Assessment of Drought Impacts on Urban Green Areas with the Climatic Drought Index in Nakhonratchasima City, Thailand

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Abstract : The study aimed to assess drought impacts on urban green areas with the climatic drought index in Nakhonratchasima City, Thailand. The Standardized Precipitation Evapotranspiration Index (SPEI) was used as the climatic drought index in this study. The study investigated and quantified the different responses of urban tree growth to drought events. The results revealed that the frequency of severe drought increased in 2017 and 2018 with the drying trend occurring in most of the study area. These results are useful for ecological assessments and planning management to mitigate the impact of drought on urban green areas. Significantly, this study is helpful to take care of urban trees growth and reduce potential damage to human health caused by air pollution e.g. PM 2.5 in urban areas.

Keywords : Drought, SPEI, Urban green area, Nakhonratchasima

1. Introduction

Droughts are recognized as a complex natural phenomena that impacts on water resources, agriculture, natural ecosystems, and society [1-4]. Recently, due to the change in climate, drought is expected to increase in frequency and severity. Additionally, drought impacts on urban tree and crop development and the yield. As a result, urban trees currently must face on a large range of additional stresses that are less strong or non-existent. This is because climate variabilities and environmental conditions within a city are overall more extreme and harmful to trees and can cause vitality loss and increase mortality risk.

Although many efforts have been made to develop methodologies to assess the drought, it is very difficult to isolate the beginning of a drought, as drought development is slow and very often the drought is not recognized until human activities, or the environment, are affected. Moreover, the effects of a drought can persist over many years after it has ended. In contrast to other extreme events such as floods, which are typically restricted to small regions and well-defined temporal intervals, droughts are difficult to pinpoint in time and space, affecting wide areas over long periods of time.

There are several climatic drought indices that have been developed to monitor, predict, and assess the severity of drought, such as the Palmer Drought Severity Index (PDSI) [5], Standardized Precipitation Index (SPI) [6], Standardized Precipitation Evapotranspiration Index (SPEI) [7], Vegetation Condition Index (VCI) [8], Effective Drought Index (EDI) [9], Reconnaissance Drought Index (RDI) [10], Soil Moisture Index (SMI) [11], Integrated Surface Drought Index (ISDI) [12], and Multivariate Standardized Drought Index (MSDI) [13] etc. Among these, the PDSI and SPI are the most popular one. The PDSI is based on a simplified water balance equation and requirements are precipitation, moisture supply, runoff and evaporation demand at the surface level. The SPI is based on precipitation anomalies, is easy to estimate and identify different types of drought [6-13]. Currently, the SPEI combines the multi-scalar features and simple calculation of the SPI with the PDSI's sensitivity to changes in evaporation demand caused by temperature fluctuations and trends [7]. The SPEI was developed by Vicente-Serrano et al. [7] and is based on a monthly or weekly climatic water balance (i.e., the difference between precipitation and evapotranspiration). The main advantage of the SPEI is its ability to identify the variability of evapotranspiration and temperature in the drought assessments. It is applicable for monitoring and exploring drought characteristics which reflects the water deficits at different time scales in a global warming context.

The objective of this study is to assess drought impacts on urban green areas with the climatic drought index such as the Standardized Precipitation Evapotranspiration Index (SPEI) in Nakhonratchasima City, Thailand. The drought disaster risk assessment is provided for the identification of drought events including duration, intensity, and frequency.

2. Study Area, Data and Methods

2.1 Study Area

The study area is Nakhonratchasima City (NC) as shown Fig. 1. NC site is located in Muang district of Nakhonratchasima province at 14’ to 16’N and 101’ to 103’E and occupies a total area of 37.5 km^2 (4.96 and 0.18 percent of Muang district and Nakhonratchasima province) with sea level 174-206 m. NC is far from Bangkok by vehicles about 255 km., by rails about 264 km. NC topography is characterized by most plain, a little slope in eastern direction, low land in the NC north and high land in the southern west. Most of soils are loamy sand. The main river is Lum Ta Klong (the major of Mun river) where flows through the NC north with length about 12 km. Authority of NC comprises of the north adjacent to 3-subdistrict administrative organization (SAO): Muen Wai, Nongkratum and Bankoh, the south adjoining 2- subdistrict municipality and 1 SAO: Nong Phailom, Pho Klang and Nong chabok, the east close to Hau THale subdistrict municipality, and the west next to 2- SAO and 1 subdistrict municipality: Ban Mai, Suranari and Pru Yai.

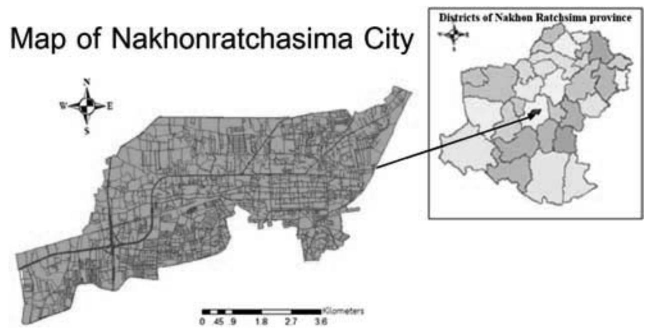

Fig. 1 Area of Nakhonratchasima City

2.2 Data Collection

For this study, climate data including temperature, precipitation, wind speed, specific humidity, and net long-wave surface radiation from Nakhonratchasima Meteorological Observation Station and The Thai Meteorological Department were collected during 2008-2018. Although, the study only used climate data from one weather station in the study area, it is good enough for the assessment of drought impacts because the study area is not large (the total area of 37.5 km^2).

2.3 Standardized Precipitation Evapotranspiration Index (SPEI)

The calculation of the SPEI parameter is a time-series of total monthly precipitation (P) and monthly potential evapotranspiration (PET). Monthly PET is estimated by the Thornthwaite equation [14] that only relies on monthly mean temperature (T) and latitude (L) to calculate the monthly average day length. Of these methods, the Thornthwaite is unique because it is based on an empirical relationship between average monthly temperature and potential evapotranspiration. The details of the SPEI computation, more thoroughly described in Vicente-Serrano et al. [7], are as follows:

Climate Water Balance

A simple climate water balance was calculated as the differences between precipitation (P) and evapotranspiration (PET) for month *j* according to:

$$D_j = P_j - PET_j \qquad (1)$$

where monthly PET is calculated by:

$$PET = 16K\left(\frac{10T}{I}\right)^m \qquad (2)$$

where *T* is monthly mean temperature (°C); *I* is heat index calculated as the sum of 12 monthly index values; *m* is the coefficient dependent on *I*: $m = (6.75 \times 10^{-7} \cdot I^3) - (7.71 \times 10^{-7} \cdot I^2) + (1.79 \times 10\text{-}2 \cdot I) + 0.492$; and *K* is a correction coefficient computed as a function of the latitude and month.

The calculated D_i values are aggregated at different time scales, following the same procedure as used for the SPI. The difference $D_{i,j}^k$ in month *j* and year *i* depends on the chosen time scale *k*. For example, the accumulated difference for one month in a particular year *i* with a 12-month time scale is calculated using:

$$X_{i,j}^k = \sum_{l=13-k+j}^{12} D_{i-1,l} + \sum_{l=1}^{j} D_{i,l} \quad for\ j < k \qquad (3)$$

$$X_{i,j}^k = \sum_{l=j-k+1}^{j} D_{i,l} \quad for\ j \geq k \qquad (4)$$

where $D_{i,l}$ is the *P – PET* difference in month *l* and year *i*, in millimeters.

Normalize the Water Balance

The log-logistic distribution was used for normalizing the *D* series to obtain the SPEI. The probability density function of a three-parameter log-logistic distributed variable is expressed as:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \qquad (5)$$

where α, β, and γ are scale, shape, and origin parameters respective, for *D* values in the range $(\gamma > D > \infty)$. The parameters of the Pearson III distribution can be obtained from Singh et al. [15]. Thus, the probability distribution function of the *D* series, according to the log-logistic distribution, is given by:

$$f(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \qquad (6)$$

Calculate the SPEI Series

The SPEI can easily be obtained as the standardized values of *F(x)*. Following the classical approximation of Abramowitz and Stegun [16]:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \quad (7)$$

$$W = \sqrt{-2\ln(P)} \; for \; P \; \leq 0.5 \quad (8)$$

where *P* is the probability of exceeding a determined D value, *P* = 1 - *F(x)*. If *P* > 0.5, then *P* is replaced by 1 - *P* and the sign of the resultant SPEI is reversed. The constants are C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, and d_3 = 0.001308.

2.4 Drought Assessments

In this section, the study discusses the method commonly used for assessment and identification of drought properties based on drought indices. Fig. 2 presents a simple plot of a drought variable included: (a) drought magnitude and (b) drought duration. A drought event from the SPEI plot can additionally be identified as drought with the highest severity, drought with the longest duration, and drought with the highest intensity.

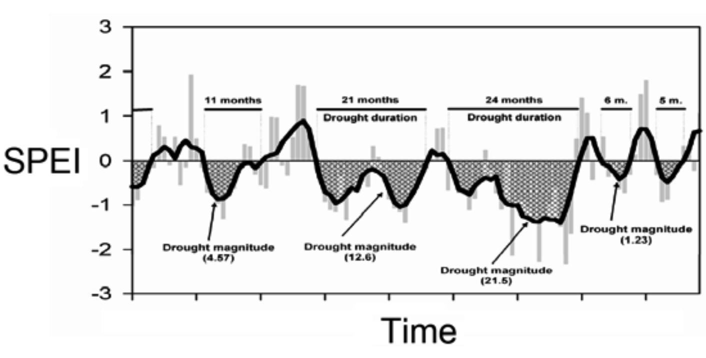

Fig. 2 The characteristics of drought magnitude and duration, modified from [7]

Tab. 1 The classification of drought events based on the SPEI values

Level	Drought Category	SPEI Values
0	Non-drought	0 ≤ Index
1	Mild drought	-1.0 < Index < 0
2	Moderate drought	-1.5 < Index ≤ -1.0
3	Severe drought	-2.0 < Index ≤ -1.5
4	Extreme drought	Index ≤ -2.0

2.4.1 Drought Classification

In this study, the goal is to provide some basic data for drought disaster risk assessment. Thus, monthly SPEI values at the variable time scale are used to identify drought events and their related indicators including duration, intensity, and frequency. Tab. 1 presents the classification of drought events based on the SPEI values.

2.4.2 Drought Duration and Intensity

The duration (m) of a drought event equals the number of months between its start and end month [17]. Severity ($\boldsymbol{S_e}$) is the absolute value of the sum of all SPEI values during a drought event. Intensity ($\boldsymbol{DI_e}$) of a drought event refers to severity divided by duration. The larger the $\boldsymbol{DI_e}$ value is, the more severe the drought. The formulas are:

$$S_e = \left|\sum_{j=1}^{m} Index_j\right|_e \quad (9)$$

$$DI_e = \frac{S_e}{m} \quad (10)$$

where e is a drought event; *j* is a month; $Index_j$ is the SPEI value in month *j; m,* S_e and DI_e are the duration, severity, and intensity of a drought event *e*, respectively.

2.4.3 Drought Frequency

Drought frequency (Fs) was used to assess the drought liability during a study period [3]. It is calculated by:

$$F_s = \frac{n_s}{N_s} x\ 100\% \tag{11}$$

where n_s is number of drought events, N_s is total number of years for the study period, and s is a station.

3. Results

3.1 Evapotranspiration

Fig. 3 shows the result of evapotranspiration (ET) during 2008 to 2018 in NC based on Thornthwaite equation. From last 3 years (2016-2018), there was a higher trend of ET. In 2010, 2011, 2013, and 2015, it was lower ET in the study area.

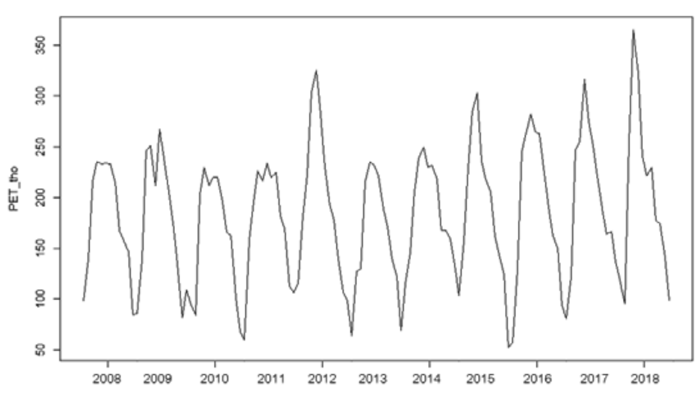

Fig. 3 Estimated ET values during 2008-2018 based on Thornthwaite equation

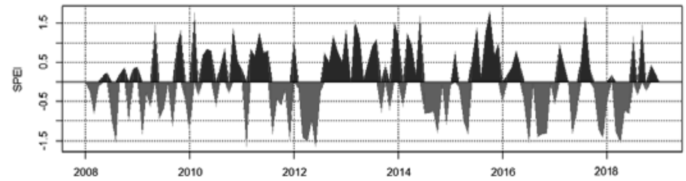

Fig. 4 Estimated SPEI values at the 1-month time scale

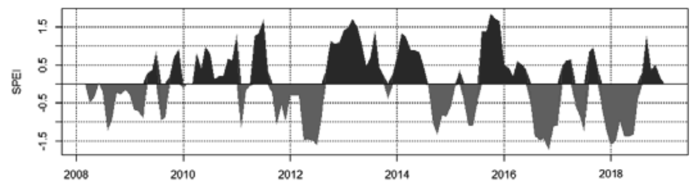

Fig. 5 Estimated SPEI values at the 3-month time scale

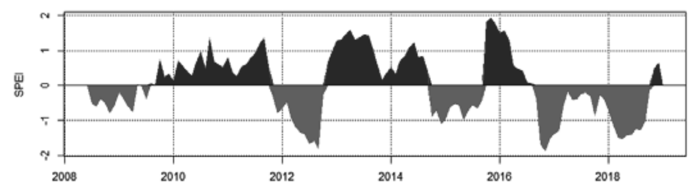

Fig. 6 Estimated SPEI values at the 6-month time scale

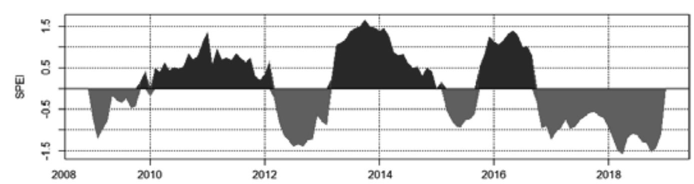

Fig. 7 Estimated SPEI values at the 12-month time scale

Tab. 2 The results of SPEI calculation at 12-month time scale

Year	Month	Max. SPEI	Drought Category
2008	November	-1.2	Moderate
2009	May	-0.5	drought
2010	October	+0.7	Mild drought
2011	February	+1.4	Non-drought
2012	June	-1.4	Non-drought
2013	October	+1.7	Moderate
2014	February	+1.5	drought
2015	June	-1.0	Non-drought
2016	May	+1.5	Non-drought
2017	January	-1.2	Moderate
2018	April	-1.6	drought
			Non-drought
			Moderate
			drought
			Severe drought

3.2 SPEI for Drought Assessment

Fig. 4-7 show the annual SPEI values at the variation of time scale including 1, 3, 6, and 12 months, respectively. From Fig. 7 (at 12-month time scale), the results briefly show that severe drought ($-2.0 < \text{Index} \leq -1.5$) occurred in year 2013 and 2018. For moderate drought ($-1.5 < \text{Index} \leq -1.0$), it was found in year 2009, 2015 and 2017. Non-drought or wet condition occurred for 3 years included 2011, 2014 and 2016. Tab. 2 also more clearly presents the results of SPEI calculation at 12-month time scale. For Fig. 4-6, it identified more details of drought events depended on the time scale.

4. Conclusions and Recommendations

The SPEI was used as the climatic drought index in this study. The results revealed that the frequency and extension of severe drought has recently increased in 2017 and 2018 with the drying trend occurring in the study area. These results informed for NC people to realize the impact of intensive drought on urban green areas.

For further research, the study will collect and run a model with longer period data of 30-50 years. Additionally, the study will run the model in more similar study areas for the comparison of the results and predict a future drought trending.

5. Acknowledgements

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