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Original Article

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Abstract

Drought is a disastrous-triggering agent that exacerbates environmental services and socio-economic conditions. Considering the impact of climate change and rainfall deficiency over the extended period, the need for a systematic way to understand drought is necessary. Therefore, this research proposed to perform an assessment of drought severity in the lower Nam Phong River Basin, Thailand using the Standardize Precipitation Index (SPI) and Water Evaluation and Planning (WEAP) model. The findings demonstrated consistent results between the SPI index and WEAP model in determining drought severity impacts. It was found that Kosum Phisai, Nam Phong, and Muang Khon Kaen Districts were the most drought affected areas. The drought risk areas were identified and classified into four zones based on the size of the affected area in %: less (25%); moderate (27%); high (22%); and extreme (26%). The outcome results can be useful for water resources planning and drought severity management in other parts of Thailand.

Keywords: drought susceptibility, SPI index, WEAP model, water scarcity, water demand

1. Introduction

Nowadays, it is a well known fact that the people in the northeast of Thailand are facing water scarcity problems in almost every year, in particular, insufficient water for domestic consumption during the dry season (Sawatpru & Konyai, 2016). More persistent anomalies in rainfall have caused extensive droughts over the northeast region. Owing to prolonged dry spells with rapid depletion of soil moisture during the crop periods, persistent droughts have frequently led to a collapse of subsistence crop yields. These issues are closely connected to climate change which has had a tremendous effect on agricultural practices with more severe impacts in the future. Thus, these facts underline the vulnerability of the agricultural sector and need for detailed investigations to deal with drought-related issues. By determining drought duration and severity across the northeast region, drought indices can play a vital role as significant implications for drought management because of their effectiveness and convenience of computation (Zhu *et al.*, 2016). Within this research, the lower Nam Phong River Basin was selected as a study site for detailed analysis because: 1) the selected study area is dependent on agriculture which is important to the economy; 2) the river ecosystems and human communities in this area are experiencing interrelated problems related to water shortage, pollution, and social conflict centered on water (Sneddon, 1998); and 3) there is a decline in its performance and growth as a result mainly due to persistent droughts. To achieve the main objective of this research, a combination of a modeling tool for water planning and allocation and drought index estimation was performed to investigate the occurrence of drought in the lower Nam Phong River Basin. With this research breakthrough, the development of a framework for

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optimal water allocation in rain-fed agriculture can be further developed.

2. Materials and Methods

2.1 Study area

The lower Nam Phong River Basin is situated in the Northeastern region of Thailand. This river basin has a total area of approximately 2,386 km^2, and the average topography varies from 150 m to 500 m above mean sea level (m+MSL) (Figure 1). The Nam Phong River is considered to be the main river in the Nam Phong River Basin with a length of about 136 km that extends from the Ubol Ratana Dam at the upstream end to the Chi River at the downstream end. Average temperatures in the study area are between 23 °C and 32 °C, whereas the mean annual rainfall is approximately 1,238 mm/year and the mean annual discharge is about 669 mm/year (Kuntiyawichai *et al.,* 2014). The dry season lasts from February to April, while the wet season takes place from May to October. In recent years, climate change has caused less rainfall along with decreases in the river level and groundwater. These factors, together with the expansion of community areas, agricultural farmland, and economic activity, are the main problems that have increased drought events in the lower Nam Phong River Basin. Furthermore, the volume of water storage from the Ubol Ratana reservoir usually reaches the minimum level during the dry season, which significantly affects drought severity at the downstream end of the lower Nam Phong River Basin. Especially in April 2016, the reservoir ran dry for the first time since its construction with its usable storage stood at -3.95% (Electricity Generating Authority of Thailand [EGAT], 2016). Consequently, the reservoir was not able to provide water for irrigation or electricity generation during that time.

2.2 Data collection

The observed daily and monthly rainfall, sunshine, and maximum and minimum temperatures for 31 years from 1980 to 2010 were obtained from the Royal Irrigation Department (RID) of Thailand, which covers eight gauging stations: Phu Wiang; Kranuan; Chum Phae; Si Chomphu; Nam Phong; Khon Kaen; Kantharawichai; and Tha Khantho. In order to distribute the amount of rainfall for each sub-basin, the Thiessen polygon method was applied in this study. The digital elevation model (DEM) with a 5x5 m resolution was used to provide insights into the topographic patterns for environmental modeling. In addition, land use and soil types in 2010 were derived from the Land Development Department of Thailand to present the details of the river basin characteristics. Water demand data for municipal and agricultural areas were obtained from various sources, which covered nine districts in the river basin (i.e. Ban Fang, Sam Sung, Kranuan, Khao Suan Kwang, Muang Khon Kaen, Kosum Phisai, Nam Phong, Non Sa-at, and Ubol Ratana).

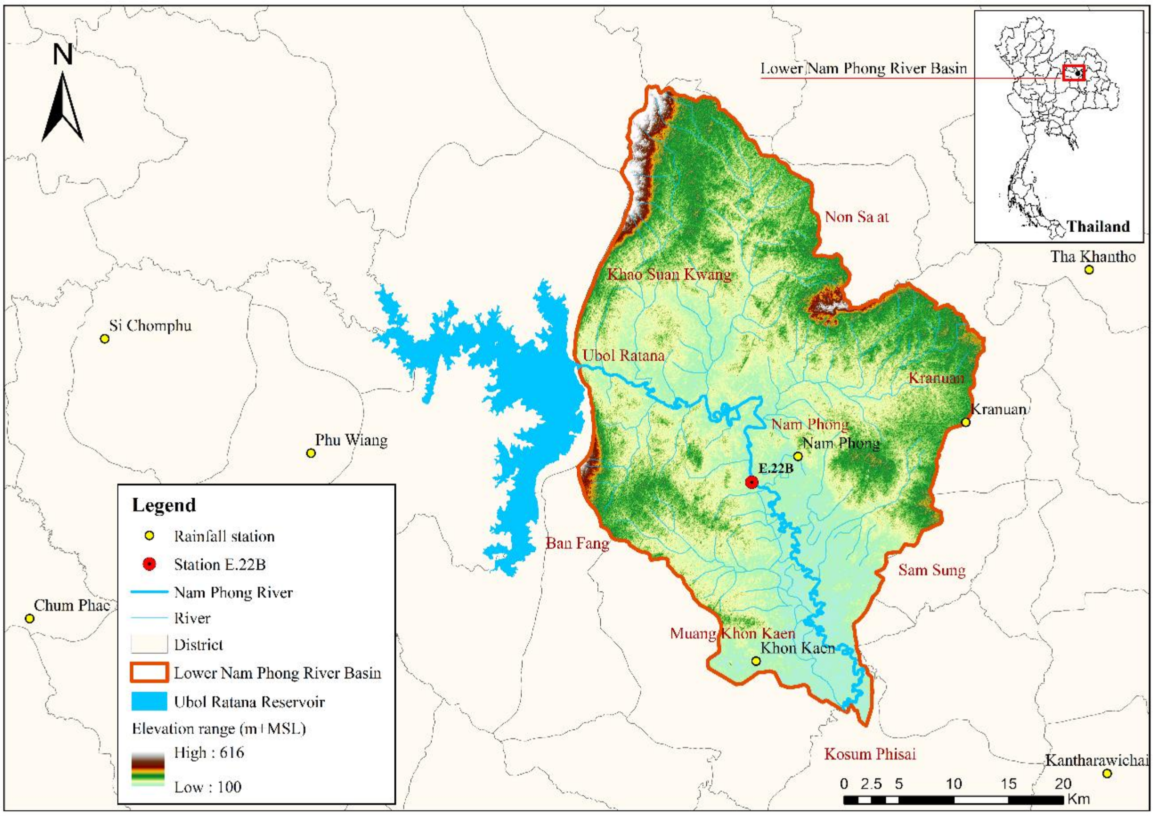

Figure 1. Map of the lower Nam Phong River Basin, Thailand.

2.3 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a single numeric value, which was developed by McKee *et al.* (1993) in order to quantify the meteorological drought caused by a deficit in rainfall across areas with markedly different climates at different timescales. In this study, the SPI index was calculated from the long-term time series of 31 years of rainfall from 1980 to 2010. The long-term rainfall record is fit to a probability distribution, which is subsequently transformed into a normal distribution and is normalized to a flexible multiple timescale. For calculation, the SPI was determined by dividing the difference between the normalized seasonal rainfall and its long-term seasonal mean for a desired timescale by the standard deviation as shown in Equation 1 (McKee *et al.*, 1993).

$$SPI = \frac{(P_{ij} - P_{im})}{\sigma} \quad (1)$$

where SPI is the Standardized Precipitation Index, P_{ij} is the seasonal rainfall at the i^{th} grid and j^{th} observation, P_{im} is long-term seasonal mean, and σ is the standard deviation.

Moreover, the SPI index for drought intensities can be classified as shown in Table 1. In brief, a drought event will occur when the SPI reaches negative values, whereas the event will end when the SPI becomes positive. Despite the fact that the timescale of SPI is flexible, a monthly rainfall time series is practically smoothed with a moving window of width equal to the number of months specified such as a 3-month SPI would use a moving window of 3 months (Zhai & Feng, 2008). This study used the SPIs of 3, 6, and 12 months to assess drought conditions in the lower Nam Phong River Basin. Based on a selection of Edwards and McKee (1997), a 3-month SPI was considered for a short-term drought index, a 12-month SPI was assigned for an intermediate-term drought index, and a 48-month SPI was defined for a long-term drought index. The filtered data can be separated into 12 monthly time series individually and fit with a gamma distribution that could describe skewed hydrologic variables without considering a log transformation (Zhai & Feng, 2008; Chow *et al.*, 1988). Additionally, the Standardized Drought Analysis Toolbox is considered as a common tool in determining the SPI index to the river basin, which was preferred in this assessment.

2.4 Water Evaluation and Planning (WEAP) model

The Water Evaluation and Planning (WEAP) model was developed by the Stockholm Environment Institute (SEI) for water resources planning and allocation issues. It used to estimate the effects of drought in municipal and agricultural systems in order to address a wide range of issues that include water conservation, water demands, water quality, ecosystem, reservoir operation, stream flow simulation, and cost-benefit analyses (SEI, 2001). In this study, two water-use sectors (i.e. agriculture and urban) were modeled for each district in the lower Nam Phong River Basin. Prior to further WEAP model simulations, the calibration process was performed by comparing the simulated and observed discharge at gauging station E.22B. The available daily discharge from 2004 to 2008 was used for calibration, whereas the years from 2009 to 2010 were used for validation (note: the observed discharge at gauging station E.22B was available only from 2004 to 2010). From the modeling perspective, the calibration process involved changing assumptions about the environmental flow requirements, patterns of historical demand, and altering demand priorities to improve the fit between observed and simulated flows (Arranz & McCartney, 2007). Therefore, in order to evaluate the goodness-of-fit of model simulations, the Nash-Sutcliffe coefficient of efficiency (NSE) and the Determination Coefficient (R^2) indices were used as calculated by Equations 2 and 3, respectively.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(X_o - Y_s)^2}{\sum_{i=1}^{n}(X_o - \bar{X})^2} \quad (2)$$

$$R^2 = \left[\frac{\sum_{i=1}^{n}(X_o - \bar{X})(Y_o - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_o - \bar{X})^2 \sum_{i=1}^{n}(Y_o - \bar{Y})^2}}\right]^2 \quad (3)$$

where *Xo* is observed data, $\bar{X}$ is the mean of observed data, *Ys* is the simulated data, $\bar{Y}$ is mean of simulated data, and n is total number of data.

Consequently, the WEAP model was configured and performed during the period of 2001 to 2010 to represent the behavior of the water demand in the river basin and compared with the SPI index.

2.5 GIS technique for drought risk determination

The spatial distribution of the SPI index obtained from the SPI series was made using the Geographic Information System (GIS) interpolation technique called Inverse Distance Weighting (IDW). In principle, the IDW estimates cell values by averaging the values of nearby sample data points (i.e. the closer a point is to the center of the cell being estimated, the more weight is given to it) (Barnali & Venkatesh, 2015). However, the disadvantage of this method is the quality of the interpolation results can decrease when the distribution of sample data points are uneven (Mitas & Mitasova, 1999).

Table 1. Classification of Standardized Precipitation Index (SPI) (McKee *et al.*, 1993).

SPI index	2.00 or more	1.50 to 1.99	1.00 to 1.49	–0.99 to 0.99	–1.00 to –1.49	–1.50 to –1.99	–2.00 or less
Class	Extremely Wet	Very Wet	Moderately Wet	Near Normal	Moderately Dry	Severely Dry	Extremely Dry

Based on the interpolated SPI spatial distribution map, the total drought risk could be determined by combining the drought hazard and its negative consequences. According to the United Nations International Strategy for Disaster Reduction (UNISDR) (2013), the drought risk referred to the potential loss of lives, assets, and ecosystem services in relation to drought, which could occur in a particular area over a specified period in the future. For this study area, the drought risk was determined by overlaying the SPI3 drought index during the period of 1980 to 2010, the water availability (water shortage) obtained from WEAP model, the physical exposure (population who might be affected), and the economic exposure. Based on the UNISDR data published in 2013, the maps of physical and economic exposures of the lower Nam Phong River Basin could be created (Figure 2). For classification, the drought risk areas were categorized into four different zones (less, moderate, high, and extreme) using the Natural Breaks (Jenks) algorithm which is widely used nowadays.

3. Results and Discussion

3.1 Rainfall distribution in the lower Nam Phong River Basin

Based on the historical data, it was revealed that the mean monthly rainfall was very high between August and September (range 200-300 mm), whereas it tended to be very low between November and April (range 10-100 mm). In addition, the mean annual rainfall was also measured and varied from 1,133 mm to 1,616 mm at eight rainfall stations located around and within the lower Nam Phong River Basin: Chum Phae; Si Chomphu; Phu Wiang; Khon Kaen; Nam Phong; Kranuan; Tha Khantho; and Kantharawichai (Figure 3). These results provide an overall picture that drought hazards might occur in the dry season because of the rainfall deficiency.

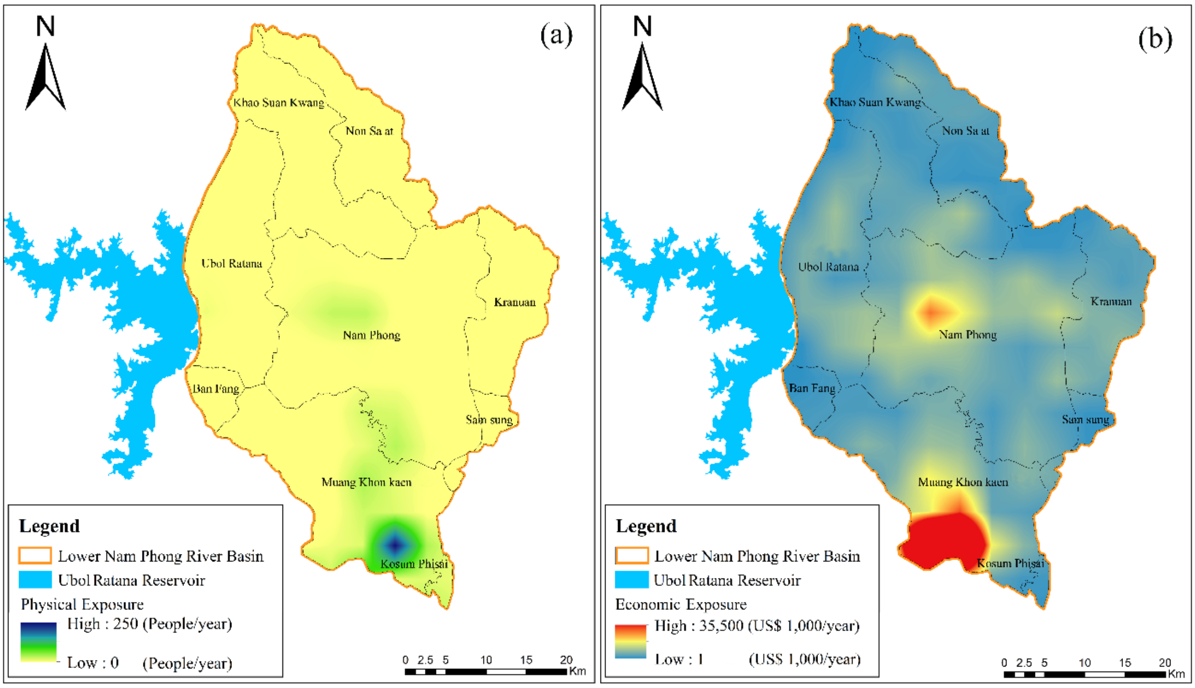

Figure 2. Maps of the (a) physical exposure, and (b) economic exposure of the lower Nam Phong River Basin (UNISDR, 2013).

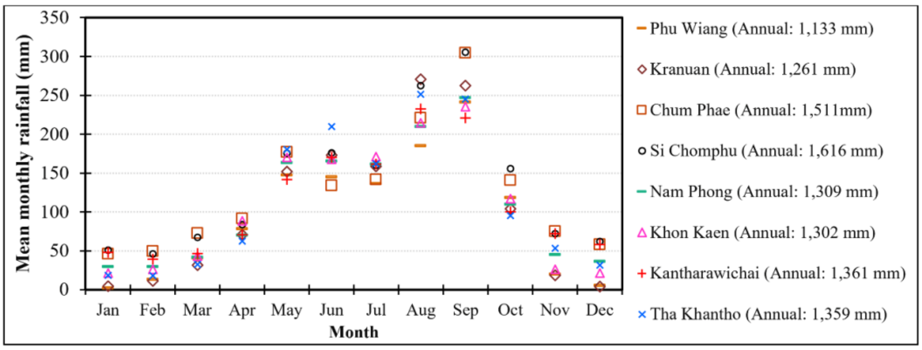

Figure 3. Mean monthly rainfall for 8 selected gauging stations.

3.2 The SPI index for drought assessment

The SPI3, SPI6, and SPI12 indices were able to estimate drought severity for each district. Based on the SPI3 index, it was found that the Si Chomphu and Kantharawichai Districts, which are located outside the study area, are the areas most affected by “extremely dry” compared with the other districts (i.e. the SPI index varied from –3.77 to –1.76). Within the lower Nam Phong River Basin, the drought hazard was found to be at a “moderately dry” level for each district (Table 2). Meanwhile, Figure 4 also illustrates that Kosum Phisai, Nam Phong, and Muang Khon Kaen Districts were rated as “severely dry” level and the SPI3 index varied from -1.50 to -1.82. The SPI3 index provided a range of negative values based on the comparison of the rainfall over a specific 3-month period of that particular year with the total rainfall from the same 3-month period of all historical years. The study also found that the SPI3 index was far more interesting than the longer time scales (SPI6 and SPI12) which showed unreliable results. The results of SPI6 and SPI12 indicated that Si Chomphu and Kanthawawichai Districts could be classified as extremely dry throughout the year with a very low constant SPI index of –6.60, whereas the SPI index for the other districts appeared to be constant with SPI values of 0.00.

Table 2. SPI3 index for drought severity in the lower Nam Phong River Basin.

District	Kosum Phisai	Ban Fang	Sam Sung	Khao Suan Kwang	Kranuan	Muang Khon Kaen	Nam Phong	Ubol Ratana	Non Sa-at
SPI index	–1.60 to –1.20	–1.40 to –1.20	–1.10 to –0.80	–1.20 to –0.90	–0.90 to +0.15	–1.70 to –1.40	–1.82 to –0.35	–1.40 to –1.00	–0.92 to –0.53

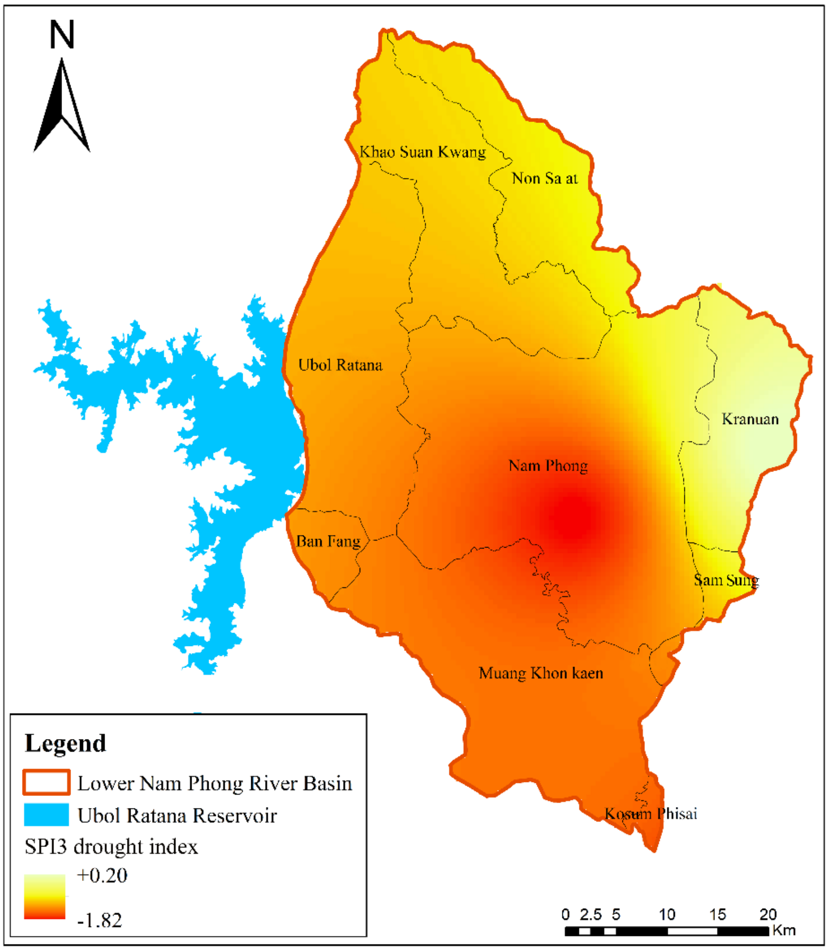

Figure 4. Map of the SPI3 drought index estimated by the Standardized Drought Analysis Toolbox.

3.3 Water scarcity in the lower Nam Phong River Basin

The WEAP model was used to evaluate water demand conditions in the river basin. In this study, the available discharge data from 2004 to 2010 was used to evaluate the WEAP model performance. The results in Figure 5 indicate good agreement between the observed and simulated daily discharge during the calibration and validation processes with the Nash-Sutcliffe coefficient of efficiency (NSE) (0.73) and the Determination Coefficient (R^2) (0.74) for calibration, and NSE=0.76 and R^2=0.83 for validation. Based on the detailed WEAP model simulations, the total amount of water scarcity from 2001 to 2010 is presented in Figure 6(b). It was found that the mean monthly water scarcity for agriculture and urban sectors from February to June varied approximately from 15 million m^3 to 46 million m^3, which means that the drought hazard is likely to increase except during the period of August to December (2 million m^3 to 7 million m^3) (Figure 7). In more detail, Table 3 shows that the water scarcity for the agricultural area (3,595.8 million m^3) was much higher than the urban area (426.7 million m^3), which was very reasonable because the lower Nam Phong River Basin is an agriculture-based area and water is of the utmost importance.

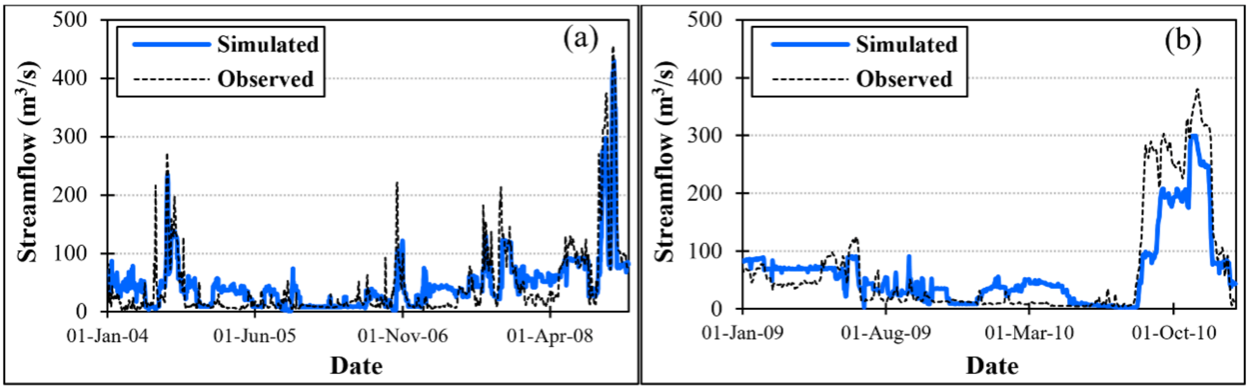

Figure 5. Comparison between the observed and simulated daily discharge (from the WEAP model) during: (a) calibration period (2004 to 2008) and (b) validation period (2009 to 2010).

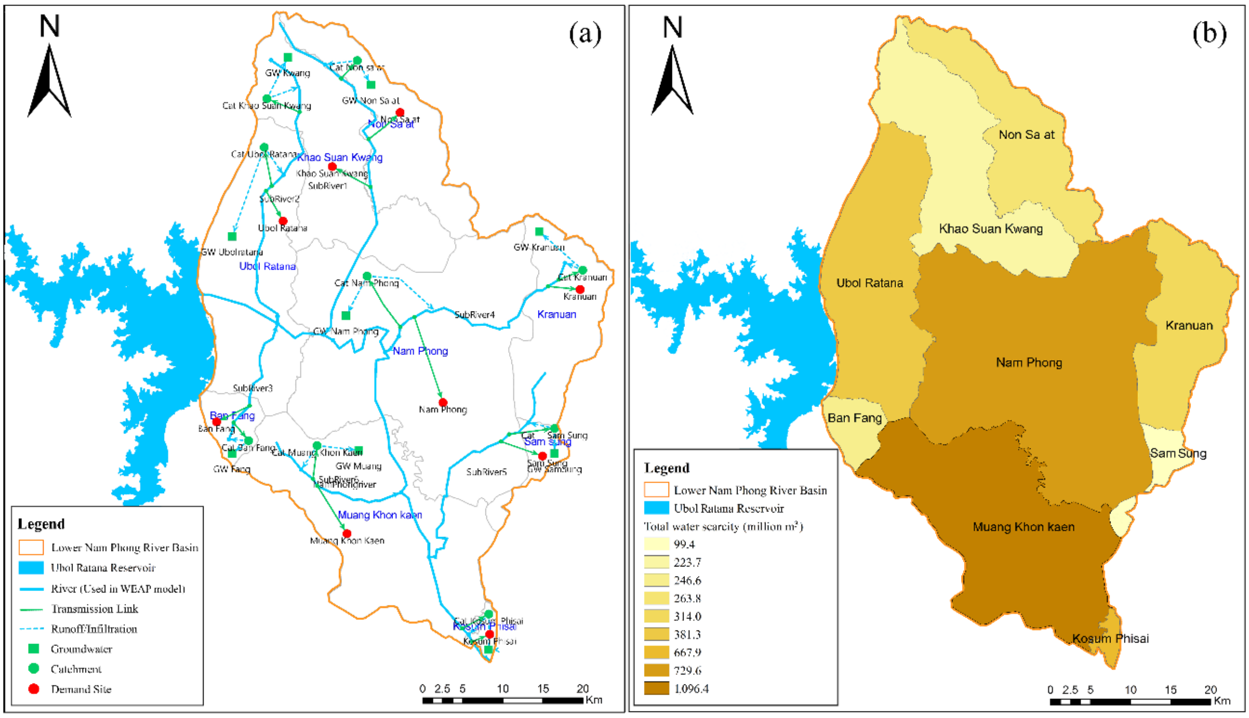

Figure 6. Maps of the (a) schematic diagram of water allocation system and (b) total water scarcity from 2001 to 2010 calculated by the WEAP model.

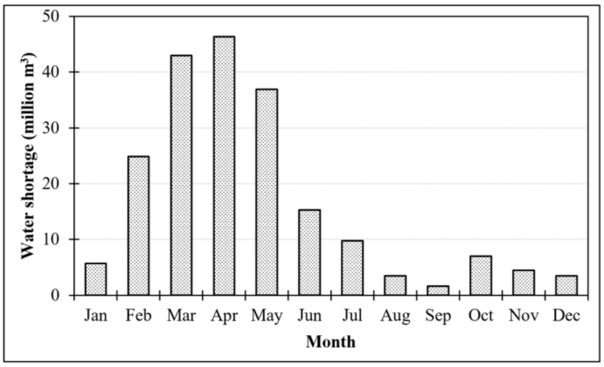

Figure 7. Mean monthly water shortage for both agriculture and urban sectors in the lower Nam Phong River Basin from 2001 to 2010.

Table 3. Water scarcity for agriculture and urban areas based on the results from WEAP model.

District	Agriculture (million m^3)	Urban (million m^3)	Total (million m^3)	(%)
Sam Sung	89.0	10.4	99.4	2.5
Khao Suan Kwang	207.7	16.0	223.7	5.6
Ban Fang	224.7	21.9	246.6	6.1
Non sa-at	242.9	20.8	263.8	6.6
Kranuan	275.3	38.8	314.0	7.8
Ubol Ratana	362.2	19.1	381.3	9.5
Kosum Phisai	645.6	22.3	667.9	16.6
Nam Phong	673.4	56.2	729.6	18.1
Muang Khon Kaen	875.2	221.3	1,096.4	27.3
Total	3,595.8	426.7	4,022.5	100.0

As clearly indicated by the historical rainfall records, a relatively low rainfall amount, which varied from 10 mm to 100 mm, appears to be very low during the dry period between November and April and results in water scarcity for agriculture and urban areas. Up to 27.3% of water scarcity calculated by the WEAP model indicated a high drought risk, especially for some districts in the lower Nam Phong River Basin (i.e. Nam Phong and Muang Khon Kaen) (Table 3). As seen in Figures 4 and 6(b), the results from the WEAP model showed a reliable finding in accordance with the values of the SPI index (from –1.82 to +0.15), which also corresponded to a study by Thavorntam and Mongkolsawat (2008). The results from the SPI3 index and WEAP model clearly identified the extreme drought zone covering the Kosum Phisai, Nam Phong, and Muang Khon Kaen Districts. The moderate drought zone appeared to be within the Khao Suan Kwang, Ban Fang, Non Sa-at, Kranuan, and Ubol Ratana Districts, whereas only Sam Sung District was defined as a low drought zone. In this case, it is likely that the results from this study will be very useful for water resources planning and allocation in the lower Nam Phong River Basin in the future.

3.4 Determination of drought risk area

To achieve a clear and easy understandable presentation on drought hazard in the lower Nam Phong River Basin, a drought risk map was developed (Figure 8). The total four indicators (i.e. SPI3 drought index, water availability, physical exposure, and economic exposure) were then used to determine drought risk conditions. As a result, the drought risk areas were identified for each type of land use and represented as percentages, which were approximately 25% in a less vulnerable area, 27% in a moderate vulnerable area, 22% in a highly vulnerable area, and 26% in an extremely vulnerable area (Table 4). From the main findings, Kosum Phisai, Nam Phong, and Muang Khon Kaen Districts will be seriously affected by drought severity in comparison to the other districts within the river basin (Sinha & Tripathi, 2016; Department of Disaster Prevention and Mitigation, 2016).

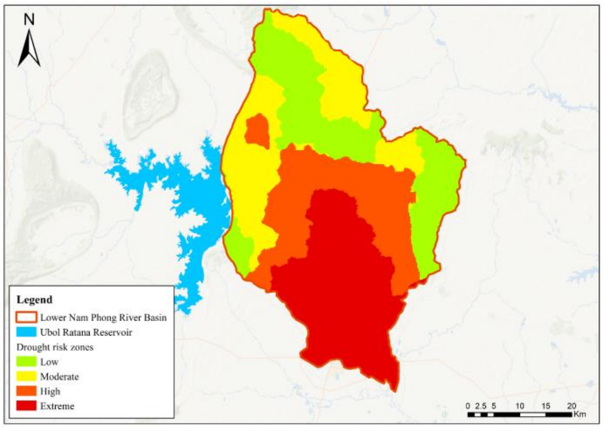

Figure 8. Map of drought risk zones in the lower Nam Phong River Basin.

Table 4. Classification for drought risk for different land use types.

Risk level	AG (km^2)	FO (km^2)	GR (km^2)	OW (km^2)	RU (km^2)	UR (km^2)	OT (km^2)	Total (km^2)	(%)
Less	392.2	113.2	62.3	9.8	16.4	4.4	3.7	602	25
Moderate	419.4	103.5	81.3	11.2	17.2	1.3	3.7	638	27
High	351.5	10.3	107.5	23.3	16.5	1.3	9.2	520	22
Extreme	422.5	6.2	84.3	33	35.5	30.3	14.5	626	26
Total								2,386	100

AG, agriculture; FO, forest; GR, grass and scrub; OW, open water; RU, rural area; UR, urban area; OT, other land uses.

4. Conclusions

Drought severity assessment in the lower Nam Phong River Basin using the SPI index and WEAP model was conducted in this research. The results demonstrated that the SPI3 index varied from –1.82 to +0.15 in the river basin which was described as a "moderately dry" condition of drought. On the other hand, the results of the WEAP model showed that water scarcity in the lower Nam Phong River Basin varied between 99.4 million m^3 to 1,096.4 million m^3during the period of 2001 to 2010. Particularly, Kosum Phisai, Nam Phong, and Muang Khon Kaen Districts were identified as the most vulnerable areas affected by drought. The drought risk areas were determined to be approximately 25% (less vulnerability), 27% (moderate vulnerability), 22% (high vulnerability), and 26% (extreme vulnerability). The findings of this study provide an insightful analysis for the characterization of the agricultural drought risk in the vulnerable areas of northeast Thailand.

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