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# Extreme Rainfall Event Analysis in Tonle Sap Lake Basin, Lower Mekong River Basin

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**Abstract:** *Daily rainfall data from six meteorological stations surrounded Tonle Sap Lake was used to analyze a statistical characteristic of rainfall distribution and trend analysis of extreme rainfall for both annual and seasonal. Daily rainfall indices were defined and analyzed based on the World Meteorological Organization guideline. Mann–Kendall's and Sen's slope estimator were used to define the statistical significance of the rainfall changes and the magnitude trends of an extreme rainfall event, respectively. As the results, statistical analysis of annual and seasonal rainfall within the study period (1985-2010) varied upon locations. In addition, the amount of rainfall in wet season contributed 84% of annual rainfall for the study period. For analysis trend of extreme rainfall showed that only a few indices at few of the stations showed statistically significant changes, the significant increasing trend of very heavy rainfall (R20mm) was found at Pursat in annual and wet season, the significant increasing and decreasing trend in dry season were found at Banteay Meanchey and Kampong Thom, respectively. Furthermore, the significant increasing trend in number of wet (NWD) and dry days (NDD) was found at two stations Pursat, Siem Reap in annual time step. Therefore, these results strongly support to the disaster management and planning through comprehensive extreme event information, regarding to the trend magnitude.*

**Keywords:** Extreme rainfall; Daily rainfall indices; Mann-Kendall, Sen's slope; Tonle Sap Lake

## 1. INTRODUCTION

Rainfall is the meteorological phenomenon that has the strong influence on human activities and the most important environmental factor limiting the development of the semiarid regions. Study of rainfall variability is essential to optimally manage the scarce water resources that are under continuous stress due to the other types of growth such as increasing water demands, increase in population, and the economic development (Nyatuame et al., 2014). For instance, high precipitation amounts and consequent flashfloods can damage field crops, destroy infrastructure and disrupt sewerage system. Understanding of temporal and spatial characteristics of rainfall distribution is essential for water resources planning and management in context of climate change and its variability. This understanding could also provide information that is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modelling, water resource assessments, climate change impacts and other environmental assessments (Wilson et al., 1979). Rainfall variability analysis would enhance the management of water resources applications as well as the effective utilization of water resources. Such information can also be used to prevent floods and droughts, and applied to the planning and designing of water resources related engineering, such as reservoir design, flood control work, drainage design, and soil and water conservation planning, etc. (Lee, 2005).

Extreme weather or climate events can have major impacts on society, the economy and the environment (Manton et al., 2001). Extreme rainfall events hanging in the number, frequency or intensity of extreme. Cambodia is prone to extreme weather events, especially floods, droughts and typhoons (Davies et al., 2014). Rainfall events are very likely to be increasing as a result of climate change and will have a much greater impact on natural and human systems than a small shift in the mean values (Degefu and Bewket, 2014).

The trend of extreme rainfall has not widely studied in Cambodia especially in Tonle Sap Lake region. This region is particularly vulnerable to the variation of water flow in a lake and make effect of biodiversity duo to the change of rainfall distribution. The Mann–Kendall (MK) test is a widely used nonparametric technique for detecting monotonic trends in hydrological and meteorological time series (Ahmad, 2015 15). With the applicable of the Mann–Kendall (MK) test for meteorological time series, this method is applied to detect trends of extreme rainfall in both annual and seasonal time step. Sen's slope method is also used to define the magnitude of the trend to know exactly

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how much the change value of trends of extreme rainfall. However, before Mann-Kendall and Sen's slope were used, Pre-whitening is also necessary calculation to remove all influence of serial correlation.

This research paper carries out a statistical analysis of the long-term rainfall data for region surrounds Tonle Sap Lake. The major objective of this work is to 1) statistically analyze the Spatio-temporal variation in annual and seasonal rainfall data of six provinces surround Tonle Sap Lake. 2) analysis of extreme seasonal and annual rainfall intensity. 3) defined trend of extreme rainfall seasonal and annual.

## 2. METHODOLOGY

### *2.1 Discription of study area*

Tonle Sap Lake is the largest lake in Southeast Asia. It is located almost in the middle of Cambodia. The Tonle Sap Lake occupies a geological depression (the lowest lying area) of the vast alluvial and lacustrine floodplain in the Lower Mekong Basin, which had been induced by the collision to the Indian Plate with the Eurasian Plate. The lake's size, length, and water volume vary considerably over the course of a year from and area of around 2,500 $km^2$, a volume of 1 $km^3$ and a length of 160 km at the end of the dry season in late April to an area of up to 16,000 $km^2$, a volume of 80 $km^3$ and a length of 250 km as the Mekong maximum and the peak of the South-West monsoon's precipitation culminate in September and early October.

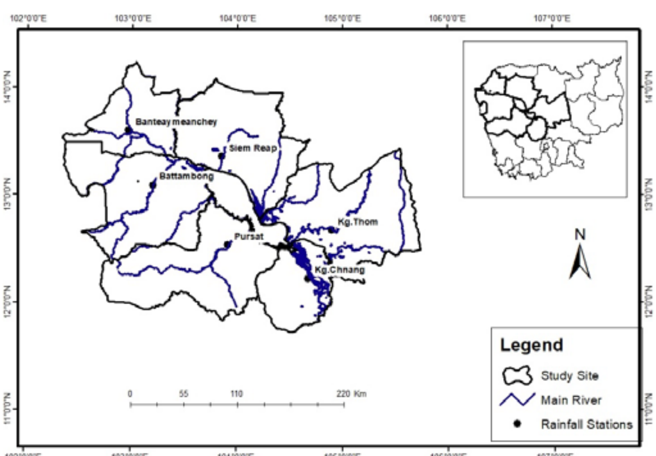


**Figure 1** Map of Tonle Sap Basin and location of rainfall stations with provinces boundary

Water levels in the lake vary by about 8 m between the dry season minimum and the wet season maximum when waters from the Mekong River back up the Tonle Sap River (Campbell et al., 2006). In climate condition context, Cambodia is a tropical climate and is governed by the monsoon winds which has two seasons (six-month wet season and six-month dry season). The southwest monsoon corresponds with the rainy season which goes from mid-May to mid-September/early October. The north-east monsoon brings dry, cooler air and stretches from November to March. The hottest days are concentrated in April, until early May (Oudry, 2016 #9).

**Figure 1** Six provinces are located around the Tonle Sap Lake which are Kampong Chhnang, Pursat, Battambang, Kompong Thom, Siem Reap, and Banteaymeanchey. Also, six meteorological stations in these provinces were selected for this study. The amount of rainfall is different because of the diverse topography. Provinces have high elevation; the amount of rainfall is high also such as in Kompong Chhnang province is located in the high elevation of six provinces then the average amount of water is very high than others.

### *2.2 Precipitation Index*

Following the WMO guidelines (Data, 2009), daily rainfall indices were defined and used. Accordingly, a day with rainfall of 1 mm or greater was defined as wet day and dry day otherwise (Data 2009). All the daily indices (**Table 1**) were then calculated from the daily data series for each station. Long-term changes in the daily, seasonal and annual rainfall indices were examined using the nonparametric Mann-Kendall's test and Sen's slope estimator, that used to determine the statistical significance of the rainfall changes and the magnitude trends of extreme rainfall event (Degefu and Bewket, 2014)

**Table 1** Definitions of daily rainfall indices used in the study (Data, 2009)

| Index | Index name | Definition | Unit |
|---|---|---|---|
| Rx1 day | Maximum one day rainfall | Highest precitation amount in one day | mm |
| Rx10 day | Maximum ten days rainfall | Highest precitation amount in ten days | mm |
| R20 mm | Very heavy rainfall days | Count of days where rainfall ≥ 20 mm | days |
| SDII | Simple daily intensity index | Mean precipitation amount in wet days | mm |
| NWD | Number of wet days | Count of wet days where rainfall ≥ 1 mm | days |
| NDD | Number of dry days | Count of dry days where rainfall < 1 mm | days |

| | | | |
|---|---|---|---|
| CDD | Consecutive dry days | Maximum length of dry spell (rainfall < 1 mm) | days |
| CWD | Consective wet days | Maximum length of wet spell (rainfall ≥ 1 mm) | days |

### *2.3 Pre-whitening method*

Pre-whitening (PW) is applied to remove the influence of serial correlation on Mann-Kendall (Yue and Wang, 2002). The PW procedure decreases the inflation of the variance of the test statistic due to serials correlation, and thus reduces the rejection rate below the rate before PW (Bayazit and Önöz, 2007). This has the following results:

- When there is no trend, the probability of Type I error is significantly reduced, almost to the theoretically correct value.
- When a trend exists, however, the power of the test is decreased as compared with the power before PW, so that sometimes it may cause a significant trend not to be detected.

### *2.4 Mann-Kendall test*

Mann-Kendall test is a non-parametric test for identifying trends in time series data. It's used to determine the trend in time series (monthly, seasonal and annual) (Río et al., 2011). The MK test whether to reject the null hypothesis ($H_0$) and accept the alternative hypothesis ($H_a$), where $H_0$ for no trend and Ha for monotonic trend. The initial assumption of the MK test is that the $H_0$ is true and that the data must be convincing beyond a reasonable doubt before $H_0$ is rejected and $H_a$ is accepted (Khambhammettu 2005). Actually, Mann-kendall test and Sen's slope method were applied in MATLAB, which used code calculation by the following equations.

Let $x_1$, $x_2$, …$x_n$ represent n data points where $x_j$ represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$$s = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

where; $$sign(x_j - x_k)\begin{cases} = 1 \text{ if } x_j - x_k > 0 \\ = 0 \text{ if } x_j - x_k = 0 \\ = -1 \text{ if } x_j - x_k < 0 \end{cases}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. Kendall describes a normal-approximation test that could be used for datasets with more than 10 values provided there are not many tied values within the data set (Douglas et al., 2000). The variance of S (VAR(S)), by the following equation:

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

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the value), and $t_p$ is the number of data points in the $P^{th}$ group.

Compute a normalized test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & \text{if S > 0} \\ 0 & \text{if S = 0} \\ \dfrac{S-1}{\sqrt{VAR(S)}} & \text{if S < 0} \end{cases}$$

The presence of a statistically significant trend is evaluated using Z value. A positive (negative) value of Z indicates an upward (downward) trend (Partal and Kahya, 2006). The statistic Z has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, $H_0$ is rejected if the absolute value of Z is greater than $Z_{1\text{-}a/2}$, where $Z_{1\text{-}a/2}$ is obtained from the standard normal cumulative distribution tables (Salmi, 2002).

Compute the probability associated with this normalized test statistic. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{z^2}{2}}$$

### *2.5 Sen's method*

Sen's slope method is used to define magnitude of trend (Shahid and climatology, 2011). The Sen's method can be used in case where the trend can be assumed to be linear. This means that linear model f(t) can be described as (Drápela and Drápelová, 2011).

$$f(t) = Qt + B$$

where $Q$ is the slope and B is a constant.

To derive an estimate of the slop $Q$, the slopes of all data pairs are calculated.

$$Q_t = \frac{x_i - x_k}{j-k} \; ; i-1,2,3,...N \; ; j>k$$

If there are n values $x_j$ in the time series, we get as many as

$$N = \frac{n(n-1)}{2} \text{ slope estimates } Q_i .$$

The Sen's estimator of the slope is the median of these N values $Q_i$. The N values of $Q_i$ are ranked from the smallest to the largest and Sen's estimator is

$$Q = \begin{cases} Q_{\frac{N+1}{2}} & \text{if N is odd} \\ \frac{1}{2}\left( Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}} \right) & \text{if N is even} \end{cases}$$

A 100(1-α)% two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution (Pingale et al., 2014).

## 3. RESULTS AND DISCUSSION

### 3.1 Seasonal and annual rainfall variation

*Wet season rainfall distribution characteristic of each station*

The rainfall data obtained from six stations including Kampong Chhnang, Battambang, Pursat, Kampong Thom, Siem Reap, and Bonteay Meanchhey were used to assess any significant difference among the six stations within the year during the study period (1985-2010). Actually, wet season is counted from May to October in this study.

**Figure 3** gives the overall information about the wet season rainfall distribution of six stations during the period study. As can see, it is obviously shown that the wet season among six stations under consideration could best be described as fluctuation or oscillatory. The rainfall distribution of these six stations are irregular, meaning the amount of rainfall is difference from year to year within the wet season. Additionally, the Kampong Chhnang station has a high oscillatory of rainfall distribution than the rest. The higher precipitation recorded in the Kampong Chhnang station with amount 1373.58 mm of average total rainfall in wet season within 30 years. On the contrary, the lowest precipitation was recorded at Bonteay Meanchey with amount 983.81 mm of average total rainfall in wet season within 30 years.

**Table 2** presents the summarized statistic of rainfall in the wet season. As the result, the high value of standard deviation could be reflected in a degree of uncertainty related to predicting the value of random variables. The relationship between standard deviation and range indicated the distribution cannot be ignored. Furthermore, based on the results of the coefficient of variation in wet season within 30 years showed that the precipitation values are much varied from the average. Actually, based on the results of coefficient of variation in wet season within 30 years is lower than 0.5, lower CV indicated the low variability from the mean, meaning the changes of rainfall distribution from year to year of the wet season are low.

*Dry season rainfall distribution characteristic of each station*

**Figure 4** the overall information about the dry season of six stations during the period study. Actually, dry season is counted from November to April in this study. As can see in **Figure 5,** it is obviously shown that the dry season among six stations under consideration could best be described as fluctuation or oscillatory. The rainfall distribution of these six stations are irregular, meaning the amount of rainfall difference from year to year within the dry season.

However, comparing the six rainfall stations, it can be observed that Siem Reap station has more regular rainfall distribution than the rests. Additionally, Kampong Chhnang station has a high oscillatory rainfall distribution than the rests. The highest rainfall recorded in the Pursat station with amount 275.36 mm of average total rainfall in

**Table 2** Total rainfall in wet season at six stations for the period (1985-2010)

| Stations | Total (mm) | Mean (mm) | SD | CV | Median (mm) | Skewnees | Kurtosis | Minimum (mm) | Maximum (mm) | Range (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Bonteay Meanchey | 983.81 | 163.97 | 76.12 | 0.47 | 154.59 | 0.35 | -0.06 | 73.99 | 275.99 | 201.99 |
| Battembong | 1079.94 | 179.99 | 81.30 | 0.45 | 173.60 | 0.35 | 0.02 | 81.56 | 301.36 | 219.80 |
| Pursat | 1132.86 | 188.81 | 85.69 | 0.46 | 180.00 | 0.37 | 0.27 | 89.53 | 318.41 | 228.88 |
| Kampong Chhnage | 1373.58 | 228.93 | 96.94 | 0.42 | 226.42 | 0.33 | -0.23 | 109.01 | 367.19 | 258.18 |
| Kampong Thom | 1252.06 | 208.68 | 95.95 | 0.46 | 199.92 | 0.36 | -0.27 | 93.30 | 348.75 | 255.45 |
| Siem Reap | 1246.51 | 206.33 | 96.95 | 0.48 | 196.88 | 0.20 | 0.43 | 87.74 | 346.83 | 259.09 |

the dry season. On the contrary, the lowest precipitation was recorded at Siem Reap with amount 138.42 mm of average total rainfall.

**Table 7** presented summarized statistic of rainfall in the dry season. The relationship between standard deviation and range indicated the distribution cannot be ignored. From observation the standard deviation values in the dry season are smaller than wet season due to less amount of precipitation, it also emphasized that rainfall distribution in the dry season is tightly grouped about the mean. Furthermore, based on the results of the coefficient of variation in dry season within 30 years showed that the precipitation values are much varied from the average. Actually, based on the results of coefficient of variation in wet season within 30 years is higher than 0.5, higher CV indicated the high variability from the mean, meaning changes of rainfall distribution from year to year of the dry season are high.

*Annual rainfall distribution characteristic of each station*

As can see **Figure 5** , from observation of six stations have shown that annual rainfall under consideration could best be described as fluctuation or oscillatory. The rainfall distribution of these six stations are irregular, meaning the amount of rainfall difference from year to year. However, comparing the six rainfall stations, it can be observed that the rainfall distribution in Siem Reap station is more regular than the rests. Additionally, the Kampong Chhnang station has a high oscillatory of rainfall distribution. The highest precipitation recorded in the Kampong Chhnang station with amount 1601.00 mm of average annual rainfall. On the contrary, the lowest precipitation was recorded at Bonteay Meanchey with amount 1154.83 mm of average annual rainfall.

Statistic of annual rainfall was summarized in **Table 6**. The relationship between standard deviation and range indicated the distribution cannot be ignored. From observation, annual's standard deviation values are smaller than a dry season but bigger than the wet season. Furthermore, based on the results of the annual coefficient of variation within 30 years showed that the precipitation values are much varied from the average.

Actually, based on the results of coefficient of variation of annual rainfall within 30 years is higher than 0.5, higher CV indicated the high variability from the mean, meaning the changes of rainfall distribution from year to year are high.

*Seasonal and Annual rainfall distribution characteristics of Tonle Sap*

After description seasonal and annual rainfall distribution characteristics of each station, the seasonal and annual rainfall data during the study period (1980s – 2010s) obtained from six stations around Tonle Sap were used to identify rainfall distribution characteristics of Tonle Sap in **Figure 2**. For annual rainfall, the results depending upon locations, annual rainfall level at each station surrounded Tonle Sap Lake varied from 1154.83 mm to 1601.00 mm, with an average annual rainfall from all station of 1400.81 mm.

**Table 5** indicates that amount of rainfall in the wet season contributed 84% of annual rainfall for the study period. For rainfall in the wet season, total rainfall in study area varied from 983.81 mm to 1373.58 mm, with average total rainfall from all stations of 1178.13 mm. Actually, total rainfall in dry season varied from 138.42 mm to 275.36 mm, with average total rainfall 213.63 mm within the study period. The high value of the standard deviation of annual rainfall indicated that rainfall data is spread widely on either side of the mean, meaning from year to year rainfall is high fluctuation. Furthermore, with the CV value, 0.96 of annual rainfall and 1.38 of dry season indicated the rainfall distribution being highly variable and not dependable or can be attributed to the length of data set being used, while in wet season CV value 0.46 means that the changes of rainfall distribution in wet season (1985-2010) are low.

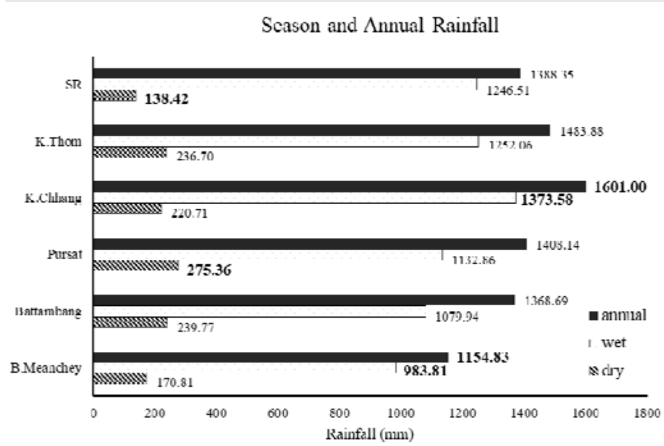


**Figure 2** Seasonal and annual rainfall of each station

### 3.2 Trends in extreme rainfall events

**Annual:** The variation and trends in extreme event indices at annual time steps at six stations are shown in **Table 3.** It shows that the annual mean maximum one day (Rx1day) rainfall amount is between 83 mm (Bonteay Meanchey) and 109 mm (Siem Reap). The mean maximum consecutive ten-day (Rx10day) amount was counted by the highest commulative rainfall intensity in the continuously raining in ten days. The result showed that (Rx10day) is ranged from 0 mm (Pursat) to 19 mm (Siem Reap). The occurrence of very heavy (R20mm) rainfall events was lowest at Bonteay Meanchey (19 days) and highest at Kampong Chhnang (28 days). There are two stations showed significant trends (α=0.05) of the number of very heavy (R20mm) which are Pursat station (increase trend 0.23 day/30years) and Kampong Thom station (decrease trend -0.28 day/30years). Noted that, the positive value shows increasing trends and the decreasing trends was shown by the negative values.

Out of 8 rainfall extreme event indices at six stations for annual time series, about 44% showed decreasing trends, 22% of them showed an increasing trend, and 34% showed no trends. However, only two stations showed significant change Pursat and Kampong Thom stations. Most of the daily indices in this study did not show significant changes in statistical terms.

**Wet season: Table 3** showed the variation and trend in extreme rainfall event indices at wet seasonal time steps at the six stations.

The wet seasonal mean maximum one day (Rx1 day) precipitation amount varied between 74 mm (Battambang) and 108 mm (Siem Reap). The mean maximum consecutive ten days (Rx10 day) amount ranged from 4 mm (Bonteay Meanchey) to 19 mm (Siem Reap). The occurrence of very heavy (R20mm) precipitation events was lowest at Bonteay Meanchey (16 days) and the highest at Kampong Chhnang (24 days). Only one of the indices at Pursat station has shown statistically significant trends, it was R20mm (increasing trend 0.13 day/30years). Out of 8 rainfall extreme event indices at the six-station, about 33% of them showed a decreasing trend, 27.7% showed an increasing trend, and 38.8% showed no trend.

**Dry season**: **Table 3** shows variation and trends in rainfall extreme event indices at dry seasonal time steps at the six-station. The value of the seasonal maximum one day (Rx1 day) is between 36 mm (Siem Reap) and 65 mm (Kampong Thom). The mean maximum consecutive ten days (Rx10 day) amount ranged from 0 mm at Bonteay Meanchey and 1 mm at Battambang. The occurrence of very heavy (R20mm) precipitation events was lowest at Bonteay Meanchey and Siem Reap (2days) and highest at Pursat (5days). Only one of indices (Bonteay Meanchey station) has shown statistically significant trend (0.10day/30years) for R20 day. Out of 8 rainfall extreme event indices at the six stations for the dry station time series, about 22.22% of them showed increasing trends, 22.22% of team showed decreasing trends, and 55.55% of them showed trend.

**Table 3** Trend in extreme rainfall events at annual and season

| Stations | Time scale | Rx1 day (mm) | Trend (mm/30 years) | Rx10 day (mm) | Trend (mm/30 years) | R20 mm (day) | Trend (No. of day/30 years) |
|---|---|---|---|---|---|---|---|
| Kampong Chhang | Annual | 96 | -1.05 | 7 | 0.0 | 28 | -0.04 |
| | Wet | 92 | -0.98 | 7 | 0.0 | 24 | 0.00 |
| | dry | 51 | -0.65 | 0 | 0.0 | 4 | -0.06 |
| Pursat | Annual | 86 | -0.47 | 9 | 0.0 | 22 | '0.23 * |
| | Wet | 86 | -0.68 | 9 | 0.0 | 19 | 0.13* |
| | dry | 56 | 0.08 | 0 | 0.0 | 5 | 0.00 |
| Battambang | Annual | 84 | 0.19 | 14 | 0.0 | 22 | -0.06 |
| | Wet | 74 | 0.30 | 13 | 0.0 | 18 | -0.10 |
| | dry | 54 | 0.28 | 1 | 0.0 | 4 | 0.00 |
| Bonteay Meanchey | Annual | 83 | -0.67 | 5 | 0.0 | 19 | 0.20 |
| | Wet | 81 | -1.10 | 4 | 0.0 | 16 | 0.10 |
| | dry | 44 | 0.95 | 1 | 0.0 | 2 | 0.1* |
| Siem Reap | Annual | 109 | -0.76 | 19 | 0.0 | 22 | 0.04 |
| | Wet | 108 | -0.65 | 19 | 0.0 | 19 | 0.09 |
| | dry | 36 | -0.23 | 0 | 0.0 | 2 | 0.00 |
| Kampong Thom | Annual | 94 | -0.01 | 9 | 0.0 | 25 | -0.28 * |
| | Wet | 90 | 0.29 | 9 | 0.0 | 21 | -0.22 |
| | dry | 65 | -0.97 | 0 | 0.0 | 4 | 0.00 |

(*significant)

**Annual**: **Table 4** showed variations and trends of annual, wet and dry day frequencies, total wet day rainfall amount and intensity and the six stations. The mean annual wet day rainfall intensity (SDII) ranged from 13mm (Battambang) to 18mm (Kampong Chhnang). Only Siem Reap showed significant increasing trend for the intensity of wet day precipitation (SDII), SDII increase at rate 0.16 mm/30 years. In number of wet day (NWD), the increasing trend (1.0 day/30years) and (1.1days/30 years) at Pursat and Siem Reap were significant, respectively. On the other hand, decreasing trend (-1.05day/30years) at Siem Reap for the NDD annual series was significant at $\alpha = 0.05$.

The mean annual maximum consecutive wet day length (CWD) was shortest (7 days) at Kampong Chhnang and Bonteay Meanchey and longest (9 days) at Siem Reap, the mean annual maximum consecutive dry day length (CDD) was shortest (74days) at Battambang and longest (97 days) at Siem Reap and Kampong Thom. Noted that only the decreasing trend (-0.04 day/30years) for the maximum wet-spell length (CWD) at Kampong Chhnang and (-1.05day/30years) for the dry-spell length (CDD) at Siem Reap were significant trend.

**Wet season**: Total wet day rainfall amount and the wet day intensity at the six stations are shown in **Table 4**. The mean seasonal wet day rainfall intensity (SDII) ranged from 13 mm to 19 mm at Battambang and Pursat, respectively. It had two significant decreasing trends at Pursat (0.08 mm/30years) and Siem Reap (-0.18 mm/30years for SDII. There are variations in the mean number of wet days (NWD) among the stations, it was lowest at Bonteay Meanchey (64 days) and highest at Siem Reap and Pursat (83 days). The opposite is for the mean number of dry days (NDD), it was lowest at Battambang (102 days) and highest at Bonteay Meanchey (120 days). There are two indices that have significant at 0.05 for the NWD, at Pursat (increasing trend 0.72 day/30years) and Siem Reap (increasing trend 1.0 day/30years). Additionally, the decreasing trend (-0.67 day/30years) at Pursat for the NDD was also significant.

The mean seasonal maximum consecutive dry day length (CDD) was shortest (7 days) at Bonteay Meanchey and longest (14 days) at Siem Reap, only decreasing trend at Siem Reap (-0.28 days/30years) was significant. For the mean annual maximum consecutive wet day length (CWD) was shortest (7 days) at Kampong Chhnang and longest (15days) at Bonteay Meanchey. There has no significant indices for CWD.

**Dry season**: Trends in wet and dry day frequencies and daily rainfall intensity. **Table 4**: The value of SDII is between 12 mm (Bonteymeanchey) and 16 mm (Kampong Chhnang). The value of NWD was lowest at Siem Reap (12 days) and highest at Pursat (19 days). But, the lowest value of NDD was at Pursat (162.48 days) and the highest value was at Siem Reap (169.16 days). According to Mann-Kendall trend test, only Bonteaymeanchey showed statistically significant increasing trend (at rate 0.31 mm/30 years) for SDII.

**Table 4** Trend in total wet days and rainfall intensity, number of wet and dry day length and maximum wet and dry day length

| Stations | Time scale | SD II (mm) | Trend (mm/30 years) | NWD (days) | Trend (No. of day/30 years) | NDD (days) | Trend (No. of day/30 years) | CDD (days) | Trend (No. of day/30 years) | CWD (day) | Trend (No. of day/30 years) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Kampong Chhang | Annual | 18 | -0.13 | 91 | 0.00 | 274 | 0.00 | 86 | 0.00 | 7 | -0.04* |
| | Wet | 18 | -0.07 | 77 | 0.00 | 107 | 0.00 | 11 | 0.00 | 7 | -0.04 |
| | dry | 16 | -0.12 | 13 | 0.00 | 168 | 0.00 | 86 | 0.09 | 3 | 0.00 |
| Pursat | Annual | 14 | -0.06 | 96 | 1.0 * | 258 | -0.83 | 90 | -0.83 | 8 | 0.00 |
| | Wet | 19 | -0.08* | 83 | 0.72* | 103 | -0.67* | 11 | -0.11 | 8 | 0.00 |
| | dry | 14 | -0.01 | 19 | 0.19 | 162 | -0.17 | 81 | -1.00 | 3 | 0.00 |
| Battambang | Annual | 13 | -0.03 | 99 | 0.25 | 266 | -0.28 | 74 | -0.28 | 8 | 0.08 |
| | Wet | 13 | 0.00 | 82 | 0.20 | 102 | -0.20 | 12 | 0.10 | 8 | 0.00 |
| | dry | 14 | -0.01 | 17 | 0.00 | 164 | 0.00 | 74 | -1.00 | 3 | 0.00 |
| Bonteay Meanchey | Annual | 15 | 0.01 | 79 | 0.36 | 286 | -0.40 | 83 | -0.40 | 7 | 0.00 |
| | Wet | 16 | -0.10 | 64 | 0.50 | 120 | -0.50 | 7 | -0.20 | 15 | 0.00 |
| | dry | 12 | 0.31* | 15 | -0.15 | 167 | 0.15 | 83 | 0.78 | 3 | 0.00 |
| Siem Reap | Annual | 15 | 0.16 * | 95 | 1.1 * | 270 | -1.05* | 97 | -1.05* | 9 | 0.09 |
| | Wet | 15 | -0.18* | 83 | 1.0* | 103 | 14.00 | 14 | -0.28* | 9 | 0.00 |
| | dry | 11 | -0.14 | 12 | 0.00 | 169 | -0.08 | 98 | -1.00 | 3 | 0.00 |
| Kampong Thom | Annual | 16 | -0.08 | 95 | 0.17 | 271 | -0.17 | 97 | -0.17 | 8 | 0.05 |
| | Wet | 18 | -0.05 | 79 | 0.00 | 105 | 0.00 | 8 | 0.06 | 12 | 0.05 |
| | dry | 16 | -0.18 | 15 | 0.17 | 166 | -0.18 | 97 | -2.43* | 3 | 0.00 |

(*significant)

It showed that there is no significant increasing or decreasing trend for NWD and NDD indices.

Trends in wet-spell and dry-spell lengths: The value and trends of (CWD) and (CDD) are shown in (Table 8 Trend in total wet days and intensity of precipitation, number of wet and dry day lengths and maximum wet and dry day lengths. The shortest length of CWD was 81 days at Battambang and Pursat, and the longest was 98 days at Siem Reap, the shortest length of CDD was 3 days for all six stations.

## 4. CONCLUSIONS

Statistical analysis characteristic of rainfall distribution and trend analysis of extreme rainfall are necessary for planning and management of water resource such as the proper design of hydro related schemes (clean water supply, reservoir, and irrigation water supply) in rapidly growing regions like Tonle Sap area. Statistical analysis of rainfall distribution and extreme rainfall were applied annually and seasonally with six stations rainfall around Tonle Sap Lake.

As the results of statistical analysis for annual and seasonal rainfall within the study period (1985-2010) showed that depends upon locations, annual rainfall level at each station surrounded Tonle Sap Lake varied from 1154.83 mm to 1601.00 mm, with the mean annual rainfall from all station of 1400.81 mm. Furthermore, total rainfall in wet season in study area varied from 983.81 mm to 1373.58 mm, with mean total rainfall from all stations of 1178.13 mm, and in dry season total rainfall varied from 138.42 mm to 275.36 mm, with mean total rainfall 213.63 mm within the study period. In addition, the amount of rainfall in wet season contributed 84% of annual rainfall for the study period. Based on CV > 0.5 showed that rainfall in annual and dry season were being highly variable and highly changes of rainfall distribution from year to year, on the contrary CV in wet season is lower than 0.5 indicated the low variability from mean, meaning the changes of rainfall distribution from year to year of wet season are low.

For analysis of extreme rainfall, trend of extreme rainfall in annual time step showed that only few indices at few of the stations showed statistically significant changes. The significant increasing trend was found at Pursat (R20mm), and the significant decreasing trend was at Kampong Thom (R20mm). While in wet season showed only one significant change, it was increasing trend at Pursat (R20mm). It also showed one increasing significant change at Bonteymeanchey (R20mm) for dry seasonal time step. In addition, for trend in number of wet and dry days showed that it has three station that had significant change for annual time series, they are Kampong Chhnang (decreasing trend CWD), Pursat (increasing change NWD), and Siem Reap (decreasing trend for SDII, CDD, and NDD, and increasing change for NWD). For wet seasonal time step, there are two station which showed significant value at Pursat (decreasing trend for SDII and NDD, and increasing change for NWD) and Siem Reap (decreasing trend for SDII, CDD and increasing trend NWD). In the dry seasonal time series, only two stations that had significant change which are Bonteymeanchey (increasing change SDII) and Kampong Thom (decreasing trend for CWD).

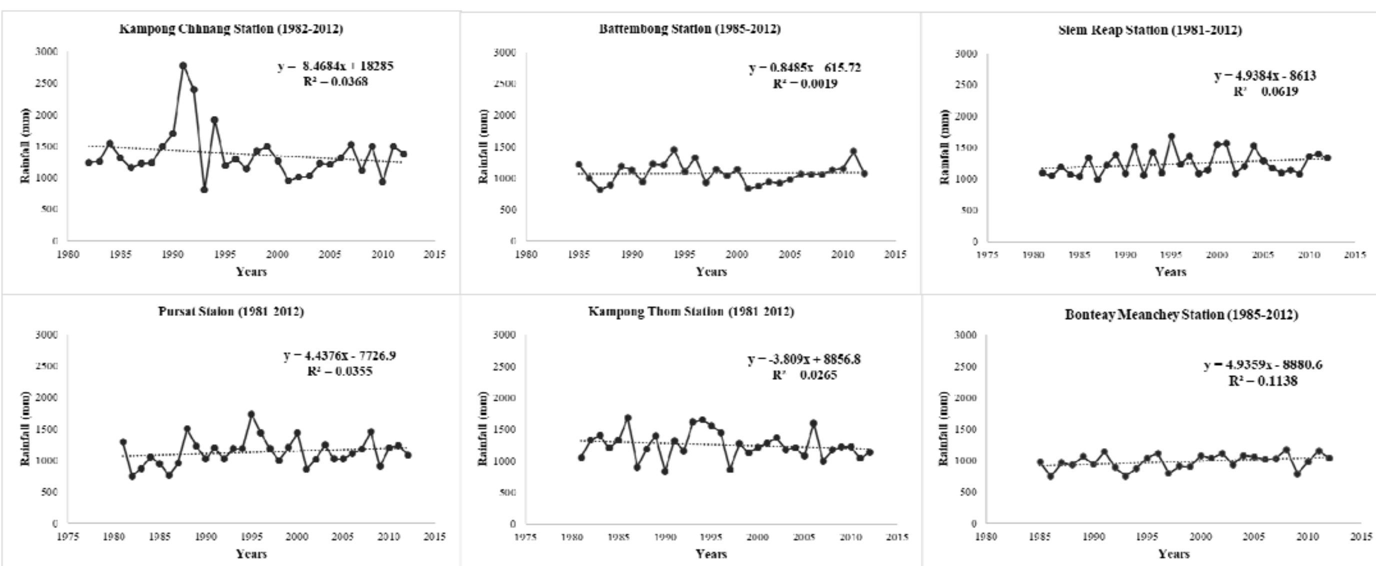


**Figure 3** Total rainfall in wet season at six stations for the period (1985-2012)

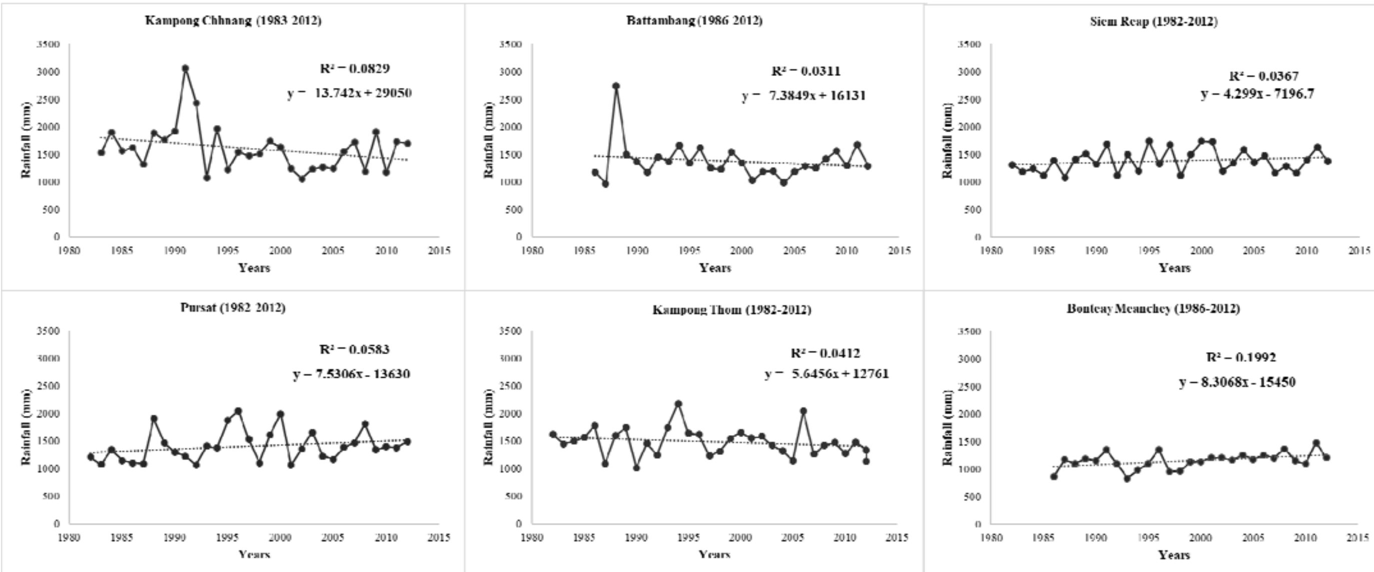


**Figure 4** Total rainfall in dry season at six stations for the period (1985-2012)

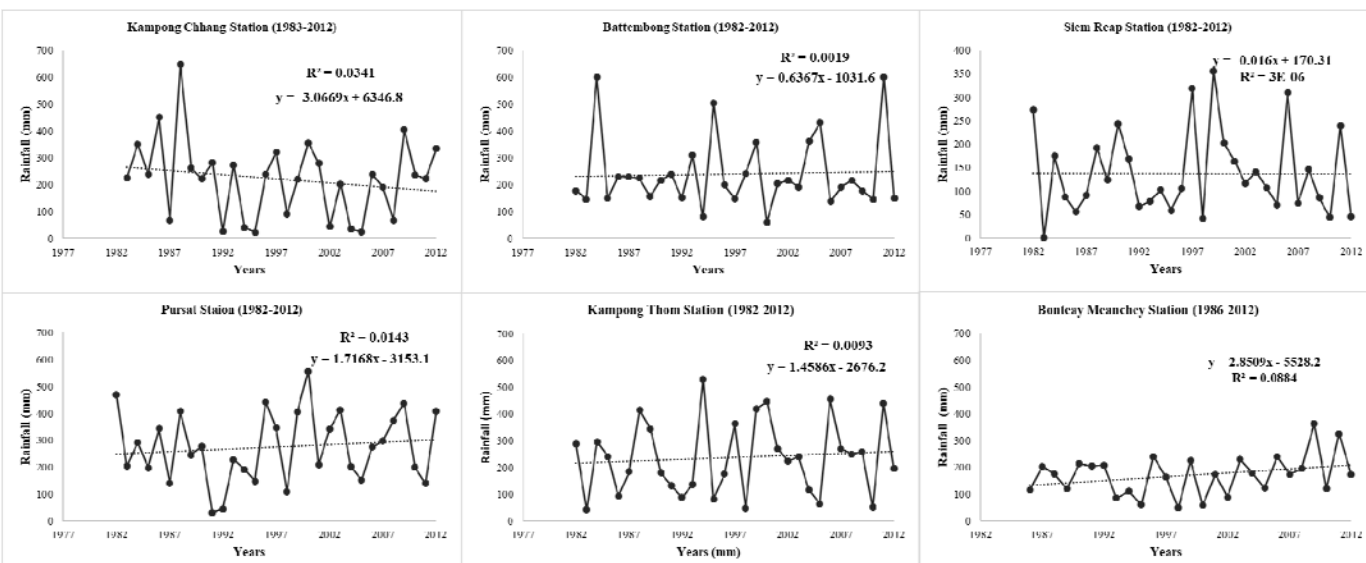


**Figure 5** Total rainfall in dry season at six stations for the period (1985-2012)

**Table 5** Statistical summary of rainfall distribution in Tonle Sap from six stations (1985-2010)

| **Tonle Sap** | Total (mm) | Mean (mm) | SD | CV | Median (mm) | Skewnees | Kurtosis | Minimum (mm) | Maximum (mm) | Range (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual | 1400.81 | 117.28 | 112.42 | 0.96 | 97.19 | 0.67 | -0.31 | 0.52 | 331.10 | 330.58 |
| Wet season | 1178.13 | 196.12 | 88.82 | 0.46 | 188.57 | 0.33 | 0.03 | 89.19 | 326.42 | 237.23 |
| Dry season | 213.63 | 35.60 | 47.33 | 1.38 | 16.81 | 1.26 | 1.04 | 0.35 | 114.96 | 114.61 |

**Table 6** Statistical summary of annual rainfall from six stations (1985-2010)

| Stations | Total (mm) | Mean (mm) | SD | CV | Median (mm) | Skewnees | Kurtosis | Minimum (mm) | Maximum (mm) | Range (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Bonteay Meanchey | 1154.83 | 96.24 | 93.78 | 0.98 | 81.51 | 0.77 | -0.10 | 0.15 | 278.50 | 278.36 |
| Battembong | 1368.69 | 114.06 | 104.46 | 0.91 | 95.74 | 0.67 | -0.35 | 1.04 | 315.32 | 314.28 |
| Kampong Chhnag | 1601.00 | 133.42 | 128.89 | 0.96 | 108.23 | 0.57 | -0.62 | 0.43 | 372.72 | 372.29 |
| Kampong Thom | 1483.88 | 126.91 | 119.83 | 0.95 | 112.32 | 0.61 | -0.34 | 1.01 | 351.73 | 350.72 |
| Pursat | 1408.14 | 117.34 | 106.81 | 0.92 | 101.93 | 0.64 | -0.16 | 0.35 | 322.80 | 322.45 |
| Siem Reap | 1388.35 | 115.70 | 120.77 | 1.05 | 83.43 | 0.78 | -0.32 | 0.11 | 345.51 | 345.39 |

**Table 7** Statistical summary of rainfall distribution in dry season from six stations (1985-2010)

| Stations | Total (mm) | Mean (mm) | SD | CV | Median (mm) | Skewnees | Kurtosis | Minimum (mm) | Maximum (mm) | Range (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Bonteay Meanchey | 170.81 | 28.47 | 39.22 | 1.39 | 13.45 | 1.39 | 1.47 | 0.15 | 96.44 | 96.29 |
| Battembong | 239.77 | 39.96 | 47.82 | 1.15 | 22.16 | 0.97 | 0.31 | 0.95 | 118.36 | 117.41 |
| Pursat | 275.36 | 45.89 | 59.50 | 1.31 | 23.29 | 1.12 | 0.56 | 0.35 | 143.21 | 142.86 |
| Kampong Chhang | 220.71 | 36.78 | 49.40 | 1.40 | 16.13 | 1.21 | 0.56 | 0.43 | 118.20 | 117.76 |
| Kampon Thom | 236.70 | 39.45 | 55.55 | 1.52 | 15.60 | 1.42 | 1.42 | 0.10 | 133.90 | 133.80 |
| Siem Reap | 138.42 | 23.07 | 32.46 | 1.51 | 10.20 | 1.49 | 1.94 | 0.11 | 79.64 | 79.52 |

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