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Research Paper

Application drought indexes to calculate the drought frequency: Case Study in the Center of Vietnam

D. D. Truong[2], D. Q. Tri[1]*, T. T. Dat[2] and L. T. T. Ha[3]

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ABSTRACT

In this paper, we used observation data of rainfall from 1981 to 2016 and average temperature to calculate drought indices: J, Ped, and SPI for the center region of Vietnam. The first advantage of three indicators is that they were based on meteorological variables such as rainfall and average temperature data. The second advantage is that it is possible to estimate the value each month, contributing to the examination of the drought details in a specific period. These indicators easily classify the degree of drought from no drought, normal to moderate and extreme drought. In this study, it is shown that when determined according to the J index, drought is more clearly delineated according to the level of drought. In addition, the J index reflects a significant level of seasonal drought. The result of drought frequency map shows that the extreme drought occurs in the two provinces of Hoi Xuan in Thanh Hoa and Quy Nhon in Binh Dinh. Through the J index, the study also statistically detailed the level of drought for some typical stations in the Central region of Vietnam.

1. Introduction

Drought is one of natural disasters and causes adverse effects on a large scale; however, the starting and ending time is often very difficult to identify (Hyman et al., 2008; Dai, 2011 and 2013). The effects of droughts often accumulate over a relatively long period, ranging from a few months to several years. Droughts can be broadly classified into four types: meteorological, agricultural, hydrological, and socioeconomic droughts, and the former three types of droughts are with respect to the shortages of precipitation, soil moisture, and runoff, respectively (Wilhite and Glantz, 1985; American Meteorological Society, 2004). According to Beran and Rodier (1985), the main characteristics of drought are to reduce the amount of water available in a period of a particular area. Yevjevich (1967) argues that the inconsistency in a precise definition of drought is one of the obstacles in determining drought. Thus, drought is a deficit of rainfall in a defined period and a shortage of flow during a period will seriously affect the water resources management (Hisdal and Tallaksen, 2000). This also includes pollution of rivers, reservoirs or other ecological water sources. Nguyen, and Nguyen (2004) drought is a phenomenon of serious, prolonged the shortage of rainfall, reducing the moisture in the air and water in the soil, depleting river and stream flows, lowering pond water level and water level in underground aquifers, etc (Tsakiris et al., 2007; Mishra and Singh, 2010; Lesk et al., 2016; Doan et al., 2019; Nguyen et al., 2019). It can be seen that almost all climatic regions can experience droughts including heavy rain areas, although the climate characteristics between regions are different. It is caused by abnormal weather climate such as less frequent rainfall in a long time or temporary shortage. If the rainfall is just enough to meet the minimum needs of production and surroundings environment, drought is also taken place, this is the prevailing situation on the

[1] Sustainable Management of Natural Resources and Environment Research Group, Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, VIETNAM, doanquangtri@tdtu.edu.vn
[2] Faculty of Environmental, Climate Change and Urban Studies, National Economics University, Hanoi, VIETNAM, tranthodat@neu.edu.vn; truongdd@neu.edu.vn
[3] Viet Nam Meteorological and Hydrological Administration, Hanoi, VIETNAM, leha246@gmail.com
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regions with monsoon climate, where there are differences between rainy and dry season. Rainfall is still the main factor causing drought, so in the framework of this study, we used the general definition of drought: “drought is the result of a lack of average natural rainfall for a long time, usually for a season or more”. Thus, drought is an extreme climate phenomenon characterized by low-standard rainfall for a long time, occurring in almost all parts of the world and affecting many economic and social fields, especially in water sources and agricultural production.

Vietnam is one of the countries affected heavily by climate change, increasing the extreme of drought along the country, causing great impacts on the environment, the economy, and political society as well as human health. Over the past 40 years, drought has been becoming increasingly serious and often occurred in the North, Central and South Vietnam. In 1997-1998 period, the rainfall season ended one month early and the total rainfall was only 30-70% compared to the average of many years, the averaged temperature monthly was 1-3^{o}C higher than the average. The hot spells occurred continuously, resulting in the water level on the rivers to be 0.5-1.5 m below averaged. The flow in rivers and streams are very small or dry, the water level of reservoirs was approximately equal to the dead water level. Saline intrusion 15-20 km into the field in Central and South Vietnam made many freshwater sources salty.

Thus, on this study, we focus on the frequency of drought in the region typically have practical significance, in order to bring solutions to prevent, contribute to reducing the harmful effects it has on life living people.

2. Materials and methods

2.1 Description of study site

The central Vietnam have the terrain extending in the north-south direction from Thanh Hoa to Binh Thuan on 9 latitudes with two main directions of the northwest-southeast areas (from Nghe An to Thua Thien Hue) and midle - south (from Da Nang to Binh Thuan) (**Fig. 1**). Topography Central hilly quite complex includes system Truong Son mountain range stretching from Thanh Hoa to the highlands Kon Tum and overhang gradually to the sea make up much nose, multiple passes split the central in the different climate. A system of many consecutive passes near the sea such as Deo Ngang, Hai Van, Cu Mong and Ca Pass are the boundaries that are not only administrative divided between some provinces but also the boundary of weather and climate. Due to the topographic conditions and the domination of many impacted weather systems, the level of drought in the Central region is often more severe than the other parts of Vietnam. Typically the drought in 1998, due to the impact of El Niño from May to October with basic features as the late summer monsoon and its intensity is weaker than the average one, taken place later than usual, less rainfall and tropical cyclone, more hot spells, so the drought had occurred particularly severe in Central region. According to a preliminary review of the central provinces (from Thanh Hoa to Binh Thuan), in the 511,892 ha of winter-spring rice cultivation, 39,866 ha of drought and 3,922 hectares of rice died; in 281,900 ha of summer-autumn rice cultivation, 82,273 ha of drought, 36,004 ha of rice died; in 318,419 ha of cultivated season rice, there are 81,230 ha of drought, 19,393 ha of rice were dead. Despite mobilizing all measures to prevent drought, it still cost 68.4 billion VND (according to damage statistics of the Ministry of Agriculture and Rural Development).

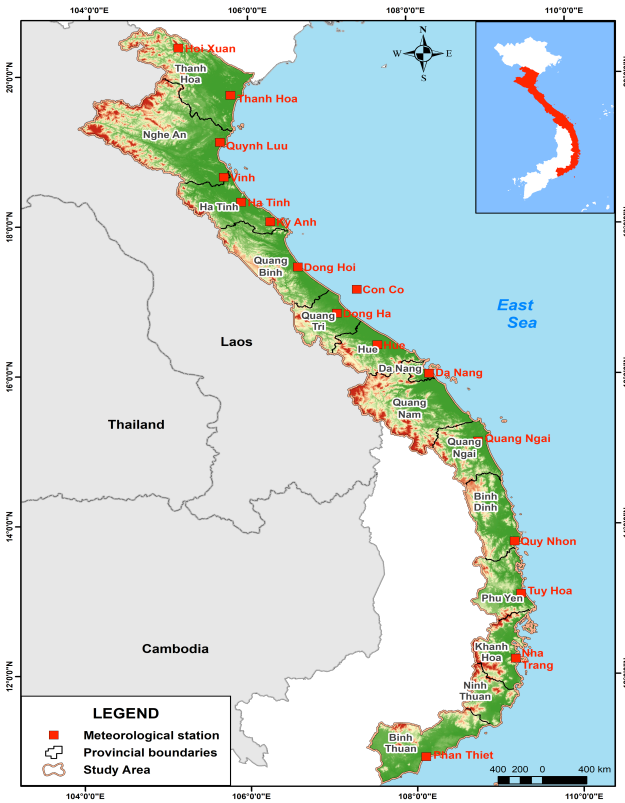


Fig. 1. Location of the study area

2.2 Data collection

In this study, we used total monthly rainfall and monthly average temperature in the period of 1981-2016 to calculate drought indicators. Observation data were collected from 16 surface observation stations in the Northern Central (B_4 region) and the Southern Central (N_1 region), includes Ha Tinh, Ky Anh, Quynh Luu, Thanh Hoa, Vinh, Dong Ha, Dong Hoi, Hue, Hoi Xuan, Con Co, Da Nang, Quang Ngai, Nha Trang, Phan Thiet, Qui Nhon and Tuy Hoa.

2.3 Standardized Precipitation Index (SPI)

McKee et al. (1993) developed and introduced the SPI index for the purpose of identifying and monitoring drought. As reported by the World Meteorological Organization WMO launched SPI is based on the

probability of precipitation for any timescale. SPI index is being used in operational more than 70 countries. The scientists appreciate the flexibility of the SPI, it is used at national institutes, universities, and meteorological and service centers around the world as part of the drought warning and forecast (Zhang et al., 2008; Vicente-Serrano et al., 2010; Zhang et al., 2012; Bonaccorso et al., 2015; Park et al., 2018). The advantage of the SPI index is that with only one input parameter is precipitation, SPI index can be calculated for different time periods, provide early warning and assess the severity of drought. SPI index is calculated by the following formula:

$$SPI = \frac{P_i - \bar{P}}{\sigma} \quad [1]$$

According to the World Meteorological Organization (WMO), the dry or wet SPI index is decentralized as shown in **Table 1**.

Table 1. Drought Classification for SPI values

No.	SPI	Degree of drought
1	≥ 2	Extremely wet
2	1.5 ÷ 1.99	Very wet
3	1.0 ÷ 1.49	Moderately wet
4	0.5 ÷ 0.99	Lightly wet
5	-0.49 ÷ 0.49	Wet
6	-0.5 ÷ -0.99	Lightly drought
7	-1.0 ÷ -1.49	Moderately drought
8	-1.5 ÷ -1.99	Severely drought
9	< -2.0	Extremely drought

2.4 Aridity Index - AI

Aridity indices were reviewed by Walton (1969) and Stadler (2005). The simplest aridity index is solely based solely on precipitation. A commonly used rainfall-based definition is that an arid region receives less than 10-in or 250 mm of precipitation per year. This criterion for aridity was used by the Intergovernmental Panel on Climate Change (IPCC, 2007). Semiarid regions are commonly defined by annual rainfalls between 10 and 20-in (250 and 500 mm). The UNESCO (1979) provides an aridity index (AI) based on the ratio of annual rainfall (P) and the rate of potential evaporation (ET_p) as follows:

$$AI = \frac{P}{ET_p} \quad [2]$$

Where ET_p is calculated by Penman (1948) formula. Warm arid areas have low P, high ET_p and very low AI values. UNESCO provides a classification of drought based on AI with dry areas defined by values less than 0.2 (**Table 2**).

Table 2. Classification of drought according to AI

No.	Values	Degree of drought
1	< 0.03	Extremely drought
2	0.03 < AI < 0.2	Drought
3	0.2 <AI < 0.5	Lightly dry
4	0.5 < AI < 0.65	Dry

Because ET_p data may not be available, it limits the use of the AI index by UNESCO. De Martonne (1926) gave a drought index (J) instead of using temperature as a function of ETp as follows:

$$J = \sum_{i=1}^{12} \frac{P_i}{T_i + 10} \quad [3]$$

The above formula applies to J index calculated for the 1-year period, with P_i is being the i-th total monthly rainfall, T_i is the i-th monthly average temperature. J index can use the formula as follows:

$$J = \frac{P}{T + 10} \quad [4]$$

However, to calculate the J index for each month, this formula can be used flexibly as follows:

$$J = \frac{12 * P}{T + 10} \quad [5]$$

The above equation is suitable for temperature T greater than -9.9^oC.

Table 3. Classification of drought according to J index

No.	Values	Degree of drought
1	≤ 5	Extreme drought
2	5 ÷ 20	Moderate drought
3	20 ÷ 30	Drought
4	30 ÷ 60	Wet
5	≥ 60	Very wet

2.5 Ped index

The Ped index introduced by Pedey (Ped, 1975) used to determine drought, this index is used at Hydro-Meteorological Centre of Russia. The advantage of this indicator is that it is easy to classify weather conditions (drought or wet) (**Table 4**). The formula is calculated as follows:

$$Ped = \frac{\Delta T}{\sigma_T} - \frac{\Delta P}{\sigma_P} \quad [6]$$

Drought will occur when the temperature increased and precipitation fell sharply.

Table 4. Classification of drought according to Ped index

No.	Values	Degree of drought
1	< 0	Wet
2	0 ÷ 1	Normally
3	1 ÷ 2	Light drought
4	2 ÷ 3	Moderate drought
5	> 3	Extreme drought

Ped index depends on temperature and precipitation variants, positive values of Ped correspond to the dry time or a warmer temperature regime, while negative values of Ped correspond to the wet weather.

In order to easily analyze and compare results easily, the study has set the thresholds for determining drought ability for the three indices J, SPI and Ped as **Table 5**.

Table 5. Classification of drought according to J, SPI and Ped index

Degree of drought	J values	SPI values	Ped values
Normal	≥ 30	≥ -0,49	< 1
Light Drought	20 ÷ 30	-0,5 ÷ -0,99	1 ÷ 2
Moderate Drought	5 ÷ 20	-1,0 ÷ -1,49	2 ÷ 3
Extreme Drought	≤ 5	< -1,5	> 3

3. Results and discussion

3.1 Drought frequency with J, SPI, Ped index

The frequency of the drought is calculated as the percentage (%) of the number of months in which the thresholds appear in the period from 1981 to 2016. The results showed that, for the B_4 region, the rate of no drought increase gradually from J index, SPI index and the most Ped index, also with the region N_1 differ slightly,

there is no drought rise from Ped to SPI index. The J index gives no drought in both regions B_4 and N_1, from 58.6-63%, while the Ped is 55.8-75.5% (**Table 6**).

For light drought, all J, SPI, Ped indexs can described, however, with different frequencies: the J and SPI index are much higher than the Ped index, with 16-28% and from 23-26%, corresponding. Ped index in light drought is 14-18% in B_4, N_1 region.

Table 6. Drought frequency (%) in Central Viet Nam

Degree of drought	B_4 region			N_1 region		
	J	SPI	PED	J	SPI	PED
No drought	63.0	74.3	75.5	58.6	71.1	55.8
Light drought	16.4	22.9	18.3	27.8	26.2	14.1
Moderate drought	4.2	2.8	3.9	7.6	2.5	3.2
Extreme drought	0.5	0.0	0.2	6.0	0.0	0.2

For light and moderate drought, J index is more useful than SPI and Ped indexs in both regions B_4 and the N_1, with a frequency corresponding to each region are 4.2% and, 7.6% respectively, while the SPI and Ped index only range from 2.5-2.8% and from 3.2-3.9%. This result shows that when the J index is determined, drought is more clearly according to the levels.

Through the analysis of three drought indicators in the Northern Central region (B_4) and the Southern Central region (N_1) during 1981-2016, it can be seen that almost indicators describe drought, however the intensity of drought has different between these indices. For J index, At Hoi Xuan (Thanh Hoa) station is the most extreme drought with frequency of 19.7%, for Ped index is Quang Ngai and Quy Nhon station which are the most extreme drought with the frequency of 1.9%, for the SPI index, Hoi Xuan and Ha Tinh station are the most extreme drought with the frequency of 1.6% (**Fig. 2b**).

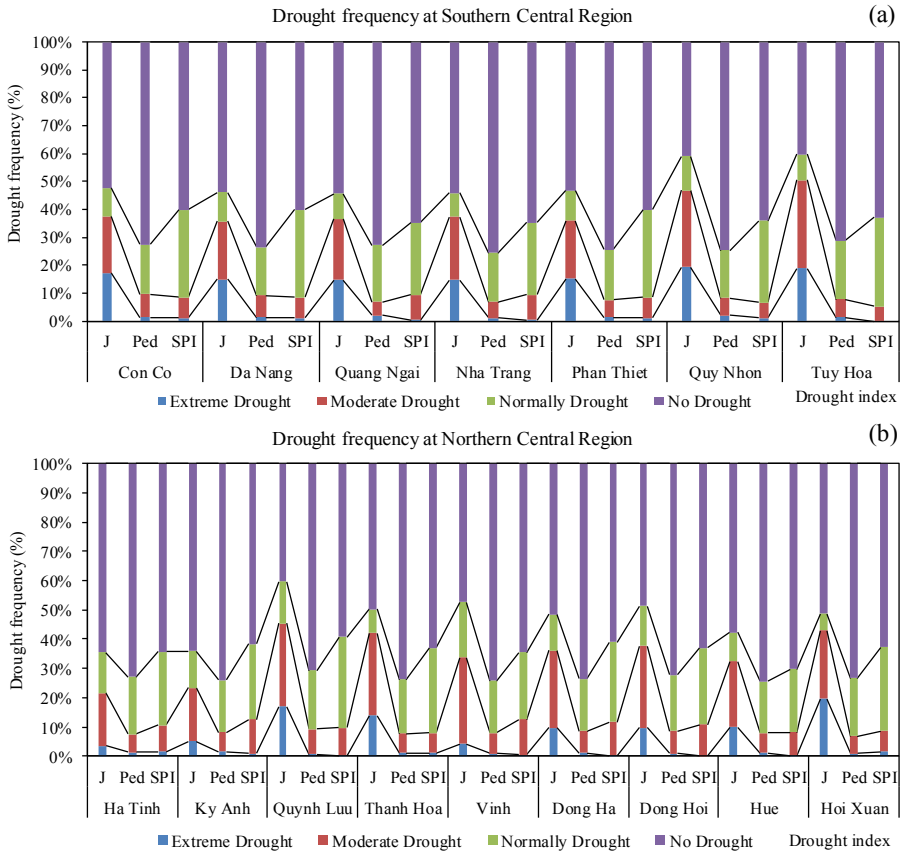


Fig. 2. Drought frequency in: (a) the Southern Central region; (b) The Northern Central region

3.2 Monthly drought frequency of three indices

In the next section, the frequency of monthly changes in the Central region (divided into 2 climate region B_4 and N_1) presented by J, SPI and Ped index. In particular, the J index gives a different frequency line to the other two indices. The J index showed the drought happens in high monthly frequency above 50% and low monthly frequency with under 50%. The other indicators, the SPI and Ped index showed the monthly drought frequency from 20% to 50% for the 12-month term.

The frequency of J index showed that the drought in the northern climate also adheres to the climate rule. Drought mainly concentrated in the winter months from January to April with frequency above 60%. The period from May to September, the frequency of drought occurs very low (under 10%) or almost no drought, because this period is the wettest seasons in Vietnam, especially in June, July and August. On September to November, in the B_4 region, the subtropical high pressure axis is only about 18-20^{o}N which makes the inter-tropical convergence zone (ITCZ) moves across through Central region. Additional, the first waves of cold air move down from China to Central Vietnam become a warm and wet air mass combined with terrain conditions facing the sea such as: the Ngang Pass, the Hai Van Pass, the Ca Pass. The combined together between air mass and terrain condition make convection clouds are formed and causes heavy rain. That is why almost no occurs drought in the wettest month from September to November. And the same with the N_1 region, drought does not appear in this period because of the late storms or tropical cyclones from South China Sea. The eastern wind convergence from the edge of the subtropical high pressure or the effects of distant circulation of low vortex areas that formed from ITCZ combined with the southwest monsoon bring heavy rainfall for the northern part of Vietnam. In the dry season, from the late November to April next year, the winter months start in the Northern part with northeast monsoon activity and it gradually and completely replaces the southwest monsoon. The northeast wind move from the North to Central region and encounters the huge Truong Son mountain range, has brought heavy rainfall for the coastal areas and the eastern side of Truong Son. After crossing and leaving a considerable amount of moisture in the eastern side of Truong Son, the cold and wet air mass becomes drier which makes drought would be easier happened in winter months in some areas such as: Ninh Thuan, Binh Thuan - areas of the Southern Central Vietnam.

With the SPI and Ped index: similar to the northern climates, in the south, the drought result of these two indicators occurring evenly from January to December with frequency from 20-40%.

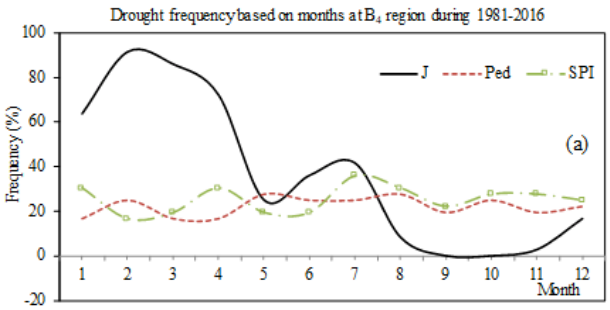


Fig. 3. Monthly drought frequency in: (a) the Northern Central region

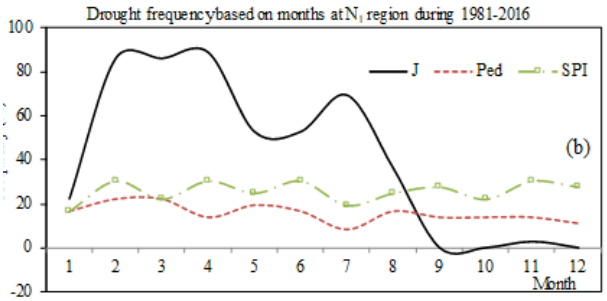


Fig. 4. Monthly drought frequency in: (b) the Southern Central region

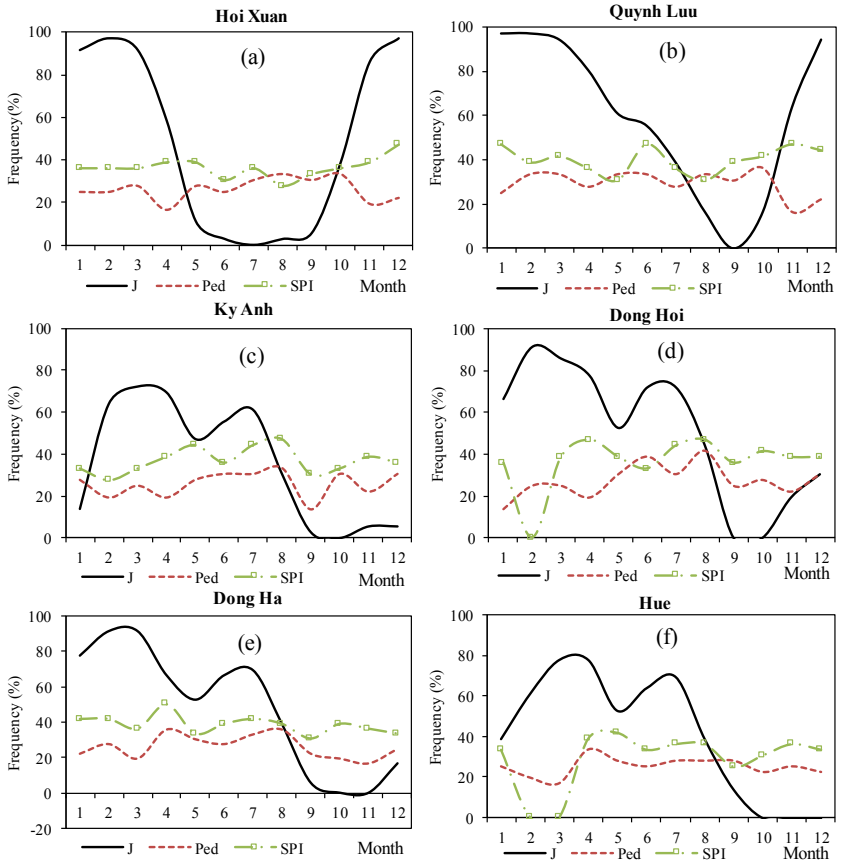


Fig. 5. Monthly drought frequency at each station in the Northern Central

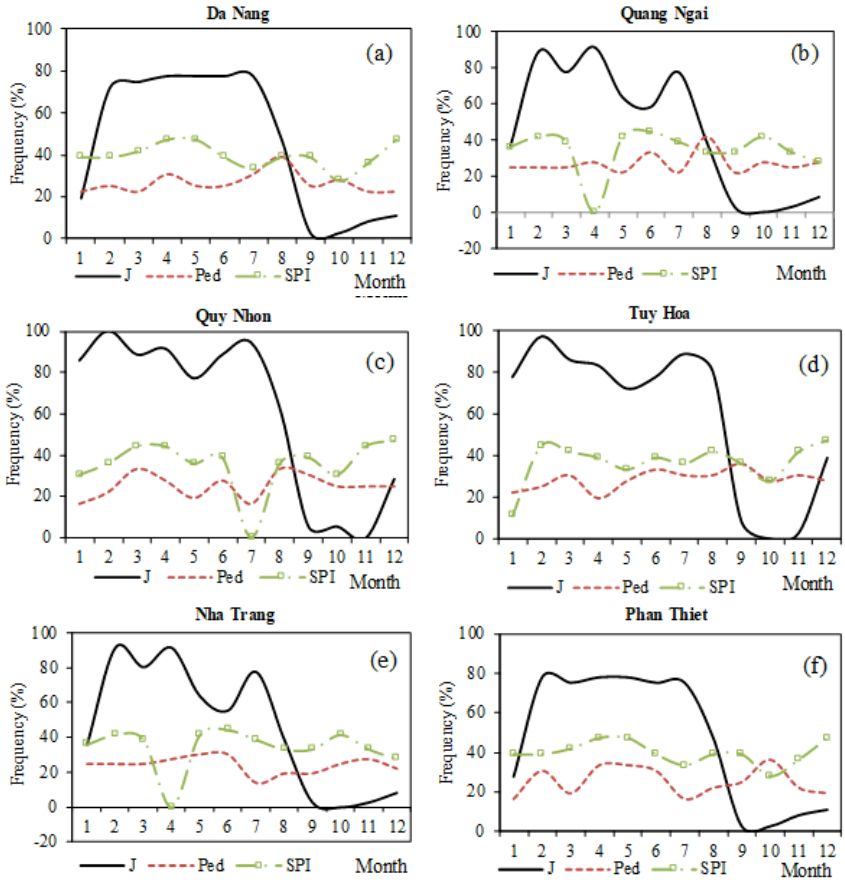


Fig. 6. Monthly drought frequency at each station in the Southern Central

3.3 Classification of drought according to J index

The monthly average drought frequency with J index from 1981-2016 in the Northern Central region shows that drought tendency is quite similar at all stations (**Fig. 6a**). Drought is usually happen in the winter months and in early spring month with the frequency of over 50% (from December previous year to April next year). Especially, February seems to be the highest month which had drought with the possibility of 85% in high possibility, followed by March with the occurrence rate of 84%. In the rainy seasons, from August to November, is less likely to occur in the drought, with the lowest frequency falling in September, with 4%. This is quite consistent with the natural climate in the North Central region, August and September were being two rainy months due to the influence of tropical convergence and disturbances such as: storms, tropical depression.

The monthly average drought frequency with J index from 1981-2016 in the Southern Central region has the same drought tendency at all stations (**Fig. 6b**). Especially, in the southern Central coast, the drought months usually occurs from February to August, and February is the highest month with the current rate of 86%. The next second month has high drought frequency is April with a rate of 84%. The month with less likely to occur drought falls in September and October, these are the two largest rainy season months in this area.

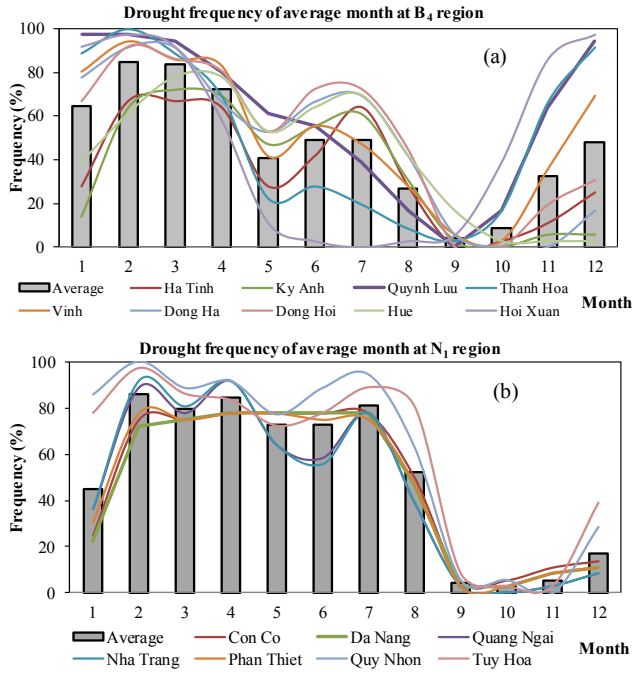
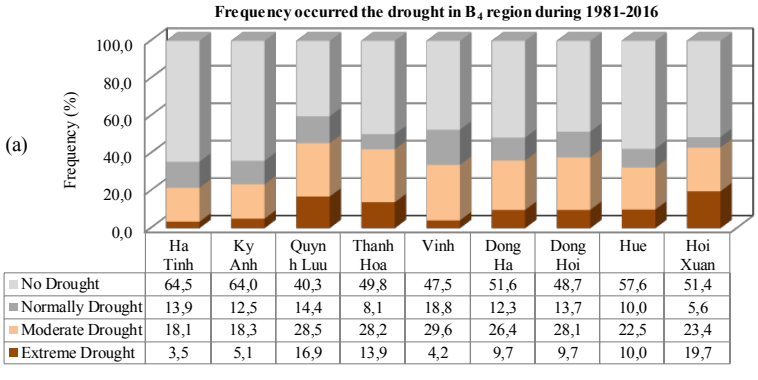


Fig. 7. Monthly average drought frequency with J index in: (a) the Norththern Central region; (b) The Souththern Central region

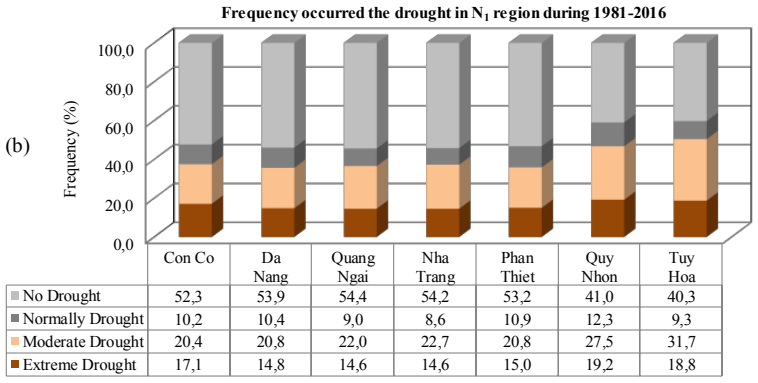
During the period of 1981-2016, at Hoi Xuan station is the most extreme drought of B_4 region with 19.7% frequency, next to Quynh Luu station with 16.9%, and Ha Tinh station is the lowest frequency of extreme drought with 3.5% (**Fig. 7a**). Statistical data see that 1990 is the year of severe drought at Ky Anh station, especially the extreme drought with 0mm total monthly rainfall occurring in April and July. In September and November are two months of rainy season in B_4 region, so there is no serious drought. At Hoi Xuan station, the extreme drought during the last 36 years fell in January 1984, October 2004. At Ky Anh station, in the years 02/2009, 4/1990, 6/2006 and 8/1985 with the total rainfall in these months is 0 mm per month. At the worst extreme drought at Dong Hoi station occurred in the years: 3/1998. At Dong Ha station, the extreme drought occurred in 6/2006, 7/1985, 7/1990, while at Quynh Luu station, extreme drought in the years: 5/2012, 12/1981.

During the period of 1981-2016, according to J index, in the N_1 region, Quy Nhon station is the most extreme drought with the monthly frequency of 19.2%, Next to Tuy Hoa station with 18.8%, and at Quang Ngai and Nha Trang stations are the lowest frequency with the same frequency of 14.6% (**Fig. 7b**). According to statistical data, some years of very severe droughts in N1 region with J index less than value 5, very severe droughts often occur in the winter months from December of the previous year to August of the following year. In February, March, and April appear the heaviest term of the year, which can be seen at Quy Nhon station appearing the most severe drought from December last year until April of the following year, occurred in the years: February 1983, January 2005, January 3, 1992, February 2010 and December 2013. At Tuy Hoa station, extreme drought occurred from February to April in the years: 02/1983, 4/1983, 02/1990, 4/1992, 3/1992, 02/2010. At Da Nang station, extreme drought in 3/1989, 4/1987, 6/1993 and 6/2006.

Fig. 8 shows that the extreme drought often occur in Thanh Hoa, Nghe An province of the Northern Central and Binh Dinh, Phu Yen, Ninh Thuan, Binh Thuan province of the Southern Central with 15 to 20% frequency. The other provinces, the extreme drought are lower with 10 to 20% frequency, especially Ha Tinh province is the lowest extreme drought in the Central with about 5 to 10% frequency.



	Ha Tinh	Ky Anh	Quyn h Luu	Thanh Hoa	Vinh	Dong Ha	Dong Hoi	Hue	Hoi Xuan
No Drought	64,5	64,0	40,3	49,8	47,5	51,6	48,7	57,6	51,4
Normally Drought	13,9	12,5	14,4	8,1	18,8	12,3	13,7	10,0	5,6
Moderate Drought	18,1	18,3	28,5	28,2	29,6	26,4	28,1	22,5	23,4
Extreme Drought	3,5	5,1	16,9	13,9	4,2	9,7	9,7	10,0	19,7



	Con Co	Da Nang	Quang Ngai	Nha Trang	Phan Thiet	Quy Nhon	Tuy Hoa
No Drought	52,3	53,9	54,4	54,2	53,2	41,0	40,3
Normally Drought	10,2	10,4	9,0	8,6	10,9	12,3	9,3
Moderate Drought	20,4	20,8	22,0	22,7	20,8	27,5	31,7
Extreme Drought	17,1	14,8	14,6	14,6	15,0	19,2	18,8

Fig. 8. Classification of drought at each station in: (a) the Northern Central region; (b) The Southern Central region

4. Conclusion

The J-index indicates the highest likelihood of drought occurrence compared to the SPI and Ped indices in the period of 1981-2016. In the calculation process, results indicators J also shows that drought appeared earlier, so this is also the factor that the index J is used to calculate the start of the drought, helping to identify earlier the starting time of drought.

After studying J index for B_4 region and N_1 region, we give some conclusions as follows:

In the Northern Central region, most of the stations in the region tend to have similar droughts; specifically, the frequency of droughts usually falls in the winter months - early spring with regular frequency of over 50%, for example from December of the previous year to April of the following year, in which February is the month with the highest frequency of drought with 85%, followed by March with the occurrence rate of 84%. The rainy season, from August to November, is less likely to happen, with the lowest frequency falling in September, with 4%. This is in accordance with climate rules in the Northern Central region, with August and September being two rainy months in the region due to the influence of tropical convergence and disturbances: inter tropical convergent zone, tropical storm. According to J-drought index, at Hoi Xuan station, the most serious drought occurs in the B4 area with the frequency of 19.7%. For Hoi Xuan station, the most extreme drought during the last 36 years fell in 01/1984, 10/2004.

In the Southern Central region, monthly drought usually occur from February to August, in which February is a regular period of drought with the frequency of 86%, the month with the frequency of drought occurrence followed by April with a frequency of 84%. Monthly droughts appear less in September and October because these are the maximum rainy season in N_1 region. According to J index, in the N_1 region, at Quy Nhon station is the place where extreme drought occurs in the area with the frequency of 19.2%. At Quy Nhon station, extreme droughts often occurs from December of the previous year until April of the following year, it occurred in: 02/1983, 01/2005, 03/1992, 02/2010 and 12/2013.

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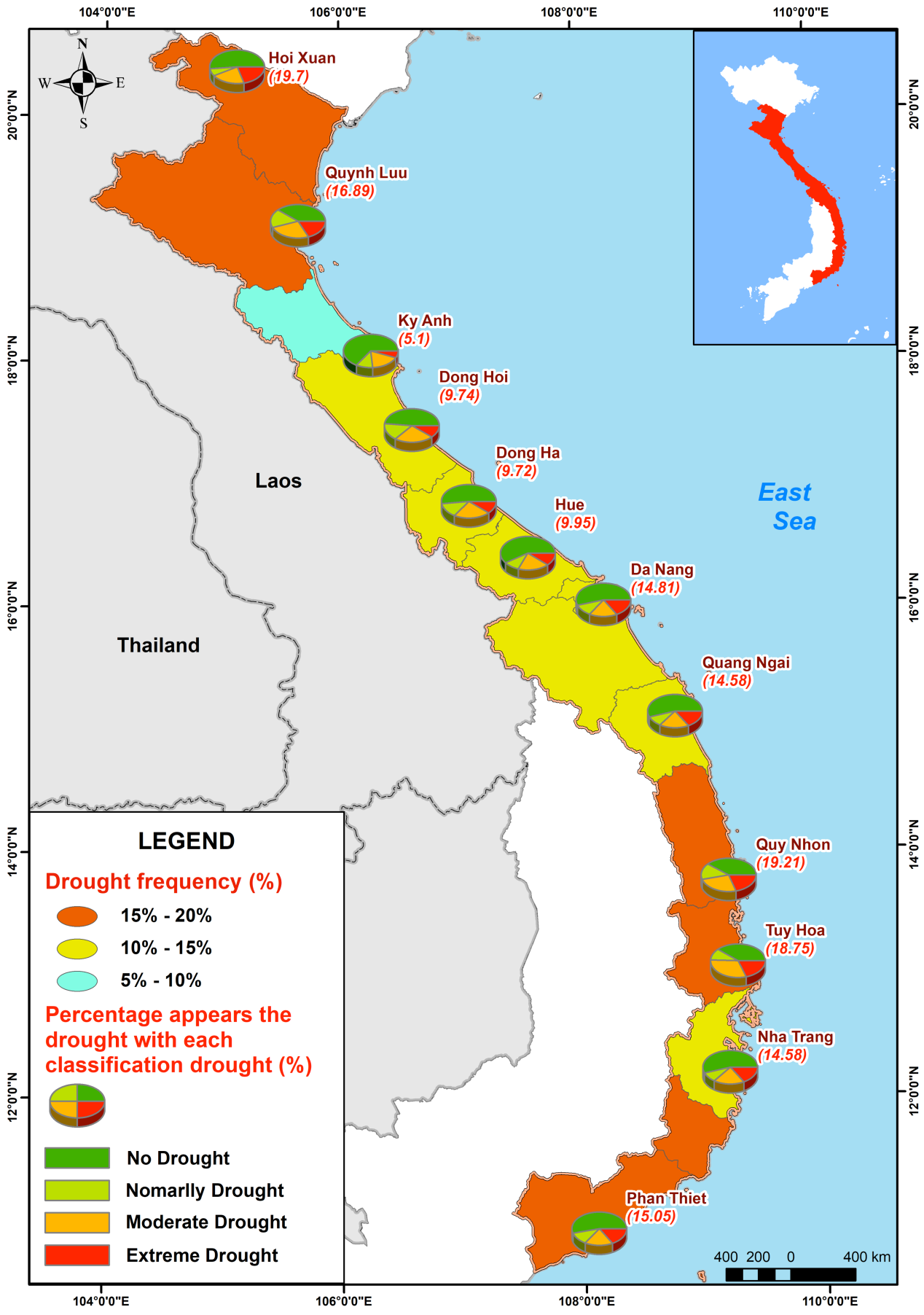

Fig. 9. Drought frequency map in the Central of Viet Nam

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Symbols and abbreviations

P	Total annual rainfall (mm)
P_i	The i-th monthly average rainfall (mm)
T	Monthly average temperature (^oC)
ΔT	deviation of air temperature (^oC)
ΔP	deviation of precipitation (mm)
σ_T	standard deviation of temperature (^oC)
σ_P	standard deviation of precipitation (mm)
ETp	rate of potential evaporation