NUEJ
Naresuan University
Engineering Journal

Drought Analysis in the Eastern Economic Corridor by using the Standardized Precipitation Index (SPI)

Polpech Samanmit, Jutithep Vongphet* and Bancha Kwanyuen

Department of Irrigation Engineering, Faculty of Engineering at Kamphaeng saen, Kasetsart University, Nakhon Pathom, Thailand

* Corresponding author e-mail: fengjtv@ku.ac.th

(Received: 26 July 2022, Revised: 27 October 2022, Accepted: 03 November 2022)

Abstract

This research aimed to analyze the severity level of drought by using the Standardized Precipitation Index (SPI) in the Eastern Economic Corridor (EEC). The six meteorological stations, Bangkok Metropolis, Chanthaburi, Chonburi/Sattahip, Koh Sichang, Pattaya, and Khao Ito, over 30 years data from 1988 to 2017, were used in this research. The three patterns of moving cumulative rainfall of 3, 6, and 12 months were used to estimate the indices of SPI3, SPI6, and SPI12, respectively. As a result, the averaged values of 3 patterns of SPI ranged from 0.035 to 0.180, which was interpreted as a level of near normal. The maximum and minimum values of the SPI could experience drought conditions in both severe to extreme drought and wet. However, the results demonstrated that more than 62 % of the SPI ranged near normal. The value of SPIs approximated moderate to extreme droughts below 17 %. The results of this research could be a part of the information to support water management in the study area to develop a suitable plan to mitigate the effect of drought in the future.

Keywords: Drought, Eastern Economic Corridor, Rainfall, Standardized Precipitation Index.

1. INTRODUCTION

Drought was a natural disaster in Thailand that hugely impacted and damaged various sectors. During the past 20 – 30 years (1989 – 2013), many provinces suffered in drought throughout the country (Wichitarapongsakun et al.,2016). The drought process affected water shortage in many activities, such as water supply, agriculture, and industry, for a long time (Damberg and AghaKouchak, 2014). Drought could be divided into four categories: meteorological, hydrological, agricultural, and socioeconomic droughts; each drought was related to and affected each other (Wilhite and Glantz, 1985). Thailand was prone to droughts in two periods: (1) winter to summer in the second half of October onwards in a drought manner and (2) in the middle of the rainy season (late June to July) in a precipitation deficit (Hydro-Informatics Institute, 2012, Thai Meteorological Department, 2016). The drought resulted from the northeast and southwest seasonal monsoons. In addition, the Enzo phenomenon caused climate variability in precipitation deficit that affected water supply problems (Thanapakpawin et al., 2011). The severity level of drought can be assessed from several drought indices, which were widely used in foreign countries and Thailand, such as Effective Drought Index (EDI), Generalized Monsoon Index (GMI), Standardized Precipitation Index (SPI), Normalized Difference Vegetation Index (NDVI), Palmer Drought Severity Index (PDSI), Etc. (Thai Meteorological Department, 2012, Pinthong and Kwanyuen, 2016, Adisa et al., 2021). The Standardized Precipitation Index (SPI) was one of the most widespread drought indices used to analyze the severity level of drought abroad, such as the analysis of drought levels in South Africa with SPI and EDI indices (Adisa et al., 2021), comparison of drought indices between SPI and SPEI in Mongolia china (Pei et al., 2020), analysis of future drought indices in RCP8.5 cases with SPI and EDI in the Langat basin, Malaysia (Huang et al., 2016), Etc. Including the analysis of drought indices in Thailand, such as the analysis of drought levels with the SPI in the Sakae Krang river basin (Wichitarapongsakun et al., 2016,Wichitarapongsakun et al.,2017), the lower Mae Klong river basin (Madusanka and Venkataramana, 2017), the Huai Ko Kaeo sub-basin of the Pasak river basin (Wichitarapongsakun, 2015), Ping River Basin (Chaito and Khamkong, 2020), 15 areas of the north (Kaingam and Chotamonsak, 2019), comparison of SPI, SPEI and SPAEI analysis results in the Chi river basin (Homdee et al., 2016), Etc. The SPI could be analyzed over several periods from 1 to 72 months. The meaning of SPI3 and SPI6 are used for the analysis of drought that occurs during the crop season, and SPI12 is used for the study of change in drought during the year (Mckee et al., 1993, Thai Meteorological Department, 2012, Sriwongsitanon, 2015).

The Eastern Economic Corridor (EEC) is an essential area for the economic development of Thailand. This study aims to support water resource management between surface water and groundwater (Conjunctive use) integrated into the water management system. To be suitable for water supply and demand according to the drought conditions in the study area That is established to enable Thailand to develop economically into a high-income country and the developed countries according to the 20-year National Strategic by focusing on enhancing the competitiveness of the manufacturing and service sectors in the industrial sector and increasing the capacity of reservoirs and allocating water to support the increasing trend of water demand (The Eastern Economic Corridor Office of Thailand, 2018).

The research objective was to analyze the severity level of drought using the Standardized Precipitation Index (SPI) based on six meteorological stations covering the area of the Eastern Economic Corridor in 3 patterns, including SPI3, SPI6, and SPI12. The purpose of this research was to study the nature, severity, and frequency of droughts in Thailand in the study area for 30 years (1988 – 2017), which will be one of the components of information supporting water management such as rainfall, runoff, water demand, water balance, Etc.

2. DATA AND METHOD

2.1 Study Area

Eastern Economic Corridor (EEC) is located in eastern Thailand, which is established to enable Thailand to develop economically into a high-income country and the developed countries according to the 20-year National Strategic by focusing on enhancing the competitiveness of the manufacturing and service sectors in the industrial sector and increasing the capacity of reservoirs and allocating water to support the increasing trend of water demand (The Eastern Economic Corridor Office of Thailand, 2018). The EEC had an area of approximately 13,266 sq. km and covered three provinces: Chachoengsao, Chonburi, and Rayong. (Figure 1)

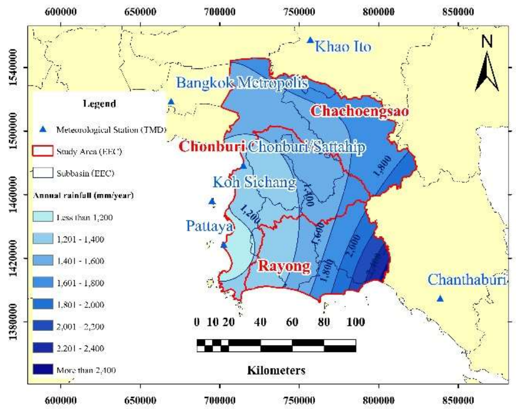


Figure 1 Study area and Average annual rainfall

2.2 Rainfall data

Observed rainfall data in this research were collected from six meteorological stations of the Thailand Meteorological Department (TMD). That was the neighborhood of the three provinces in the area of the EEC to cover the context of the drought situation covering the study area, consisting of Bangkok Metropolis, Chanthaburi, Chonburi/Sattahip, Koh Sichang, Pattaya, and Khao Ito (Table 1 and Figure 1), during the years 1998 – 2017 (30 years). The Double-mass curve method was used to verify the consistency of cumulative annual rainfall at six stations (Wichitarapongsakun et al., 2016, Taesombat, 2012).

The average annual rainfall of the six meteorological stations ranged between 1,110.17 – 2,959.62 mm/year. The maximum value was 4,028.06 mm/year in 2006 at the Chanthaburi station. The minimum value was 708.23 mm/year in 1993 at the station of Pattaya.

2.3 Standardized Precipitation Index (SPI)

The standardized Precipitation Index (SPI) was developed to analyze the severity level of drought based on cumulative rainfall for interest (Mckee et al., 1993). The SPI could be studied over several periods from 1 month to 72 months, allowing water supply estimates from short to long periods. The SPI period was selected with sufficient rainfall to affect the five types of water resources: soil moisture, Groundwater level, stream, reservoir storage, and snow. A short period of 3 and 6 months was recommended for the growing season, and a more extended period of 12 and 24 months for the changing of drought during the year.

Generally, precipitation had a Gamma Distribution function (Mckee et al., 1993). However, since the determination of the SPI requires cumulative rainfall, it was determined using the Cumulative probability Density Function (CDF), then transformed to a standard normal (Z) with a mean of 0 and variance of 1. The SPI can analyze the severity level of drought or humidity of rainfall in each area. For equations (1) to (6) show in this paper and more detail, refer to reference reports and research articles (Thai Meteorological Department, 2012, Sriwongsitanon, 2015).

The cumulative probability Density Function (CDF) is Shown as Equation **(**1).

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1}e^{-t}dt \tag{1}$$

In a month where no rain was reported When x = 0, the cumulative density function must be converted to Equation (2).

$$H(x) = q + (1-q)G(x) \tag{2}$$

Where q is the number of non-rainy days (m) divided by the number of days studied (n), and G(x) is the Cumulative probability Density Function (CDF).

The SPI index can be calculated from Equation **(3)** and Equation (4) as follows:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{3}$$

Where $0 < H(X) \leq 0.5$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \tag{4}$$

Where $0.5 > H(X) < 1$

where (t) can be obtained from Equation **(5)** and Equation (6).

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \tag{5}$$

Where $0 < H(X) \leq 0.5$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \tag{6}$$

Where $0.5 > H(X) < 1$

Where $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$

Table 1 Meteorological stations data and Average annual rainfall for 30 years (1988 – 2017)

Stations ID	Stations name	Latitude	Longitude	Mean	Maximum	Minimum
484550	Bangkok Metro.	13.73333	100.56667	1,730.50	2,783.18	985.77
484800	Chanthaburi	12.60000	102.11667	2,959.62	4,028.06	1,509.01
484590	Chonburi/Sattahip	13.36667	100.98333	1,367.00	2,110.24	836.17
484600	Koh Sichang	13.16667	100.80000	1,162.46	1,682.17	865.28
484610	Pattaya	12.91667	100.86667	1,110.17	1,655.96	708.23
484300	Khao Ito	14.07776	101.37988	1,735.55	2,581.20	1,189.48

The percentage of drought occurrences of SPI equations (3) and (4) can be classified as the drought classification level criterion, as shown in Table 2.

Table 2 Drought classification according to the SPI

Category	SPI
Extreme drought	< -2.00
Severe drought	-1.50 to -1.99
Moderate drought	-1.00 to -1.49
Near normal	-0.99 to 0.99
Moderate wet	1.00 to 1.49
Severe wet	1.50 to 1.99
Extreme wet	> 2.00

Source: Mckee et al. (1993)

This research analyzed the SPI with 3 patterns based on the cumulative monthly rainfall of 3, 6, and 12 months to be SPI3, SPI6, and SPI12, respectively, with 6 meteorological stations from the years 1988 to 2017 (30 years).

3. RESULTS AND DISCUSSION

Drought analysis of SPI with three different periods was illustrated by Table 3 The mean SPI values of all meteorological stations ranged from 0.035 to 0.180, interpreted as near normal. At the same time, the maximum and minimum values ranged from 1.920 to 3.127 and -4.182 to -1.529, indicated as severe to extreme wet and drought, respectively. For example, the maximum values of SPI3 were 2.916 at Koh Sichang, and SPI6 and SPI12 were 2.648 and 3.127, respectively, at the station of Chanthaburi. The minimum values of SPI3, SPI6 and SPI12 were -3.744, -4.182 and -2.613 at the stations of Khao Ito, Bangkok Metropolis and Pattaya, respectively.

Table 4 to Table 6 demonstrated the possibility of drought severity in the percentage of the whole simulation time, and Figure 2 to Figure 4 showed drought incidence in terms of both wet (> 0.99) and drought (< -0.99) over 30 years (1988 – 2017), with a nonspecific pattern. The SPI3 significantly indicated the possibility of drought to near normal as the percentage of 68.99 – 71.51 (%) at all meteorological stations. In contrast, moderate, severe and extreme droughts ranged from 5.31 – 11.17 (%), 3.07 – 4.19 (%), 0.84 – 3.35 (%), respectively. As same as, SPI 6 also interpreted the possibility of drought to near normal with the percentage 67.89 -72.39 (%), while moderate, severe and extreme droughts ranged from 4.51 - 10.99 (%), 2.25 – 4.79 (%), 0.56 - 3.10 (%), respectively. Finally, the SPI12 also interpreted almost

Table 3 Classification of SPI by meteorological stations

Stations	SPI3			SPI6			SPI12		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Bangkok Metropolis	0.058	2.137	-3.528	0.068	2.279	-4.182	0.081	2.014	-2.011
Chanthaburi	0.035	2.637	-2.778	0.070	2.648	-2.300	0.067	3.127	-1.553
Chonburi/Sattahip	0.067	2.385	-2.661	0.081	1.920	-2.676	0.090	2.058	-2.026
Koh Sichang	0.091	2.916	-3.449	0.130	2.621	-2.543	0.180	2.211	-1.529
Pattaya	0.065	2.419	-3.074	0.085	2.408	-2.976	0.121	1.963	-2.611
Khao ITo	0.059	2.559	-3.744	0.079	2.291	-2.030	0.089	2.215	-2.163

Table 4 Percentage of SPI3 by meteorological stations

Category	Bangkok Metropolis	Chanthaburi	Chonburi/Sattahip	Koh Sichang	Pattaya	Khao ITo
Extreme drought	2.79	1.40	1.68	0.84	3.35	1.12
Severe drought	3.07	3.91	3.91	3.91	4.19	4.19
Moderate drought	7.26	5.31	8.10	9.50	5.31	11.17
Near normal	68.99	71.51	69.83	69.27	69.55	69.27
Moderate wet	12.01	11.17	9.22	7.26	13.13	7.26
Severe wet	4.75	4.47	6.15	7.26	2.79	5.87
Extreme wet	1.12	2.23	1.12	1.96	1.68	1.12

Table 5 Percentage of SPI6 by meteorological stations

Category	Bangkok Metropolis	Chanthaburi	Chonburi/Sattahip	Koh Sichang	Pattaya	Khao ITo
Extreme drought	1.69	0.56	1.41	0.56	3.10	0.56
Severe drought	4.79	3.66	3.38	2.25	4.51	2.54
Moderate drought	6.20	7.89	9.01	9.58	4.51	10.99
Near normal	72.39	70.42	70.14	67.89	71.27	72.11
Moderate wet	9.30	8.45	9.58	10.70	11.83	6.48
Severe wet	5.07	4.79	6.48	5.07	3.94	6.48
Extreme wet	0.56	4.23	0.00	3.94	0.85	0.85

Table 6 Percentage of SPI12 by meteorological stations

Category	Bangkok Metropolis	Chanthaburi	Chonburi/Sattahip	Koh Sichang	Pattaya	Khao ITo
Extreme drought	0.29	0.00	0.29	0.00	1.43	0.29
Severe drought	6.02	0.29	4.01	0.29	5.44	3.15
Moderate drought	6.02	10.60	9.74	7.74	5.44	7.74
Near normal	71.63	73.64	69.63	70.77	73.07	77.36
Moderate wet	8.60	8.88	11.46	9.46	12.61	5.44
Severe wet	7.16	2.58	4.01	7.16	2.01	4.58
Extreme wet	0.29	4.01	0.86	4.58	0.00	1.43

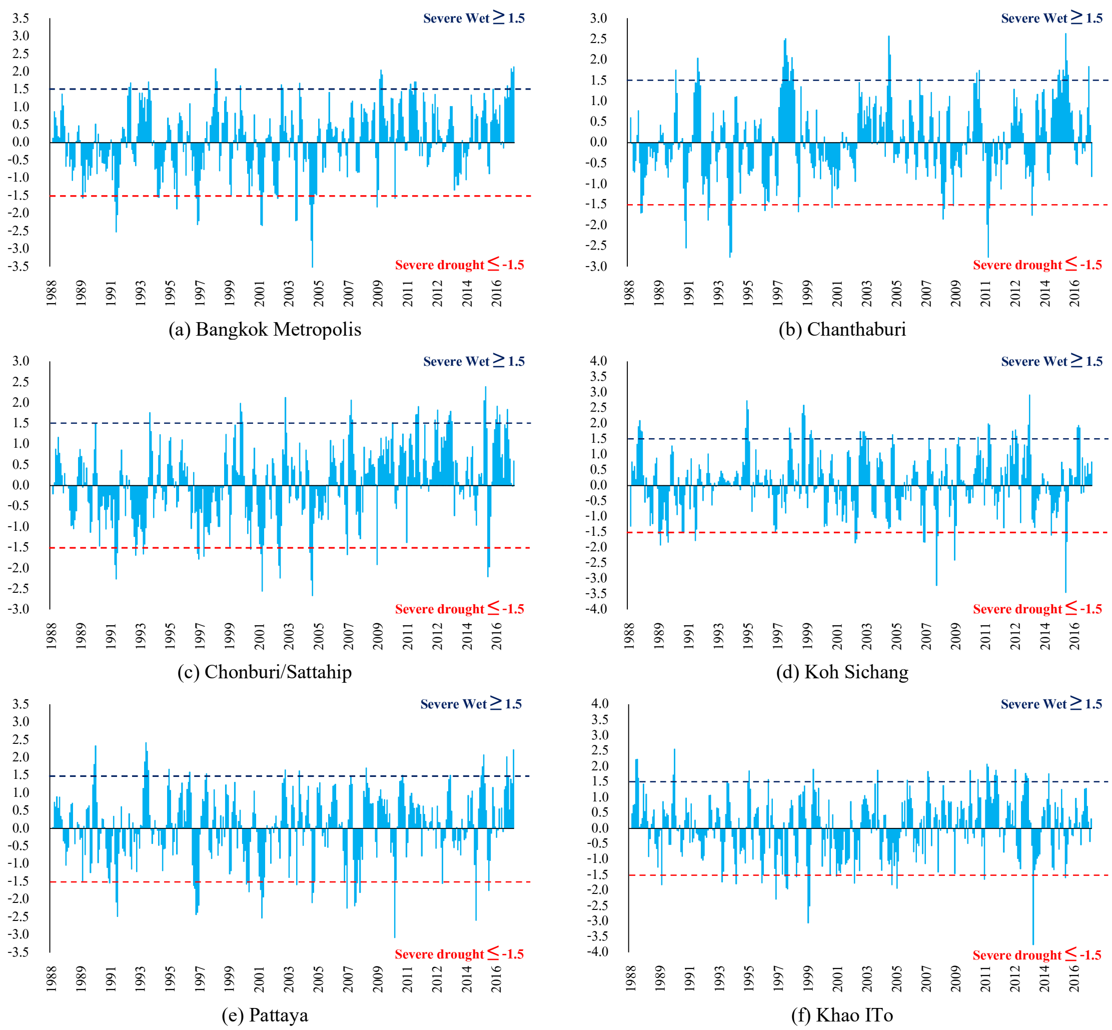
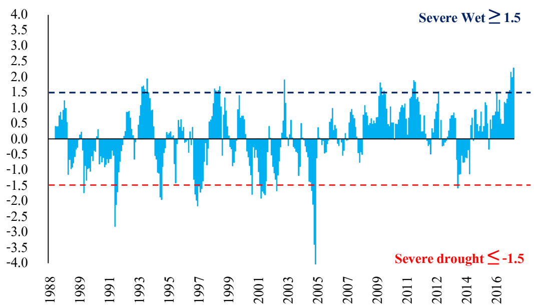


Figure 2 Changes in the SPI3 Index Classified by Meteorological Stations

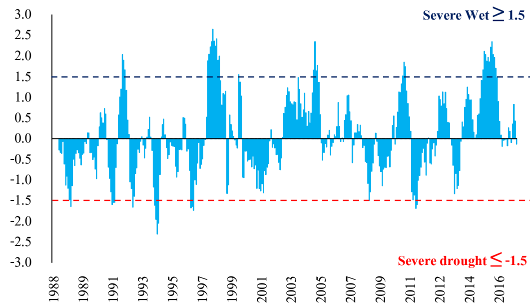
NUEJ
Naresuan University
Engineering Journal

simulation time to near normal with 69.63 - 77.36 (%), while moderate, severe and extreme droughts ranged from 5.44 – 10.60 (%), 0.29 – 6.02 (%) and 0.00 – 1.43 (%), respectively.

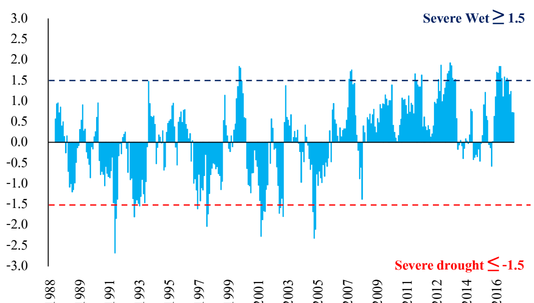
Shows consecutive periods of drought for the SPI12, as it was an indicator of year-to-year drought changing by considering the SPI ≤ -1.5 (severe to extreme drought). Bangkok Metropolis had five periods: May – June 1992, November 1997 – April 1998, July – October 2001, January – July 2002, and February – April 2005. Chanthaburi had a maximum annual rainfall of 1 month (April 1995). Chonburi/Sattahip had four periods: November 1993 – April 1994, September – October 2001, February – April 2002, and July – August 2005. Koh Sichang had only one month (July 2001). Pattaya had four periods: April – September 1992, October – December 2000, April – December 2001, and January – July 2002. Khao Ito had two periods: August – September 1999 and October 2001 – April 2002.



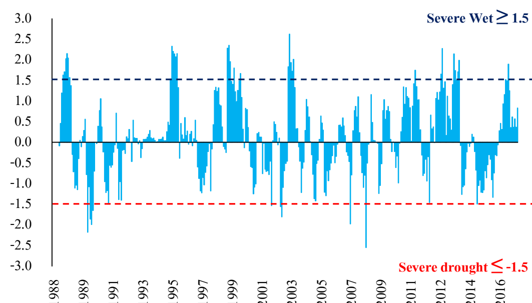
(a) Bangkok Metropolis



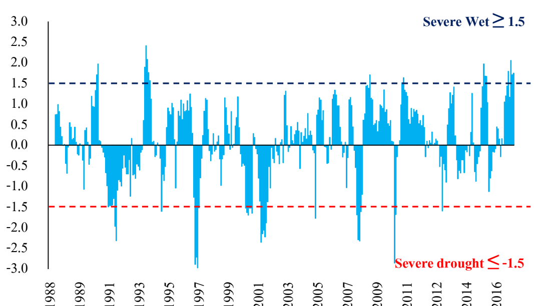
(b) Chanthaburi



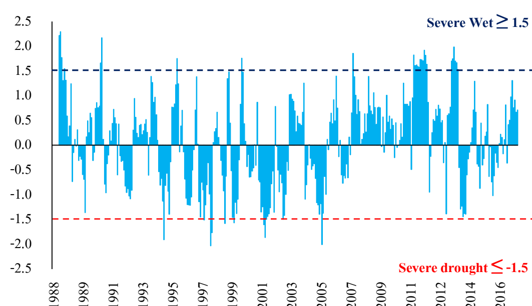
(c) Chonburi/Sattahip



(d) Koh Sichang



(e) Pattaya



(f) Khao ITo

Figure 3 Changes in the SPI6 Index Classified by Meteorological Stations

The results of the analysis of all SPI showed that most of the study areas had near-normal rainfall. From the percentage of the SPI was close to near normal at 62%. However, there were also different levels of drought likelihood.

4. CONCLUSION

The drought severity levels were analyzed using the Standardized Precipitation Index (SPI) in the Eastern Economic Corridor (EEC) area. The six meteorological stations were analyzed in three patterns, including SPI3, SPI6, and SPI12. The result showed that the mean of three SPI patterns ranged from 0.035 to 0.180, which was interpreted as the range of near normal. Considering the maximum and minimum values of the SPI in all periods, it was found that the value was greater than 1.5 and less than -1.5, respectively. Therefore, they indicated drought occurrence in both severe to extreme drought and severe to extreme wet. However, the likelihood of drought was at different levels in percentage. Most of the percentage of drought was more than 62 (%) in the study area, which experienced drought as near normal. The likelihood of drought (< -0.99) since moderate to extreme drought in the 30 years (1988 – 2017). There was a range below 17 % of the likelihood of drought and wet (100 %) in all SPI patterns, which was a slight likelihood of drought. The possibility of wet (> 0.99) since moderate to extremely wet in the 30 years (1988 – 2017) ranged below 21 % of the likelihood of drought and wet (100 %) in all SPI patterns. However, it was found that drought in the study area had uncertain patterns of drought and wet by considering the drought incidence curve. Hence, it is necessary to consider optimizing the water management plan according to the drought conditions.

However, in the analysis of drought levels, other indices consider other relevant climate variables, such as Temperature, Soil moisture, and satellite images, such as the Normalized Difference Vegetation Index (NDVI), which can be used to analyze with the SPI for more excellent reliability. Finally, the SPI was a convenient index that can be used to analyze the severity level of drought because it uses only rainfall data to represent the drought situation, with the data over 30 years. That took a long time to explore the accuracy of the results. Moreover, this research will be a starting point for further analysis of the SPI in the form of future projections of rainfall data under climate change in the study area.

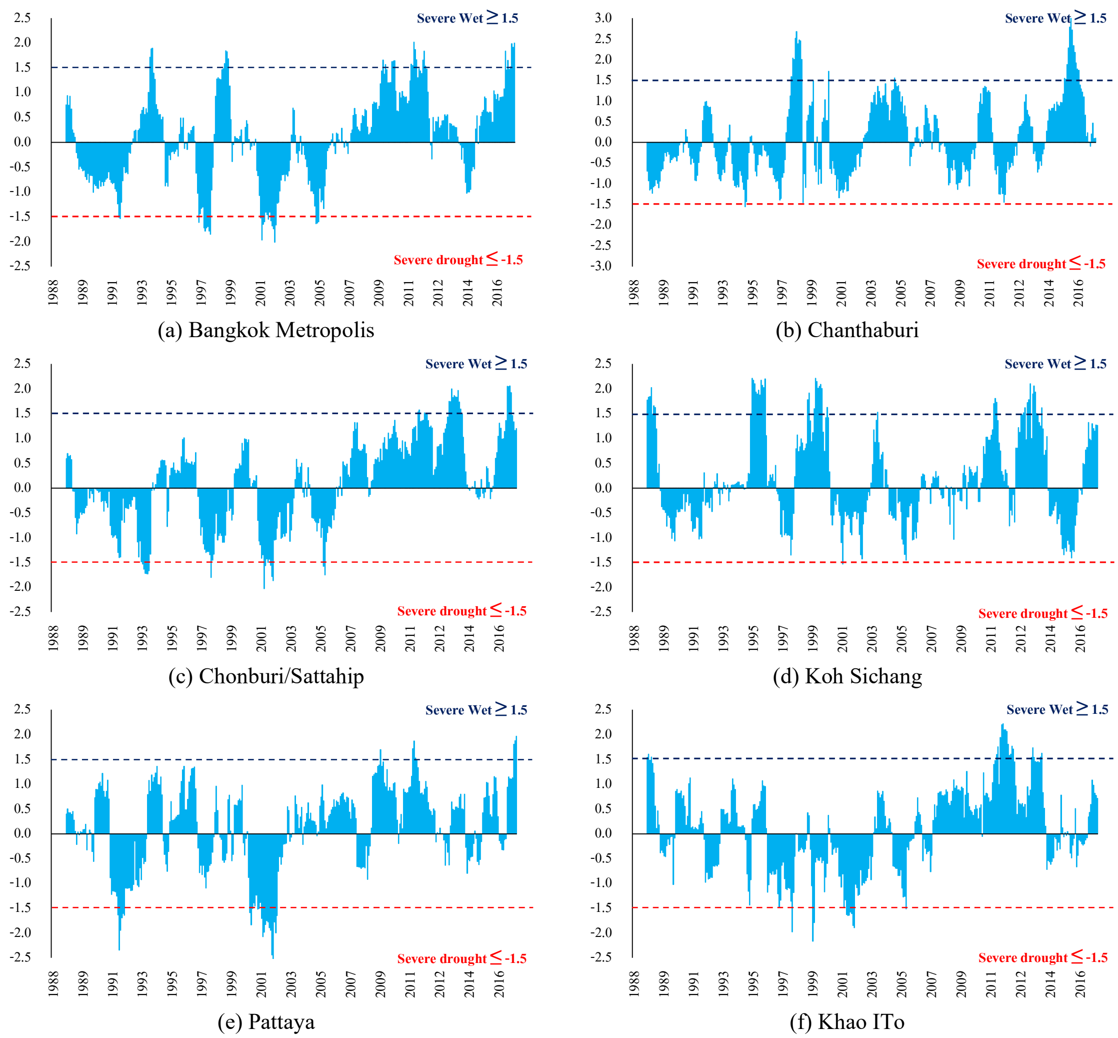


Figure 4 Changes in the SPI12 Index Classified by Meteorological Stations

5. ACKNOWLEDGMENT

I want to thank the advisors and members of the Department of Irrigation Engineering for providing knowledge and advice for completing the research.

6. REFERENCES

Adisa O. M., Masinde M. and Botai J. O. (2021). Assessment of the Dissimilarities of EDI and SPI Measures for Drought Determination in South Africa. Water 2021 13(82), 1-17. DOI: 10.3390/w13010082

Chaito, T. and Khamkong, M. (2020). Time Series Model for Standardized Precipitation Index in the Ping River Basin of Chiang Mai Province. The Journal of KMUTNB 2020, 1-14. DOI: 10.14416/j.kmutnb.2020.12.012

Damberg L.and AghaKouchak A. (2014). Global trends and patterns of drought from space. Theoretical and applied climatology 2014; 117(3-4), 441-448.

Homdee, T., Pongbut, K. and Kanae, S. (2016). A Comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand. Agriculture and Natural Resources 50, 211-219. DOI: 10.1016/j.anres.2016.02.002

Huang Y. F., Ang J. T., Tionga Y. J., Mirzaei M. and Mat M. Z. (2016). Drought Forecasting using SPI and EDI under RCP-8.5 Climate Change Scenarios for Langat River Basin, Malaysia. Procedia Engineering, 154, 710-717.

Hydro-Informatics Institute. (2012). Data collection and data analysis for the 25 rivers basin and model for flood and drought in the Ping river basin (in Thai). Available Source: http://www.thaiwater.net/web/

Kaingam, V. and Chotamonsak, C. (2019). Analysis of Drought in Northern Thailand Using Standardized Precipitation Index. J Sci Technol MSU 39(3), 313-322.

Madusanka T. and Venkataramana S. (2017). Characterization of future drought conditions in the Lower Mekong River Basin. Weather and Climate Extremes 17, 47-58. DOI: 10.1016/j.wace.2017.07.004

Mckee T. B., Doesken N. J. and Kleist J. (1993). The Relationship of Drought frequency and duration to time scales. Eighth Conference on Applie Climatology, American Meteorological Society, Jan 17-23, Anaheim CA, 179-186.

Pei Z., Fang S., Wang L. and Yang W. (2020). Comparative Analysis of Drought Indicated by the SPI and SPEI at Various Timescales in Inner Mongolia, China. Water 2020 12(1925), 1-20. DOI: 10.3390/w12071925

Pinthong, A. and Kwanyuen, B. (2016). Drought Monitoring by Composite Drought Index. Rajamangala University of Technology Thanyaburi 15(2), 45-53. DOI: 304080-1-10-20180403

Sriwongsitanon, N. (2015). Drought Monitoring and Early Warning for Thailand. Department of Water Resources Engineering, Kasetsart University, 17-27.

Taesombat, W. (2012). Engineering Hydrology. Department of Irrigation Engineering, Kasetsart University Kamphaeng saen campus, 96-100.

Thai Meteorological Department. (2016). Climate Change. Available Source: https://www.tmd.go.th/info/info.php?FileID=86/

Thai Meteorological Department. (2012). Study on Drought Index in Thailand 2012, Agro - meteorological Division, Meteorological Development Bureau, 33-60.

Thanapakpawin P., Boonya-aroonnet S., Chankarn A., Chitradon R. and Snidvongs A. (2011). Chapter 7 Thailand drought risk management: macro and micro strategies. Droughts in Asian Monsoon Region (Community, Environment and Disaster Risk Management, Volume 8) Emerald Group Publishing Limited 2011; 8, 121-140.

The Eastern Economic Corridor Office of Thailand. (2018). Combined diagram for the development of the Eastern Economic Corridor 2017 - 2022. The Eastern Economic Corridor Office of Thailand (EECO), 71-80.

Wichitarapongsakun, P. (2015). Drought Analysis in the Rain-fed Agriculture Area Using the Standardized Precipitation Index (SPI) in the HuaiKoKaeo sub-basin of the Pasak River Basin. 12th THAICID National Symposium, 150-163.

Wichitarapongsakun, P., Sarin, C., Klomjek, P. and Chuenchooklin, S. (2016). Meteorological drought in the Sakea Krang River basin using the Standardized Precipitation Index (SPI) and the Meteorological Drought Index (D). Naresuan University Journal: Science and Technology 2016 ; 24(3), 123-135. DOI: 1549--4903-1-10-20161011_2

Wichitarapongsakun, P., Sarin, C., Klomjek, P. and Chuenchooklin, S. (2017). Rainfall prediction and meteorological drought analysis in the Sakae Krang River basin of Thailand. Agriculture and Natural Resources 50, 490-498. DOI: 10.1016/ j.anres.2016.05.003

Wilhite D. A. and Glantz M. H. (1985). Understanding: the drought phenomenon: the role of definitions. Water international 1985l ; 10(3), 111-120.