Techno-Science Research Journal 10(1) (2022) 33-44

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Techno-Science Research Journal

Journal Homepage: http://techno-srj.itc.edu.kh/

Techno-Science Research Journal

# Trend and Stationarity Analysis of Streamflow in Prek Thnot River Basin

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Received: 02 November 2021; Accepted: 12 February 2022; online: June 2022

**Abstract:** *Precipitation variation always has an effect on the river streamflow. The change in discharge greatly impacts aquatic habitats, environmental amenities, recreational opportunities, irrigated agriculture production, hydropower production, and other industrial water uses. Therefore, studying the streamflow trends is important guidance for stakeholders and decision-makers to make a long-term and suitable management strategy. The aim of this study was to analyze the trend of monthly streamflow in the Prek Thnot River of the Lower Mekong Basin. Daily streamflow data of four stations recorded in the Prek Thnot River between 1997 and 2011 were assessed using the Mann-Kendall (MK) test and Sen's slope estimator to evaluate the statistical characteristics of streamflow distributions for the trend analysis. The result highlight that these statistics of the streamflow were observed that monthly flow begins to increase from May to October and rapidly decreases from November to April. The rainy season of streamflow is higher than the dry season. From the statistical analysis in the Prek Thnot River Basin, the streamflow trend slightly decreased from 1997 to 2011. Furthermore, the annual peak and low flows occurred in 2001 and 2005, approximately 83 and 11.5 $m^3/s$, respectively. Results Mann-Kendall test of monthly streamflow were revealed only at the significant level of 0.1 in May for Tasal Dam, while the slope magnitude estimated by Sen's Slope estimator is about 0.45. The slope was positive during the early rainy season, indicating that the monthly streamflow quantity increased during this period. The tests also revealed that most months were no trend evidence and had a sign fluctuation of streamflow throughout the period.*

**Keywords:** Streamflow trend; Statistical analysis; Mann-Kendall (MK) test; Sen's Slope estimator, Prek Thnot River Basin

## 1. INTRODUCTION

In general, observational and historical hydroclimatologic data are used in planning and designing water resources projects. There is an implicit assumption, so-called stationarity implying time-invariant statistical characteristics of the time series under consideration, in all water resources engineering works. The average long-term changes impact regional water resources and intensify the global hydrological cycle [1]. Besides altering the global hydrological processes, it also would affect the precipitation patterns under various spatial and temporal scales, affecting streamflow emergence and stream systems [2,3]. Since precipitation is the primary influence on streamflow in the watershed, it causes the stream to increase and decrease [4].

The change in discharge had affected aquatic ecosystems, environmental amenities, recreational opportunities, production in irrigated agriculture, hydropower production, and other industrial uses [1, 5]. Since streamflow is very sensitive to small-scale precipitation variability [6, 7], it might also impact the altering of trends. According to Abghari et al. [8]; Afshar et al. [9], studying the trends of streamflow, therefore, is an important rudimentary for stakeholders and decision-makers to decide long-term management strategies. Owing to these issues, the streamflow information from various rivers around the world was collected, including the Mekong River.

Several methods are accessible for studying the assessment of the trends. Some studies on trend recognition used parametric methods such as t-tests and F-tests [10,11], while some studies used non-parametric methods such as the Mann-Kendall (M.K)

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test [12,13]. The M.K statistical test was selected caused by a non-parametric method suitable with hydrological time series data for this study. Additionally, it is one of the most popular and effective tests used for detecting and analyzing the trend in hydrological time series [14], such as water quality, streamflow, and precipitation time series [15]. In fact, Hirsch and Slack [16] were the first to suggest a postponement of the Mann–Kendall test for analyzing trends (particularly against the serial correlation effects). Later on, many studies were carried out on the Mann-Kendall (M.K.) tests. Lettenmaier et al. [17] used to indicate the long-term trends in precipitation, mean temperature, temperature range, and streamflow over the continental USA. As a result, an increase in precipitation during autumn was found in a quarter of the entire stations, mostly located in the central part of the USA [17]. Yue and Hashino [18] used to study long-term trends in Japanese annual and monthly precipitation and, as a result, this study found significant negative trends. Zhang et al. [19] analyzed total precipitation in Canada during the 20th century and pointed out a prevailing wetter pattern in the Canadian climate.

On the other hand, the Mann-Kendall test assumes that residuals are normal [20]. According to Viessman, Lewis, Knapp, and Harbaugh (1989), many hydrological variables have a significant right skewness, partially attributable to the impact of natural events and do not follow a normal distribution. Sen's Slope estimator is therefore shown to be an effective tool for developing linear connections. Sen's slope has an advantage over the regression slope in that it is unaffected by outliers and severe data mistakes. The median of the pair-wise slopes between each pair of points in the dataset is used to calculate Sen's slope [21-23]. Since there were positive signs of applying the tests into many studies, the Mann-Kendall (M.K.) tests and the Sen's Slope estimator were selected as key indicators for analyzing and detecting trends in this study.

Trend analysis has proved to be useful for effective water resources planning, design, and management [13]. Furthermore, this study could provide a useful information source for future planning and managing water resources in the area. The objectives of this study were to: (1) characterizes the statistical analysis of monthly, seasonally, and annually flow distribution in the Prek Thnot River, (2) characterizes the annual and seasonal variation of streamflow, and (3) detects the changing trends of monthly streamflow by using Mann-Kendall (M.K.) tests.

## 2. METHODOLOGY

### *2.1* Study area

The Prek Thnot River Basin covers six provinces (Koh Kong, Kampong Speu, Kampot, Sihanouk Ville, Takeo, Kandal, and Phnom Penh) of Cambodia. The river's total catchment area is about 6,124 km$^2$, with a river length of 227 km from the Cardamom Mountains in the southwest area of Cambodia (Fig.1). The Prek Thnot River Basin lies between latitudes 11°00' to 12°10' N and longitudes 103°40' to 105°10' E, which is a representative inland river basin in the plate and plateau regions and it drains to the outlet at the Bassac River, which is a tributary of the Lower Mekong River (Mekong Delta) at the south of Phnom Penh. This basin consists of four flow stations and eight meteorological stations. Moreover, the basin receives an average annual rainfall of 1,104.9 mm, and the average flow of 167 m$^3$/s is estimated from 1997-2011. The dry season encompasses six months, November to April. During these periods, the flow typically reaches a minimum at the end of the season between February and April [24].

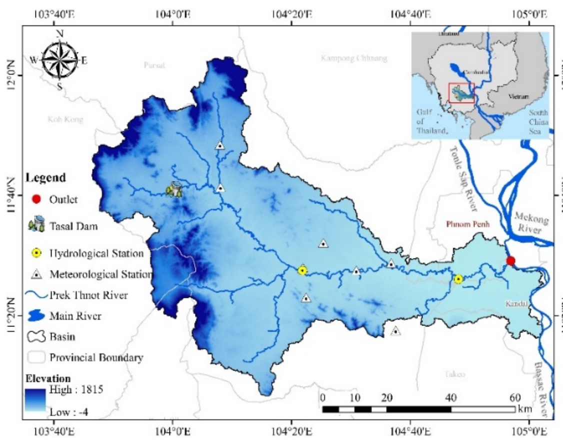


**Fig. 1.** Location of the study area.

### *2.2 Data collection*

The streamflow data were collected from four hydrological stations of Prek Thnot River Basin, located in Kampong Speu province, including Tasal Dam, Peam Khley station, Kampong Toul station, and the outlet of river (Bassac River). The observed flow was recorded as a daily time step for 15 years (1997–2011). The observed data was from the Department of Hydrology and Rivers Work (DHRW) of the Ministry of Water Resources and Meteorology (MOWRAM).

### *2.3 Statistical characteristics distribution*

The descriptive statistics are simple and brief numerical summaries of the empirical frequency distribution of the random variable. Moreover, descriptive statistics were used over the graphical representation of data to provide the sample numerical information to infer later the population's probabilistic behavior [25]. In general, descriptive statistics broke down into two measurements, measure of central tendency and measure of variability [26]. Similarly, in this study, the measure of central tendency such as Mean and Median, and measure of variability include Standard Deviation, Variance, Minimum and Maximum variable, Range, Skewness, and Kurtosis, were used to study the descriptive statistics.

*2.3.1 Mean*

The mean of a sample of size N is defined by (Eq. 1):

$$\bar{x} = \left( \frac{1}{N} \sum_{i=1}^{N} x_i \right) \qquad \text{(Eq. 1)}$$

where:

$x_i$ = the individual observed value in the sample

$N$ = sample size, i.e., the total number of observed values

$\bar{x}$ = means of the sample size n.

*2.3.2 Median*

The median M of a sample is the middle value of the ranked sample if N is odd. If N is even, it is the average of the two middle values. The cumulative relative frequency of the median is 0.5. For asymmetrical distribution, the mean and the median are similar. If the distribution is skewed to the right, then M < m, and when skewed to the left, M > m.

*2.3.3 Range*

The range of a sample is the difference between the largest and smallest sample value. Since the sample range is a function of only two of the N sample values, it contains no information about the data distribution between the minimum and maximum values.

*2.3.4 Standard deviation*

The standard deviation s is the root of the variance and provides a measure for the dispersion of the data in the sample set in the same dimension as the sample data. It is estimated by (Eq. 2):

$$S = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} \left( x_i - \bar{x} \right)^2} \qquad \text{(Eq. 2)}$$

where,

$S$ = sample standard deviation

$x_i$ = the individual observed value in the sample

$N$ = sample size, i.e., the total number of observed values

$\bar{x}$ = means of the sample size n.

*2.3.5 Coefficient of variation*

A dimensionless measure of dispersion is the coefficient of variation CV defined as the standard deviation divided by the mean (Eq. 3):

$$CV = \frac{s}{\bar{x}} \qquad \text{(Eq. 3)}$$

*2.3.6 Skewness*

The skewness is derived from the third central moment of the distribution, scaled by the standard deviation to power three. An unbiased estimate for the coefficient of skewness can be obtained from the following expression (Eq. 4):

$$\text{Skewness} = g_1 = \frac{N}{(N-1)(N-2)} \frac{\sum_{i=1}^{N} \left( x_i - \bar{x} \right)^3}{s^3} \qquad \text{(Eq. 4)}$$

Positively and negatively skewed distributions and symmetrical distributions are shown in Fig. 2.

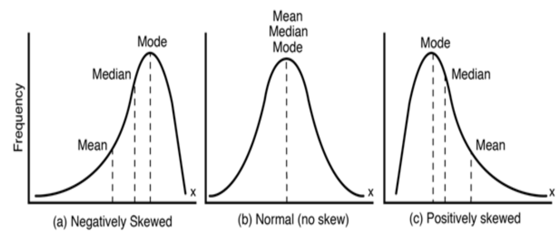


**Fig. 2.** Illustration of skewness

*2.3.7 Kurtosis*

Kurtosis is the fourth moment of the distribution about the mean, scaled by the 4th power of the standard deviation. The kurtosis refers to the extent of peakedness or flatness of a probability distribution compared to the normal distribution. The standard normal distribution has a kurtosis of 3, so if the values are equal, greater, or lower than that, the distribution is mesokurtic, leptokurtic, and platykurtic, respectively (Fig.3). The sample estimate for kurtosis is (Eq. 5):

$$g_2 = \frac{N^2 - 2N + 3}{(N-1)(N-2)(N-3)} \frac{\sum_{i=1}^{N} \left( x_i - \bar{x} \right)^4}{s^4} \qquad \text{(Eq. 5)}$$

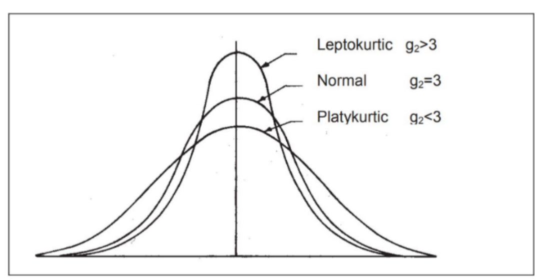


**Fig. 3.** Illustration of Kurtosis

*2.4 Mann-Kendall test*

The Mann–Kendall test is a non-parametric test employed to detect statistical significance and slopes of the trend lines, where the least square linear fitting method was used to determine [14,27,28]. The purpose of doing the test is to examine whether a random response variable monotonically increases or decreases with time [29]. Another benefit of this test is that the data does not need to follow any particular distribution [30]. The test is based on the null hypothesis ($H_0$), which means there is no trend in the series. The test has three alternative hypotheses in the series evolution: negative, null, and positive. The Man-Kendall Test-statistic $S$ is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_i) \quad \text{(Eq. 6)}$$

where:

$$S = \operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad \text{(Eq. 7)}$$

The variance of $S$ denoted by $\sigma_s^2$ is computed as:

$$\sigma_s^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{q} t_j(t_j-1)(2t_j+5)}{18} \quad \text{(Eq. 8)}$$

where:
n = the number of data point
q = the number of tied groups in the data set
$t_j$ = the number of data points in the tied group

Then, S and $\sigma$ were used to compute the test statistic $Z_S$ as (Eq. 9):

$$Z_s = \begin{cases} \frac{S-1}{\sigma} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \frac{S+1}{\sigma} & \text{if} \quad S < 0 \end{cases} \quad \text{(Eq. 9)}$$

The null hypothesis ($H_O$) for this test is that there is no trend, and the alternative hypothesis ($H_a$) is that a trend in the two-sided test or that is an upward trend (or downward trend) in the one-sided test. Positive $Z_S$-statistics ($Z_S$) values show increasing trends, while negative $Z_S$-statistics ($Z_S$) values show decreasing trends. Testing trends are done at a specific significance level. The null hypothesis is rejected, and a significant trend exists in the time series when $Z_{S.S.} > Z_{1-\alpha/2}$. In this study, the critical value of Z-statistics (Z1-α/2) was obtained from the standard normal distribution table at 1%, 5%, and 10% significant levels.

*2.5 Sen's slope estimator*

Sen [22] devised a non-parametric method for calculating the slope of a trend in a sample of n pairs of data. Sen's approach estimates the slope of the trend using a linear model, and the variance of the residuals should be constant throughout time, computed as:

$$Q_i = \frac{X_j - X_k}{j - K} \quad \text{for} \quad i = 1, \ldots, n \quad \text{(Eq. 10)}$$

where $X_j$ and $X_k$ denote the data values at times $j$ and $k$ $(j > k)$, respectively. If each period has just one datum, N = n (n - 1)/2, where n is the number of time periods. $N = n(n-1)/2$ is the number of observations in one or more time periods. The $n$ values of $Q_i$ are ordered from the least to the biggest, and the median of slope, also known as Sen's slope estimator, is calculated as follows:

$$Q_{med} = \begin{cases} Q_{[(n+1)/2]}, & \text{if n is odd} \\ \frac{Q_{[n/2]} + Q_{[(n+2)/2]}}{2}, & \text{if n is even} \end{cases} \quad \text{(Eq. 11)}$$

The $Q_{med}$ sign denotes a data trend, with the value indicating how steep the trend is. The confidence interval of $Q_{med}$ at a particular probability should be obtained to evaluate if the median slope is statistically distinct from zero. The confidence interval for the time slope, it is calculated as follows [31]:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{\operatorname{Var}(S)} = Z_{1-\alpha/2}\sigma_s \quad \text{(Eq. 12)}$$

where $Z_{1-\alpha/2}$ is derived from the standard normal distribution table, and $\sigma_s^2$ is described in (Eq. 8). The confidence interval was calculated at three levels of significance in this research (α = 0.1, α = 0.05, and α = 0.01). $M_1 = (n - C_\alpha)/2$ and $M_2 = (n + C_\alpha)/2$ are then calculated. The lower and upper confidence interval bounds, $Q_{min}$ and $Q_{max}$, are the $M_1$th and ($M_2$ + 1)th greatest n-ordered slope estimates, respectively [31]. If the two limits ($Q_{min}$ and $Q_{max}$) have the same sign, the slope $Q_{med}$ is statistically distinct from zero. In hydrometeorological time series, Sen's slope estimator is extensively utilized [32,33].

These techniques have several benefits that make them helpful for evaluating atmospheric chemistry and climatological data. Missing values are acceptable, and the data does not have to fit into any certain distribution.

## 3. RESULTS AND DISCUSSION

*3.1 Streamflow distribution characteristics*

*3.1.1 Daily streamflow distribution*

Daily streamflow is the data source that can be used for analyzing the monthly, seasonally, and annually streamflow in a river or any stretch of water. Analysis of the variability of daily streamflow in space and time is important for planning, developing, and managing water resources [34]. In Fig.4, the plots illustrate the daily time step of flow and the relation between flow and rainfall. In Fig.4, the flow value was maximum in the year 2010 (574 $m^3/s$) at Tasal Dam, while others were in the year 2000, Peam Khley (1,014 $m^3/s$), Kampong Toul (1,319 $m^3/s$), and outlet of river (1,386 $m^3/s$).

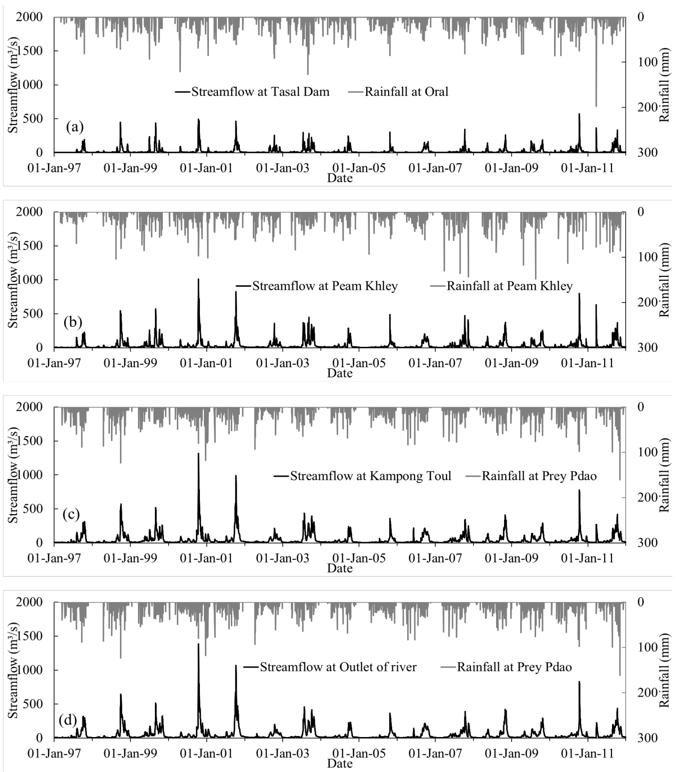


**Fig. 4.** Daily flow and rainfall for the 15 years of the stations in Prek Thnot river

### *3.1.2 Monthly streamflow distribution characteristics*

Monthly streamflow data is converted from the daily streamflow. The purpose of transforming the daily data into monthly data is to understand the streamflow pattern for the year. The monthly streamflow distribution characteristics of the Prek Thnot river are indicated by the monthly flow data of each month of the year for 15 years (1997-2011) acquired from four stations, including Tasal Dam, Peam Khley, Kampong Toul, and outlet of river of Prek Thnot catchment. Based on the monthly streamflow analysis of each station, the mean monthly streamflow is shown in Fig. 5a. The peak flow is occurred in October, during the low flow in February. Moreover, the flow increases from May to October and rapidly decreases from November to April. By this figure, the flow level throughout the year can be identified. Fig.5b represents the monthly streamflow, which only adds up to the other two parameters, including maximum and minimum flows. The maximum flow is happened in October approximately 513 $m^3/s$ at the outlet of river, while the minimum flow in February about 9 $m^3/s$ at the Tasal Dam.

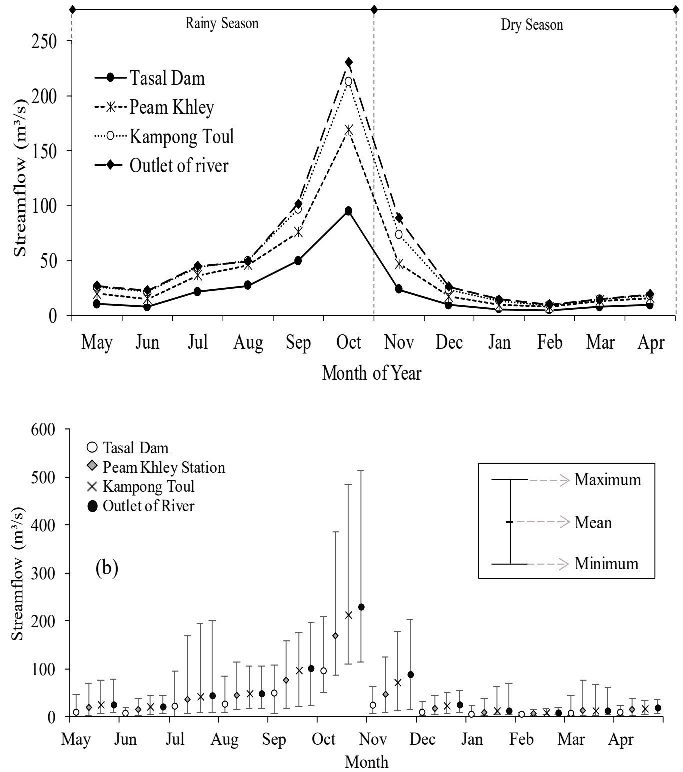


**Fig. 5.** Average monthly streamflow from four stations in Prek Thnot River Basin from 1997-2011

Table 1 describes the statistical characteristics of monthly streamflow data in four stations. It shows that the highest mean value of each station always occurred in October, which is a month of the rainy season, while the lowest streamflow mean value occurred in February, which is a month of the dry season. The mean value of each month in this table reveals that there is always the variable of streamflow amount from month to month throughout the year in each station. Moreover, the Standard Deviation (SD) value of each station had the highest value in October. Still, it is lower than the mean value in October, while the Standard Deviation (SD) values of each station in January, March, and July are higher than the mean values of these months. Thus, the relation points out that the divergences from the normal distribution cannot be failed to consider. According to the Coefficient of Variance (CV) of each station as well, which is the ratio of the standard deviation to the mean, its value is close, or over to 1, it reveals the magnitude of variability in the relation of the Standard Deviation (SD) and the Mean value to the mean of the flow population value.

**Table 1** The result of monthly streamflow descriptive statistics for the four stations of Prek Thnot River Basin between 1997 and 2011

| Parameters ($m^3/s$) | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tasal Dam** | | | | | | | | | | | | |
| Mean | 9.97 | 7.53 | 21.13 | 26.90 | 49.23 | 94.91 | 23.42 | 9.43 | 5.48 | 4.48 | 7.53 | 9.19 |
| Max | 47.53 | 18.94 | 95.82 | 85.89 | 107.94 | 208.76 | 62.93 | 32.50 | 23.10 | 9.49 | 44.73 | 24.91 |
| Parameters ($m^3/s$) | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
| Min | 1.52 | 1.28 | 1.47 | 8.29 | 8.09 | 50.26 | 6.17 | 3.26 | 2.28 | 2.33 | 2.38 | 2.30 |
| SD | 10.78 | 5.20 | 29.57 | 21.07 | 27.67 | 47.55 | 14.88 | 7.56 | 4.99 | 2.14 | 10.47 | 6.93 |
| Median | 7.17 | 6.82 | 7.59 | 22.56 | 39.90 | 85.98 | 19.30 | 6.69 | 4.14 | 4.19 | 5.07 | 8.23 |
| CV | 1.08 | 0.69 | 1.40 | 0.78 | 0.56 | 0.50 | 0.64 | 0.80 | 0.91 | 0.48 | 1.39 | 0.75 |
| Range | 46.01 | 17.66 | 94.35 | 77.60 | 99.84 | 158.50 | 56.75 | 29.24 | 20.82 | 7.16 | 42.34 | 22.62 |
| Skewness | -3.40 | -1.26 | -1.90 | -1.76 | -0.59 | -1.34 | -1.36 | -2.52 | -3.56 | -1.05 | -3.66 | -1.57 |
| Kurtosis | 12.46 | 1.40 | 2.62 | 3.53 | -0.26 | 1.10 | 2.34 | 6.43 | 13.29 | 0.49 | 13.78 | 1.91 |
| **Peam Khley** | | | | | | | | | | | | |
| Mean | 19.55 | 14.68 | 36.33 | 45.44 | 75.50 | 168.59 | 46.90 | 17.02 | 9.35 | 7.54 | 13.03 | 15.69 |
| Max | 70.15 | 38.34 | 169.48 | 115.15 | 158.61 | 386.07 | 125.28 | 45.41 | 39.12 | 15.20 | 77.50 | 38.30 |
| Min | 3.59 | 3.22 | 6.82 | 14.64 | 16.81 | 87.43 | 9.35 | 4.68 | 3.26 | 3.47 | 3.52 | 3.75 |
| SD | 16.78 | 9.78 | 43.23 | 29.00 | 41.98 | 86.44 | 30.41 | 11.18 | 8.51 | 3.40 | 18.09 | 9.88 |
| Median | 13.94 | 12.32 | 20.99 | 39.92 | 76.37 | 138.02 | 45.61 | 13.59 | 7.04 | 6.82 | 7.97 | 14.57 |
| CV | 0.86 | 0.67 | 1.19 | 0.64 | 0.56 | 0.51 | 0.65 | 0.66 | 0.91 | 0.45 | 1.39 | 0.63 |
| Range | 66.56 | 35.13 | 162.65 | 100.51 | 141.80 | 298.64 | 115.94 | 40.73 | 35.85 | 11.72 | 73.98 | 34.55 |
| Skewness | -2.24 | -1.15 | -2.40 | -1.45 | -0.47 | -1.64 | -1.17 | -1.49 | -3.46 | -0.74 | -3.69 | -1.45 |
| Kurtosis | 5.70 | 1.07 | 6.41 | 1.60 | -0.56 | 2.06 | 1.89 | 1.83 | 12.72 | -0.09 | 13.99 | 1.83 |
| **Kampong Toul** | | | | | | | | | | | | |
| Parameters ($m^3/s$) | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
| Mean | 25.41 | 21.05 | 43.66 | 49.40 | 96.56 | 212.76 | 73.35 | 23.03 | 12.87 | 8.97 | 14.23 | 17.96 |
| Max | 77.56 | 44.18 | 194.98 | 106.59 | 175.61 | 484.26 | 176.87 | 51.30 | 63.44 | 17.20 | 68.53 | 34.98 |
| Min | 7.73 | 5.58 | 9.10 | 17.32 | 22.06 | 110.56 | 13.98 | 7.64 | 5.20 | 4.05 | 3.86 | 5.14 |
| SD | 19.17 | 11.74 | 48.64 | 27.33 | 50.10 | 113.72 | 44.00 | 14.05 | 14.22 | 3.87 | 15.63 | 8.68 |
| Median | 18.73 | 17.24 | 23.71 | 44.17 | 95.22 | 178.61 | 78.41 | 16.85 | 9.50 | 7.92 | 9.72 | 16.21 |
| CV | 0.75 | 0.56 | 1.11 | 0.55 | 0.52 | 0.53 | 0.60 | 0.61 | 1.11 | 0.43 | 1.10 | 0.48 |
| Range | 69.83 | 38.60 | 185.88 | 89.27 | 153.55 | 373.70 | 162.89 | 43.65 | 58.24 | 13.15 | 64.67 | 29.84 |
| Skewness | -1.68 | -0.91 | -2.45 | -1.09 | -0.25 | -1.55 | -0.77 | -0.89 | -3.66 | -0.69 | -3.41 | -0.58 |
| Kurtosis | 2.84 | -0.26 | 6.77 | 0.61 | -1.32 | 1.79 | 0.84 | -0.63 | 13.83 | -0.44 | 12.30 | -0.06 |
| **Outlet of river** | | | | | | | | | | | | |
| Mean | 26.94 | 22.38 | 44.78 | 49.11 | 101.56 | 230.44 | 88.57 | 25.70 | 14.35 | 9.71 | 14.36 | 19.17 |
| Max | 78.93 | 45.51 | 201.58 | 105.52 | 196.09 | 513.47 | 203.90 | 54.92 | 70.57 | 19.92 | 61.25 | 35.92 |
| Min | 8.47 | 6.52 | 10.12 | 18.25 | 23.43 | 113.58 | 15.26 | 8.63 | 5.80 | 4.37 | 4.05 | 6.41 |
| SD | 19.57 | 11.95 | 49.69 | 26.60 | 53.21 | 124.96 | 51.64 | 15.32 | 15.82 | 4.33 | 13.79 | 8.81 |
| Median | 20.15 | 18.17 | 23.65 | 41.45 | 93.07 | 184.65 | 95.76 | 18.44 | 10.15 | 8.59 | 10.72 | 19.70 |
| CV | 0.73 | 0.53 | 1.11 | 0.54 | 0.52 | 0.54 | 0.58 | 0.60 | 1.10 | 0.45 | 0.96 | 0.46 |
| Range | 70.46 | 38.99 | 191.46 | 87.28 | 172.66 | 399.89 | 188.65 | 46.29 | 64.77 | 15.54 | 57.20 | 29.51 |
| Skewness | -1.57 | -0.91 | -2.54 | -1.01 | -0.31 | -1.49 | -0.57 | -0.83 | -3.65 | -0.98 | -3.20 | -0.42 |
| Kurtosis | 2.36 | -0.26 | 7.33 | 0.38 | -1.12 | 1.53 | 0.24 | -0.75 | 13.79 | 0.61 | 11.02 | -0.42 |

*3.1.3 Seasonal Streamflow Distribution haracteristics*

Seasonal streamflow analysis is necessary to prepare for appropriate response in disaster relief, management of hydropower reservoirs, water supply, agriculture, and navigation [35]. The seasonal streamflow was divided into two major seasons in Cambodia, the rainy season (May-October) and the dry season (November-April) (Fig.5). The seasonal streamflow distribution characteristics were indicated by the seasonal streamflow data of each season for 15 years (1997-2011) obtained from the four stations, including Tasal Dam, Peam Khley, Kampong Toul, and the outlet of Prek Thnot river. Table 2 shows that the mean values of Tasal Dam, Peam Khley, Kampong Toul, and outlet of river are higher in the rainy, which recorded the value of 35 $m^3/s$, 60 $m^3/s$, 192 $m^3/s$, and 208 $m^3/s$, respectively, while they are lower in the dry season. The Standard Deviation (SD) is examined to monitor the variability of a set of values which shows that the SD value is lower than the mean value during the rainy season, while it is higher than during the dry season. The Coefficient of Variance (CV) values were calculated to indicate how far the streamflow data spread out of the mean streamflow. For instance, in Table 2, the CV is close or over to one for both rainy and dry seasons at each station in Prek Thnot river.

**Table 2** Descriptive Statistic of Seasonal Streamflow Data (Dry Season (November through April) and Rainy Season (May through October) for the four stations of Prek Thnot river from 1997 to 2011

| Parameters ($m^3/s$) | Tasal Dam | | Peam Khley | | Kampong Toul | | Outlet of river | |
|---|---|---|---|---|---|---|---|---|
| | Rainy Season | Dry Season | Rainy | Dry | Rainy | Dry | Rainy | Dry |
| Mean | 34.94 | 9.92 | 60.02 | 18.26 | 74.81 | 25.07 | 79.20 | 28.64 |
| Max | 94.91 | 23.42 | 168.59 | 46.90 | 212.76 | 73.35 | 230.44 | 88.57 |
| Min | 7.53 | 4.48 | 14.68 | 7.54 | 21.05 | 8.97 | 22.38 | 9.71 |
| SD | 32.96 | 6.90 | 57.44 | 14.49 | 72.73 | 24.13 | 79.28 | 29.85 |
| Median | 24.01 | 8.36 | 40.88 | 14.36 | 46.53 | 16.10 | 46.95 | 16.77 |
| CV | 0.94 | 0.70 | 0.96 | 0.79 | 0.97 | 0.96 | 1.00 | 1.04 |
| Range | 87.38 | 18.94 | 153.91 | 39.36 | 191.71 | 64.38 | 208.06 | 78.86 |
| Skewness | 1.50 | 2.01 | 1.75 | 2.11 | 1.80 | 2.24 | 1.85 | 2.27 |
| Kurtosis | 2.04 | 4.40 | 3.16 | 4.76 | 3.21 | 5.19 | 3.38 | 5.31 |

*3.1.4 Annual Streamflow Distribution Characteristics*

Streamflow variability in each time scale is a major element of the hydrologic cycle in the Prek Thnot river. The average annual streamflow was significantly varied for four stations in the Prek Thnot river from 1997 to 2011 (Fig. 6). The results show that the annual streamflow characteristics in 2000 and 2001 were highest caused by the historical flood condition in Cambodia, while lowest caused by drought conditions in this period. Moreover, the extreme variability of streamflow between Tasal Dam and Peam Khley stations, on average based on statistics analysis caused by Tasal dam operation in the upper of the Prek Thnot river. In contrast, the other stations, such as Peam Khley, Kampong Toul and outlet of river, are slightly streamflow variability for the period of record (1997-2011).

According to Fig. 6, the highest average streamflow of the four stations, Tasal Dam, Peam Khley, Kampong Toul, and outlet of the river, were 33 $m^3/s$ (2003), 60 $m^3/s$ (2003), 75 $m^3/s$ (2001), 83 $m^3/s$ (2001) respectively. Additionally, the lowest average streamflow was 11.5 $m^3/s$ (Tasal Dam), 28 $m^3/s$ (Kampong Toul), 30 $m^3/s$ (outlet of the river) in 2005, and 21 $m^3/s$ (Peam Khley station) in 1997. Additionally, Table 3 reveals the average streamflow of the Prek Thnot river according to these four stations varies from 22 $m^3/s$ to 54 $m^3/s$ for each year of the period of record (1997-2011).

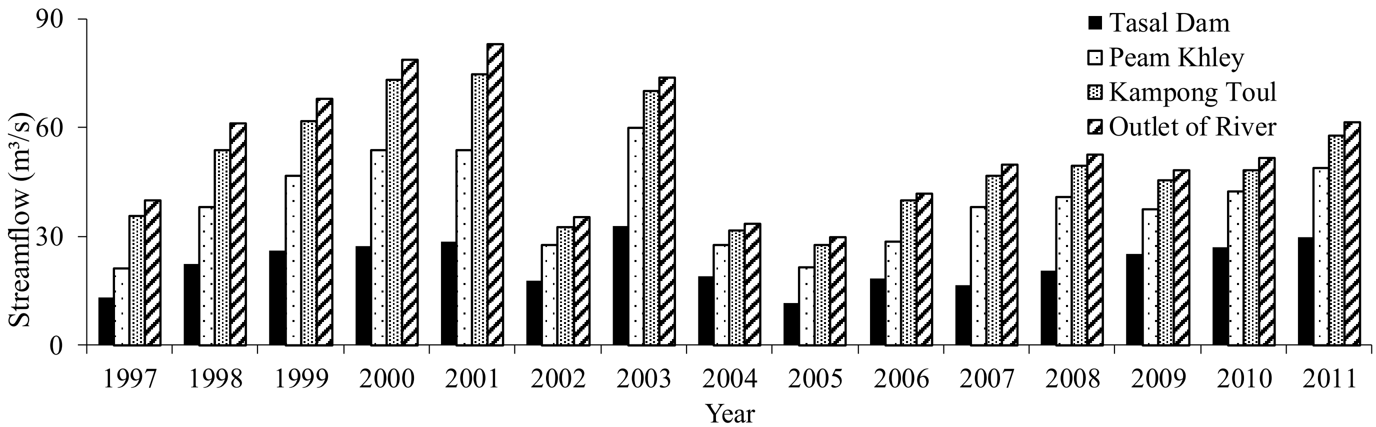


**Fig. 6.** Average annual streamflow from four stations in Prek Thnot river from 1997 to 2011

**Table 3** Descriptive statistics of the annual streamflow for the four stations for 15 years

| Station | Mean ($m^3/s$) | Max ($m^3/s$) | Year of occurrence | Min ($m^3/s$) | Year of occurrence | SD ($m^3/s$) | CV | Cs | MD ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|
| Tasal Dam | 22.57 | 33.12 | 2003 | 11.57 | 2005 | 6.41 | 0.28 | -0.12 | 5.44 |
| Peam Khley | 39.39 | 60.49 | 2003 | 21.54 | 1997 | 12.17 | 0.31 | 0.07 | 9.76 |
| Kampong Toul | 50.23 | 75.42 | 2001 | 27.92 | 2005 | 15.38 | 0.31 | 0.29 | 12.37 |
| Outlet of river | 54.23 | 83.70 | 2001 | 29.93 | 2005 | 16.89 | 0.31 | 0.32 | 13.81 |

### *3.2 Variation of streamflow*

#### *3.2.1 Seasonal streamflow variation*

In Cambodia, the rainy season is generally between May and October, while the dry season occurs typically from November to April. Using the calculation of the average streamflow from the four stations were shown in Table 4, the graph can be generated, as shown in Fig. 5a. The graph illustrates the variability increase of streamflow in the rainy season and the variability decrease of streamflow in the dry season. Table 4 shows that the highest flow of each station was in October (the rainy season), ranging from 94 $m^3/s$ to 231 $m^3/s$, whereas the lowest flow occurred in February (the dry season), ranging from 4 $m^3/s$ to 10 $m^3/s$.

**Table 4** Average Streamflow seasonally for 15 years (1997-2011) of four the stations shown as months in each season

| Parameters (m3/s) | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tasal Dam | | | | | | | | | | | | |
| Mean | 9.97 | 7.53 | 21.13 | 26.90 | 49.23 | 94.91 | 23.42 | 9.43 | 5.48 | 4.48 | 7.53 | 9.19 |
| Max | 47.53 | 18.94 | 95.82 | 85.89 | 107.94 | 208.76 | 62.93 | 32.50 | 23.10 | 9.49 | 44.73 | 24.91 |
| Min | 1.52 | 1.28 | 1.47 | 8.29 | 8.09 | 50.26 | 6.17 | 3.26 | 2.28 | 2.33 | 2.38 | 2.30 |
| Peam Khley | | | | | | | | | | | | |
| Mean | 19.55 | 14.68 | 36.33 | 45.44 | 75.50 | 168.59 | 46.90 | 17.02 | 9.35 | 7.54 | 13.03 | 15.69 |
| Max | 70.15 | 38.34 | 169.48 | 115.15 | 158.61 | 386.07 | 125.28 | 45.41 | 39.12 | 15.20 | 77.50 | 38.30 |
| Min | 3.59 | 3.22 | 6.82 | 14.64 | 16.81 | 87.43 | 9.35 | 4.68 | 3.26 | 3.47 | 3.52 | 3.75 |
| Kampong Toul | | | | | | | | | | | | |
| Mean | 25.41 | 21.05 | 43.66 | 49.40 | 96.56 | 212.76 | 73.35 | 23.03 | 12.87 | 8.97 | 14.23 | 17.96 |
| Max | 77.56 | 44.18 | 194.98 | 106.59 | 175.61 | 484.26 | 176.87 | 51.30 | 63.44 | 17.20 | 68.53 | 34.98 |
| Min | 7.73 | 5.58 | 9.10 | 17.32 | 22.06 | 110.56 | 13.98 | 7.64 | 5.20 | 4.05 | 3.86 | 5.14 |
| Outlet of river | | | | | | | | | | | | |
| Mean | 26.94 | 22.38 | 44.78 | 49.11 | 101.56 | 230.44 | 88.57 | 25.70 | 14.35 | 9.71 | 14.36 | 19.17 |
| Max | 78.93 | 45.51 | 201.58 | 105.52 | 196.09 | 513.47 | 203.90 | 54.92 | 70.57 | 19.92 | 61.25 | 35.92 |
| Min | 8.47 | 6.52 | 10.12 | 18.25 | 23.43 | 113.58 | 15.26 | 8.63 | 5.80 | 4.37 | 4.05 | 6.41 |

*3.2.2 Annual streamflow variation*

The year-to-year variations of streamflow are caused by weather conditions such as rainfall, temperature and seasonal climatic patterns, land use and land cover change, hydraulic structure along the main river, and human activity on water resources management in the catchment. The main influence on streamflow is rainfall runoff in the watershed. One of the most common human-induced changes in a flowing-water system is a long-term or permanent change in the volume of water flowing through the river or stream channel. These variations cause irregular rising and falling of river water levels, affecting the lives of the stream system. Therefore, the study of annual variation of streamflow is useful to visualize the year-to-year variation of mean annual flows for the period of record, whether the discharge for the study period increased or decreased. The average annual streamflow from the four stations is shown in Table 5. The streamflow slightly decreased from 1997 to 2011 based on the Trendline in Fig.7. The four graphs in Fig.8 indicate the annual variations of streamflow. The blue dash line on each graph displays if the flow increased or decreased from 1997 to 2011 in the four stations of Prek Thnot river. The Tasal Dam, Kampong Toul, and outlet of the river show a trend of increasing streamflow (red dash line), whereas the Peam Khley station shows a decreasing trend (red dash line).

**Table 5** The average annual streamflow from the four stations

| Year | Average streamflow (m3/s) | | | |
|---|---|---|---|---|
| | Tasal Dam | Peam Khley | Kampong Toul | Outlet of river |
| 1997 | 13.28 | 21.32 | 35.71 | 39.83 |
| 1998 | 22.32 | 38.14 | 53.87 | 61.11 |
| 1999 | 26.06 | 46.89 | 61.81 | 68.07 |
| 2000 | 27.46 | 53.70 | 73.23 | 78.78 |
| 2001 | 28.55 | 53.69 | 74.77 | 82.98 |
| 2002 | 17.66 | 27.61 | 32.52 | 35.28 |
| 2003 | 32.78 | 59.91 | 69.98 | 73.76 |
| 2004 | 18.92 | 27.73 | 31.68 | 33.48 |
| 2005 | 11.51 | 21.50 | 27.77 | 29.78 |
| 2006 | 18.50 | 28.73 | 39.86 | 41.75 |
| 2007 | 16.66 | 38.03 | 46.63 | 49.97 |
| 2008 | 20.45 | 40.89 | 49.41 | 52.60 |
| 2009 | 25.27 | 37.61 | 45.62 | 48.28 |
| 2010 | 27.13 | 42.53 | 48.43 | 51.77 |
| 2011 | 29.92 | 48.77 | 57.76 | 61.40 |

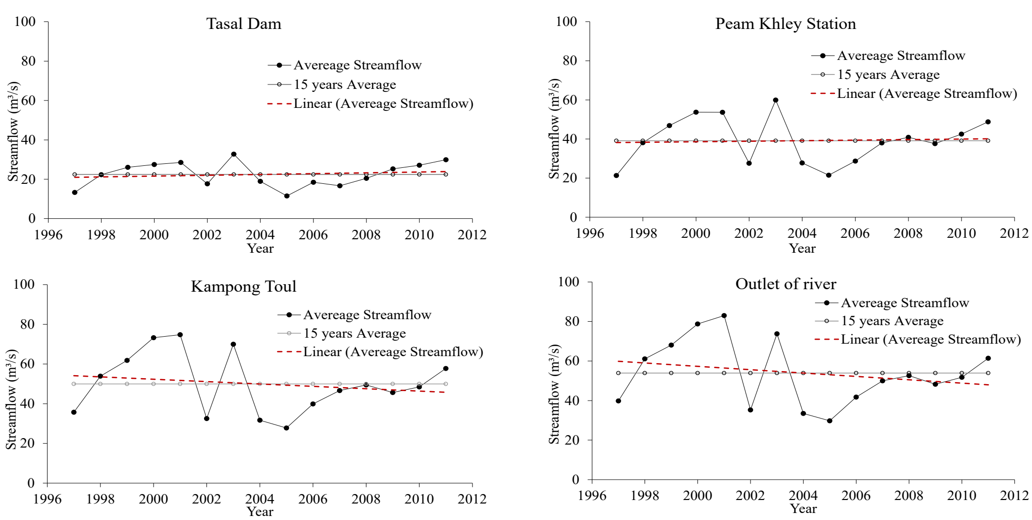


**Fig. 7.** The average annual streamflow from the four stations, the average streamflow of each station for 15 years, and its trendline

*3.3 Mann-Kendall (M.K.) test*

As mentioned in section *2.3*, Trends analyses were conducted using the Mann–Kendall (M.K.) test. Applying the procedures of the M.K. test on the Prek Thnot river, such as (the statistic of Mann-Kendall, Normalized test statistic, P-value, and level of significance), the trend result of the calculation finally is summarized in Table 6. The Mann-Kendall statistic value and the computed normalized test statistic are used to show the trend variation, depending on the decision of the probability level of significance (1%, 5%, and 10%). The Mann-Kendall test's trend analysis of monthly average streamflow reveals no sign of trend in Peam Khley station, Kampong Toul, and outlet of river. Oppositely, for Tasal Dam, which is only a significant level of 0.1 or 90% confidence level in May, the rest have no significant trend.

*3.4 Sen's slope*

A Mann-Kendall method is a statistical tool that can detect the trend and show either increasing or decreasing trends. Moreover, Sen's slope can tell the magnitude of the parameter that means how much flow has changed. Here, Sen's slope was estimated month-by-month to detect trends for all the four selected stations. The results have demonstrated no station with statistically significant trends at the significance levels 0.1, 0.05 and 0.01 (Table 7). Only at Tasal Dam in May has a slope at a significance level of 0.1, and the slope value is 0.45. Moreover, from March to July (mid of the dry and rainy seasons), Sen's slope result showed a positive slope sign. It could translate that these periods have experienced increases in the monthly streamflow quantity. It also means that the period between August and December in Tasal Dam and the outlet of the river experienced a decrease in the monthly streamflow. Thus, the monthly streamflow was reduced in the rainy season caused by the Tasal dam storing water in the reservoir for operation hydropower and agriculture used in the dry season.

**Table 6** Trend analysis using the Mann-Kendall method shown as monthly

| Station | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tasal Dam | * | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. |
| Peam Khley | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. |
| Kampong Toul | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. |
| Outlet of river | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. | n.t. |

*significance at alpha=0.1; **significance at alpha=0.05; ***significance at alpha=0.01; n.t. No Trend

**Table 7** Trend analysis using Sen's slope method shown as monthly

| Station Name | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tasal Dam | 0.45* | + | + | - | - | - | - | - | + | - | + | + |
| Peam Khley | + | + | + | - | + | + | + | - | + | + | + | + |
| Kampong Toul | + | + | + | - | - | + | - | - | + | - | + | + |
| Outlet of river | + | + | + | - | - | - | - | - | + | - | + | + |

*significance at alpha=0.1; **significance at alpha=0.05; ***significance at alpha=0.01

## 4. CONCLUSIONS

This study analyzes the hydrological trend in the Prek Thnot River Basin to identify the movement and the magnitude of monthly streamflow. This study's objectives were to examine the statistic of daily, monthly, seasonally, and annually flow distribution and variation in the Prek Thnot River and detect the changing streamflow trends by using Mann-Kendall (M.K.) tests and Sen's Slope estimator. From the statistical analysis in the Prek Thnot River Basin, the streamflow trend slightly decreased from 1997 to 2011. Moreover, the highest peak in this study was approximately 83 $m^3/s$ of average streamflow at the outlet of Prek Thnot River Basin in 2001, while the lowest flow occurred in 2005 about 11.5 $m^3/s$. From the Mann Kendall test analysis in the Prek Thnot basin from 1997 to 2011, most months and stations have revealed no trend evidence. However, Tasal Dam is at a significant level of 0.1 or 90% confidence level in May.

Furthermore, the result of Sen's Slope estimator at the early rainy season showed the positive sign of slope, and it could translate that these periods have experienced increases in the monthly streamflow quantity. The trend analysis of monthly average streamflow by the Mann-Kendall test showed only a significant trend at alpha 0.1 or 90% confidence level in May at Tasal Dam with the slope value of 0.45.

It is essential to characterize the flow distribution characteristics in the whole Prek Thnot River Basin to identify the altering of hydrological trends and its magnitude of causing the variation of streamflow. Therefore, the impact of flow variation should be taken into consideration.

## ACKNOWLEDGMENTS

The authors would like to acknowledge the Cambodia Higher Education Improvement Project (Credit No.6221-KH) of the Ministry of Education, Youth and Sports (MOEYS) for financial support of the study. The authors would also like to thank the Ministry of Water Resources and Meteorology (MOWRAM) and Mekong River Commission (MRC) of Cambodia for providing the data.

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