7 years (though with considerable gaps), and the rest of the stations have less. In order to examine the spatial and temporal variability of precipitation in the Tonle Sap region, daily rain-gauge datasets for the 6 locations are used. The data are from January 1981 to December 2012 at 6 stations namely Kompong Chhnang, Pursat, Battambang, Banteay Meanchey, Siem Reap and Kompong Thom (Figure1). Rainfall data were obtained from the Ministry of Water Resources and Meteorology (MoWRAM). All the stations that were chosen had a long enough record of data (>30years) for the validity of the time series and trend analysis results. There are no missing data in the time series. The stations are irregularly distributed throughout the Tonle Sap region, and their records cover the longest period available for the highest quality data covering the area. Data availability and summary of rainfall data various rain-gauge stations considered for this study are shown in Table 1.

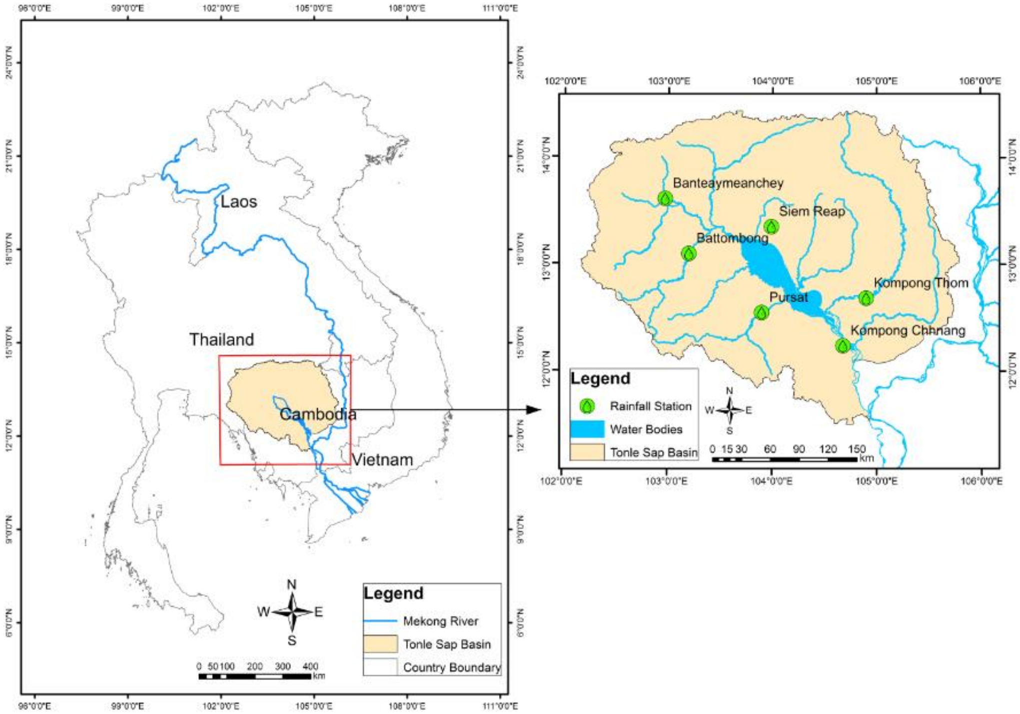

Fig. 1: Location of the rainfall station

Table 1: Geographical coodinates of rainfall data from 6 meteorological stations considered for the study

Station	Latitude (deg)	Longitude (deg)	Period of record available	Length of record used (year)
Kg. Chhnang	12° 41' 10"	104° 54' 00"	1981-2012	31
Pursat	12° 33' 00"	103° 54' 00"	1981-2012	32
Battambang	13° 06' 00"	103° 12' 00"	1985-2012	28
B. Meanchey	13° 36' 52"	102° 58' 13"	1985-2012	28
Siem Reap	13° 34' 00"	103° 15' 00"	1981-2012	32
Kg. Thom	12° 14' 28"	104° 40' 39"	1981-2012	32

2.3 Spatial analysis method

Rainfall mean characteristics

In an attempt to study monthly heterogeneity of rainfall amounts, a modified version of Precipitation Concentration Index (PCI) (Zhai et al., 2014) is used. This index, described as:

$$I = 100 \times \frac{\sum_{i=1}^{12} p_i}{\left(\sum_{i=1}^{12} p_i\right)^2}$$

where p_i is the rainfall amount of the i^{th} month. As described by Galloway et al. (2004), PCI values below 10 indicate a uniform monthly rainfall distribution in the year, whereas values from 11 to 20 denote seasonality in rainfall distribution. Values above 20 correspond to climates with substantial monthly variability in rainfall amounts. IDW (Inverse distance weighting) interpolation methods shall be used to describe the spatial patterns of PCI in the study area.

Spatial distribution of rainfall variability

Coefficients of variation *(CV)* for 6 stations have been computed to investigate the spatial pattern of the inter-annual variability of annual rainfall totals over the study area. The coefficient of variation is defined as:

$$CV = \frac{\left(\sigma_s / \bar{R}_s\right)}{100\,(per\,cent)}$$

where $\bar{R}_s$ is the long-term mean annual rainfall and σ_s is the standard deviation of annual rainfall totals for the station *s*.

2.4 Trend of change analysis

2.4.1 Intervention analysis

Cumulative Summation (CUSUM)

Intervention analysis has been carried using the Cumulative Summation (CUSUM) technique to detect changes in the mean value of a sequence of ordered time observation (Zhang et al., 2005).

The computed CUSUM value *(s_i)* at any time *i* is given as:

$$s_i = \sum_{i=1}^{i} \left(x_i - \bar{x}\right)$$

where x_i is the regularly spaced observation and $\bar{x}$ average of the total series.

When the series under test is free from any interventions, the plot of y_i versus *i* should normally oscillate around the horizontal axis. A steady decline or rise of this plot (or drastic departure from oscillatory patterns in that regard) would suggest the possibility of intervention from the year of observation (corresponding to the relevant *'i'*) of such a change. Positive slopes on these charts indicate a period of above average values of rainfall (hence a 'wet' period in this context) with a negative slope indicating otherwise (Bouraoui et al., 2002). For this initial analysis of temporal trends, we used as many long-term records as possible and did not concentrate on a common period of record at all stations (Buda et al., 2009).

Step change analysis

The rank-sum test is a non-parametric test for difference in medians of two subsets of data representing pre- and post-intervention period is used to test for any step changes. This test goes by many names such as the Wilcoxon rank-sum test, the Mann–Whitney test or the Wilcoxon–Mann–Whitney rank-sum test (Howden et al., 2009).
The standard outline in computing the rank-sum test statistic suggested by CRCCH (2005) is given below:

(i) Rank all the data, from 1 (smallest) to *N* (largest). In the case of ties (equal data values), use the average of ranks;

(ii) Compute a statistic *S* as the sum of ranks of the observations in the smaller group (the number of observations in the smaller group is denoted as *n*, and the number of observations in the larger group is denoted as *m*); and

(iii) Compute the theoretical mean and standard deviation of S under Ho for the entire sample:

$$\mu = n(N+1)/2$$
$$\sigma = \left[n\,m\left(N+1\right)/12\right]^{0.5}$$

The standardized form of the test statistic Z_{rs} is computed as:

$$\begin{aligned} Z_{rs} &= (S-0.5-\mu)/\sigma && \text{if } S > \mu \\ Z_{rs} &= 0 && \text{if } S = \mu \\ Z_{rs} &= |S+0.5-\mu|/\sigma && \text{if } S < \mu \end{aligned}$$

The null hypothesis, H_0, is that no change has occurred in the time series or that the two samples come from the same population (i.e.have the same median) is accepted when the computed Z_{rs} is less than the Z value obtained from a normal distribution table at 5% significance level.

The Mann-Kendall (MK) Test

The Mann-Kendall (MK) test is a non-parametric test to determine if trends can be identified in a temporal series including a seasonal component. This nonparametric trends test is the result of an improved test initially studied by Mann and followed by Kendall, being finally optimized by test (Howden et al., 2009). The test is based on the null hypothesis H_0 meaning that there are no trends in the series. The test has 3 alternative hypotheses in the series evolution: negative, null and positive.

The Seasonal Kendall test (Howden et al., 2009) is a non-parametric and can be used to analyses trends of rainfall, stream flow and water. The Mann- Kendall Test- statistic S is given as:

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

where

$$\begin{aligned} S = \operatorname{sgn}(x_j - x_k) &= 1 && \text{if } x_j - x_k > 0 \\ &= 0 && \text{if } x_j - x_k = 0 \\ &= -1 && \text{if } x_j - x_k < 0 \end{aligned}$$

The variance of S denoted by σ_S^2 is computed as:

$$\sigma_S^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{q} t_j (t_j - 1)(2t_j + 5)}{18}$$

where n is the number of data points, q is the number of tied groups in the data set, and t_j is the number of data points in the j^{th} tied group.

Then S and σ_S^2 were used to compute the test statistic Z_s as:

$$\begin{aligned} Z_s &= \frac{S-1}{\sigma} && \text{if } S > 0 \\ &= 0 && \text{if } S = 0 \\ &= \frac{S+1}{\sigma} && \text{if } S < 0 \end{aligned}$$

A positive value of S indicates that there is an increasing trend and a negative value indicates a decreasing trend. The null hypothesis H_0 that there is no trend in the data is either accepted or rejected depending if the computed Z_S statistics is less than or more than the critical value of Z-statistics obtained from the normal distribution table at 5% significance level.

3. RESULTS AND DISCUSSION

3.1 Anuual Rainfall chatacteristics

Rainfall variability in space and time is one of the most relevant characteristics of the climate of TSL. Annual rainfalls in the study region from available 6 stations were shown in Figure 2.

From the basic daily rainfall data, monthly means, median, percentiles, seasonal totals, and other basic statistic were computed monthly and annually. The annual rainfall data of 6 stations of TSL basin are averaged to get the time series of annual average rainfall for the period approximately 1150 mm to 1600 mm according to locations. The mean annual rainfall over TSL basin for this period is 1390 mm. On average the rainfall varies greatly from month to month and location to location and has two noticeable peaks per year. The first peak occurs at the beginning of the wet season between May and June as the monsoon rains move north. There is then a period of lower rainfall between June and August. The monsoon returns south during August through October duringwhich time the rainfall is usually heavier and can cause widespread flooding.

The descriptive statistics of annual rainfall such mean rainfall (R_e), maximum rainfall (R_x) minimum rainfall (R_m), standard deviation (SD), skewness (C_s), mean deviation (MD), at each of these meteorological stations have also been given in Table 2. It is clearly evident that the average annual rainfall in the Tonle Sap Lake basin varies from 1100 mm to 1600 mm.

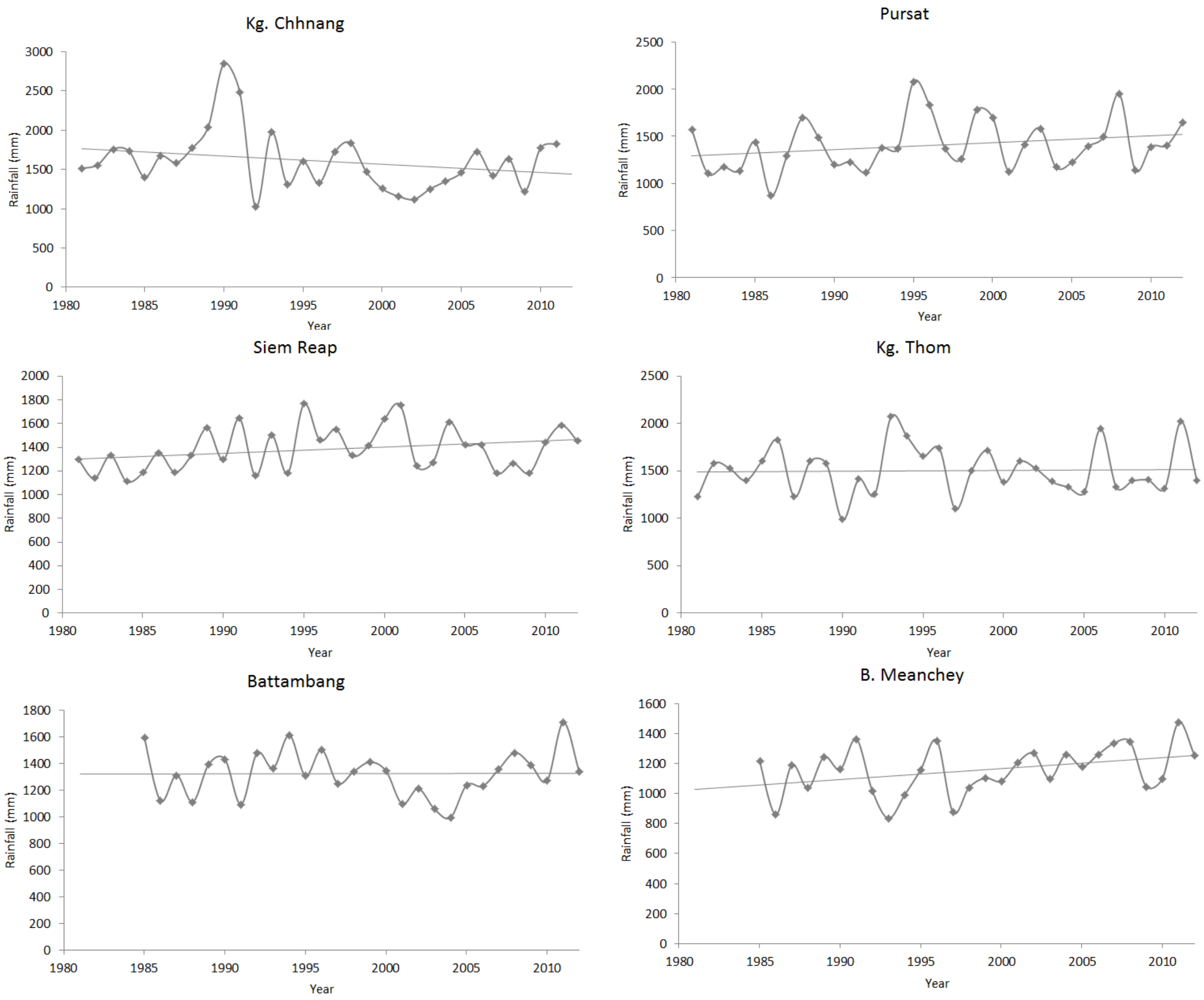

Fig. 2: Annual rainfall from 6 stations in Tonle Sap Lake region from the 1980s to 2012

Table 2: Basic statistical characteristics of the annual rainfall data for the 6 stations from 1980s to 2012 include: mean rainfall (Re), maximum rainfall (Rx) minimum rainfall (Rm), standard deviation (SD), skewness (Cs), mean deviation (MD)

No	Station	Re (mm)	Rx (mm)	Year of occurrence	Rm (mm)	Year of occurrence	SD (mm)	Cs	MD (mm)
1	Kg. Chhnang	1601	2853	1990	1027	1992	379	1.4	275
2	Pursat	1407	2081	1995	871	1986	273	0.6	211
3	Battambang	1322	1707	2011	994	2004	175	0.1	136
4	B. Meanchey	1156	1476	2011	835	1993	159	-0.3	127
5	Siem Reap	1382	1765	1995	1111	1986	185	0.4	155
6	Kg. Thom	1504	2070	1993	9084	2011	258	0.4	205

From the daily rainfall, coefficient variation (CV) and Precipitation Concentration Index (PCI) were calculated to confirm the interannual variability and indicator of the temporal distribution of precipitation, respectively. Table 3 shows the result of CV and PCI. The CV shows that interannual variability was average in the whole area, with values ranging from 13% to more than 23%. Base on the result of CV, intra-annual distribution of rainfall amounts was not variable in space and time. The results of PCI analysis show the regular intra-annual rainfall distribution (PCIs are approximately 15) throughout the region. It is strong evidence that the study area is the uniform monthly distribution. The spatial presentation of the mean annual rainfall can be helpful for a better understanding of mean annual rainfall variations throughout the TSL basin. Therefore, mean annual rainfall of the 6 observed stations were calculated and interpolated to prepare the map of the spatial pattern of mean annual rainfall trends which is shown in Figure 3 (a) together with coefficient variation (Figure 3 (b))

Table 3: Result of coefficient variation (CV) and Precipitation Concentration Index (PCI) calculation for the 6 stations from the 1980s to 2012 for Tonle Sap Lake region

Station name	CV (%)	PCI	PCI Class definition
Kompong Chnang	24	15.4	Uniform monthly distribution
Pursat	19	15.0	Uniform monthly distribution
Battambang	13	14.9	Uniform monthly distribution
Banteaymeanchey	14	15.6	Uniform monthly distribution
Siem Reap	13	16.9	Uniform monthly distribution
Kompong Thom	17	15.7	Uniform monthly distribution

3.2 Temporal rainfall variability

Intervention analysis

The computed Cumulative Summation *(CUSUM)* rainfall value *(s_i)* at any time *i* for each station were obtained and plotted as shown in Figure 4. The CUSUM chart shows the accumulation of rainfall of current of the year observed and previous year annual rainfalls. The annual rainfall time series for the 6 stations clearly show that for the majority of the periods the annual rainfall has been below the long-term mean. It appears that there were a number of temporary interventions for all stations and a general downward trend from about 1980s to 1990s except for Kompong Chhnang station. However, some interventions have also been seen for Kompong Thom station, from the year 1980s. Therefore, these needed to be confirmed through step change analysis as said in the previous session.

Step change analysis

Step change analysis results are assessed based on the confidence level calculated through the use of the previously described statistical tests. Step change analysis was conducted to confirm and ascertained the CUSUM findings as shown in Table 4.

Result of Step change analysis shows that there is no significant change for all the six-station throughout the observed period in Tonle Sap Lake region. For all station, the value of *Z* test statistic is lower than the critical value of 1.96 at (5% or) 0.05 significance level. Indications are that there has no indeed been the significant change in rainfall. To confirm this result from the step of change analysis, trends of annual rainfall will be discussed in the next session.

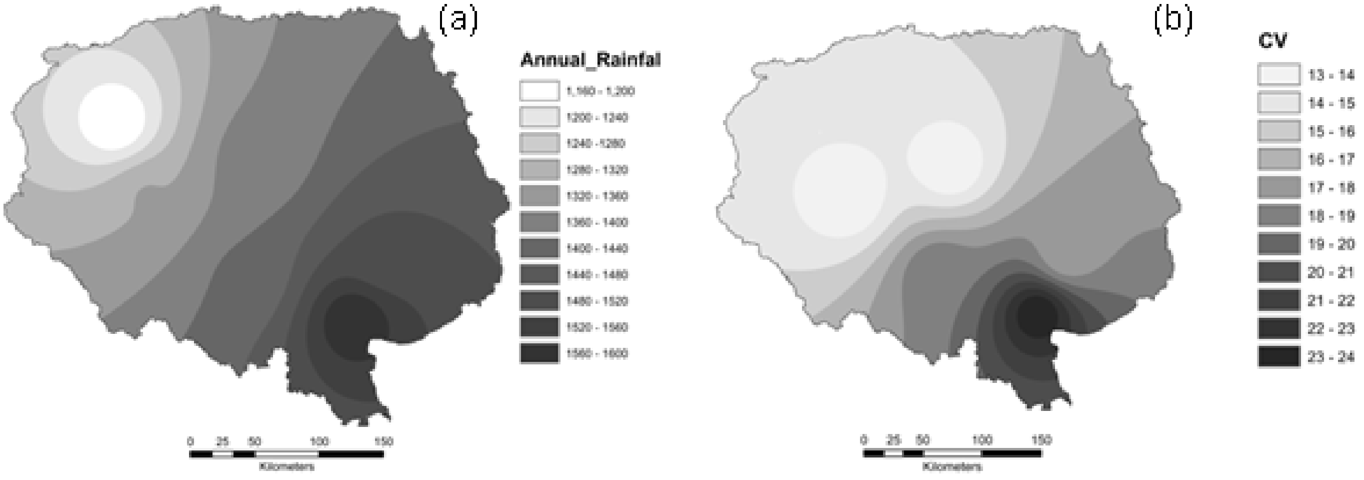

Fig. 3: Annual rainfall in the Tonle Sap Lake region (1981–2012) (a) Mean annual rainfall (Rbar) distribution (b) Spatial distribution of interannual variability of annual rainfall (CV)

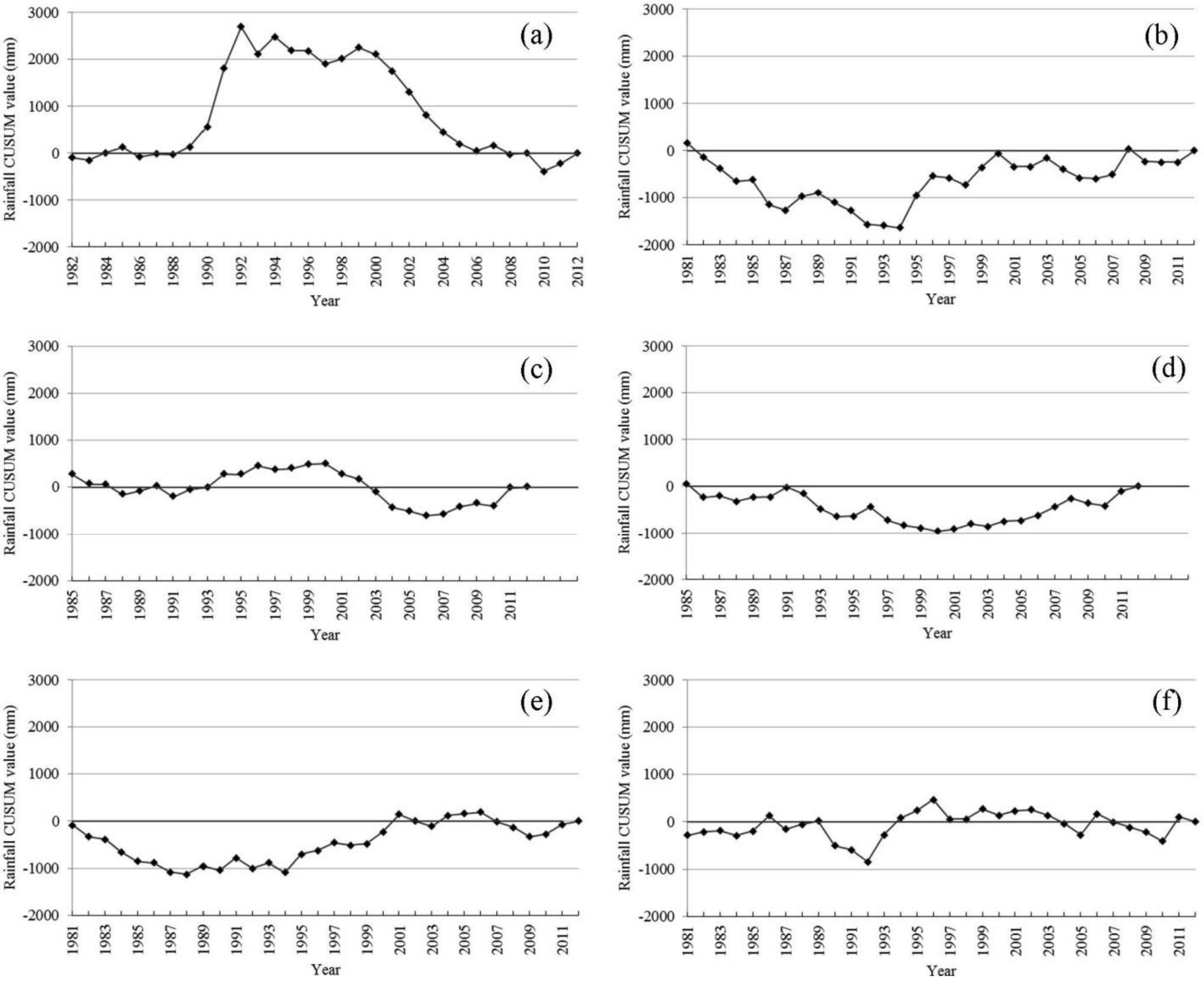

Fig. 4: CUSUM plot using observed annual for (a) Kompong Chhnang, (b) Pursat, (c) Battambang, (d) Banteay Meanchey, (e) Siem Reap, (f) Kompong Thom

Table 4 Result of step change analysis for 6 stations in Tonle Sap Lake basin (1981–2012)

Station name	Test statistic *Zs*	Critical value at alpha=0.05	Result
Kompong Chnang	-4.70	1.96	No significance
Pursat	-4.77	1.96	No significance
Battambang	-4.47	1.96	No significance
Banteaymeanchey	-4.43	1.96	No significance
Siem Reap	-4.80	1.96	No significance
Kompong Thom	-4.80	1.96	No significance

Trends of annual rainfall

Trends analyses were conducted using the Mann–Kendall (MK) test as described earlier and the results are summarized in Table 5. There was no evidence of significant trends in the annual rainfall at 0.05 significance level for all the individual stations as the computed *Z* statistics were found to be less than the critical value of 1.96. Although the trends are not significant, the rainfall is generally decreasing as evident from the negative values of the Mann–Kendall-statistics, *S*.

Table 5 Trend analysis using Mann–Kendall method (the 1980s–2012)

Station name	Mann–Kendall statistic *S*	Test statistic *Zs*	Critical value at alpha=0.05	Result
Kompong Chnang	-61	-1.02	1.96	No significance
Pursat	96	1.54	1.96	No significance
Battambang	-14	-0.26	1.96	No significance
Banteaymeanchey	98	1.92	1.96	No significance
Siem Reap	88	1.41	1.96	No significance
Kompong Thom	-18	-0.28	1.96	No significance

The trend analysis of annual average rainfall time series by Mann–Kendall test reveals that there was no presence of significant trends in the annual rainfall at the 0.05 significance level for all the individual stations. Mann–Kendall normalized test statistics (Z) were found to be less than the critical value of 1.96.

Table 4: Slope direction and trend ("+" positive slope, "-" negative slope, "grey shade" is significant slope)

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kompong Chnang	-	+	+	-	+	-	-	-	+	-	-	+
Pursat	+	+	+	+	+	+	+	+	-	+	-	+
Battambang	+	+	+	+	+	+	-	-	-	+	-	-
Banteaymeanchey	-	-	+	+	+	-	+	-	+	+	+	-
Siem Reap	+	+	+	+	+	-	+	-	+	+	+	+
Kompong Thom	+	+	+	+	+	-	+	+	-	-	-	+

The trend of Monthly rainfall

A month-by-month Kendall analysis was done to detect the trends for all 6 selected stations, and the results are shown in Table 4. The results have clearly shown a few stations with statistically significant trends 5% significance levels. Unlike annual rainfall and number of rainy days per year, the monthly rainfall also showed both increasing and decreasing trends depending on the station. From January to May (mid of dry season to start of rainy season) MK test result showed the positive slope and could translate that theses period has experienced increases in the monthly rainfall amounts.

4. CONCLUSIONS

The study aimed to analyze rainfall trend in Tonle Sap Lake regions of the Lower Mekong Basin and to determine if these time series belonged to a similar regime, have had any significant trends. An understanding of the rainfall trend in the study has included the spatial and temporal distribution and trend analysis in rainfall. To reveal the behaviors of annual and monthly rainfall for trends in observed data series of available 6 stations in more than 30 years from the 1980s to 2012, Step change analysis and the nonparametric Mann–Kendall test has been applied. The applied methods presented similar results for annual rainfall trend. It emphasizes that the time-series of the annual rainfall variation in Tonle Sap Lake basin presented no significant trend (statistically significant at $p<$ 0.05) for all stations,although some increase trends in rainfall for all the individual stations were observed with positive values of the Mann Kendall test. The result of monthly trend shows the presence of increasing in the monthly rainfall amounts from January to May (mid of dry season to start of rainy season) in the investigated period. The results also suggest the need for further investigation on the shift analysis and the number of rainy day year, which could be one of the major causes of in the Tonle Sap Lake basin.

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