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To cite this article: C N X Quang *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **652** 012020

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# Assessment of meteorological drought in the Vietnamese Mekong delta in period 1985-2018

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**Abstract.** Drought is one of a major natural disaster that causes tremendous damage to the ecological environment and social-economic in the Vietnamese Mekong Delta (VMD). Drought characteristics are invaluable knowledge for better management of water resources and agriculture production, especially under climate change context. This study investigated the spatiotemporal trend, intensity, duration, and frequency of meteorological droughts over VMD by using the Standardized Precipitation Evaporation Index (SPEI). The SPEI at multiple time scales (3, 6 and 12 months) are determined by using the monthly precipitation and temperature data between 1985 and 2018 obtained from ten meteorological stations in VMD namely Ba Tri, Cang Long, Soc Trang, Bac Lieu, Rach Gia, Ca Mau, Chau Doc, Can Tho, Cao Lanh, and My Tho. SPEI detected ten extreme drought events from 1985-2018 that matches with the historical extreme drought events reported in VMD. It means SPEI could be a useful indicator to support for drought management and mitigation in the future. The extreme drought event from October 2013 to September 2016 was the highest intensity and most prolonged duration from 1985-2018. The El Niño is considered to strongly influence on extreme drought events in VMD as all extreme drought events are highly associated with El Niño periods. The intensity, duration and frequency of drought events increased from 1985 to 2018. Drought events are more severe in VMD in recent years. Extreme drought also tends to cover for over VMD region. Adaption measures are essential to cope with drought disaster, especially in the agricultural and aquacultural sectors.

## 1. Introduction

Drought is a hydrologically extreme event imposing seriously adverse impacts on social, economic, and environmental sustainability. In the Vietnamese Mekong Delta (VMD), drought and saline intrusion have destructive influences on agriculture, social-economic and ecosystems such as crop damage, domestic water supply shortages, and ecological environment degradation. Recently, drought and saline intrusion have appeared with higher intensity and frequency. In the last five years, two extreme events of drought and saline intrusion occurred in the dry season in 2015-2016 and 2019-2020. The Ministry of Agriculture and Rural Development (MARD) reported that drought and saline intrusion in the dry season 2019-2020 affected 16,500 ha of the 2019 crop (on rice and shrimp land), mainly in Ca Mau province, 41,900 ha/1,541,000 ha of the Winter-Spring crop, and caused domestic water shortage of a total of about 96,000 households (about 430,000 people) [1]. Therefore, drought monitoring and



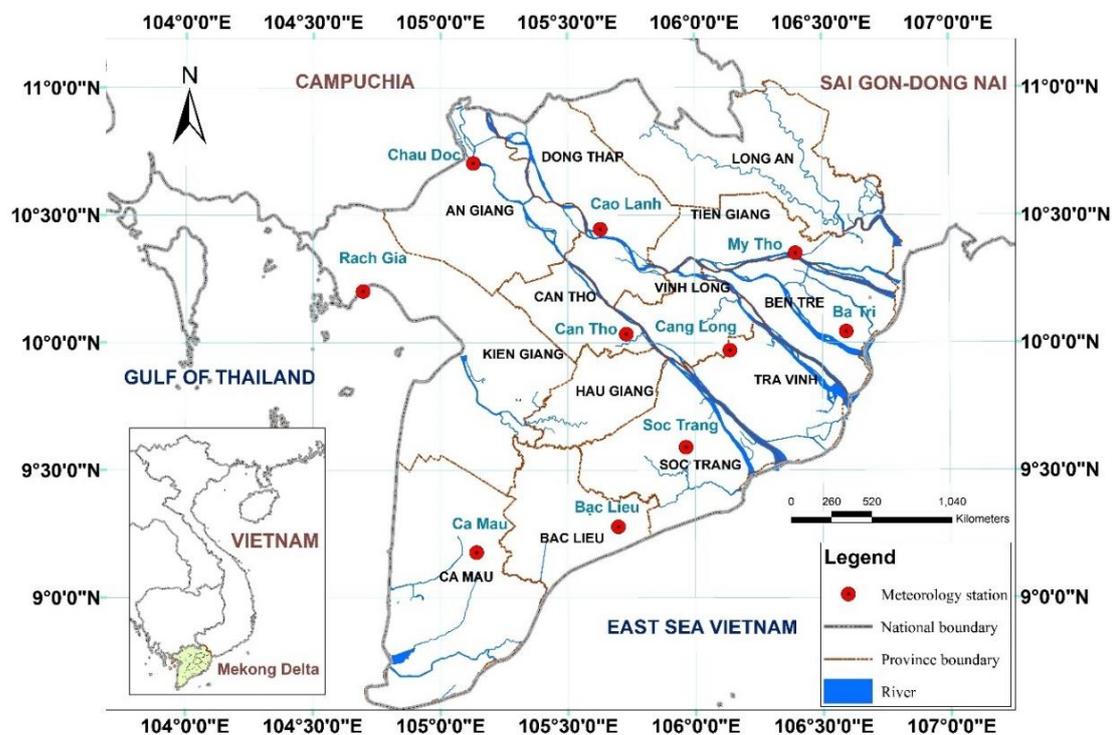
management and mitigation of drought loss in VMD are one of the most priorities of both the central and local governments.

Identifying the drought characteristics is particularly crucial to support for drought management and mitigation drought loss. Various previous research works have been conducted to investigate the drought conditions in VMD using the Standardized Precipitation Index (SPI) [2][3][4] developed by McKee [5]. Although SPI is widely and successfully applied for drought assessment, it is deficient when considering the impact of the temperature component on drought condition, which strongly impacts on the overall water balance and water use of a region. To overcome the limitation of SPI, Vicente-Serrano [6] developed the Standardized Precipitation Evaporation Index (SPEI) based on precipitation and temperature data. SPEI is an extension of SPI and has the advantage of including the effects of temperature variability on drought assessment.

In this study, SPEI employed to investigate the drought characteristics for the historical period 1985-2018 in VMD. The monthly rainfall and temperature dataset collected from ten meteorological stations located in the study region, as displayed in **Figure 1**, are used. The spatial-temporal trend, intensity duration, and frequency of drought are assessed by using the SPEI values calculated with different times scales of 3-month (SPEI-3), 6-month (SPEI-6), and 12-month (SPEI-12).

## 2. Study area

VMD is located in southwest Vietnam, and it is the downstream of the Mekong River Basin (**Figure 1**). The total area of VMD is approximately 39,734 km<sup>2</sup>. The study area has characteristics of tropical monsoon weather, with two distinct seasons. The rainy season starts from May to October, and the dry season starts from November to April. From January to June, the average rainfall is deficient in this area, at about 20–30% of total annual rainfall. Drought has caused serious damage to agriculture and aquaculture sector in VMD.



**Figure 1.** Map of the Vietnamese Mekong Delta and location of the meteorological stations

### 3. Data and methods

#### 3.1. Data

Monthly precipitation and temperature data are required to calculate SPEI. Guttman [7] recommends that the data length should be at least 20-30 years, but 50-60 years (or more) is more preferred. In this study, the 34 years of monthly precipitation data covering from 1985 to 2018 collected at ten meteorological stations in VMD. The station names are Ba Tri, Cang Long, Soc Trang, Bac Lieu, Rach Gia, Ca Mau, Chau Doc, Cao Lanh, Can Tho, and My Tho. The location of these stations displayed in **Figure 1**.

#### 3.2. Methods

The Standardized Precipitation Evapotranspiration Index (SPEI) was first proposed by Vicente-Serrano [6] as an improved drought index that is especially suited for studies of the effect of global warming on drought severity. To calculate SPEI, we first calculate the monthly time series of (P–PET) at each station with different 1-month averaging periods. The log–logistic distribution (LL2) is then fitted to (P–PET) and standardized in the same way as SPI and SRI [6]. The calculation procedure of SPEI has been explained by Vicente-Serrano [6]. The R package is used to determine SPEI in this study.

Drought classify is based on the classification system shown in the SPI value table below (Table 1) to define drought intensities resulting from the SPEI [5]. Drought, according to the SPEI, starts when the SPEI value is equal or below -1.0 and ends when the value becomes positive.

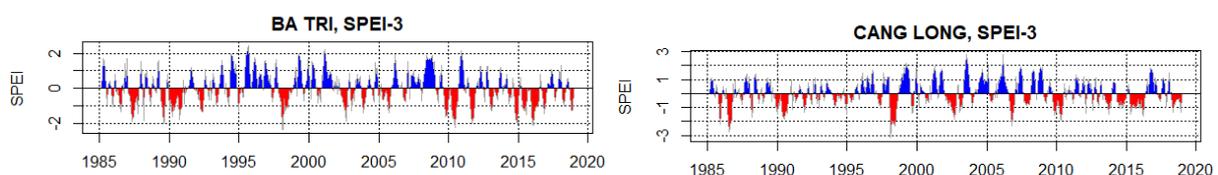
**Table 1:** Drought classification based on the SPEI value

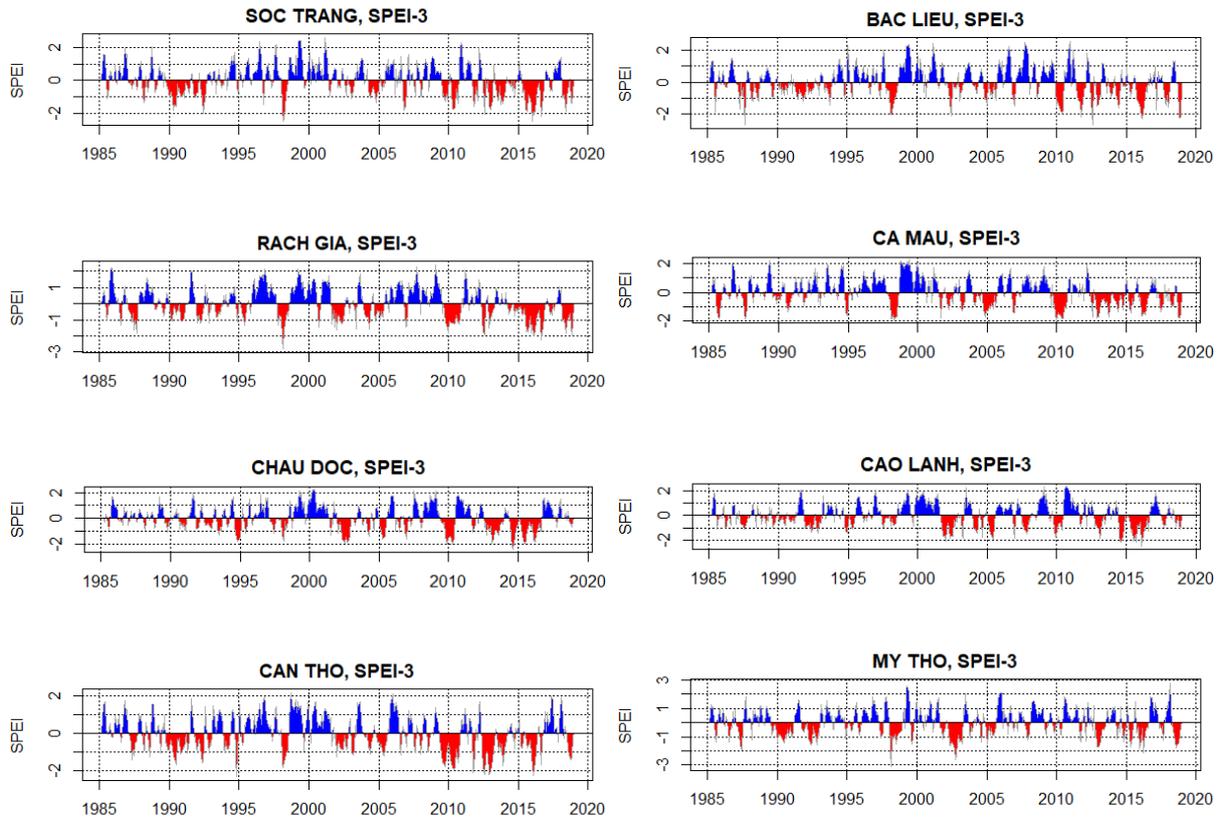
SPEI values	Drought category	SPEI values	Drought category
+ 2.0	extremely wet	-1.0 to -1.49	moderately dry
1.5 to 1.99	very wet	-1.5 to -1.99	severely dry
1.0 to 1.49	moderately wet	-2 and less	extremely dry
-0.99 to .099	near normal		

According to G. B. Lyra, the spline method is the best method used to interpolate the meteorology maps with the best values of angular coefficient and lower intercept for the regression between observed and interpolated rainfall [8]. The spatial distribution map of SPEI value over VMD is plotted by using the spline interpolation method with the weight of 11.5. The cross-validation technique was used to assess the accuracy of the interpolated values at each station. The estimated SPEI values, which is interpolated at the grids cover the meteorology stations that reserved for validation, is saved to be compared with the calculated values, removed before. The Spatial Analyst extension of ArcGIS software was used to create the spatial distribution map of SPEI over VMD.

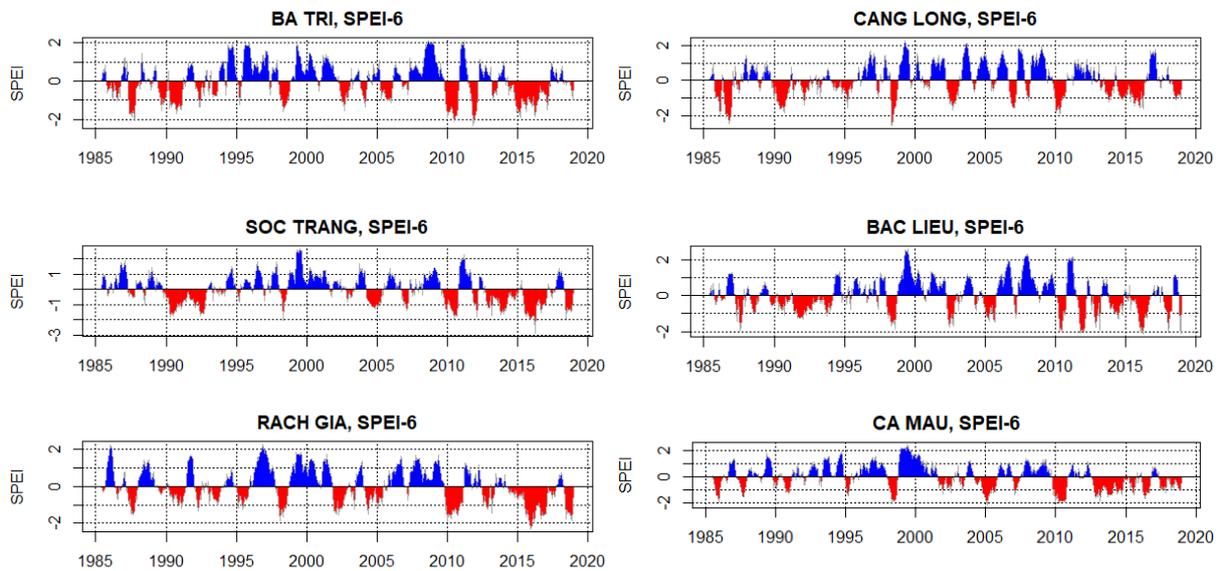
### 4. Results and discussion

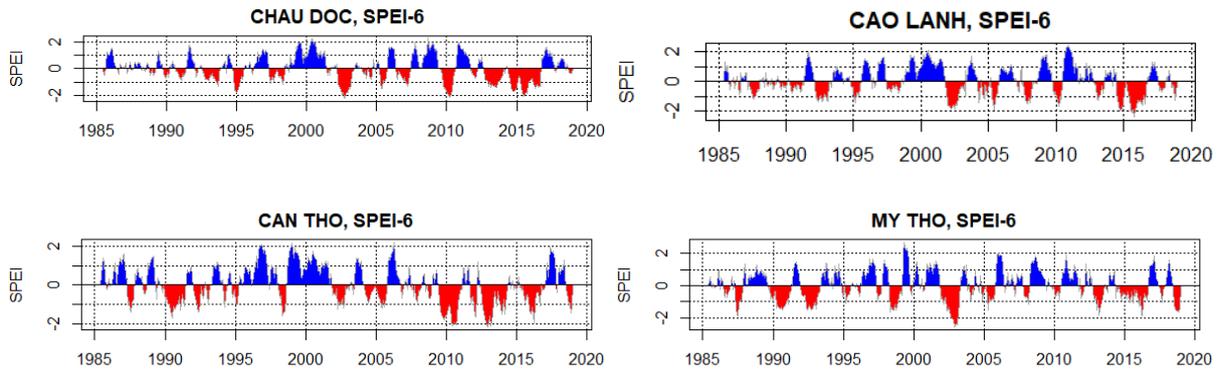
Figure 2, 3, and 4 show the temporal evolution of SPEI calculated at different time scales (3-month (SPEI-3), 6-month (SPEI-6), and 12-month (SPEI-12)) from 1985 to 2018 at ten meteorological stations in VMD. The positive and negative value of SPEI represents the wet and dry periods, respectively. The SPEI values at multi timescales implied complex variations of drought conditions in VMD. The SPEI-3 reflects the characteristics of short-term drought and the seasonal variability of drought conditions. The SPEI-6 and SPEI-12 demonstrate the characteristics of long-term drought variability.



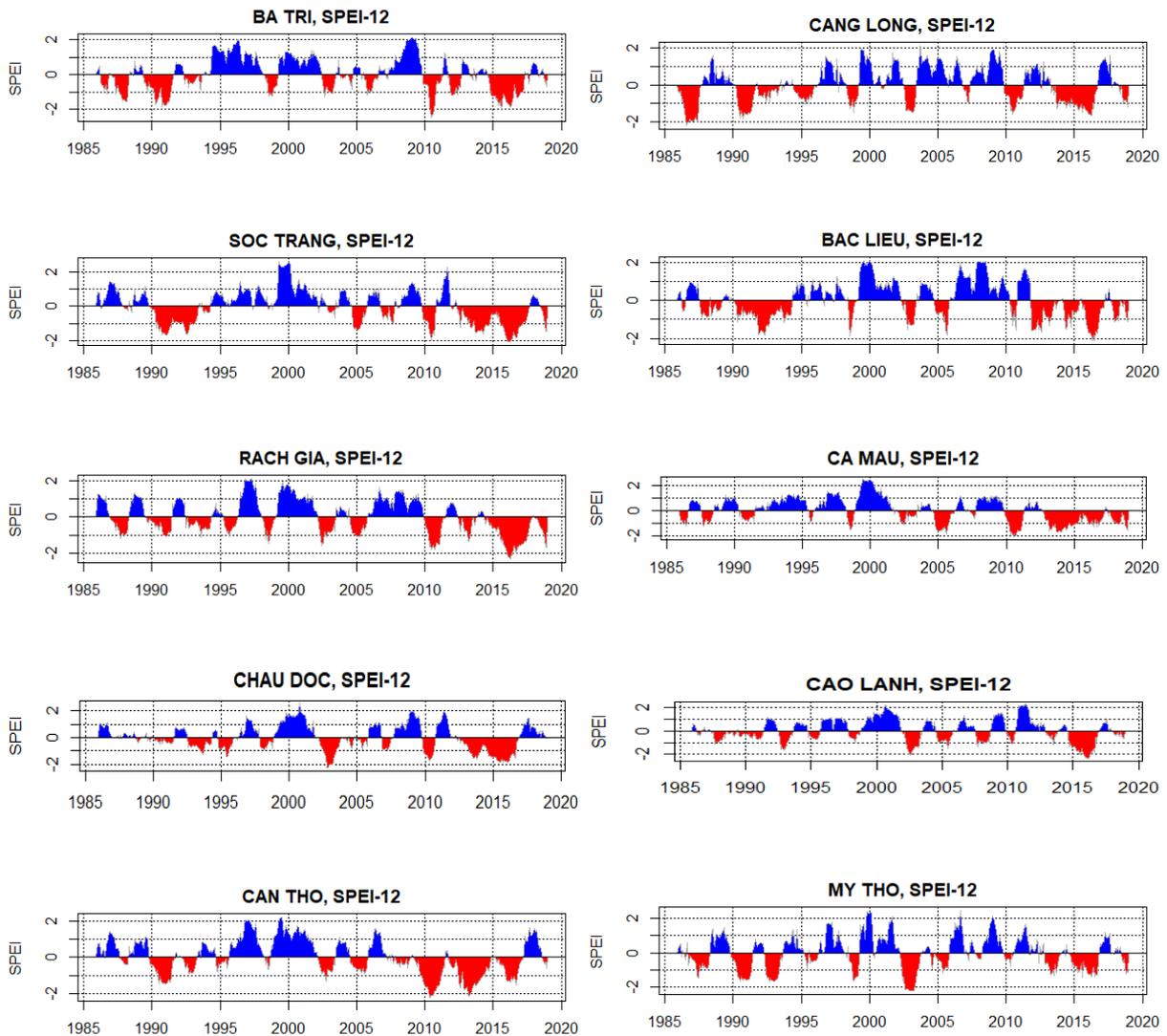


**Figure 2.** Evolution of SPEI-3 at ten meteorological stations for the period of 1985-2018 in VMD





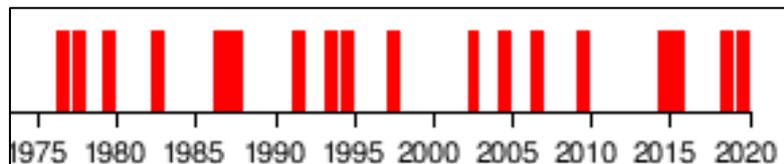
**Figure 3.** Evolution of SPEI-6 at ten meteorological stations for the period of 1985-2018 in VMD



**Figure 4.** Evolution of SPEI-12 at ten meteorological stations for the period of 1985-2018 in VMD

The SPEI values detected the severe drought events impacted at large spatial scale (at least four meteorological stations are concurrently under severe drought condition) were from May to October 1987, December 1989 to July 1991, January 1992 to September 1993, January 1995 to July 1995, May 1998 to September 1998, February 2002 to February 2003, June 2004 to September 2005, November 2009 to October 2010, November 2012 to March 2013, and October 2013 to September 2016. The severe drought events captured by SPEI consists of the reported drought events in VMD. It means SPEI is a very potent tool for monitoring and forecasting drought in the future. Most of the severe drought events are associated with the El Niño period, as shown in Figure 5. It implies that El Niño periods strongly influence to severe drought events in VMD.

As visualization in Figure 2, 3, and 4, the drought intensity tends to increase from 1985-2018. Among these severe drought events, October 2013 to September 2016 is the most severe drought event in term of intensity and duration. The occurrence of drought events is also more frequency from 1985-2018. Drought at Can Tho, Rach Gia, Soc Trang stations is more severe to compare with other stations. The drought was not very severe at Chau Doc and Cao Lanh stations located at upstream VMD in the period 1985-2000, but it likely was more severe in recent years.



Source [9]

**Figure 5.** Evolution of El Niño from 1978 to 2020

Table 2 shows the months of severe and extreme drought event according to values of SPEI-3 at ten meteorological stations from 1985 to 2018. The results indicated that Chau Doc station has the highest numbers of the severe drought month (thirty months), but it has the low numbers of the extreme drought month (three months) to compare with other stations. Cang Long station has the lowest numbers of the severe drought month (only three months), but the numbers of the extremely dry month are quite large (seven months). The severe drought months at Ca Mau station is relatively high (twenty-nine months), but the extreme drought did not occur at this station. Bac Lieu station has the highest extreme drought months in VMD (ten months, haft extreme drought months occurred from 2015-2018). Overall, the numbers of severe and extreme dry months were likely increasing from 2010. The frequency, duration, and intensity of drought events were increasing from 2010 to 2018. Besides, the spatial coverage of extreme drought events also expanded over VMD from 2015 - 2018.

**Table 2:** Severe and extreme drought months based on the SPEI-3 value

Station	1985-1989		1990-1994		1995-1999		2000-2004		2005-2009		2010-2014		2015-2018		Total	
	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E
Ba Tri	5	1	2	0	0	2	1	0	3	0	6	3	2	2	19	8
Cang Long	4	2	2	0	2	4	1	0	1	1	2	0	1	0	13	7
Soc Trang	0	0	4	1	3	2	0	0	2	0	7	1	7	3	23	7
Bac Lieu	2	1	0	0	2	1	1	1	1	0	7	2	4	5	17	10
Ca Mau	4	0	1	0	6	0	2	0	1	0	10	0	5	0	29	0
Rach Gia	2	0	0	0	1	2	3	0	1	0	4	0	10	2	21	4
Chau Doc	0	0	3	0	2	0	6	0	5	0	7	3	7	0	30	3

Cao Lanh	0	0	0	0	0	0	8	1	6	0	4	2	2	5	20	8
Can Tho	0	0	3	1	3	0	0	0	3	0	9	4	4	1	22	6
My Tho	3	0	2	0	2	1	3	2	1	0	3	0	5	1	19	4

Note: S: Severe drought; E: extreme drought

Figure 6 and 7 represent the spatial distribution of the minimum values of SPEI-3 of the extreme drought events in 1987, 1998, 2010, and 2016 respectively. It can be seen that the spatial distribution of SPEI changed significantly from 1987 to 2016. During the extreme drought that appeared in 1987, droughts at upstream stations such as Chau Doc and Cao Lanh were less severe than those at coastal stations such as Ben Tre, Cang Long, Bac Lieu, Soc Trang. But during the extreme drought that appeared in 2016, the drought was severe for the entire VMD. Drought tends to expand for the entire VMD region from 1987 to 2016.

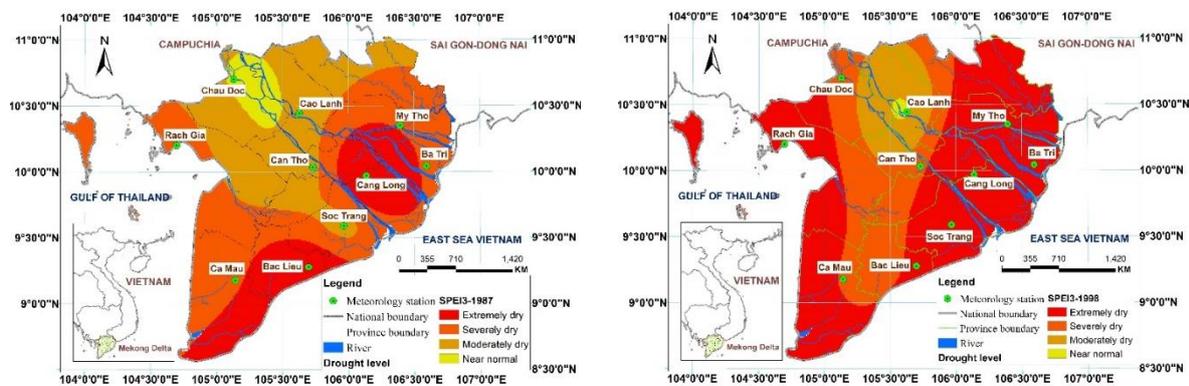


Figure 6. Spatial distribution of minimum values of SPEI-3 of drought events in 1987 and 1998

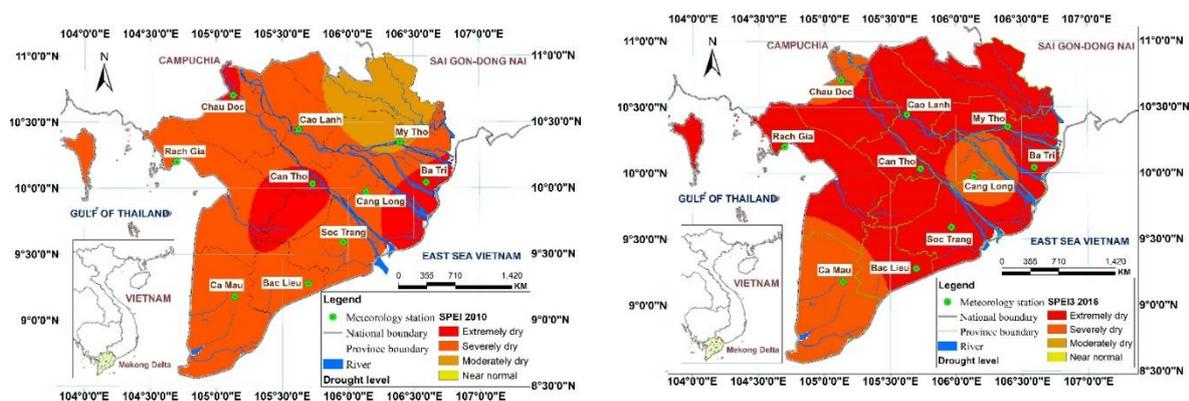


Figure 7. Spatial distribution of minimum values of SPEI-3 of drought events in 2010 and 2016

### 5. Conclusions

The characteristics of drought conditions in VMD were quantitatively analyzed using the SPEI values of different timescales (3, 6, and 12 - month). Results showed that the SPEI could detect drought events well in terms of temporal evolution, intensity, frequency, duration and spatial distribution. VMD experienced ten extreme drought events between 1985 and 2018 (from May to October 1987, December 1989 to July 1991, January 1992 to September 1993, January 1995 to July 1995, May 1998 to September 1998, February 2002 to February 2003, June 2004 to September 2005, November 2009 to October 2010, November 2012 to March 2013, and October 2013 to September 2016). The extreme drought event from

events from October 2013 to September 2016 was the highest intensity and most prolonged duration among ten extreme drought events. The El Niño has strongly influenced to extreme drought event in VMD as all extreme drought events are highly associated with El Niño periods. The intensity, duration and frequency of drought events increased from 1985 to 2018. Drought events are more severe in VMD in recent years. Extreme drought also tends to cover for over VMD region.

### Acknowledgments

The authors would like to acknowledge the financial support from the research project KHCV-TNB.ĐT/14-19/C11, funded by Ministry of Science and Technology.

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