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ARTICLE

Spatio-temporal variations in meteorology drought over the Mekong River Delta of Vietnam in the recent decades

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Abstract
In recent years, Mekong Delta of Vietnam is severely affected by salinity intrusion and water scarcity due to climate variability. In this study, a comprehensive analysis of meteorology drought was conducted to detect drought events using the Standardized Precipitation Index at 3-, 6-, 9- and 12-month time scale based on monthly precipitation data from 46 precipitation gauge stations for a period of 1984–2015. The aim of the study is to assess the degree of meteorology drought from 1984 to 2015 in potential crop growing areas to provide early warnings and monitor drought events to minimize their negative effects. The results indicated that meteorological drought occurred at the central provinces of the study area in the period 1985–1994, the northeastern and northwestern provinces in the period 1995–2004 and 10 recent years (2005–2014) meteorological drought shifted toward southern coastal provinces. The analyzed results also showed a tendency to decrease in frequency of drought is recorded while a tendency to increase in the spatial distribution of drought with moderate and severe droughts is recorded. Among the major droughts, 1990–1992 was evaluated the most extreme drought with 85% of the study area covered by the extreme drought with peak value of − 2.63 recorded and lasting for 29 months.

Keywords Climate variability · Drought · Salt intrusion · Water scarcity · SPI

Introduction

In recent years, droughts appear frequently with high intensity (FAO 2016; RCSA 2016). These phenomena exacerbate in severity and impact negatively on agriculture, water resources as well as other sectors (Miyan 2015; IPCC 2007). The impact of drought affects the global ecosystem as whole but varies from region to region, and the impact are minimal in developed countries (Asadi et al. 2015; MNRE 2016). Specifically, Mekong Delta of Vietnam (MDV) is suffering from climate variability and facing serious socioeconomic problems especially in agricultural sectors due to increasing droughts which lead to water scarcity (APN 2010; RCSA 2016). In 2016, Vietnam recorded the worst drought event in 90 years and 52 out of 63 provinces having been affected by drought; 18 provinces were declared states of emergencies (FAO 2016; Vu et al. 2018). Agriculture contributes 14.62% of Vietnam's GDP (RCSA 2016; Vo and Huynh 2014). But, 80% of Vietnam population depends on agriculture (FAO 2016; RCSA 2016).

Among all the natural hazards, drought ranked as first and affecting people directly (Miyan 2015; IPCC 2007). Miyan (2015) reported that climate change is the major cause of droughts worldwide. He stated that studies on historical drought events can help to give early awareness on negative impact in droughts. According to the report of Centre for Low Carbon Futures (CLCF), climate change has been impacted on many regions in Asia in 2020s year and will increase the drought severity compared with the period 1990–2005 years (Halwatura et al. 2016; RCSA 2016).

So far, many studies were conducted to measure and estimate meteorological droughts quantitatively by using drought index (Kwak et al. 2016; Yu et al. 2017) such as PDSI—Palmer Drought Severity Index (Liang et al. 2007;

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Yan et al. 2016), MSPI—Multivariate Standardized Precipitation Index (Bateni et al. 2018; Bazrafshan et al. 2014), SWSI—Surface Water Supply Index (Barua et al. 2009; Shafer and Dezman 1982), SRI—Standardized Runoff Index (Shukla and Wood 2008; Jang et al. 2017), RDI—Reconnaissance Drought Index (Asadi et al. 2015; Jamshidi et al. 2011), EDI—Evapotranspiration Deficit Index (Bayissa et al. 2018), SPEI—Standardized Precipitation Evapotranspiration Index (Mallyaa et al. 2016; Kumar et al. 2013) and SPI (Juliani and Okawa 2017; McKee et al. 1993). These common tools have been used to control and monitor droughts (Hao et al. 2016; Khedun et al. 2012).

Drought indices as mentioned above, the SPI was widely used in predicting and monitoring drought events (Bayissa et al. 2018; Jamshidi et al. 2011) around the world. For example, Rahmat et al. (2015) applied the SPI to investigate droughts in Victoria, Australia. They concluded that the SPI was shown to be satisfactory in assessing and monitoring droughts in Australia. Kwak et al. (2016) used the SPI to assess meteorological drought in the Nakdong River basins in South Korea. Suryabhagavan (2016) also applied the SPI to study potential crop growing areas in Ethiopia. Juliani and Okawa (2017) analyzed drought scales in Minas Gerais, Brazil, by applying the SPI. They concluded that the SPI could be used in the drought forecasting for other regions in Brazil. Yu et al. (2017) also applied the SPI to detect trends in precipitation in Hexi Corridor, northwest China. They reported that the SPI at 12-month time scale could be useful in agriculture production and rational use of water resources.

Therefore, studies on historical events of drought play an important role in controlling as well as minimizing damage caused by drought. This study therefore focused on drought trends in the MDV by using SPI to estimate the spatial and temporal distribution of the meteorological drought in the period of 1984–2014. The SPI has advantages compared to other tools such as it can be applied in different time scales to provide drought early warning (Bayissa et al. 2018; McKee et al. 1993). Another advantage is the input value only required precipitation data (Asadi et al. 2015; Jamshidi et al. 2011).

Materials and methods

Study area

The Mekong Delta (8°34′–11°10′N and 104°25′–106°48′E) is also known as the southern part of Vietnam and the largest rice warehouse in Vietnam (MDP 2013; RCSA 2016). It covers 1.7 million hectares of land with crops, the paddy rice area accounted for 53.93% and rice output accounted for 56.13% of Vietnam (Dan et al. 2015; RCSA 2016). The terrain of the study area is lowered from north to south with an average elevation of approximately 0.3–2.0 m above sea level (Vu et al. 2018; Vo and Huynh 2014) (Fig. 1).

Study area is located in monsoon tropics, and it is dominated by monsoon circulation which includes northeast monsoon from November to April of the next year and southwest monsoon from May to October. Rainy season coincides with the southwest monsoon, and it is characterized by hot, humid and heavy rain, while the dry season often coincides with northeast monsoon; it is characterized by dry, hot and a very little rainfall (Dinh et al. 2012; Vu et al. 2018). The climate brings its own nuances, which is a humid tropical monsoon; the high temperature throughout the year varies between 26 and 29 °C, and the mean annual rainfall varies 1370 mm at An Giang province and 2394 mm at Ca Mau province, of which about 85% falls in the rainy season (Table 1, Fig. 2). Precipitation has a strong variation seasonal and intensity; precipitation intensity increased from May to October and reaches its peak in October after intensity decreased from November to April of the next year.

Mean monthly precipitation dataset for 32 years (1984–2015) at 13 provinces in the MDV was represented by 46 precipitation gauge stations. The 46 precipitation gauge stations were selected to analyze, assemble and detect drought trends. The length of recorded precipitation data series in the study area was sufficiently covered to capture the fluctuations of precipitation with missing data of less than 10% to ensure the reliability of the statistical analysis (FAO 2016; Yu et al. 2017).

Methodology

The SPI was created by McKee et al. (1993), which is used to forecast meteorological drought (Teodoro et al. 2015; Svoboda et al. 2012). SPI has been successfully applied in many regions as South Korea, Ethiopia, Australia, and India (Bateni et al. 2018; Suryabhagavan 2016). In addition, at the Inter-Regional Workshop on Indices and Early Warning Systems for Drought in 2009, World Meteorological Organization (WMO) recommended the use of SPI for monitoring meteorological droughts (Bayissa et al. 2018; Hayes et al. 2011). The SPI then has been applied by National Weather Services of countries namely Argentina, Brazil, Chile, Paraguay, Uruguay, and China (Rivera and Penalba 2014). Specifically, precipitation data values are the transformation into standardized normal distribution. The cumulative probability distribution function is determined as the distribution of precipitation in the observation time series. The standard gamma probability distribution function then is defined by Eq. (1).

$$g(x) = \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^{\alpha} \Gamma(\alpha)}; \quad (x > 0) \tag{1}$$

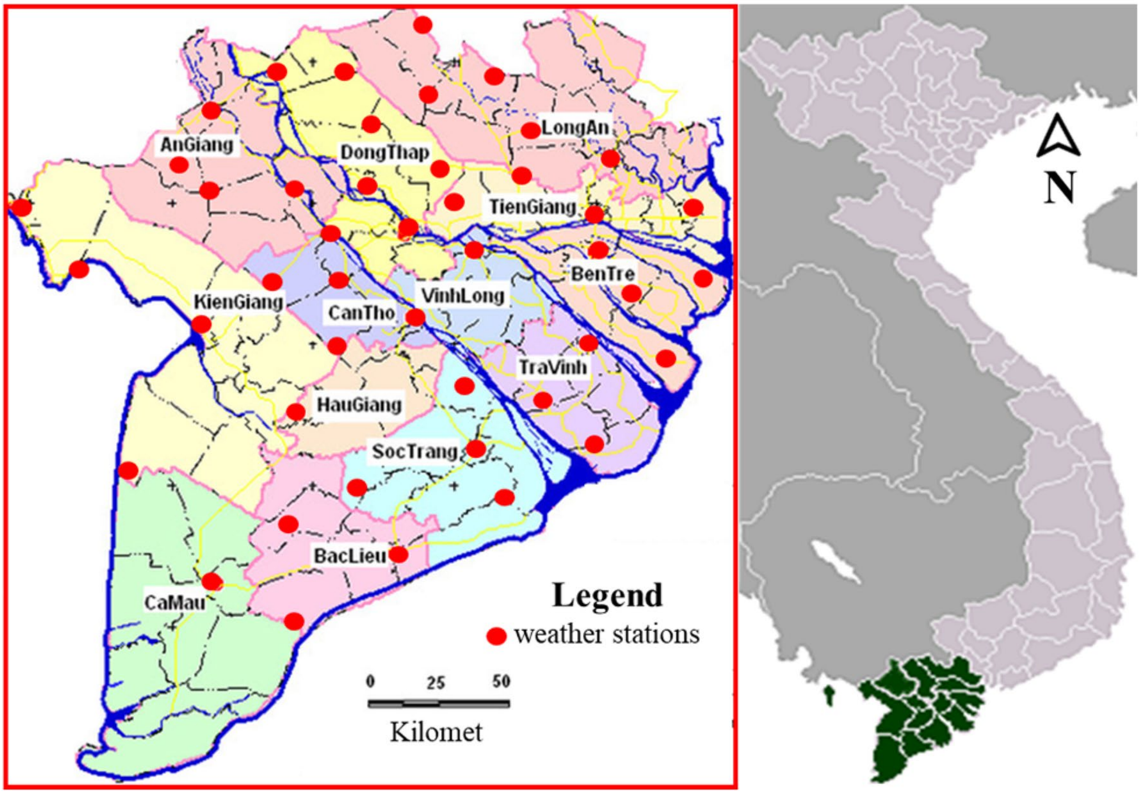

Fig. 1 Illustration of study area with weather observation stations

Table 1 Mean annual rainfall (MAR) and standard deviation (SD) at all provinces for the period of 1984–2015

Name	MAR (mm)	SD (mm)	Longitude (E)	Latitude (N)
An Giang	1370	81.38	105°08′09	10°33′24
Can Tho	1586	112.97	105°33′20	10°08′16
Hau Giang	1847	109.78	105°38′28	09°45′33
Tien Giang	1397	89.81	106°20′37	10°22′36
Dong Thap	1360	80.44	105°37′58	10°27′21
Vinh Long	1489	97.78	105°57′32	10°14′41
Soc Trang	1848	121.01	105°58′26	09°36′13
Bac Lieu	1895	125.21	105°45′22	09°34′40
Kien Giang	2154	126.93	105°12′01	09°54′23
Ca Mau	2394	139.05	105°07′35	09°10′15
Tra Vinh	1539	97.60	106°20′04	09°57′04
Ben Tre	1505	110.38	106°24′44	10°19′53
Long An	1643	110.84	106°10′35	10°54′26

where β is a scale parameter, α is a shape parameter, x is the precipitation amount, and $\Gamma(\alpha)$ is the gamma function.

Where the parameter α, β in Eq. (1) is calculated by Eqs. (2) and (3)

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{3}$$

In Eq. (3), $\bar{x}$ is the sample mean of the precipitation data series and $\hat{\alpha}$ is a distribution parameter.

The factor A in Eq. (2) is calculated by Eq. (4)

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{4}$$

In Eq. (4), n is number of precipitation observations.

Letting $t = \frac{x}{\hat{\beta}}$.

We have a distribution function $G(x)$, from which probabilities can be obtained from Eq. (5)

$$G(x) = \int_0^t g(t)\mathrm{d}t \tag{5}$$

According to Wu et al. (2007) due to a precipitation, distribution may contain zeros; therefore, the mixed distribution

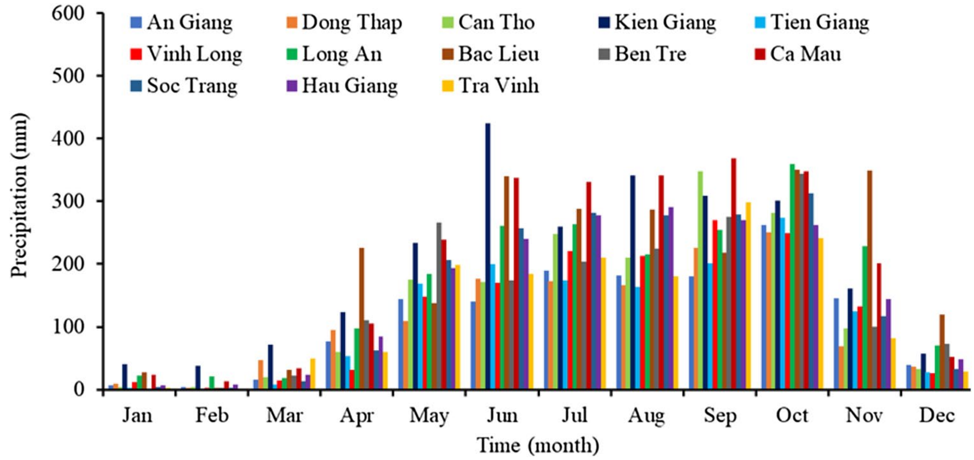

Fig. 2 Mean monthly precipitation at all provinces for the period of 1984–2015

function of zeros and continuous precipitation amounts are given by Eq. (6).

$$H(x) = q + (1 - q)G(x) \tag{6}$$

In Eq. (6), q is the probability of a zero, and it is determined by the ratio k/l, in which k is the number of zeros in a precipitation data series l.

Finally, the SPI is estimated by Eq. (7) for calculating the negative SPI values, while Eq. (8) applies the positive values.

$$\text{SPI} = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 d_3 t^3}\right) \quad \text{for} \quad 0 < H(x) \le 0.5 \tag{7}$$

$$\text{SPI} = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 d_3 t^3}\right) \quad \text{for} \quad 0.5 < H(x) \le 1.0 \tag{8}$$

Where t in Eqs. (7) and (8) is defined by Eqs. (9) or (10).

$$t = \sqrt{\frac{1}{H(x)^2}} \quad \text{for} \quad 0.0 < H(x) \le 0.5 \tag{9}$$

$$t = \sqrt{\frac{1}{(1.0 - H(x))^2}} \quad \text{for} \quad 0.5 < H(x) \le 1.0 \tag{10}$$

Where c_0, c_1, c_2, d_1, d_2 and d_3 are parameters and they are given as follows (Wu et al. 2007; Rahmat 2015) $c_0 = 2.515517$; $c_1 = 0.802853$; $c_2 = 0.010328$; $d_1 = 1.432788$; $d_2 = 0.189269$; and $d_3 = 0.001308$.

Accordingly, the positive and negative values of the SPI (Table 2) imply precipitation is higher and lower mean precipitation value. An area will be considered as drought if the SPI value of the area approaches −1.0 or smaller (Asadi et al. 2015; Rahmat 2015).

Table 2 Classification scale for SPI values

SPI values	Category
0 to −0.99	Near normal
−1.0 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
<−2.0	Extreme drought

Results and discussion

Temporal distribution of drought events

Figures 3, 4, 5 and 6 present the analyzed results of temporal drought characteristics over the study area. The SPI of 3-, 6-, 9 and 12-month time scales was analyzed to identify peak drought intensity, occurrence year and the longest duration of drought during period 1984–2015. Four significant drought events occurred including 1991–1993, 2002–2003, 2010–2011 and 2014–2015 years.

Among the events, drought in 1990–1992 was evaluated as the most extreme drought. Eleven out of 13 provinces the exception of Kien Giang and Ca Mau provinces (Table 3) occurred with a peak value of SPI-12-month drought scale was −2.63 at Hau Giang province and duration of the drought was 29 months (Fig. 7).

Severe and extreme droughts were occurred in six provinces with risk peak value −3.57 at Dong Thap province and lasting in 14 months at Tien Giang province for period of 2002–-2003, but for period 2010–2011, drought was occurred only in 6 out of 13 provinces where severe drought was occurred in An Giang, Kien Giang and Hau Giang provinces, while extreme drought was occurred in Vinh Long, Soc Trang and Ca Mau provinces with risk peak value −2.30 and lasting in 11 months at Ca Mau province. For 2014–2015, in 12 out of 13 provinces (the

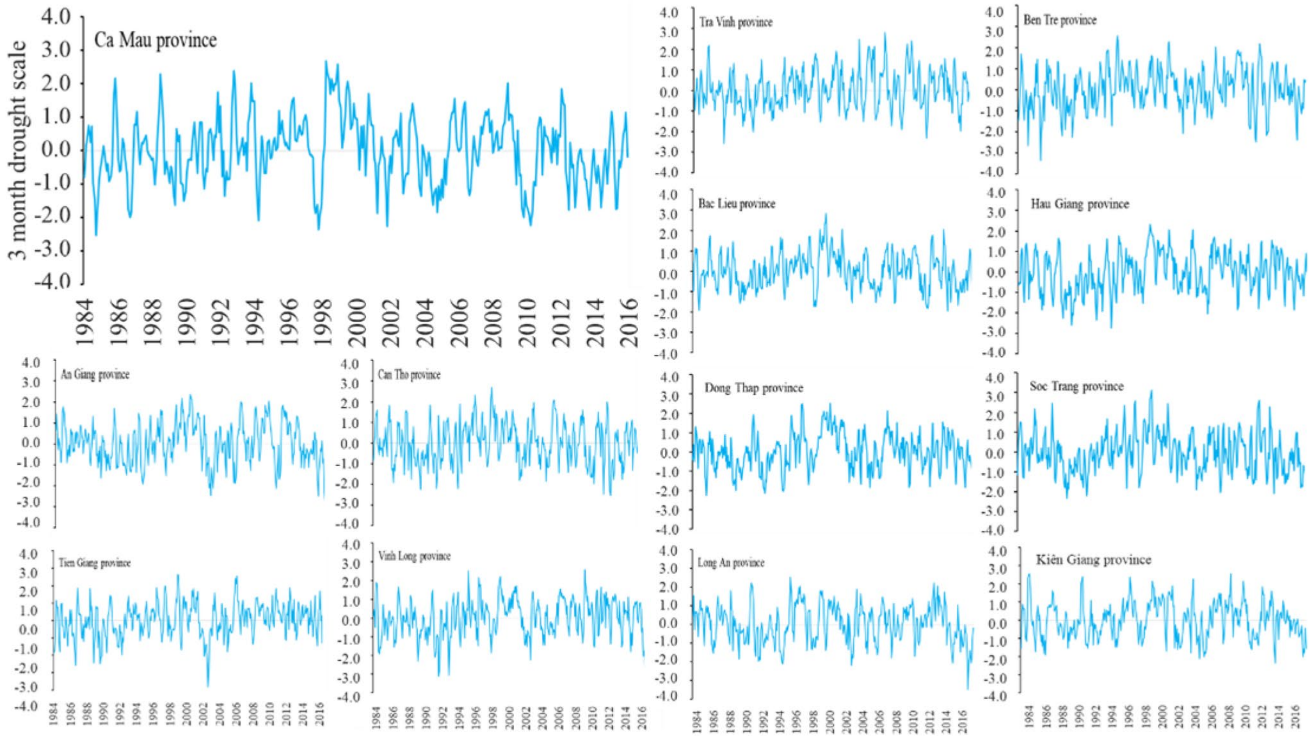

Fig. 3 Values of the SPI-3-month drought scale for the period from 1984 to 2015

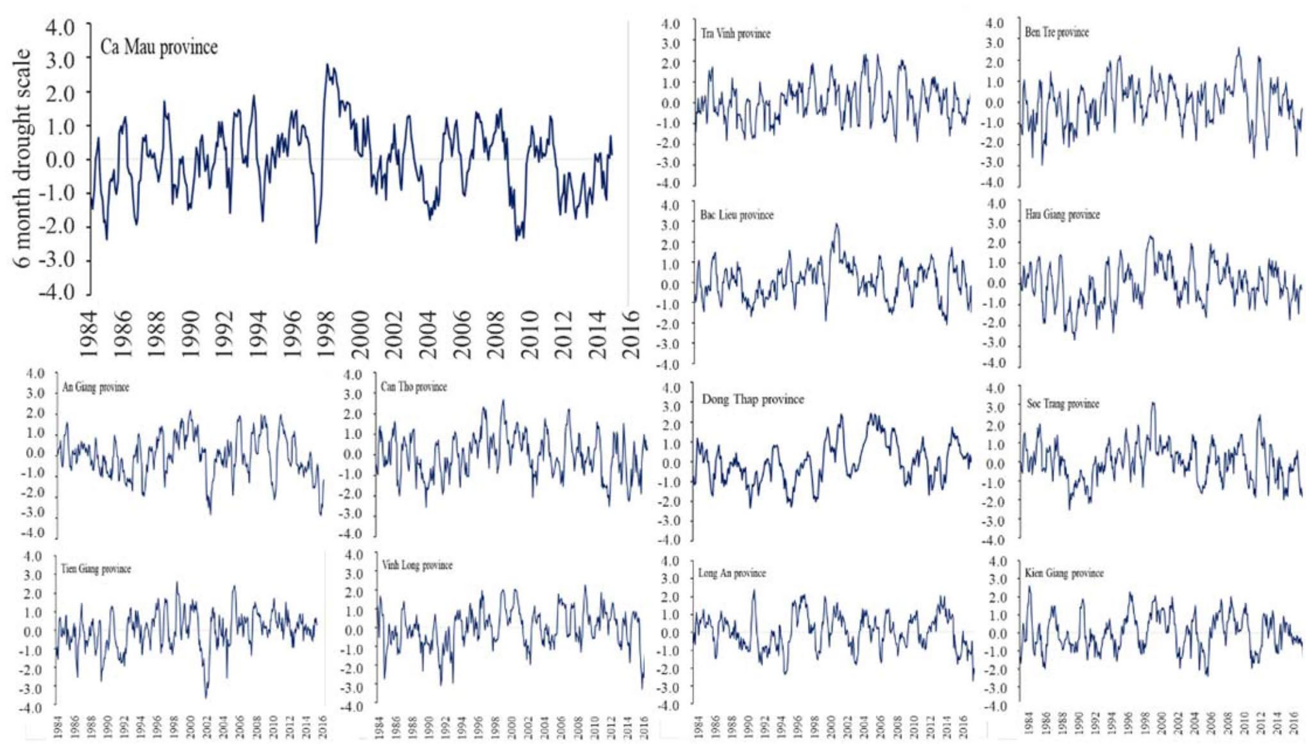

Fig. 4 Values of the SPI-6-month drought scale for the period from 1984 to 2015

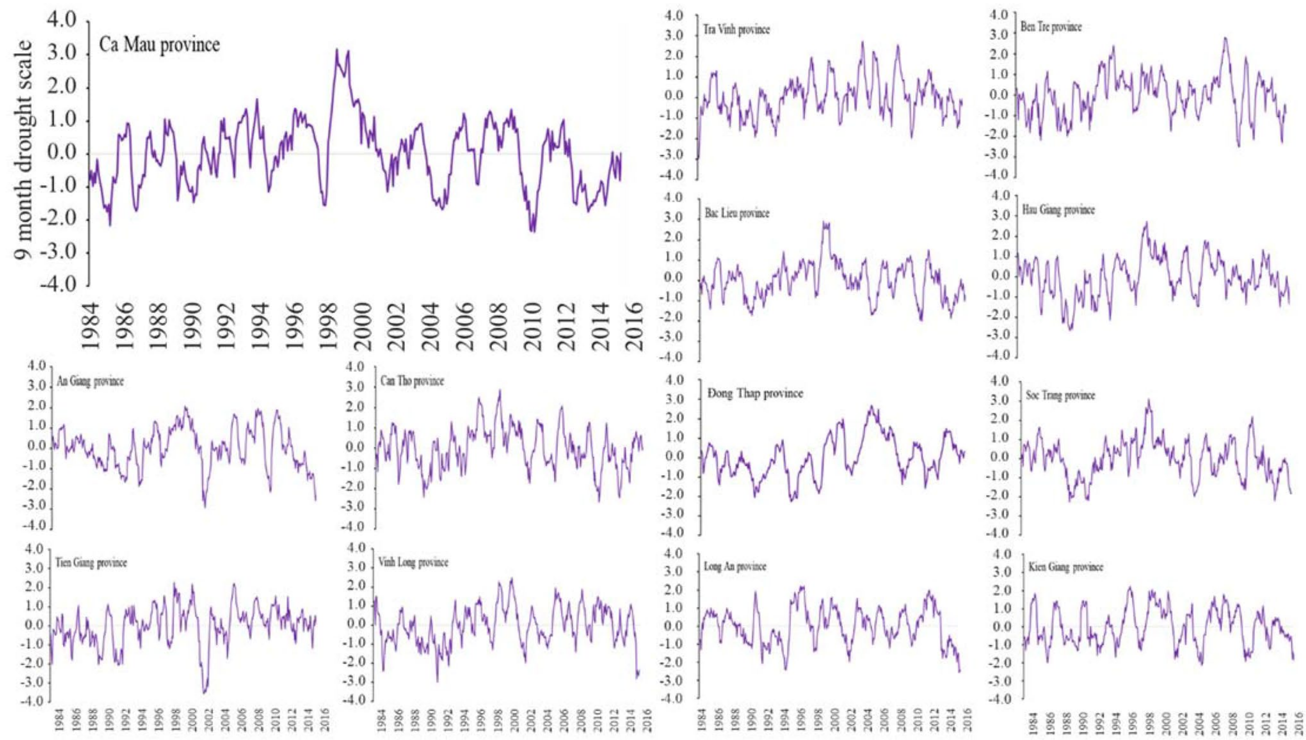

Fig. 5 Values of the SPI-9-month drought scale for the period from 1984 to 2015

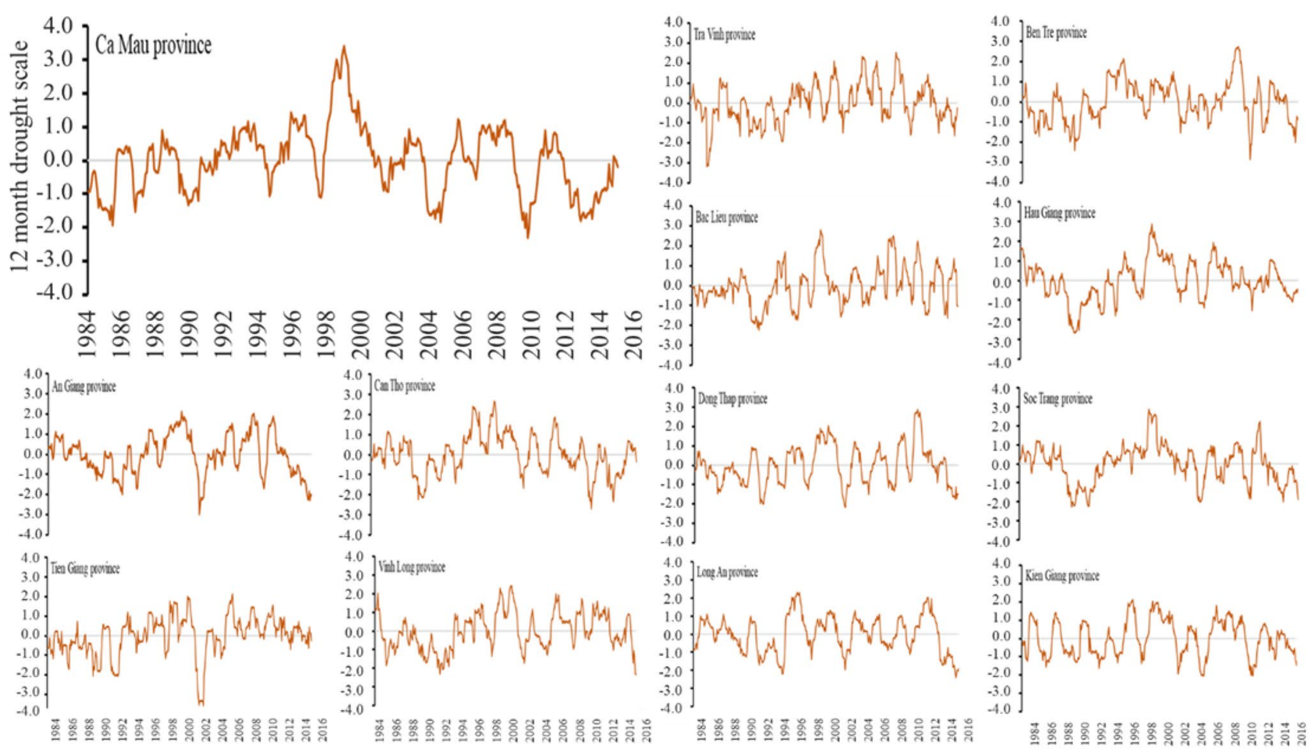

Fig. 6 Values of the SPI-12-month drought scale for the period from 1984 to 2015

Table 3 Provinces occurred extreme drought in the stage 1990–1992

Province	Drought intensity	Year
An Giang	−2.12	1991
Can Tho	−2.24	1990
Hau Giang	−2.63	1991
Tien Giang	−2.07	1990
Dong Thap	−1.99	1990
Vinh Long	−2.03	1992
Soc Trang	−2.25	1990
Bac Lieu	−2.23	1990
Tra Vinh	−2.01	1990
Ben Tre	−2.41	1990
Long An	−2.41	1990
Kien Giang	–	–
Ca Mau	–	–

"–" is no meteorological droughts

exception of Tien Giang province) severe and extreme droughts were occurred with a peak value of −2.39 and lasting for 24 months at Long An province (Fig. 7).

Figure 8 and Table 4 present the number of drought events occurred during period of 1984–2015 and their impacts over the entire study area. In the period of 1984–2015, moderate, severe and extreme droughts were occurred 33.69 times/32 years, 18.84 times/32 years and 7.30 times/32 years, respectively. Meanwhile, inland provinces recorded more extreme drought occurrence than the coastal provinces. The analyzed results showed that the moderate drought was occurred in study area more than once per year and extreme drought is less occurred than moderate and severe droughts. This confirms that inland provinces received less water vapor compared to coastal provinces, so extreme drought frequently occurred.

Temporal distribution of drought stages

Three drought stages including 1985–1994, 1995–2004 and 2005–2014 were also brought out to analyze precisely (Fig. 8, Table 5). In the period of 1985–1994, occurrence of moderate, severe and extreme droughts with average occurrences 14.8 time/10 years, 7.5 time/10 years and 3.5 time/10 years appears in the study area.

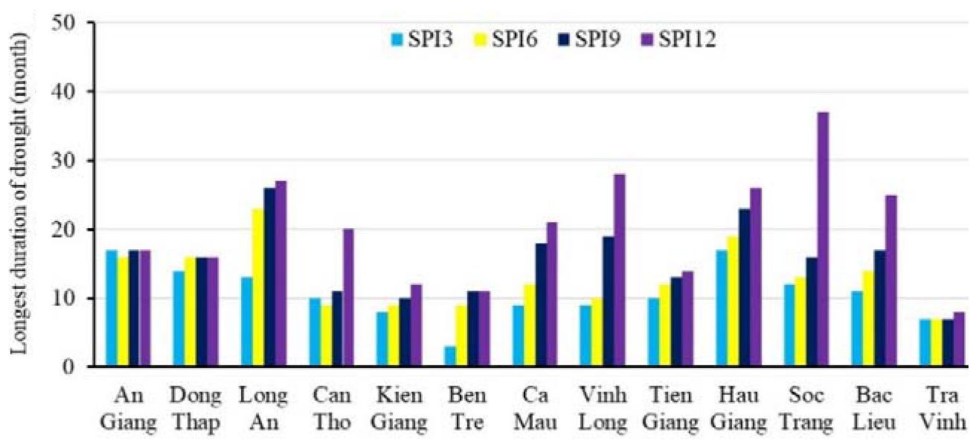

Fig. 7 Longest duration of drought indicated by SPI of 3-, 6-, 9 and 12-month drought scales

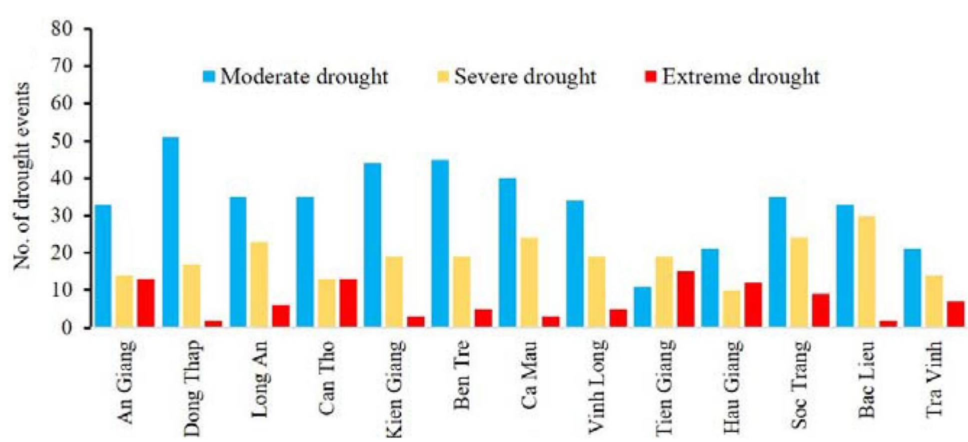

Fig. 8 Number of SPI-12-month drought scales occurred at stations in the period 1984–2015

Table 4 Drought properties based on the SPI of 12-month drought scale

Province	No. of drought events			Max intensity
	Moderate	Severe	Extreme	
An Giang	**33**	14	**13**	− 2.99 (2002)
Can Tho	**35**	13	**13**	− 2.70 (2010)
Hau Giang	21	10	**12**	− 2.66 (1991)
Tien Giang	11	19	**15**	− 3.57 (2003)
Dong Thap	**51**	17	2	− 2.16 (2002)
Vinh Long	**34**	19	5	− 2.33 (2015)
Soc Trang	**35**	24	9	− 2.25 (1990)
Bac Lieu	**33**	30	2	− 2.23 (1990)
Kien Giang	**44**	19	3	− 2.04 (2010)
Ca Mau	**40**	24	3	− 2.30 (2010)
Tra Vinh	21	14	7	− 3.16 (1986)
Ben Tre	**45**	19	5	− 2.84 (2010)
Long An	**35**	23	6	− 2.39 (2015)

Negative sign implies meteorological drought intensity

During this stage, the extreme drought did not occur at coastal provinces such as Kien Giang and Ca Mau. They are known as two coastal provinces with the most abundant moisture in the study area, and mean annual precipitation is relatively high, 2154 mm (at Kien Giang province) and 2394 mm (at Ca Mau). During 1995–2004, compared to 1985–1994, moderate, severe and extreme droughts were less occurred and only approximately 5.5 time/10 years, 3.2 time/10 years and 1.5 time/10 years were recorded, respectively, and extreme drought did not appear in the coastal provinces (Fig. 9), while for stage 2005–2014, moderate, severe and extreme droughts were more appeared than for stage 1995–2004 but also less than stage 1985–1994 with 8.9 time/10 years, 4.2 time/10 years and 1.8 time/10 years, respectively. For this stage, the extreme drought only found in coastal provinces namely Ben Tre, Soc Trang, Kien Giang and Ca Mau, while extreme drought did not occur in the most other provinces. Extreme drought occurred in the coastal provinces where the amount of moisture is very plentiful; in the past ten years (2005–2014), the occurrence of extreme drought is abnormal. Comparison with the pattern of their occurrence in the past, severe drought was recorded.

Spatial distribution of drought stages

The spatial distributions of SPI corresponding to 3-, 6-, and 9-month drought scales (not shown) and 12-month drought scale are divided into periods of 1985–1994, 1995–2004 and 2005–2014 as shown in Fig. 10. The analyzed results

Table 5 Statistic of drought moderate, severe and extreme events appeared through the stages

Stage	Drought scale	An Giang	Vinh Long	Can Tho	Hau Giang	Tien Giang	Tra Vinh	Bac Lieu	Dong Thap	Long An	Ben Tre	Soc Trang	Kien Giang	Ca Mau
1985 1994	Moderate	15	24	16	3	7	6	8	18	13	18	18	27	19
	Severe	4	8	7	9	16	6	13	6	6	13	5	2	3
	Extreme	1	4	5	11	6	7	2	0	0	1	9	0	0
1995 2004	Moderate	4	6	3	4	3	3	11	15	7	5	0	7	4
	Severe	3	1	1	1	3	5	5	5	7	1	3	5	2
	Extreme	7	0	0	0	9	0	0	2	2	0	0	0	0
2005 2014	Moderate	10	3	13	7	1	2	11	11	9	11	15	9	14
	Severe	3	0	7	1	0	2	1	0	6	4	8	6	17
	Extreme	0	0	7	0	0	0	0	0	0	3	3	7	3

The red boxes implies the drought scales have occurred in coastal provinces of study area

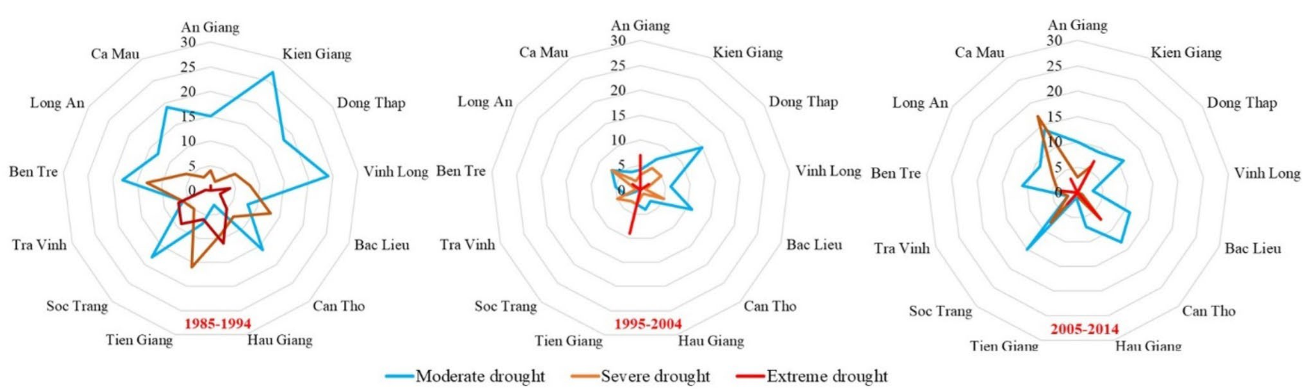

Fig. 9 Number of drought events corresponding to occurred moderate, severe and extreme drought for periods of 1985–1994, 1995–2004 and 2005–2014

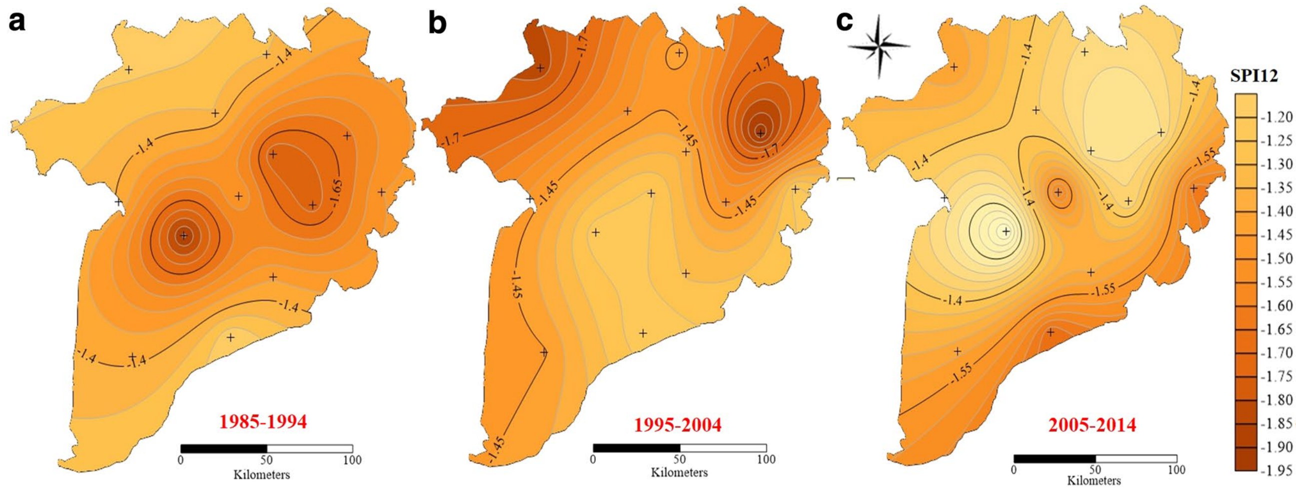

Fig. 10 Spatial distributions of drought for stages 1985–1994, 1995–2004 and 2005–2014

of drought risk using Arcview GIS software showed that moderate and severe drought occurred in the central provinces in the period of 1985–1994 only (Fig. 10a). This is explained by a mean annual precipitation at the central provinces decreased significantly compared to other regions and droughts, therefore, are occurred more drought than other regions.

For the period of 1995–2004, moderate and severe drought also appeared in the northeastern and northwestern provinces (Fig. 10b). The main reason is during the period of 1995–2004 mean annual precipitation at the northeastern and northwestern provinces also decreased significantly, while for the period of 2005–2014, the drought trends gradually shifted to southern coastal provinces, which can be clearly observed in Fig. 10c.

The analyzed results of precipitation data showed that mean annual precipitation in the period 2005–2014 at the coastal provinces significantly decreased and this explained why the coastal provinces are considered to have abundant precipitation, are occurred extreme drought.

Conclusion

The study analyzed drought time scales to estimate the spatial and temporal drought distributions in the period 1984–2015. Four main drought intervals were detected including 1990–1992, 2002–2003, 2010–2011 and 2014–2015 where in stage 1990–1992 the most extreme drought occurred at 11 out of 13 provinces with risk peak −2.63 recorded and lasts for 29 months.

On average, the moderate, severe and extreme droughts appeared 33.69 times/32 years, 18.84 times/32 years and 7.30 times/32 years, respectively. Results also showed that the study area has become drier during stage 2005–2014 and the spatial distribution of drought has tended to shift to coastal provinces where they are considered to be abundant moisture content. It implies that the study area in the stage 2005–2014 received less precipitation than the stages 1985–1994 and 1995–2004.

The results have indirectly indicated that the southern and southeast coastal provinces of the study area where agricultural activities are mainly depending on precipitation are facing the threat of water shortage.

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