ASSESSMENT OF DROUGHT INDICES USING DIFFERENT METHODS IN SOUTH CENTRAL COAST OF VIETNAM

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ABSTRACT

Drought is a naturally occurring periodical event associated with significant decrease of water availability over a region. In the South Central Coast of Vietnam, drought causes great economic and environmental damage. Various methods are used for the identification and quantification of drought. Among them, drought index K, based on the water balance have been recently developed and used for Vietnam, however, single drought index does not provide the comprehensive drought information since climatic conditions vary from region to region. The objectives of the study are to compute severity of past drought events using various meteorological drought indices and to compare the quantitative values of drought attributes obtained using various meteorological drought indices. Results of the study indicated that three indices (K_y, SPI, RDI) indicate extreme drought rarely occurs, moderate drought and non-drought are common occurrences from 1984 to 2017 in study area. While comparing three indices, K_y, SPI and RDI did not reflect the accurate drought situation in the study area based on actual recorded drought. Therefore, a new drought index ($K_{y\ (w)}$) based on annual evapotranspiration and precipitation was recommended to be used for monitoring drought. This study would be helpful to national hydro meteorological services for monitoring and early warning of drought and future climate change adaptation in the region.

1. INTRODUCTION

Drought is one of the worst disasters in the world. Drought is a climatic phenomenon that is caused by the deficiency of precipitation over a certain period of time, leading to a water shortage for human activities and environment (Sivakumar et al., 2010). In the last 4 decades, droughts accounted for only 6% total number of natural disasters but it caused 35% of deaths and 8% of total economic losses (WMO, 2014). Drought affects all part of our environment and our life such as economic, environmental and social impacts in both direct and indirect ways. Therefore, understanding drought components have drawn the attention of meteorologists, hydrologists, and agricultural scientists (Vu et al., 2014). There are many different methodologies used for monitoring droughts such as SPEI and PDSI (Palmer 1968) in the United States, CZI by the meteorological Centre of China (Wu et al.2001), DI by National Meteorological Centre of Australia (Gibbs and Maher 1967), RDI in many meteorological services of European countries, and SPI (McKee et al. 1993), however, single drought index does not provide the comprehensive drought information since climatic conditions vary from region to region. Based on our best knowledge, two widely indices for drought are the Palmer Drought Severity Index (Palmer, 1965) and the Standardized Precipitation Index (McKee et al., 1993) that have been applying in mostly Asia countries. For example, Yusof et al. (2014) applied SPI to assess rainfall characteristic over Peninsular Malaysia. Zhang et al. (2014) used SPI of 3 months to monitor winter wetness and dryness in Southeast China. Vu (2014) investigating drought over the Central Highland, Vietnam, using SPI and regional climate models. The choice of drought index is very important for effective monitoring of drought in a region. Therefore, the main emphasis of present study is the comparison of various drought indices and to evaluate the applicability and performance of drought indices in South Central Coast of Vietnam. The specific objectives of this study are (1) to compute severity of past drought events using various meteorological drought indices and (2) to compare the quantitative values of drought attributes obtained using various meteorological drought indices. In addition, deep understanding outcome of the present study would be helpful to national hydro meteorological services for monitoring and early warning of drought and future climate change adaptation in the region.

2. DATA COLLECTION AND METHODOLOGY

2.1. Study area and data collection

The study area included mainland of three southernmost provinces (Khanh Hoa, Ninh Thuan, and Binh Thuan) in the South Central Coast of Vietnam. It lies between latitude from 10^{0}33’42”N to 12^{0}53’26”N, and longitude from 107^{0}23’41’’E to 109^{0}26’45”E. Weather in this area is influenced by the coastal plain and Truong Son Mountain Range with tropical monsoon climate characterized by high temperature and precipitation with very high variability.

Table 1. Description of climate data collected.

SN	Data	Number	Spatial/Temporal Resolution	Time period
1	Precipitation	30 stations	Daily	1984-2017
2	Temperature	11 stations	Daily	1984-2017
3	Humidity	11 stations	Daily	1984-2017

Sources: Vietnam Institute of Meteorology, Hydrology and Climate Change (IMHEN), 2017

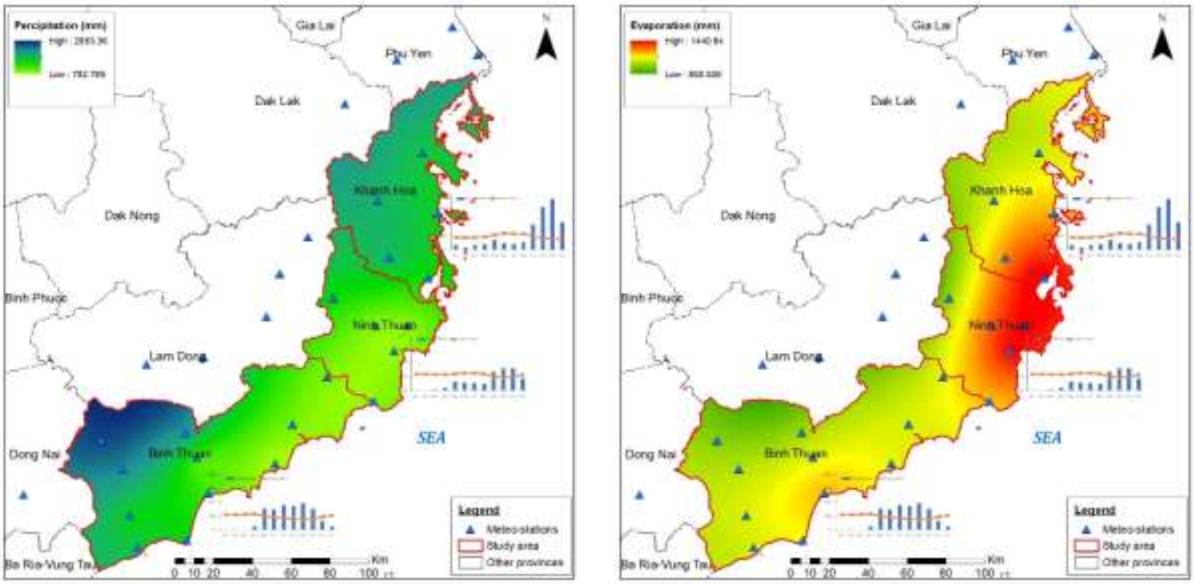


Figure 1. Distribution of total annual precipitation (left) and evaporation (right)

2.2. Methodology

A variety of drought indices have been developed to quantify whether or not a region is experiencing a drought and to categorize the seriousness of the drought. In the study area, we selected 2 different methods to quantify drought index (K) as listed bellows:

2.2.1. Drought index (K)

In this method, the drought is assessed by meteorological drought index which is determined by the **Drought index (K)** (MONRE, 2012).

$$K_{th} = K_1 = \frac{E_{0(th)}}{R_{(th)}} \qquad (1)$$

Where, *K_{th} (K_1): Drought index in month;*

R_{th}: Total monthly precipitation;

$E_{0\,(th)}$: Total monthly evaporation.

In this equation (1), if K_{th} = 1, the evapotranspiration is equal to precipitation; if K_{th} <1 evapotranspiration is less than rainfall; and if K_{th} > 1 the evapotranspiration is greater than the rainfall, i.e. the month is considered to be drought.

Table 2. Drought classification.

No.	K_{th} values	Drought category	Symbol
1	< 1	Non drought	Kh_N
2	≥ 1 - 2	Moderate drought	Kh_1
3	≥ 2 - 4	Severe drought	Kh_2
4	≥ 4	Extreme drought	Kh_3

The drought category is suggested by MONRE (2012) as follows (table 2).

The annual drought is calculated by the following formula:

$$K_y = \frac{\sum E_{0(y)}}{\sum R_y} \qquad (2)$$

Where, *Ky: Annual drought index;*

R_y: Total Annual precipitation;

$E_{0\,(y)}$: Total Annual evaporation.

2.2.2. Standardize precipitation index (SPI) and Reconnaissance Drought Index (RDI)

SPI is consider as the main meteorological drought index that countries should use to monitor and establish drought level for early warning (Hayes, 2011). The method used for SPI computation was developed by McKee et al. (1993) and Edwards and McKee (1997) and widely applied to study relative departures of precipitation from normality (Tue et al., 2016). The SPI is based on the probability of precipitation for any time. The probability of observed precipitation is then transformed into an index.

In comparison with SPI, DRI is more representative than SPI because it considers the full water balance instead of precipitation alone, hence, Tsakiris & Vangelis (2005) proposed meteorological droughts to be conceptualized as water deficits representing the water balance deficit between input (precipitation) and output (reference evapotranspiration). The RDI is expressed in three forms: the initial value (α_k), normalized RDI (RDI_n) and standardized RDI (RDI_{st}) which used for comparison in this study.

The SPI and RDI formula has been mentioned in several studies (Thomas at el., 2016; Jain, V. K at el., 2015; Nazahiyah at el., 2014; Karavitis at el., 2011). In time scales, RDI_{st} and SPI values were calculated for the time scales of 12 months for the period of hydrological years of 1984/85–2016/17. To avoid the solution derived directly from the pertinent distributions graphs, the SPI and RDI calculating tool was applied.

Table 3. Drought classification by SPI value and RDI_{st} value

No.	SPI / RDI values	Drought category
1	> 2	Extremely wet
2	1.50 ÷ 1.99	Severely wet
3	1.00 ÷ 1.49	Moderately wet
4	0.99 ÷ -0.99	Near normal
5	-1.00 ÷ -1.49	Moderate drought
6	-1.50 ÷ -1.99	Severe drought
7	< -2	Extreme drought

3. RESULTS AND DISCUSSION

The study was carried out to compare the two drought indices for applicability in the Vietnam. The common steps to compare drought indices are as follows: (1) Calculation of drought indices (Figure 2); (2) Comparison of the drought characteristics by identifying each drought index (Figure 3); and (3) Comparison of drought indices using historical annual drought.

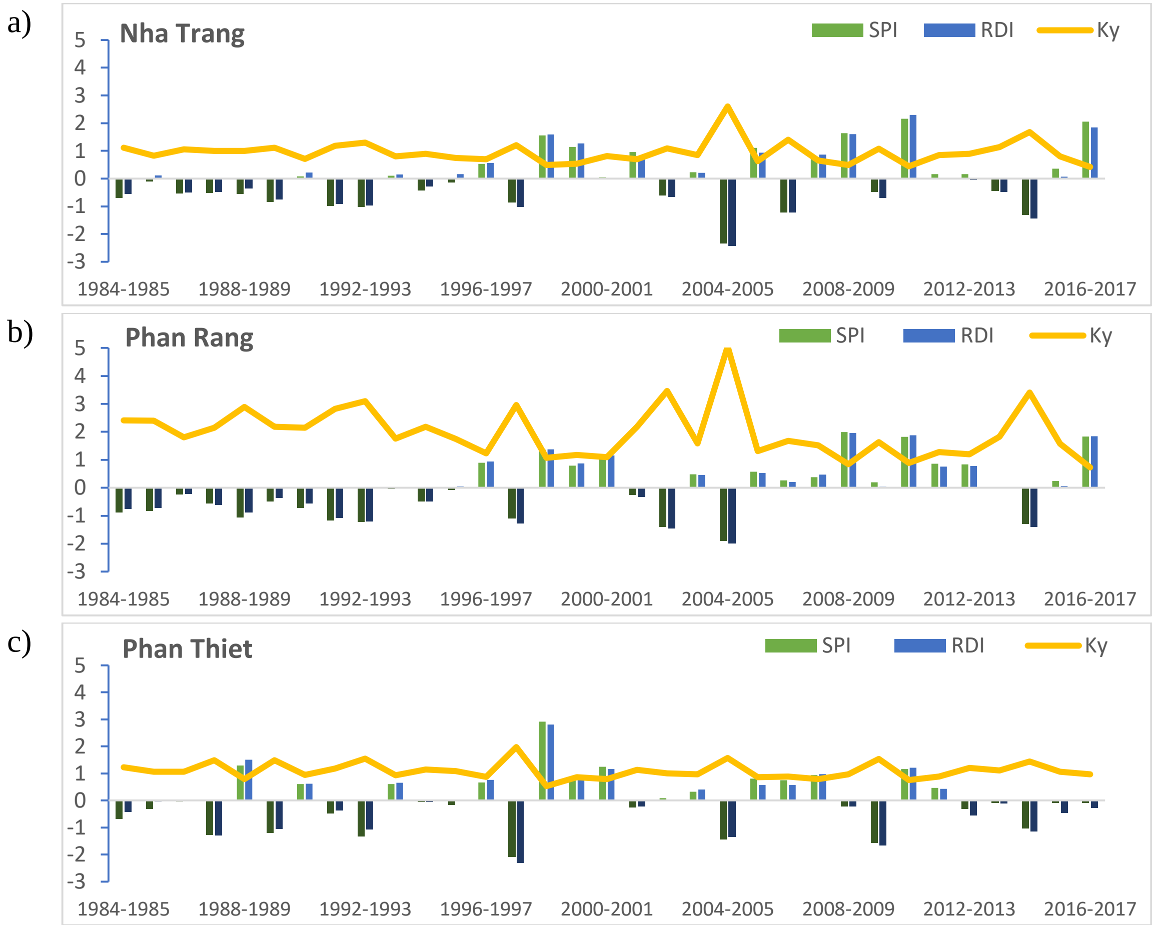


Figure 2. Drought indices at (a) Nha Trang (b) Phan Rang (c) Phan Thiet station.

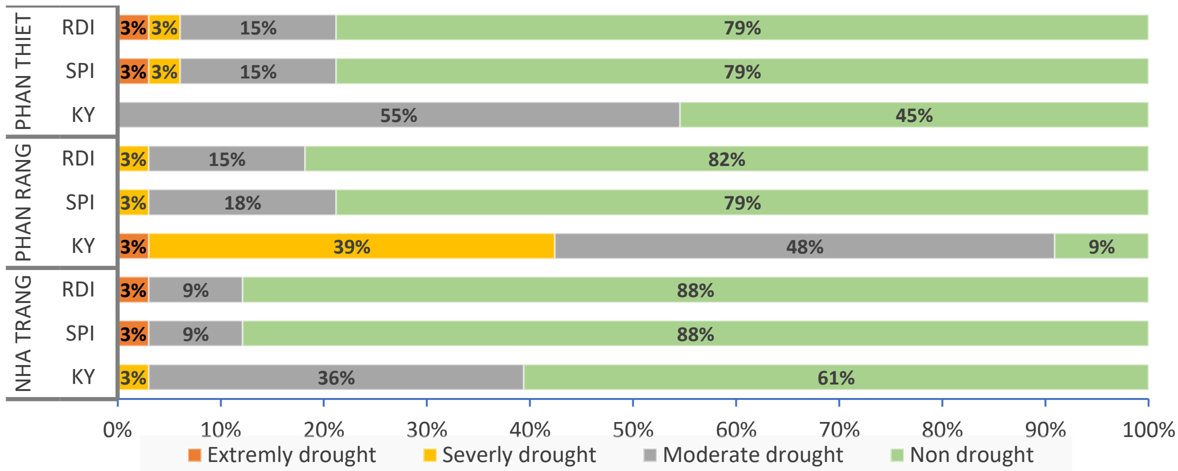


Figure 3. Comparison of percentage of drought severity categories identified

As seen in the figure 2, SPI and RDI have similar value trend, ranging from -3 to +3 in which values > -1 (non-drought) majority occupying (> 80%) and values < -2 (extreme drought) account for 2% of the SPI and 1% of the RDI. The calculation result of the drought index K_y shows that: the value <1 (non-drought) accounts for 49%, and values $\geq$ 4 (extreme drought) account for 1%. Frequency of drought occurrence in 3 meteorological stations which located in each province were shown in the figure 3. The SPI and RDI show that: from 1984 to 2017, drought occurs seriously in Nha Trang (extreme drought) and Phan Rang (severe drought) in water year 2004-2005, while in Phan Thiet drought was at extreme in 1997-1998 and at severe in 2009-2010; The remaining years are mainly non-drought (26/33 years in Nha Trang and Phan Rang, 29/33 years in Phan Thiet). Using the K_y index shows that drought: in Phan Rang occurs more frequently and severely than in other areas, extreme drought occurred in 2004-2005, severe drought occurred in 13/33 years, moderate drought occurred in 16/33 years, and only 3 years is not drought; and in Nha Trang and Phan Thiet, it is mostly non-drought or moderate drought. Drought events determined based on the Ky, SPI and RDI indices will be compared with the actual drought records in the study area in recent years (table 4).

Table 4. Comparative of drought indices based on drought events from 2014 to 2017

Hydrological year	Drought category			
	Observed drought *	***K_y***	***SPI***	***RDI***
Nha Trang station (Khanh Hoa province)				
2014 - 2015	Severe drought	Moderate drought	Moderate drought	Moderate drought
2015 - 2016	Moderate drought	Non-drought	Non-drought	Non-drought
2016 - 2017	Non-drought	Non-drought	Non-drought	Non-drought
Phan Rang station (Ninh Thuan province)				
2014 - 2015	Extreme drought	Severe drought	Moderate drought	Moderate drought
2015 - 2016	Severe drought	Moderate drought	Non-drought	Non-drought
2016 - 2017	Non-drought	Non-drought	Non-drought	Non-drought
Phan Thiet station (Binh Thuan province)				
2014 - 2015	Extreme drought	Moderate drought	Moderate drought	Moderate drought
2015 - 2016	Extreme drought	Moderate drought	Non-drought	Non-drought
2016 - 2017	Moderate drought	Non-drought	Non-drought	Non-drought

** Sources: People's Committee of Khanh Hoa, Ninh Thuan and Binh Thuan province (2014, 2015, 2016); FAO (2016); The UN (2016), and MARD (2016).*

In table 4, the dryness levels which were determined by Ky, SPI and RDI indices were lower than the actual recorded drought in the study area. The cause of its difference is due to the climatic characteristics in the study area with a clear division of rainy and dry seasons. In the rainy season, total annual rainfall occupied from 70% to 90% total rainfall a year whereas dry season is almost no or very little rain. Therefore, we proposed the weighted drought index to determine the drought index K because of precipitation is unevenly distributed a year in the study area.

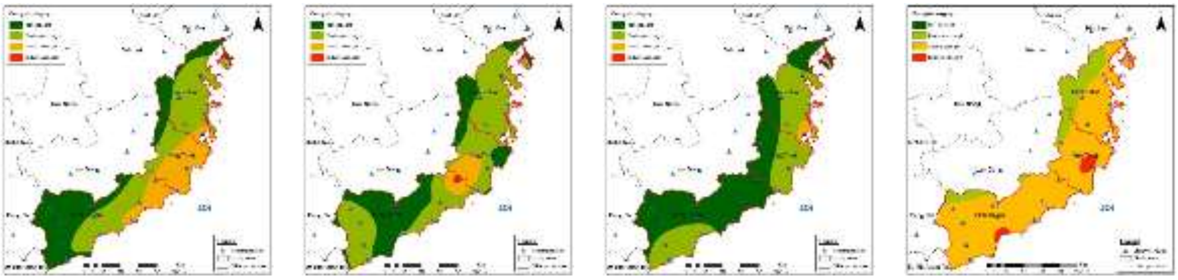
$$K_{y(w)} = \frac{a \times \sum \frac{E_{0(wet)}}{R_{wet}} + b \times \sum \frac{E_{0(dry)}}{R_{dry}}}{\mathrm{a + b}} \qquad (3)$$

Where, $K_{y(w)}$: *Annual drought index;*

R_{wet}; R_{dry}: *Total rainfall in rainy (wet) season and dry season;*

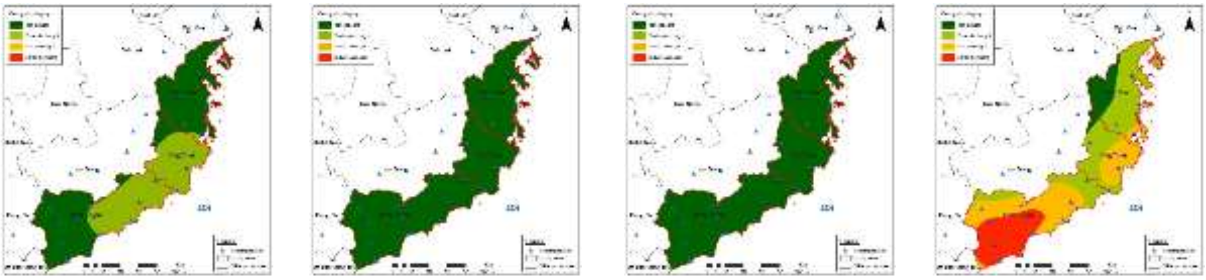
$E_{0(wet)}$; $E_{0(dry)}$: *Total evaporation in rainy (wet) season and dry season;*

a, b: number of month in in rainy (wet) season and dry season, a+b =12.



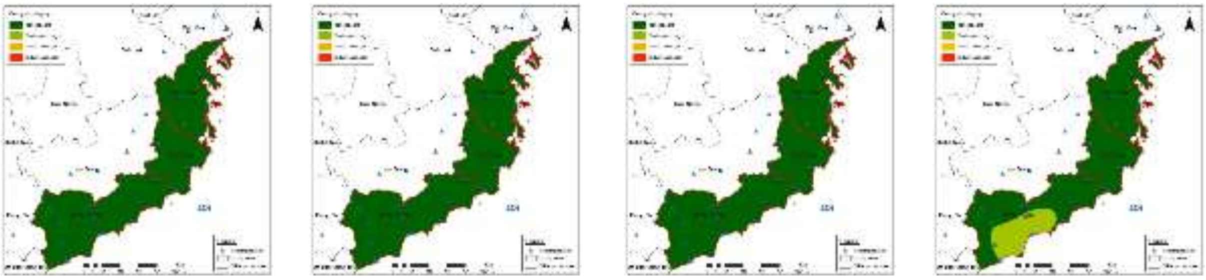
a) b) c) d)

Figure 4. Spatial distribution of drought using different methods: (a) K_y, (b) SPI, (c) RDI and (d) $K_{y(w)}$ in hydrological year 2014-2015



a) b) c) d)

Figure 5. Spatial distribution of drought using different methods: (a) K_y, (b) SPI, (c) RDI and (d) $K_{y(w)}$ in hydrological year 2015-2016



a) b) c) d)

Figure 6. Spatial distribution of drought using different methods: (a) K_y, (b) SPI, (c) RDI and (d) $K_{y(w)}$ in hydrological year 2016-2017

Drought zoning of the study area in the last 3 years is shown in figures 4, 5 and 6 shows that the results of drought zoning based on the $K_{y(w)}$ index are similar trend with actual drought records. Although the $K_{y(w)}$ method is relatively accurate in drought characteristics in the study area, however, it still has a few limitations, for example it does not indicate the onset and end of droughts which are important features of drought monitoring.

4. CONCLUSION

This study was designed to evaluate three indices for the assessment of drought occurrences in the South Central Coast of Vietnam. The results of the study indicated that RDI and K method require evapotranspiration and rainfall data while the SPI requires only rainfall data However, utilization of the K or RDI might be better for monitoring agricultural droughts

Due to the climatic characteristics of the south central coast of Vietnam, rainfall is mainly concentrated in the rainy season whereas the dry season is less rainy and prolonged, using K_y, SPI and RDI did not reflect the accurate drought situation in the study area because of its drought characteristics lower than the actual recorded drought. Therefore, a new drought index based on annual evapotranspiration and precipitation was recommended to be used for monitoring drought

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