

# Spatial Rainfall Variability and an Increasing Threat of Drought, According to Climate Change in Uttaradit Province, Thailand

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# Abstract

This study presents the work commenced in northern Thailand on spatial and temporal variability of rainfall. Thirty years (1988-2017) rainfall data of eight meteorological stations were used for assessing temporal variability and trend analysis. The results showed decreasing trend in rainfall from its first half of the observed study period (1988-2002) to last half of the time period (2003-2017) in total average annual as well as monsoonal average rainfall by 14.92% and 15.50% respectively. It was predicted from linear regression results that by 2030 the average annual and monsoonal rainfall will drop by 35% and 34.10% respectively. All stations showed negative trend except Fakara met-station in annual rainfall. In the seasonal trend analysis, the results showed decreasing trend almost in all met-stations. Mann-Kendall trend test was applied to assess the trend. All met-stations show significant negative trend. To assess drought in the study area, Standardized Precipitation Index (SPI) was applied to 12-month temporal time period. The results predicted meteorological drought in the near future. The spatial distribution of rainfall presented changing phenomena in average annual, monsoonal, winter, and summer seasons in both analyzed periods.

# **Keywords**

Climate Change, Temporal Variability, Meteorological Drought, Mann Kendall Test, Standardized Precipitation Index

# **1. Introduction**

Climate change is considered as the main cause of environmental problems that

we are currently facing. Climate change has become a globally convincing truth based on the collected data by the world's meteorological community. Positive and negative effects of the climate change witness according to the exposure of the area around the globe. Rainfall in Thailand is influenced by two monsoons winds *i.e.* southwest and northeast. The southwest monsoon commences in May and ends in October which brings warm humid air from Indian Ocean to Thailand and is the main cause of intense rainfall in the study area but this rainy season is also influenced by inter tropical convergence zone and tropical cyclone. The second monsoon season starts from mid October and culminates in mid of February. This brings cold and dry air from China to northern and northeastern parts of Thailand [1]. There are various studies which show the influence of El Niño (warming) and La Niña (cooling) on the climate over East Asian and Indo-China regions; it normally takes 2 - 7 years for a completely natural cycle [2] [3]. The connotation among ENSO and the northeast monsoon affects the amount of rainfall in the southern part of Indo-China Peninsula [2]. The negative influences of El Niño (warming) and La Niña (cooling) can cause extreme events i.e. drought, flood. Thailand has experienced drought in 1997, 1999, 2008, 2014, 2015 and 2016, and floods events in 1980, 2006, 2010, and 2011 [4]. Agriculture, water management, and weather forecasting necessitate proper valuation of rainfall. The met-stations are the main source of recorded rainfall data in this regard [5]. As rainfall is the most significant factor for production of agriculture sector in Thai economy. Consecutively, in 2015 and 2016 Uttaradit province faced the meteorological drought [6]. In July 2015, average rainfall all over Thailand was 46% lower than its normal rainfall [7]. The main objective of this study is to observe the trend of rainfall and drought conditions in Uttaradit Province, Thailand. The aim of this paper is to examine the variations in rainfall in terms of trend, variability, spatial and temporal distribution and drought using standardized precipitation index (SPI) in Uttaradit province. To achieve the research objective, we proposed several methods such as Mann-Kendall trend test, Sen's slope estimation test and Standardized Precipitation Index (SPI).

#### **Study Area**

Uttaradit province is located in northern part of Thailand with an area of 7383 Km<sup>2</sup> (**Figure 1**). Total population of the province is 460,400 [8]. Elevation of the province ranges from 1 m to 1751 m above mean sea level. The main river in the province is Nan river and the province is in the valley of Nan river. Length of the river is 740 km which passes through the provinces of Phitsanlouk, Nan, Uttaradit, Phichit and Nakhon Sawan. During thirty years (1981-2010) average monthly temperature is 27.5°C and average annual rainfall in the province is 1371 mm.

## 2. Materials and Methods

#### 2.1. Data and Methods

The daily rainfall data from 1988-2017 (30 years) of eight rainfall stations were



Figure 1. Distribution of rainfall stations in Uttaradit Province.

analyzed in this study (Table 1). The distribution of rainfall stations is shown in Figure 1. The rainfall data was acquired on request from Thai meteorological department, Thailand (TMD). The rainfall data was grouped into two 1988-2002 and 2003-2017 for further investigation of changes in spatial and temporal distribution over Uttaradit province. The changes over the province were observed with total annual rainfall, monsoonal rainfall and interpolation technique. Monthly average rainfall of two periods was used to investigate the temporal changes in precipitation [9].

# 2.2. Mann-Kendall Trend Test

Mann-Kendall is rank based non-parametric trend test was developed by [10] [11]. It is a commonly used the test to detect linear or nonlinear trend in time series data. It is based on two hypotheses, one is null ( $H_0$ ) and the other is known as alternative hypothesis ( $H_1$ ). The null hypothesis ( $H_0$ ) confirms the nonexistence of any trend while the  $H_1$  shows the existence of the trend in time series data. The MK is derived using the following equation:

Met Station	Long	Lat	Min	Max	Mean	STD
ThaPla	17.648	100.054	49.40	2520.90	1205.407	419.73
Laplae	17.986	100.878	260.10	2056.30	1373.67	373.06
Fakkai	18.025	101.073	0	1526	914.30	421.38
Ban Khok	17.473	100.337	0	1883.60	965.32	458.14
Thong Saen Khan	17.702	100.369	0	1471.20	975.10	396.63
Tamboan Tha Pla	17.905	100.827	0	1885.40	993.39	549.25
Fakraa	17.557	100.111	0	1469.10	929.21	368.19
Huai Mo Mun	17.286	100.089	574.10	2241	1368.45	336.16

Table 1. Statistical details of meteorological stations in study area.

$$S = \sum_{i=j}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i)$$
(1)

where

$$\operatorname{sgn}(x_{j} - x_{i}) = \begin{cases} +1, & x_{j} > x_{i} \\ 0, & x_{j} = x_{i} \\ -1, & x_{j} < x_{i} \end{cases}$$
(2)

The statistics of variance has been calculated as:

$$Var(S) = \frac{1}{18} \Big[ n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \Big]$$
(3)

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0\\ 0 & \text{if } S = 0\\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases}$$
(4)

In Equation (1)  $x_i$  and  $x_j$  are the observational data of the time series in the years *i* and *j*, *n* denotes the number of observation in the data series,  $t_p$  is the number of ties for the *p*th value, and *q* denotes the number of tied values. The  $Z_{MK}$  values can come both in positive and negatives, the positive shows the increasing trend while negative values indicates the decreasing trend in time series data. There are two hypotheses: one is the null hypothesis of no trend and the alternative hypothesis indicating significant trend in the data. When  $|Z_{MK}| > Z_{1-\alpha/2}$ , the H<sub>0</sub> is rejected and H<sub>1</sub> is accepted that means a significant trend exists in the time series.  $Z_{1-\alpha/2}$  is the critical value of Z from the standard normal table,  $Z_{1-\alpha/2}$  value is 1.96 for 5% significance level.

#### 2.3. Sens's Slope Estimation Test

Sen's slope estimation test has been commonly used for climatic data [12] [13]. In this study, SS method was used for precipitation data for estimation of its slope. The slope of entire, associated data [14] was computed as:

$$F(t) = Qt + B \tag{5}$$

Here, Q specifies slope, while B is a constant value. In order to get the slope estimation (Q), initially the slopes (value) of the entire time series data was calculated:

$$Q_i = X_i - X_j / j - k \tag{6}$$

In the above Equation (6),  $i = 1, 2, 3, 4, \dots, N$ , whereas, at time *j* and k (j > k),  $X_j$  and  $X_k$  are the values of data pairs, respectively. The median of *N* values of  $T_i$  has been expressed as the SSE, given as:

$$Q_{med} = \begin{cases} Q[(N+1)/2] & \text{if } N \text{ is odd} \\ \frac{Q[N/2] + Q[(N+2)/2]}{2} & \text{if } N \text{ is even} \end{cases}$$
(7)

Therefore, if N appears odd, SS is analyzed as  $Q_{med} = T(N+1)/2$ . However, if it appears even, then SS will eventually be analyzed as  $Q_{med} = T(N/2) + T(N+2)/2$ . Thus,  $Q_{med}$  is computed to get the slope magnitude using non-parametric model. If  $Q_i$  is positive, it shows increasing trend while negative  $Q_i$  represents decreasing trend in time series data analysis.

#### 2.4. Standardize Precipitation Index (SPI)

Several indices like SPI, VCI, TCI, SPEI, RDI, PDSI and SSI etc. by drought experts to analyze drought condition and severity in an area [15]-[21]. In this study SPI is applied to assess drought condition in the study area. This index was first used and developed by McKee *et al.* (1993). SPI require only long term precipitation data to analyze the drought in an area [22] [23]. This index is considered more reliable for heterogeneous topographical area and can assess drought for different time scales [24]. The SPI and its categories are given below in (Table 2). Mathematical formulation of SPI is given below:

$$SPI = \frac{X - \overline{x}}{\sigma} \quad [25] \tag{8}$$

where X is the monthly precipitation,  $\overline{x}$  is mean of monthly precipitation data and  $\sigma$  represents standard deviation. SPI were calculated by using SPI\_SLX6 calculator. Table 1 shows the threshold values for different intensities of drought.

Values	Condition		
≥2.00	Extremely wet		
1.50 - 1.99	Severely wet		
1.00 - 1.49	Moderately wet		
-0.99 - 0.99	Near normal		
-1.001.49	Moderately drought		
-1.501.99	Severe drought		
≤-2.00	Extreme drought		

Table 2. SPI values and its categories.

## 3. Results and Discussion

#### 3.1. Trend Analysis and Spatial Variability

In this study trend analysis method was applied to annual and monsoonal rainfall over the eight rainfall stations and it was revealed from the trend that in near future the amount of rainfall will be decreasing. The average annual rainfall for the periods of 1988-2002 and 2003-2017 are 1179 and 1003 mm respectively.

It can be easily observed that amount of rainfall decreased by 14.92% from first half to the second and 15.50% of monsoonal rainfall decreased from 1988-2002 to 2003-2017. The total average annual rainfall during 1988-2017 is 1091 mm and it is estimated using linear regression method that by 2030 it will drop to 700 mm, which is 35% decrease from the average annual rainfall of 1988-2017. The average monsoonal rainfall between 1988-2017 is 956 mm and it is predicted using linear regression method that by 2030 it will drop to 630 mm. Trend analysis results are in good agreement with a study in North-Eastern Thailand [26] and are shown in Figure 2.

These predictions are indicating the rainfall shift; the amount of rainfall is rapidly decreasing in monsoon period as compared to annual rainfall. These alarming changes showed that the study area will face more severe meteorological drought conditions in the near future. These findings are useful for disaster managers, concerned government organizations and decision makers to take the necessary step in its response.

The time series of annual rainfall over eight rainfall stations plotted to represent the variation in rainfall crossways in the province. As the annual rainfall from 1988-2017 showed a decreasing trend but the variation (spatial variability) in rainfall showed an increasing trend from its first half to the second by 19.57%.

#### 3.2. Annual and Seasonal Mann-Kendall Trend Analysis

In this study, precipitation data of eight meteorological stations of Uttaradit province was analyzed to assess the trend. The results (Table 3) of all stations



Figure 2. Trend analysis of total annual, average and spatial variability over space.

Time series	First year	Last year	Ν	Test Z	Sig	Q
ThaPla	1988	2017	30	-0.36		-2.22
Laplae	1988	2017	30	-0.89		-7.78
Fakkai	1988	2017	30	-1.30		-12.76
Ban Khok	1988	2017	30	-1.27		-8.12
Thong Saen Khan	1988	2017	30	-1.03		-10.44
Tambon Tha Pla	1988	2017	30	-2.50	*	-30.20
Fakara	1988	2017	30	0.37		3.37
Huai Mo Mun	1988	2017	30	-1.11		-7.92

Table 3. Mann-Kendall and Sen's slope analysis of annual rainfall data for period of1988-2017.

shows negative  $Z_{MK}$  values except Fakara met-station, it means there is a decreasing trend in the amount of rainfall. Except Tambon Tha Pla met station and no other met-station shows any significant trend.

The MK trend analysis was applied to seasonal rainfall to assess the trend and results shown that in winter season five station shows negative  $Z_{MK}$  values and three stations (Ban Khok, Thong Saen Khan, & Fakara) shows the increasing trend (**Figure 3(b)**) but not a single met-station showed any significant increasing or decreasing trend. Moreover, when MK trend analysis was applied to summer season the same trend was found as of the annual rainfall but in summer season the met-station Tambon Tha Pla shows more significant decreasing trend in the amount of precipitation (**Figure 3(c)**). In monsoon season the amount of precipitation increase at the met-stations of ThaPla and Fakara. All other stations show decreasing trend but there is no significant trend found in amount of rainfall (**Figure 3(d)**). It means overall there is decreasing trend which is in a good agreement with the previous study [26].

## 3.3. Sens's Slope Analysis

Sen's slope estimation test was applied to all meteorological stations for the annual, and three seasonal rainfall (**Table 4**). Sen's slope estimation test applied to  $Q_{\text{annual}}$ , and results revealed that Fakara is the only station which adores the positive and the topmost slope magnitude (Q = 3.375), which is followed by ThaPla station (Q = -2.225). Except Fakara station, other seven stations show negative and fluctuating slope magnitude (**Table 4**; Figure 4(a)). Likewise, SS estimation test was applied on all met stations of  $Q_{\text{winter}}$ , and results discovered that Fakara met-station has the uppermost slope magnitude (Q = 0.775), followed by Ban Khok station (Q = 0.605). Thong Saen Khan and ThaPla have rather smaller values comparatively (Q = 0.475 and -0.07) respectively. Laplae met station which is at high elevation grasp the lowest slope magnitude *i.e.* Q = -0.594 (**Table 4**; Figure 4(b)). Using SS estimation test for  $Q_{\text{summer}}$ , results revealed that all stations have negative trend except Fakara met station which did not show any trend (Q = 0) but this station showed topmost and positive trend in  $Q_{\text{annual}}$ 



**Figure 3.** Met stations with increasing and decreasing trends with 5% significance level for the rainfall time series period of 1988-2017. (a) Annual rainfall trend; (b) Winter season trend; (c) Summer season trend; (d) Monsoon season trend.

Table 4. Sen's slope estimation of the Met-stations for rainfall in Uttaradit provin	nce
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Met-station	$Q_{\rm annual}$	Q <sub>winter</sub>	Q <sub>summer</sub>	Q <sub>monsoon</sub>
Tha Pla	-2.225	-0.07	-6.3	0.428
Laplae	-7.78	-0.594	-5.233	-6.467
Fakkai	-12.76	-0.109	-5.817	-10.2
Ban Khok	-8.127	0.605	-5.8	-10.2
Thong Saen Khan	-10.44	0.475	-4.65	-8.967
Tambon Tha Pla	-30.2	-0.329	-12.635	-21.8
Fakara	3.375	0.775	0	1.694
Huai Mo Mun	-7.922	-0.173	-2.755	-4.435

Note:  ${}^{*}Q$  is the Sen's slope estimation for annual and seasonal rainfall.



**Figure 4.** Sen's slope estimation (magnitude) for (a) Annual (b) Winter (c) Summer & (d) Monsoon Rainfall in Uttaradit Province.

and  $Q_{\text{winter}}$ , respectively (**Table 4**; **Figure 4(a)** & **Figure 4(b)**).

The lowermost slope magnitude (Q = -12.635) in  $Q_{\text{summer}}$  for Tambon Tha Pla station which is on the moderate elevated area. Correspondingly, by testing SS estimation on  $Q_{\text{monsoon}}$  on all meteorological stations, Fakara retains the superior slope magnitude (Q = 1.694), which is followed by ThaPla (Q = 0.428). The lowest slope magnitude retains by Tambon Tha Pla met-station (Q = -21) and other lasting met-stations specify inconsistency in case of  $Q_{\text{monsoon}}$  (Table 4; Figure 4(d)).

# 3.4. Spatial and Temporal Rainfall Distribution

Spatial trend of average annual, monsoonal, summer and winter season rainfall distribution during 1988-2017 was assessed and presented into two groups 1988-2002 and 2003-2017 in Figures 5(a)-(f). Spatial trend of rainfall was



**Figure 5.** Rainfall distribution. (a) Total rainfall between 1988-2002; (b) Monsoonal rainfall between 1988-2002; (c) Summer and winter season rainfall between 1988-2002; (d) Total rainfall between 2003-2017; (e) Monsoonal rainfall between 2003-2017; and (f) Summer and winter season rainfall between 2003-2017.







Figure 7. Spatio-temporal pattern of 12-months SPI for December in different meteorological stations.

assessed using spline interpolation technique. It is clear from Figure 5(a) that average annual rainfall during 1988-2002 showed a rising trend from east to west and southwest; though, during 2003-2017 (Figure 5(d)) the magnitude of rainfall rising towards the west and north. The extent of average annual rainfall through 1988-2002 is higher than the period of 2003-2017 by 1100 mm.

The trend of monsoonal season rainfall during the periods of 1988-2002 and 2003-2017 are rising in southwest direction (Figure 5(b) and Figure 5(e)) but the amount of rainfall decreased from first period to second period by 500 mm. In summer and winter season, the average rainfall rising towards southwest for the period of 1988-2002 (Figure 5(c)) but for the period of 2003-2017 it is rising towards the north part (Figure 5(f)) and amount of rainfall decreased from first period to second period by 248 mm. The comparison of average monthly rainfall between 1988-2002 and 2003-2017 studied and showed in Figure 6. The differences in distribution of average monthly rainfall between the two dated showing that monsoonal season (May-October) receive more than 80% of average annual rainfall.

The average monthly rainfall is decreasing from the period of 1988-2002 to 2003-2017. There are two peaks in the first period, in the months of May and August; however, in the second period the peaks were found in the months of August and September (**Figure 6**). The average monsoonal season rainfall decreased by 15.26% from first period to the second. The trend of average monthly rainfall of the wet season (Monsoon) is exposing that it is moving towards the dry conditions and in near future the province will face the meteorological drought.

#### 3.5. SPI Analysis Based on 12-Month Return Period

SPI for 12-month return period is used to assess the drought condition in an area that prevails for more than two seasons. It takes accumulated precipitation of whole year. **Figure 7** indicates that the drought conditions in the Uttaradit Province are not the same both in temporal and spatial dimension. The Thong Saen Khan rainfall-station witnessed severe drought in 1996, 1997, 2017 and moderate drought in 2015. In the Ban Khok rainfall-station moderate drought was found from the analysis in the years of 2005, 2006, 2007 and 2017. Similarly, in Fakkai rainfall-station two moderate drought years (2006, & 2015) and three severe drought years was 2010, 2014 and 2017.

Similarly, the severe drought condition was also witnessed in Fakraa rainfall-station during 1988-2015 in the years of 1988, 1989 and same like other station in 2017 as well. In the rainfall-stations of Laplae, Huai Mo Mun and Tha Pla the year of 2017 witness the history extreme drought in the study region. Laplae also witnessed severe drought in 2015 and moderate drought in 2016. While the situation of drought in Tambon Tha Pla rainfall-station was totally different from other stations as up to 2011 the rainfall situation was more than higher than normal in almost all years but after 2011 there is a consecutive moderate type of drought prevailing in the area.

## 4. Conclusions

During the past 30 years (1988-2017) annual rainfall data were collected for Uttaradit province which shows decreasing trend. It was observed that average annual rainfall during the period of 1988-2002 was higher than the second period (2003-2017) by 14.92%. The annual monsoonal rainfall showed decreasing trend of 15.50% from its first half. It was observed more than 80% of the annual rainfall contributed by the monsoonal season and meanwhile it was estimated using linear trend method that by 2030 monsoonal rainfall will be decreasing from average monsoonal rainfall (1988-2017) by 34.10%, same the average annual rainfall was also predicted for 2030 using linear trend method which showed a decreasing trend with 35%. Thus, it can be concluded that decreasing trend of annual and monsoonal rainfall will lead to the meteorological drought and deficiency of precipitation leads towards all other types of droughts [27].

Variations were found in annual rainfall with a decreasing trend from the period of 1988-2002 to 2003-2017 by 19.57%. This study indicated that there are differences in both periods. It was also observed during the spatial distribution of the rainfall that Mae-Phun sub-district of Laplae district received more rainfall in both periods which was the worst affected area during May, 2006 flood and mudslide event [8] [28]. In average monthly rainfall, the decreasing trend was observed from the period of 1988-2002 to 2003-2017 except January and June. Other than the aforementioned two months, 0.5% - 50% decrement in monthly rainfall has been observed in all other months during the time period of 2003-2017 in contrast to average monthly rainfall in 1988-2002.

Mann-Kendall test was applied to annual rainfall data for the whole period which resulted in only a significant trend found in Tambon Tha Pla meteorological station. Later, rainfall variability and drought conditions were spatially assessed using SPI technique. Annual rainfall data of 8 meteorological station falls in Uttaradit province were taken into consideration SPI analysis. In study area, met-stations located at high elevated areas received comparatively low rainfall as compared to the stations located at moderate and low altitudes. SPI results showed two different dry periods found, (moderate and severe) on the basis of 12-month SPI results revealed the dry period from 2005-2017.

This study focused on the rainfall variability and its increasing threat towards drought over Uttaradit was assessed using past 30 years rainfall data. Therefore, keep in mind the finding of this study, the detailed studies on climate variability, drought assessment recommended in order to minimize the negative impacts of such potential hazards.

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## **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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