Analyzing Spatial Pattern of Drought in the Northeast of Thailand using Multi-Temporal Standardized Precipitation Index (SPI)

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ABSTRACT

The Northeastern part of Thailand has been frequently subjected to drought as results of erratic distribution of rainfall, dry spells in the rainy season and low water holding capacity of soil. The Standardized Precipitation index (SPI) is an index based on the probability of recording a given amount of precipitation. Therefore the probability of rainfall being less or more than a certain amount can be determined. Drought event means a particular rainfall event gives a low probability on the cumulative probability function. Using this index, the severity and pattern of droughts are examined. The objective of this study was to analyze Spatial Pattern of Drought in the Northeast of Thailand using multi-temporal SPI. Daily rainfall data for the period 1976-2004 from 308 rainfall stations distributed in the Northeast region were collected, analyzed and digitally encoded into GIS database. The Kriging Method was applied for spatial interpolation of mean annual rainfall to obtain spatial mean annual rainfall for the whole region. The spatial interpolation of SPI was also done using Kriging Method and the spatial pattern of drought and its severity were assessed from SPI values at various durations. The result indicated that the pattern of rainfall increased from southwest to northeast. Moderate and severe droughts were mostly found in the south and the southwest of the region. The frequency, area extent and severity of drought assessed from SPI could be benefit for sustainable water resources management and the development of mitigation strategies of drought events in the region.

1.INTRODUCTION

The Northeastern part of Thailand has been frequently subjected to drought in several parts of the region although the amount of rainfall is relatively high. The major causes of drought are erratic distribution of rainfall, dry spells in the rainy season from June to July and also in last two weeks of September and low water holding capacity of soil. The most serious negative result from drought is water deficiency for agriculture, the major economic sector in the region, which impacts human life, property and agricultural production in the region and the country as a whole.

A rainfall period in the Northeast of Thailand starts from May to October which is influenced by the Southwest and the Northeast monsoon. The pattern of increasing rainfall was found from the Southwest to the Northeast of the region. The greatest variability of rainfall was found in the southwest which drought impacted several provinces in this area (Saenjan et al, 1990). In addition, in the southwestern and the central part of the region, unevenly distributed rainfall in the rainy season was found extensively and extended for longer periods which happened in the middle of June (Siripon, 2000). Drought risk area in the Northeast of Thailand was studied by using remotely sensed data and GIS to establish 3 drought risk layers; Meteorological drought, Hydrological drought and Physical drought. The study revealed that high drought risk areas were found in the Southwest and extended to the Northwest of the region while the low risk areas were found in the Northern and Northeastern part of the region along the Mekong River (Mongkolsawat, et al, 2001).

Drought means insufficient precipitation over extended periods (Loukas, 2004). The pattern of drought could be identified by assessment of rainfall and water resources availability. The new meteorological index, the standardized precipitation index (SPI) was developed by Mckee et al. (1993) to quantify precipitation deficits for several time scales. SPI is an index based on the cumulative probability of recording a given amount of precipitation at a station. Therefore the probability of rainfall being less or more than a certain amount can be determined. Drought event means a particular rainfall event gives a low probability on the cumulative probability function. The advantages of SPI are not only representing the amount of rainfall over a particular time scale, but also indicating the relation to the average of this amount which will be helpful to define drought experience of a station. The SPI output is in units of standard deviation from the median, based on the time record period with longer time period is more likely to get a better result (Rouault et al, 2003).

Several studies used SPI for real time monitoring and analysis of drought. SPI was applied to monitor the intensity and spatial extension of droughts at different time scales in South Africa (Rouault et al, 2003). Llod-Huges and Sounders (2002) used SPI to analyze drought climatology for Europe and the results indicates that the proportion of Europe experiencing extreme and moderate drought conditions has changed significantly since the 20th century. Drought severity and its characteristic in Thessaly region, Greece, were examined using SPI and the study indicated that moderate and severe drought is common in Thessaly region (Loukas et al, 2004). Using SPI index to analyze spatial pattern of drought can examine the characteristic of drought and can give an indication of probability of recurrence of drought at various levels of severity.

The purpose of this study is to establish spatial pattern of drought in the Northeast of Thailand using multi-temporal SPI.

2. STUDY AREA

The study area is in the Northeast of Thailand, covers an area of about 170,000 sq.km. and lies between the latitudes of 14° to 18° N and the longitudes of 101° E to 106° E. The most extensive areas are restricted to paddy fields, crop fields, a small portion is forested. The topography is characterized by small hills and gentle undulating terrain with sparse vegetation cover. The remaining forests are isolated patches of remnant forest. The area is underlain by a thick sequence of Mesozoic rock, mainly Maha Sarakam Formations which consist of sandstone, siltstone and interbedded rock salts. The soils are inherently low in fertility and have sandy textures. The study area is shown in figure 1.

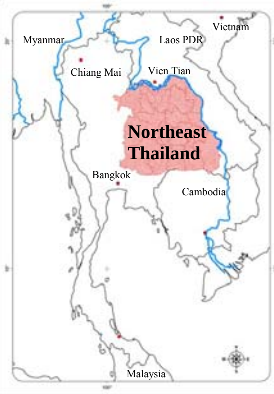

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Figure 1. Study area

3. METHODOLOGY

3.1 Rainfall data collection and analysis

Monthly rainfall data during the year 1976 to 2004 from 308 stations of the Thai Meteorological Department (TMD) stations distributed throughout the study area were collected and digitally encoded into GIS database. Mean annual rainfall of each station was calculated for 29 years. Median of mean annual rainfall of each year was selected as a representative of each station during this study periods. Thus, there are 308 values preparing for interpolation.

Exploratory analysis of rainfall data was examined to explore the frequency distribution of rainfall and the local characteristics of spatial autocorrelation of rainfall in different location over the study period. The interpolation of mean annual rainfall for the 29 years period was performed using the Kriging Method to get a spatial pattern of rainfall data. The appropriate variogram model for rainfall data was the Gaussian model because the variation was very smooth and the nugget variance was very small compared to the spatially dependent random variation (Burrough et al, 1998). Cross validation was used to check for measuring the residual between the point and the surface created.

3.2 Calculation of coefficient of variance (CV)

A measurement of reliability of rainfall at each station for the study periods was calculated using CV. High CV values indicate a large variation in rainfall over the study period (Saenjan et al, 1990). The formula for CV is;

$$CV = \left(\frac{s}{\bar{x}}\right) x 100$$

Where s = standard deviation and $\bar{x}$ = mean

3.3 SPI calculation

The SPI is the number of standard deviations of which the observed value deviated from mean. Computation of SPI is firstly done by transforming precipitation value into a normal distribution. SPI is calculated by fitting a Gamma probability density function to a given frequency distribution of precipitation totals for a station. Then, each probability density function is transformed into the standardized normal distribution with mean of zero and variance of one, which is the value of the SPI (Loukas et al, 2004). The steps and equations to calculate SPI are as follows;

The precipitation data are calculated using the Gamma probability density function which is defined as;

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad for\ x > 0 \qquad (1)$$

Where β and α are the scale and shape parameter respectively, x > 0 is the amount of precipitation and $\Gamma(\alpha)$ is the gamma function. β and α are estimated from Maximum Likelihood solutions as follows;

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (2) \qquad\qquad \hat{\beta} = \frac{\bar{X}}{\hat{\alpha}} \qquad (3)$$

Where $A = \ln(\bar{X}) - \frac{\sum \ln(X)}{n}$

n is the number of observations

These resulting parameters are used to calculate the cumulative probability of an observed amount of precipitation for the given month and time scale. Since the gamma distribution, g(x), is undefined for x=0 and q= P(x=0) > 0 where P(x=0) is the probability of zero precipitation, then the cumulative probability will become;

$$H(x) = q + (1 - q)G(x)$$

Then, the cumulative probability distribution is transformed into the standard normal distribution by this equation;

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad for\ 0 < H(x) <= 0.5 \qquad (4)$$

where $t = \sqrt{\ln \frac{1}{(H(x))^2}}$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad for\ 0.5 < H(x) < 1 \qquad (5)$$

where

$$t = \sqrt{\ln\left[\frac{1}{(1 - H(x))^2}\right]}$$

and

c_0 = 2.515517, c_1= 0.802853, c2= 0.010328, d_1= 1.432788, d_2= 0.189269, d_3= 0.001308 (Lloyd-Hughes et al, 2002)

The SPI value classifications are shown in table 1. This table also gives the corresponding probabilities of occurrence of each severity from the normal probability density function (Rouault et al, 2003).

Table 1. SPI classification

SPI value	Drought category
2.0 and above	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

For this study, SPI calculated both Multi-temporal and Spatial SPI to facilitate the quantitative comparison of drought incidence over the 29 years period and 308 different rain gage locations. 6-month SPI was calculated from total rainy season from May to October and 12 month-SPI was calculated to describe long-term drought. SPI values of equal or less than -1.0 were used to determine drought intensity according to table 1. The frequency of occurrence of drought years was determined by looking at the number of the dry station (SPI < -1) since 1976.

For Spatial SPI, the precipitation means are calculated from the precipitation amounts of every rain gage station each year to compute SPI value. Then, Krigging method was applied to get a spatial pattern of the severity of drought from SPI value.

4. RESULTS & DISCUSSION

4.1 Rainfall in 29 years period

From exploring rainfall data, annual rainfall of the region ranged from the minimum in the Southwestern part, 778.25 mm, to a maximum in the Northeastern part, 3,021.50 mm. An example of fluctuating annual rainfall at 2 stations in the Southwest (Nakhon Rachasima Station) and the Northeast (Nakhon Phanom Station) of the study area is shown in figure 2 where rainfall has fluctuated overtime. Rainfall in September and October in the Northeast comes from The Northeast monsoon where the amount of rainfall is higher than in the Southwest.

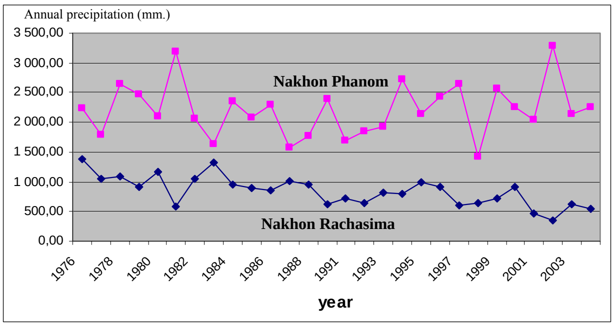

Figure 2. Annual Precipitation for 2 rainfall stations.

In most areas or over 70% of the Northeast receives annually between 983-1437 mm. of rainfall, the areas along the Mekong river have rainfall of 1437-2345 mm. annually (figure3). The spatial autocorrelation of rainfall in the study areas were examined from Semivariogram and covariance cloud.

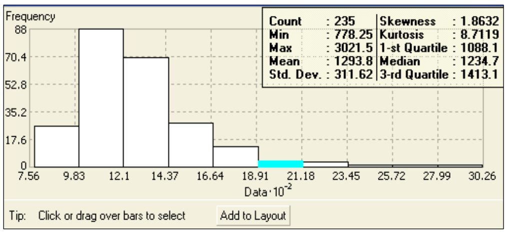

Figure 3. The frequency distribution of annual rainfall.

The Semivariogram and covariance cloud in figure 4 shows the high variation of rainfall in the stations located in the Southern and the Northern part while low variation in rainfall in the stations in the Northwest and the Southeast of the region. The analysis of spatial pattern of rainfall by the Kriging interpolation method found that the spatial pattern of mean annual rainfall for 29 years periods increased from the Southwest to the Northeast which is shown in figure 5.

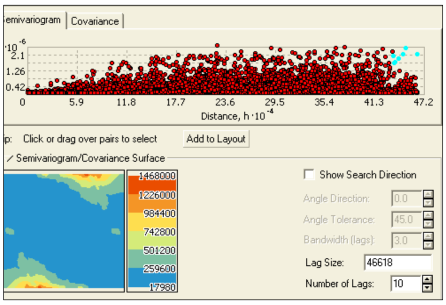

Figure 4. Semivariogram/covariance cloud of rainfall in the region.

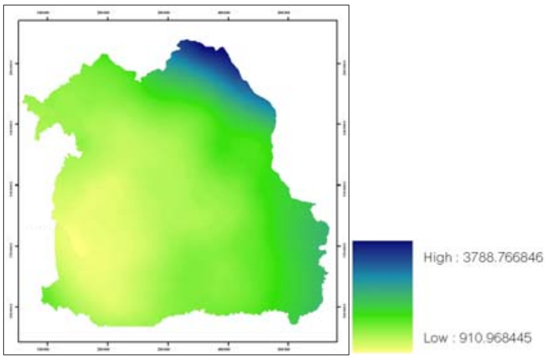

Figure 5. The spatial pattern of mean annual rainfall in 29 years period.

4.2 Coefficient of variance analysis (CV)

A measurement of reliability of rainfall at each station for the study periods was done using CV analysis. The spatial pattern of CV of rainfall of 6 months and 12 months are shown in figure 6a and figure 6b respectively. CV of rainfall 6 months is calculated from monthly rainfall in rainy period from May to October each year. The values of CV 6 months vary from minimum 10.84% to maximum 44.26%. High CV values were found in the Western and the Southern part of the region. The values of CV 12 months vary from minimum 10.30% to maximum 68.58% and these values are higher than the values of CV 6 months. High CV values indicate the great variability in rainfall. The high values of CV 12 months were also found in the Western part of the region which indicates that the risk of agricultural activity in these areas is severe, because of erratic rainfall.

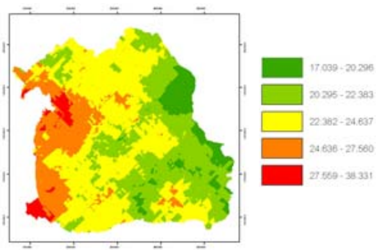

Figure 6a. CV 6 month

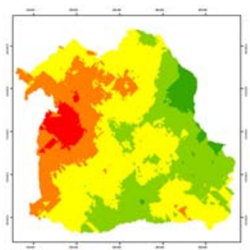

Figure 6b. CV 12 month

4.3 Multi-temporal SPI

The dry or wet years can be told from SPI values at the stations which highly deviate from the median over the study period. Figures 7a and 7b show the SPI of 3, 6 and 12 months since 1976 at two stations in the Northeast (Nakhon Phanom Station) and the Southwest (Nakhon Rachasima Station) of the study area. At the northeast station, the worst dry years appear in 1979, 1986, 1989, 1997 and 2003. Dry periods appear more frequently in SPI 3 months. At the Southwest station, the worst dry year was in 1981, 2001 and 2003. This station experienced drought more often in SPI 3 months.

Decadal variety of rainfall since 1976 can be observed from the number of dry or wet stations. Figure 8a and 8b show the number of dry stations (SPI 6, 12 month < -1) for 308 stations from 1976 to 2004 with 10-year window running mean so that the mean of dry station per decade could be indicated. Form figure 8a, the highest number of dry station (SPI 12 month < -1) occurred in 2003 about 127 stations. The average of dry station is 43. The mean averages of dry station per decade fluctuate over time. It was lower than the average until1988 and increased over the average until 1997, dropped again in 1998 and increased higher than the average since 1999. In addition, from figure 8b, the highest number of dry stations (SPI 12 month < -1) was in 1993. The average of dry station is 39. The mean average of dry station per decade was lower than the average until1988 and increased over the average until 1999 and after this time the number of dry station was lower than the average again. From this observation, drought in the region was more severe in the 10-year period from 1988 to 1999.

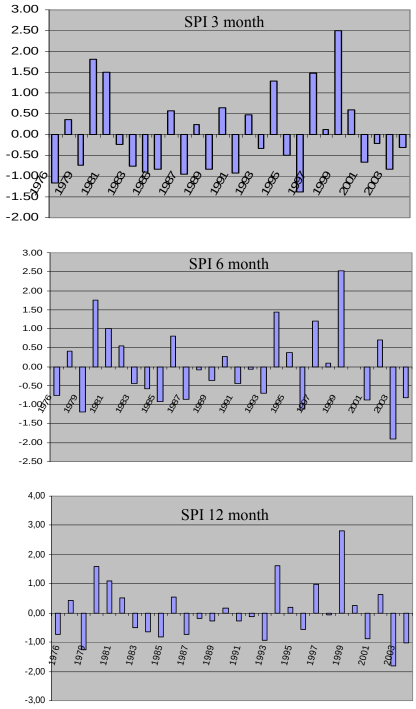

Figure 7a. SPI 12 month at the Northeast station

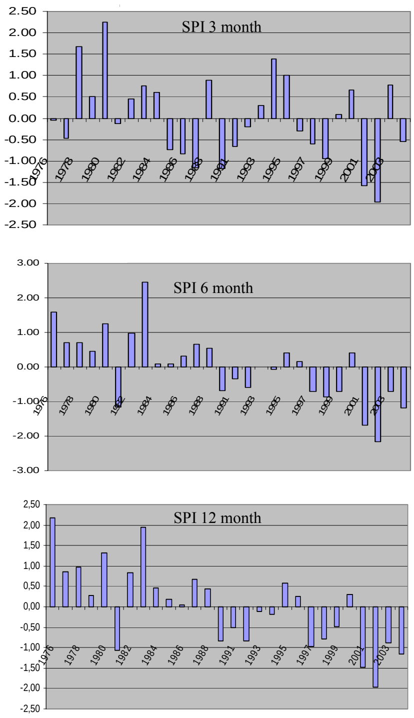

Figure 7b. SPI 12 month at the Southwest station

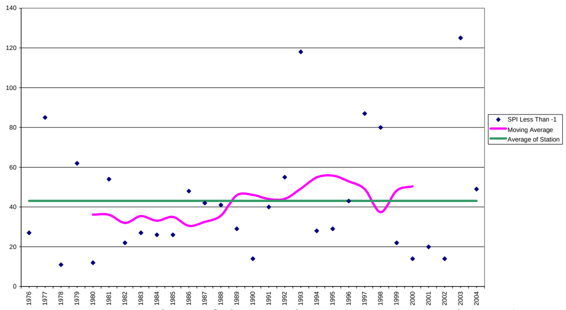

Figure 8a. Number of dry stations (SPI 6 month < -1)

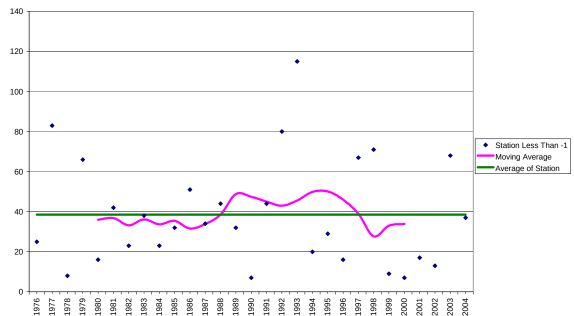

Figure 8b. Number of dry stations (SPI 12 month < -1)

4.4 Spatial SPI

The spatial extension and intensity of drought from SPI 6 month and SPI 12 month from 1976 are shown in figure 9 and figure 10 respectively. The spatial distribution of SPI 6 month and SPI 12 month is similar in the area mostly affected by drought which is mostly found in the Western and Southern part of the region. The severity of drought for SPI 6 month and SPI 12 month in the region is mainly classified into 3 groups. Moderately dry to extremely dry are found in the Western and Southern part, near normal is found in the central part and moderately to extremely wet are found in the North and Northeast of the region. The worst drought was in 1979, 1981, 1986, 1997 and 2001 for SPI 6 months and SPI 12 months. However, the drought affected areas are more severe and extend larger for SPI 6 months.

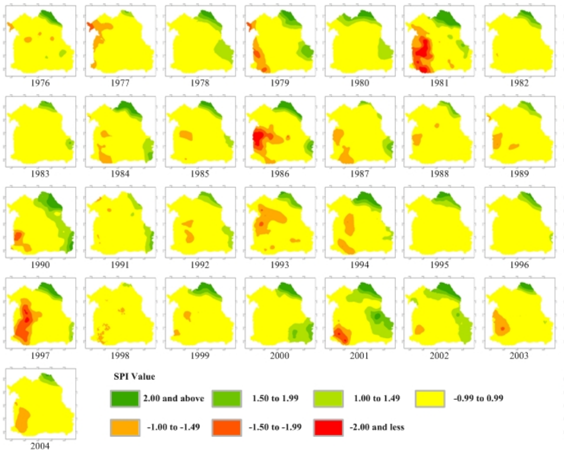

Figure 9. Spatial extension of the SPI 6 month since 1976

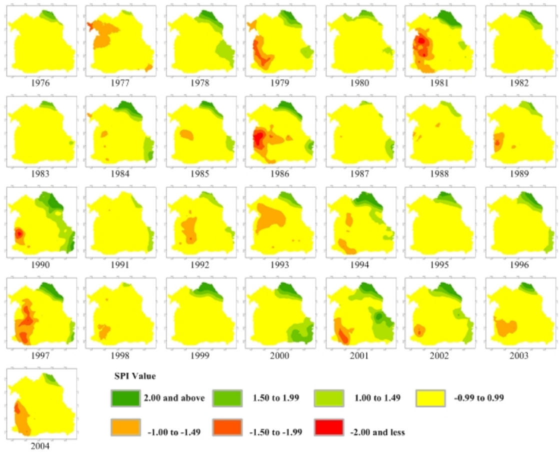

Figure 10. Spatial extension of the SPI 12 month since 1976

5. CONCLUSION

The analysis of spatial pattern of drought using spatial SPI and temporal SPI from rainfall data is useful to determine the spatial distribution, characteristics of drought, evaluate drought affected areas and drought frequency in the Northeast of Thailand. By analyzing spatial pattern of rainfall data in the region was found that spatial pattern of mean annual rainfall for 29 years periods increased from the Southwest to the Northeast. A measurement of reliability of rainfall at each station for the study periods using CV analysis indicated that the high values of CV 6 months and 12 months were found in the Western part of the region. Multi-temporal SPI at various time scales was used to indicate drought occurrences at the station and its severity. From the observation of decadal variety of rainfall since 1976 by looking at number of dry rainfall station (SPI < -1) it was indicated that drought in the region was more severe in the 10 year period from 1988 to 1999. For spatial variation of drought in the region during the study periods, the most affected area of drought was found in the western and southern part of the region and its severity, which associated with the pattern of rainfall, decreased from Southwest to Northeast. The worst dry year from spatial SPI was in 1979, 1981, 1986, 1997, and 2001 which drought affected areas are more severe and extend larger for SPI 6 months. The frequency, area extent and severity of drought assessed from SPI could benefit for sustainable water resources management and the development of mitigation strategies of drought events in the region.

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