Characteristics of Meteorological Drought Indices in the Northern of Thailand

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ABSTRACT

Climate variability and climate change cause of drought events. Drought is a significant impact of economic, environment and social. The suitable methods in inspecting and monitoring provide useful information that can be used to build up prevention and mitigation planning from drought impacts. The study purposes were to find out the suitable drought index and its trend for the Northern of Thailand. The 10 stations meteorological data during 1951-2020 were used for the drought indices calculation. The indices were Standardized Precipitation Index (SPI), Deciles index and Moisture Available index (MAI) at 1, 3, 6 month timescales and monthly Palmer Drought Severity Index (PDSI). It found that PDSI was the most appropriate index. Consequently, the Mann-Kendal test was used to investigate the trend of PDSI for long-term (40 years) and short-term (20 years) periods. There was no trend of drought intensity for long-term period but found in 4 stations for short-term period. The PDSI can be used for drought monitoring and prediction by using numerical weather prediction products.

1. INTRODUCTION

Drought is important natural disaster threatening to the human lives and properties. Drought results from levels of precipitation are lower than the average precipitation for the normal 30 year periods [1]. The climate normals are average climatological data for 30 year periods finishing in a year ending with 0 [2].

Drought can be classified as meteorological, agricultural, hydrological and socioeconomic droughts [3]. Drought events are natural occurrences of climate variability. Climate change affects many sectors of Thailand such as economic, environment, agriculture, water resource and tourism [4]-[8]. Increasing in frequency, intensity and duration of drought may be result of climate change [9]. Intergovernmental Panel on Climate Change AR6 [10] stressed high confidence that increases the frequency and intensity of agriculture and ecological droughts in some regions as well as medium confidence of the increases meteorological and hydrological droughts.

A drought index can provide a measure of the drought severity and be used as the basis for specific management measures. Drought indices are used to track droughts and vary depending on season and region [11]. Until now, many kinds of drought indices have been developed, using classical meteorological variables. Some of these indices can be used only in special circumstances; the others can be used for wider area [12].

In Thailand meteorological drought indices such as percent of normal, deciles and Generalized Monsoon Index (GMI) which calculated from rainfall data were used to investigate of drought in each region of Thailand and also river basin [13],[14]. MAI was used to study the minimum rainfall that is suitable for crop water requirement and period of time which soil moisture would be sufficient for crop cultivation in Thailand [15], [16]. Jamphon [17] used SPI in different time scales (3, 6 and 12 months) to investigate the intensity of drought in Thailand. Potisam [18] compared annual and seasonal SPI with drought damage reports for upland crop and paddy field in upper Mun river basin. It found that for paddy field the annual SPI provides better results than seasonal SPI. For upland crop both annual and seasonal SPI can indicate drought with almost the same accuracy. Baimoung et al [19] analyzed the relationship between SPI and the drought effect on vegetation in term of Vegetation Condition Index (VCI) in upper basin of Chao Phraya river. It was found that 60 and 90 days SPI were properly on monitoring and warning meteorological drought impacts than 10 and 30

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days SPI. Then it was preformed drought monitoring and disseminate via Thai Meteorological Department website. Some studies evaluated multiple existing drought indices and proposed index with historical drought records in river basins to consider drought index that was the most accuracy for drought detection [20], [21]. In addition, Pinthong and Kwanyuen [22] developed composite drought index for weekly monitoring drought with consist of PDSI, SPI, MAI, weekly stream flow and Normalized Differences Vegetation Index (NDVI).

The drought phenomenon has often ruined many regions of Thailand, especially the Northern and the Northeastern. The impacts of drought occur in several sector such as agriculture, industry, economic and social, etc. When the severe drought occur in the Northern which is not only affect in the part but also effect to other areas because the rivers in Northern are the sources of water use in the Central part and the capital of the country [23],[24]. Therefore, if the suitable drought index for the Northern is developed, it will be used to monitor or predict drought events and understand the trend of drought. It is useful for drought preparedness and mitigation that would increase well-being and quality of life.

The study purposes were the following: (1) To find out the suitable drought index for the Northern of Thailand by comparing the four commonly used drought indices that have studied and used in Thailand such as SPI, Deciles, MAI and PDSI with historical drought records in the same areas. (2) To investigate the drought trend based on the suitable index for the Northern of Thailand.

2. STUDY AREA AND DATA

Study Area

The Northern of Thailand consists of 15 provinces, namely Chiang Mai, Chiang Rai, Lamphun, Lampang, Mae Hong Son, Phrae, Nan, Phayao, Uttaradit, Sukhothai, Tak, Kamphaeng Phet. Phitsanulok, Phetchabun and Phichit. Geographically, the Northern is characterised by several mountain ranges and the river valleys. The Ping, Wang, Yom, and Nan rivers flow southwards through mountain valleys and unite in the lowlands of the lower-Northern and the upper-central part to form the Chao Phraya river. Most of the Northern part are agricultural area and forestry. Many provinces have developed from agriculture-based economies to businesses, services, and industries, led by Chiang Mai. The climate patterns of the Northern divide into three seasons: rainy, winter and summer. The average annual rainfall is 1230.9 mm. The average maximum and minimum temperatures are 32.9°C and 21.2°C, respectively [25], [26]. Fig. 1 show the site of the meteorological stations in the study area.

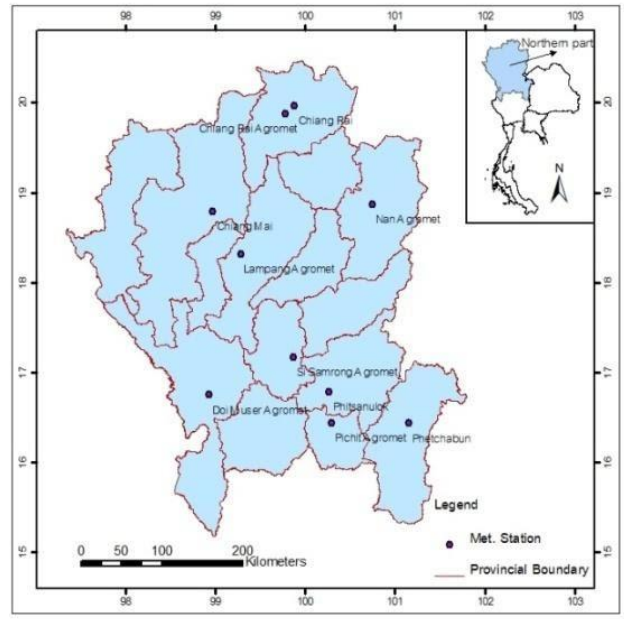


Fig. 1. Site of meteorological stations in the Northern of Thailand.

Data

Meteorological data

The daily rainfall data during 1951-2020 from 10 meteorological stations in Northern of Thailand are used to calculate drought indices that require long historical data. The other meteorological data for daily temperature, wind speed, sunshine hours and relative humidity during 1981-2020 are used to estimate potential evapotranspiration by Penman-Monteith method [27] for MAI and PDSI calculation. All meteorological dataset are derived from the Thai Meteorological Department. The measurement of sunshine hours is not performed in all meteorological stations in Thailand. There are measurements in some observing stations and all agrometeorological station. Therefore, this study used data from 10 meteorological stations that measure sunshine hours in the study area.

Drought affected area

The Department of Disaster Prevention and Mitigation (DDPM) handles disaster management responsibilities and also provides information on disaster prevention and mitigation in Thailand. DDPM reports damages from drought such as affected people and household, agricultural areas, livestock and total damages but does not classify the severity of drought. In the past, DDPM had announced drought affected areas at provincial level before changing to district level in 2011. Therefore, the list of districts and provinces affected by drought during 2011-2016 are used in this study to examine the drought events at the location of the referred stations. The 10 meteorological stations are located in 9 provinces, namely Chiang Mai, Chiang Rai, Lampang, Nan, Sukhothai, Tak, Phitsanulok, Phetchabun, and Phichit. Most of the stations are located in the urban areas of Mueang district in each provinces. Except for Lampang and Sukhothai provinces, the stations are located in Hang Chat and Si Samrong district respectively.

3. METHODOLOGY

Drought indices

Standardized Precipitation Index (SPI)

The SPI was developed by McKee *et al*. [28] as a drought indicator to quantify the precipitation deficit for many time scales. Different time scales may reflect lags in water resources to precipitation anomalies. The calculation of SPI requires precipitation record in long-term for a desired time scale. The record is fitted to probability distribution and transformed to a normal distribution so that the mean SPI is zero. Labedzki [29] found that the SPI at 1-3 month time scale is better than 6 month time scale in reflection of agricultural drought development. It corresponds to the results by Bussay *et al*.[30].

Deciles Index

The deciles index was developed by Gibbs and Maher [31]. The long-term precipitation distribution is divided into tenths distribution, each 10 categories called a decile. The first decile is the amount not exceeded by the lowest 10% of the record. The second decile is between the lowest 10% and 20%. These deciles are computed continuously until the tenth decile, the largest amount in the record. The deciles index was used in the Australian Drought Watch System [32].

Moisture Available index (MAI)

The MAI was proposed by Hargreaves [33]. The MAI is a ratio of 75% probability precipitation to potential evapotranspiration. In drought application, the observed precipitation is used instead. Dry month is consider by the MAI less than 1.0. The severity of drought is inferred from the length of dry month.

Palmer Drought Severity Index (PDSI)

The PDSI was developed by Palmer [34] to measure the moisture supply departure and defined the moisture condition between locations and between months were standardized as index for any comparisons. The PDSI is based on the analysis of the elements of surface water balance and on the comparison of their actual value to their climatical potential values. The PDSI calculation was considered with monthly precipitation, evapotranspiration and soil moisture conditions. The PDSI has been vastly used for various applications in the United States [35].

Drought index comparison.

Most droughts in Thailand occur during dry period from winter to summer seasons. Therefore, the historical records of agricultural drought affected areas from the DDPM between January and May from 2011 to 2016 were used to find out the drought events for each month in the districts which 10 meteorological stations are located. The drought records of 5 months per year within 6 years for 10 meteorological stations were represented as a total of 300 drought events. For all total events, there were 121 events that DDPM reported as drought and there were no drought report in 179 events.

The SPI, Deciles and MAI were calculated for each month at multiple timescales (i.e., 1, 3 and 6 months). SPI and deciles evaluate precipitation conditions relate to water supply on specific time periods. Also, MAI evaluates soil moisture conditions for a specific time. These timescales reflect of drought impacts on different water resources availability. For PDSI was calculated only monthly because PDSI evaluates soil moisture condition by water balance accumulation from the past to the considered month.

The drought indices such as SPI, Deciles, MAI and PDSI were compared with historical records of drought which are not identified for severity classification. Therefore, the many level severity classification on drought and wetness of the indices were reclassified by gathering into a group of Drought, Near Normal and Wet. Table 1 show the classification of These indices.

Table 1. Classification of SPI, Deciles, MAI and PDSI

Index	Drought	Near Normal	Wet
SPI	≤ -1	-0.99 to 0.99	≥ 1
Deciles	1 to 4	5 to 6	7 to 10
MAI	≤ 1	1.01 to 1.33	≥ 1.33
PDSI	≤ -1	-0.99 to 0.99	≥ 1

The frequency distributions were constructed from drought indices values between January and May during 2011- 2016. The indices values were classed together with the corresponding classes of Drought, Near Normal and Wet. Then, they were counted into each drought and no drought events.

Mann-Kendall Trend Test (MK)

The Mann-Kendall Trend test was first proposed by Mann [36] and further studied by Kendall [37]. The MK is used to detect the trend of variability over the time. It is a non-parametric test that works for all distributions. The MK is commonly used because it is not affected by deficit and erroneous measurement of a data series. The MK test checks the alternative hypothesis of increasing or decreasing trend and the null hypothesis of no trend. For the data series, $X = \{x_1, x_2, ..., x_n\}$, when $n > 10$. The test statistic Z is calculate as follow:

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sqrt{Var(s)}} & if\ s < 0 \end{cases} \quad (1)$$

where

$$Var(s) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k-1)(2t_k+5)] \quad (2)$$

$$s = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (3)$$

$$sgn(x_j - x_i) = \begin{cases} 1 & if\ x_j - x_i > 0 \\ 0 & if\ x_j - x_i = 0 \\ -1 & if\ x_j - x_i < 0 \end{cases} \quad (4)$$

where, *Var(s)* is variance of the statistic *S*, *m* is the number of tied group, t_k is the number of data points in the *k*th tied group. For the statistic *Z*, the value $Z > 0$ means the data series has an increasing trend, while $Z < 0$ means it has a decreasing trend.

The MK test was used to investigate trend of the suitable drought index for the study area. The null hypothesis was tested at confidence level of 95%. The trend investigation were performed in long-term and short-term. The time scale of short-term is shorter than a standard climatic averaging period (30 years) and time scale of long-term is longer than a standard climatic averaging period. Variability in short-term and long-term are usually referred to as climate variability and climate change respectively [38].

4. RESULTS AND DISCUSSIONS

Comparison of drought Indices

SPI, Deciles and MAI were calculated for 1, 3, 6 months timescales (SPI 1m, SPI 2m, SPI 3m, Deciles1m, Deciles2m, Deciles3m, MAI1m, MAI2m, MAI3m). PDSI were calculated for a monthly period. These values from a suitable index would be corresponding to the historical drought records. The 121 historical drought events derived from considering each month at the location of 10 meteorological stations in 6 years between January and May. The events of Drought, Near Normal and Wet estimated via indices were counted for the historical drought events (Table 2). The results indicated that SPI 1m, SPI 2m, SPI 3m, Deciles1m, Deciles 2m, Deciles 3m were not related to the historical records in which the most of estimated values of these indices were in categories of Near Normal and Wet. In conversely, the MAI1m, MAI2m, MAI3m and PDSI were consistent with the historical records which these estimated values of MAI at 1, 3, 6 months timescales and PDSI were in categories of Drought more than Near Normal and Wet.

Likewise, these suitable indices could estimate the values which were corresponding to no drought event in history as well. Therefore, the investigation of the indices for historical no drought events were performed with the same techniques as drought events. Subsequently, the comparison of the drought indices in 179 historical no drought events were shown in Table 3. The results indicated that most of the estimated values of SPI1m, SPI2m, SPI3m, Deciles1m, Deciles2m and Deciles3m were in categories of Near Normal and Wet which were corresponding to historical no drought records. Conversely, most of the estimated values of MAI1m, MAI2m and MAI3m were in the category of Drought and not related to the historical records. For PDSI, the estimated values were almost equally in categories of Drought and No Drought (Near Normal and Wet).

Table 2. Drought indices comparison between January and May during 2011- 2016 in drought record events

Index	Drought (event)	Near Normal (event)	Wet (event)
SPI1m	17	75	29
SPI3m	17	73	31
SPI6m	14	74	33
Deciles1m	40	21	60
Deciles3m	39	23	59
Deciles6m	45	18	58
MAI1m	94	7	20
MAI3m	109	5	7
MAI6m	109	10	2
PDSI	75	44	2

Table 3. Drought indices comparison between January and May during 2011- 2016 in no drought record events

Index	Drought (event)	Near Normal (event)	Wet (event)
SPI1m	19	119	41
SPI3m	22	110	47
SPI6m	15	127	37
Deciles1m	55	38	86
Deciles3m	41	36	102
Deciles6m	52	49	78
MAI1m	162	7	10
MAI3m	176	1	2
MAI6m	131	22	26
PDSI	90	81	8

From the comparison of all 10 drought indices in historical drought and no drought record periods, it was found that SPI and Deciles have been generally given with estimated values in the No Drought category in both events. Whereas, MAI and PDSI have been generally given with estimated values in the Drought category in drought events. These results might be caused by SPI and Deciles which were based only on precipitation parameters that were input of water balance, but the factors of output were also important and resulted in water deficiency. Lastly, after the comparison to no drought period, it was found that PDSI was more suitable for the Northern than other used indices. Subsequently, it could be concluded that PDSI corresponded to agricultural droughts in the study area. The results agree with Baimoung et al. [39] who assessed PDSI in dry seasons during 1992-2000 in 19 agrometeorological stations of Thailand then summarized that these were corrected with agricultural droughts (described by NDVI).

Trends of PDSI

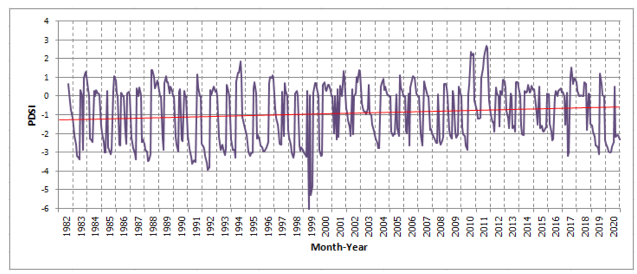
The changes in long-term and short-term monthly PDSI estimated values of 10 meteorological stations in the study area were analyzed by using the Mann-Kendall trend test. The long-term and short-term periods were during 1981-2020 (40 years) and 2001-2020 (20 years) respectively. Most stations have data records more than 30 years, except Phichit and Doi Muser agrometeorological stations that were established since 1992 and 1994 respectively. The result was shown in Table 4.

Table 4. Mann-Kendall trend test result of long-term and short term of PDSI

Meteorological station	MK value (Z)	
	1981-2020	2001-2020
Chiang Rai	-0.74	-1.25
Chiang Rai Agromet	-0.19	-2.18*
Chiang Mai	1.79	-0.11
Lampang Agromet	2.72*	-1.29
Nan Agromet	-2.58*	-5.19*
Si Samrong Agromet	-0.2	-0.35
Doi Muser Agromet**	0.61	0.63
Phitsanulok	-0.59	-2.16*
Phetchabun	-0.04	-0.98
Phichit Agromet **	-3.13*	-4.54*

*Statistically significant at 0.05 significant level
**Data period at Doi Muser and Phichit Agromet are 27 and 29 years respectively

According to long-term MK results, there was a statistically significant non-trend in most stations. An increasing trend has occurred in Lampang agrometeorological station. The drought severity was decreasing, as there were PDSI values in a tendency toward the less negative values. On the contrary, a decreasing trend has occurred in Nan agrometeorological station. The drought severity was increasing, as there were PDSI values in a tendency toward the more negative values. Graphs of PDSI value based on monthly series in long-term periods (purple) and the trend line (red) for Lampang and Nan agrometeorological station were shown in Fig.2. From 40 years long-term PDSI analysis of 8 stations, it found the trend in 1 station was increasing and 1 station was decreasing. The detected trend may be because of the local effects of geographic circumstance in term of mountainous areas with orchard coverage in each station.



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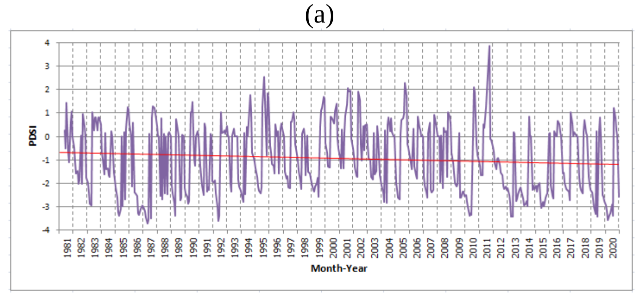


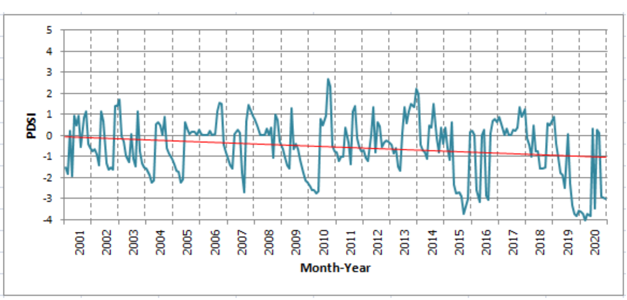
(b)

Fig. 2. The PDSI values of Lampang (a) and Nan (b) agrometeorological stations base on monthly series during 1981-2020.

For The short-term MK results, there were statistically significant of non-trend in 6 stations. A decreasing trend has occurred in Chiang Rai, Nan and Phichit agrometeorological stations as well as Phitsanulok meteorological station. Graphs of PDSI value of all 4 stations based on monthly series in short-term periods (blue) and the trend line (red) were shown in Fig. 3. The comparison of short-term and long-term PDSI analysis of 8 stations which have completed 20 and 40 years data (except Doi Muser and Phichit agrometeorogical stations), it found that the short-term MK values of all stations were negative values and less than long-term MK values. From short-term PDSI analysis of 10 stations, there were statistically significant decreasing trend in 4 stations which was more than long-term PDSI analysis. The recently decadal increasing in drought severity might be resulted from the climate change and the environment change conditions of those meteorological stations surrounding that change from agricultural areas in the past to urban areas in currently existing.

5. CONCLUSIONS

The Northern of Thailand was affected by drought almost every year. Monitoring of drought event is useful for drought preparedness and prevention. The selection of drought index that corresponds the real event for drought monitoring is important. Comparison of SPI, Deciles and MAI at 1, 3 and 6 month timescales and PDSI with historical drought records were examined in case of drought and no drought events between January and May during 2011- 2016. For drought event, most value of SPI and Deciles at 1, 3 and 6 month timescales were in category of No Drought (Near Normal and Wet). Most value of MAI at 1, 3 and 6 month timescales and PDSI were in category of Drought. For no drought event, most value of MAI at 1, 3 and 6 month timescales were in category of Drought. But the value of PDSI were almost equally in categories of Drought and No Drought. Therefore, the PDSI was more suitable for evaluating agricultural drought than the other used indices. The result may be caused of PDSI is based on local water balance that continuous accumulated from the past. The PDSI considers the influences of precipitation, evapotranspiration and soil moisture condition which also result in water deficiency



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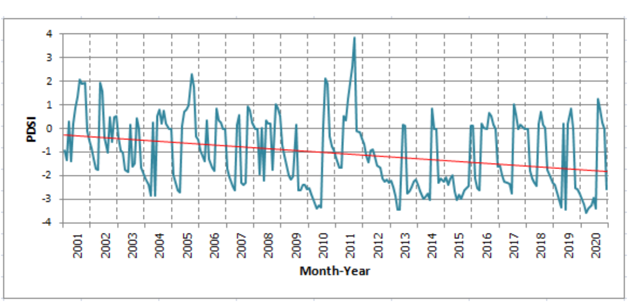

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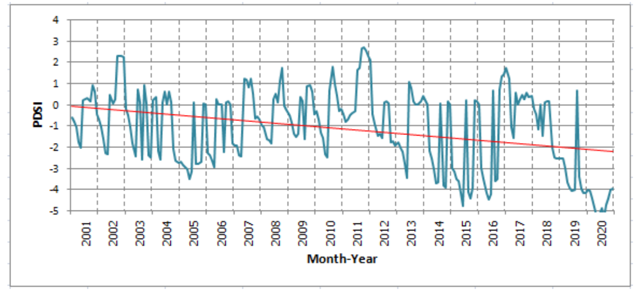

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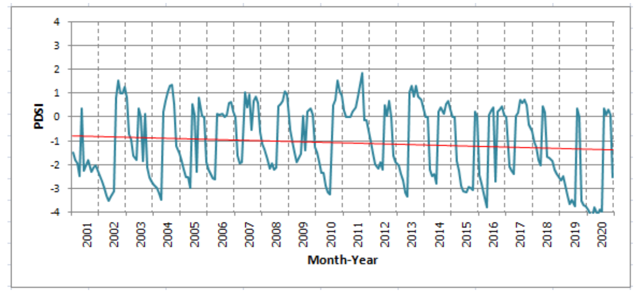

(d)

Fig. 3. The PDSI values of Chiang Rai (a), Nan (b) and Phichit (c) agrometeorological stations as well as Phitsanulok (d) meteorological station base on monthly series during 2001-2020.

The investigation of long-term PDSI changes in 10 meteorological stations by using MK showed that there was no significant trend in most stations. Only 1 station was an increasing trend and 1 station was a decreasing trend. It might be concluded that the intensity of drought in the Northern had no trend in the long-term climate records. The short-term PDSI change showed that there was the variability of drought with increasing trend of drought intensity in Chiang Rai, Nan and Phichit agrometeorological stations as well as Phitsanulok meteorological station.

Consequently, the PDSI could be used as a measure for detecting and monitoring drought in the Northern of Thailand and also applying for drought prediction with the numerical weather prediction products in the future. In addition, these results can be used for supporting decision makers and related organizations in natural disaster managements. For instance, whenever PDSI values show the onset of drought in early dry season and the weather outlook is predicted continuously less rainfall, the results will be persisted of drought. Moreover, these information is useful for early warning system of related institutions in drought preparedness to reduce the impacts of drought damages. And for all agriculturist or farmer may be used these information for selecting the suitable crops that use less water and can manage the available water usage throughout the crop growing period. Lastly, the related departments with water resources management such as the Royal Irrigation Department can use the information for the efficiency water management in order to have sufficient water for consumption, agriculture, environment preservation, industrial activities, etc. during drought periods.

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