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ASSESSMENT OF METEOROLOGICAL DROUGHT IN THANH HOA PROVINCE

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Abstract. The drought degree at Thanh Hoa province was assessed through drought index K and monthly drought frequency. According to the climate averages, the annual mean drought index K<1 represents that the region is humid for the whole year. However, in terms of the drought degree, during the winter period (from November to February of the following year), this is a drought period throughout the study area with a K value ranging from 1 to 3.9 with 2 classes: mild drought, and moderate drought. The extreme drought years often coincide with the years of strong El Niño. The drought regionalization for Thanh Hoa province was built based on statistical processing of drought degree for each meteorological station in the area, and criteria for determining drought seasons and the number of months with significant drought frequency ≥ 30%. The results divided Thanh Hoa province's territory into 3 drought classes: mild drought, moderate drought, and extreme drought. The results of the assessment of meteorological drought in the Thanh Hoa province are the scientific basis for the arrangement and conversion of crop structure in agricultural production and making an important contribution to the prevention and mitigation of drought hazards.

Keywords: meteorological drought, Thanh Hoa province, drought index, drought frequency.

1. Introduction

Drought disaster is one of the natural disasters that has serious impacts on many aspects of the ecological environment, socio-economic conditions, and human health. Particularly, in the present trend of global socio-economic development, increasing human impacts on the natural environment such as deforestation for hydroelectric power and overlogging lead to a reduction in the ability to regulate the function of surface water, and lowering groundwater levels, inappropriate land use planning along with global

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climate change and increased extreme weather events (El Nino and La Nina), which make drought worse in many areas.

At the 15th session of the Conference of the Parties (COP15) of the United Nations Convention to Combat Desertification (UNCCD) in Abidjan, Côte d'Ivoire reported that since 2000, the number and duration of drought events had increased by 29%. drought accounts for 15% of natural disasters but causes the greatest loss of life with about 650,000 deaths during the period 1970-2019. From 1998 to 2017, at a global scale, drought caused economic losses of about $124 billion. In 2022, drought occurred seriously in many regions of the world, on continents such as Europe, America, Africa, and Asia, causing more than 2.3 billion people to face water stress situation; Nearly 160 million children faced severe and prolonged drought [1].

At present, there is not a common definition of drought and its criteria due to the local variable on drought characteristics and their impact. According to WMO, there are about 50 different definitions of drought conditions based on the relationship between hydrometeorological conditions, but in a general sense, the mentioned definitions were based on the shortage of precipitation over a relatively long period. Drought can be classified into 4 types, including meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought [2]. Of these, meteorological drought most objectively reflects the drought caused by climatic and weather conditions, and this drought type cannot be prevented.

Several methods were developed as drought assessment tools, such as measuring rainfall deficit, decreasing surface water flows and shortage of water stocks, and using a drought index. Drought indices are commonly used worldwide to quantify the assessment of drought conditions and drought severity [3, 4]. Investigation of drought characteristics such as severity, duration, and frequency plays an important role in planning and managing water resources in river basins [5].

In the world, there are many different meteorological drought indices such as the Lang humidity index (1913); Koppen humidity index (1918); De Martonne humidity index (1926); Reidel humidity index (1920); Angstrem humidity index (1936); Selianinov humidity index (1948); standardized precipitation index SPI (1993); Palmer drought severity index (1965), standardized evapotranspiration - precipitation relationship index SPEI (2010), ... Over the past decade, by using drought indices, the drought monitoring field has made great strides, with a number of monitoring and early warning systems established in several countries and regions. Each drought index has its own advantages/disadvantages, and each may not accurately represent drought conditions for all other regions [6]. Depending on each drought index, different sets of input variables were required for the calculation process, but in general, critical parameters include rainfall, temperature, soil ability for water maintenance, and other additional parameters for representing moisture conditions in the system.

Among the meteorological drought indices, the standardized precipitation index (SPI) and standardized evapotranspiration-precipitation relationship index (SPEI) are the most well-known and widely used index. They are a measure of the severity of unusual drought events, which can be calculated for different periods of precipitation accumulation (e.g., 1 to 48 months), and are statistically linked to impacts on diverse economic and environmental fields [7]. However, there is no unified drought index to

describe drought conditions, and many drought indices are used as a tool to monitor meteorological drought [8]. Therefore, the application of drought indices depends on the specific conditions of each region as well as the availability of a monitoring database system in a particular region.

Vietnam is in the tropical humid monsoon climate zone, with abundant water resource potential, but due to profound seasonal climate differentiation, every year the country has a period of excess moisture, which goes in hand with a period of severe moisture deficiency, and drought often occurs [9]. The results of the drought assessment in Vietnam provided an overview of the drought characteristics and their distribution in several regions [10, 11]. Many drought indices have been used to assess the current situation and the impact of drought on the socioeconomic situation [12-15]. Within the past 60 years, more droughts occurred in the whole country, with an increase in drought frequency and intensity. More severe drought events appeared, almost during the winter-spring crop period (from January to April) and the summer-autumn crop period (from May to August) [16]. Drought during the winter season often occurs in the Northern, Southern, and Central Highlands regions; Drought during the Summer season prevails in the Northern Central and Southern Central regions. Drought frequency is higher in winter time in comparison with summer time and can appear all months in some locations in the Central Highlands and the Southern regions [11, 17].

The serious drought from 1997 - 1998 occurred nationwide due to the El Nino phenomenon, lasting 15 months (April 1997 - June 1998), the total drought-affected area was 898,962 hectares (accounting for 16% of the cultivated area) with 122,081 hectares of cropland lost, about 35,000 hectares of burned forest, more than 4 million people lacking domestic water, and the budget for drought solutions at over 10,000 billion VND [10]. In 2003, 2006, 2010, and 2015, droughts caused the absolute loss of thousands of hectares of rice crop, and the accounting damage for each drought event was about 2,500 - 5,000 billion VND.

Due to the impact of climate change, drought disasters are likely to appear with increasing frequency and intensity. To eliminate drought loss, it is necessary to identify the causes, drought zoning, and drought intensity and improve drought forecasting capacity. Therefore, choosing drought indices to assess, monitor, and warn of drought is very important. Determining drought characteristics such as beginning, ending, duration, and extent as well as intensity, frequency, and relationship between drought and climate is an extremely necessary task [18].

Thanh Hoa province is in the North Central region of Vietnam, 150 km south of Hanoi capital, and 1,560 km from Ho Chi Minh City. The North borders three provinces of Son La, Hoa Binh, and Ninh Binh, the South borders Nghe An province, the West borders Hua Phan province (Lao People's Democratic Republic), and the East borders the Gulf of Tonkin. The province's terrain gradually lowers from west to east, divided into 3 distinct geographic regions, including the mountainous and midland regions with an area of 839,037 hectares (75.44% of the whole provincial area), involving 2 sub-regions, mountains with an average altitude of 600 - 700 m, and slope of over 25º, and midland with an average altitude of 150 - 200 m, and slope from 15 - 20º; the delta area has an area of 162,341 hectares (14.61% of whole provincial area) characterized by flat land and local flood regime; the coastal area has an area of 110,655 hectares, accounting for 9.95%

of the entire province's area, a narrow land along 102 km of coastline, characterized by relatively flat terrain, sandy and muddy beaches, and river mouths. The province's temperature and humidity regime are divided into two distinct seasons: the low-rainy season (from November to April of the following year) with low temperatures due to the influence of the Northeast monsoon circulation; the rainy period (from May to October) with high temperatures and activity of tropical cyclones. The local regime of sun, wind, evaporation, and flow... also affects the temperature and humidity regime of the province. Therefore, determining the level of drought in the territory is also one of the tasks that contribute to preventing and mitigating natural disasters.

Therefore, the purpose of the study is to assess the degree of meteorological drought in Thanh Hoa province, based on the appropriate selection of drought indices, calculate index value, and drought zoning on a map that presents meteorological drought distribution, provide a scientific base to help manage and use water resources reasonably and effectively, and ensure sustainable socio-economic development and adaptation to global climate changes.

2. Content

2.1. Data used and study method

2.1.1. Data used

The calculation is mainly based on collected data series about meteorological parameters at 7 meteorological stations, and 14 hydrological stations during the period 1961-2020 (Table 1), and takes into account the collected data from 14 rain gauges (Monitoring of those rain gauges was stopped in 2017).

Table 1. Meteorological and hydrological stations at Thanh Hoa Province

No.	Station name	Longitude	Latitude	No.	Station name	Longitude	Latitude
1	Hoi Xuan[1]	105°07’	20°22’	12	Giang[2]	105°45’	19°52’
2	Bai Thuong[1]	105°23’	19°54’	13	Kim Tan[2]	105°40’	20°07’
3	Yen Dinh[1]	105°40’	19°59’	14	Lang Chanh[2]	105°15’	20°08’
4	Thanh Hoa[1]	105°47’	19°45’	15	Len[2]	105°50’	19°58’
5	Sam Son[1]	105°54’	19°45’	16	Ly Nhan[2]	105°35’	20°01’
6	Nhu Xuan[1]	105°34’	19°38’	17	Muong Lat[2]	105°34’	20°32’
7	Tinh Gia[1]	105°47’	19°27’	18	Ngoc Tra[2]	105°46’	19°36’
8	Cam Thuy[2]	105°28’	20°12’	19	Quang Chau[2]	105°51’	19°46’
9	Chuoi[2]	105°39’	19°39’	20	Thach Quang[2]	105°31’	20°21’
10	Cu Thon[2]	105°53’	19°58’	21	Xuan Khanh[2]	105°34’	19°55’
11	Cua Dat[2]	105°18’	19°53’				

Note: [1:] meteorological station, [2:] hydrological stations.

Source: Vietnam Institute of Meteorology, Hydrology and Climate Change.

- Best track data of Tropical Cyclones (TC) operating in the northwest Pacific region (WNP) during the period 1961-2020 published by the China Meteorological Administration (CMA) (https:// tcdata.typhoon.org.cn/en/zjljsjj_zlhq.html).

- Data on El Nino years in the period 1961 - 2020 (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php).

2.1.2. Study method

The drought index is the ratio between the main revenue and the main expenditure portions in the local water balance. The drought index (K) is calculated as follows:

- Monthly drought index (K_{th}) is calculated according to the formula:

$$K_{th} = \frac{E_{th}}{R_{th}} \quad (1)$$

E_{th} is the monthly average of Piche evaporation (mm); R_{th} is the monthly average of rainfall (mm).

- Annual drought index (K_n) is calculated according to the formula:

$$K_n = \frac{E_n}{R_n} \quad (2)$$

E_n is the annual average of Piche evaporation (mm); R_n is the annual average of rainfall (mm).

The drought degree was classified based on drought index value, with 5 classes: very moisture (K < 0.5); moisture (K: 0.5 - 1.0); mild drought (K: 1.0 - 2.0); moderate drought (K: 2.0 - 4.0); and extreme drought (K > 4.0) [10].

- The drought degree at a particular location was determined by monthly drought frequency (P_{th}):

$$P_{th} = \frac{m(H_{th})}{n(H_{th})} \quad (3)$$

P_{th} is the monthly drought frequency; H_{th} is the month with drought events; $m(H_{th})$ is the number of years in which the drought month occurred; $n(H_{th})$ is the number of years when monthly drought monitoring is implemented

Monthly drought events are determined from the monthly rainfall series R_{th}. Depending on the climate season, there are different monthly drought standards. Here, we use the drought month criteria depending on particular seasons, suggested by Ngu N.D (2002) [13]:

- Drought month in the winter season (from November to February of the following year): $R_{th} \leq 10$ mm.

- Drought months in the spring season (March and April) and the autumn season (September and October): $R_{th} \leq 30$ mm.

- Drought month in the summer season (from May to August): ≤ 80 mm.

2.2. Results and discussion

Calculation results of drought index K (Table 2) show that most areas of Thanh Hoa province have a drought period (K_{th} > 1) lasting from November, December to February or March of the following year, with 4-5 months duration.

Table 2. Monthly and yearly drought value at Thanh Hoa Province

Station name	Monthly drought index value K_{th}												K_n	Drought duration
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Hoi Xuan	2.4	2.8	1.5	0.7	0.4	0.3	0.2	0.2	0.2	0.3	1.1	2.6	***0.4***	Nov-Mar
Bai Thuong	1.5	1.6	0.9	0.6	0.3	0.3	0.3	0.2	0.2	0.3	0.8	2.4	***0.4***	Dec-Feb
Yen Dinh	3.4	3.1	1.5	0.9	0.5	0.6	0.5	0.2	0.2	0.4	1.2	3.9	***0.6***	Nov-Mar
Thanh Hoa	2.4	1.9	1.0	0.9	0.6	0.6	0.5	0.3	0.2	0.3	1.1	2.6	***0.5***	Nov-Mar
Sam Son	2.5	2.2	0.8	0.9	0.6	0.9	0.6	0.3	0.2	0.4	1.1	2.6	***0.6***	Nov-Feb
Nhu Xuan	1.7	1.9	1.0	0.9	0.6	0.8	0.7	0.3	0.2	0.3	0.8	2.5	***0.5***	Dec-Mar
Tinh Gia	1.2	1.0	0.7	0.8	0.6	0.9	0.6	0.3	0.2	0.2	0.8	1.9	***0.5***	Dec-Feb

2.2.1. Yearly drought index

K_n values ranged from 0.4 to 0.6. This shows that, if only considered in terms of K_n, then Thanh Hoa province was sufficiently moist all year round. However, from year to year, the value of the annual drought index has changed relatively significantly. There are some years when the drought index is only about 0.3-0.4, but in special years it may reach 0.6-0.8. Particularly, during El Niño [19], the K_n index deviation is positive at almost all monitoring stations; the K_n index can be 2-3 times higher than the average of many years, and 3- 4 times higher than the years with low K_n values (1977, 1987, 1991; 1998, 2003) (Figure 1).

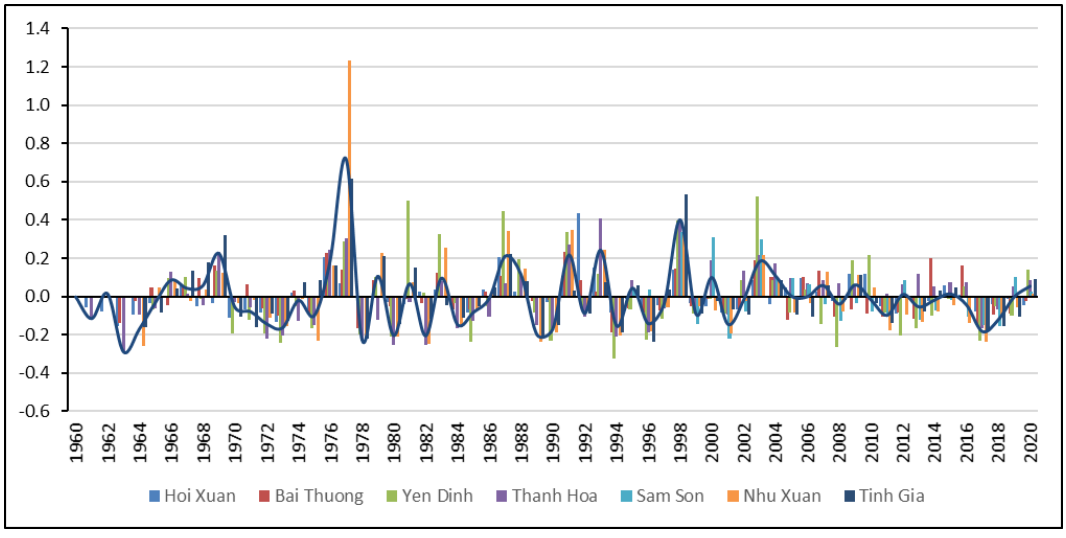

Figure 1. Deviation graph of yearly drought index value in Thanh Hoa province

2.2.2. Monthly drought index

The calculated results of the monthly drought value K_{th} show that the K_{th} value at the above-mentioned stations was highly variable, ranging from 0.2 – 3.9. Each year, there are about 4-5 drought months (from November, December to February, or March of the following year) with a K_{th} value > 1, with 1-3 months (from December to February of the following year) with a K_{th} value >2.

The monthly drought variation of the province has 1 maximum and 1 minimum peak. The maximum peak usually appeared in December with K_{th} values ranging from 2 to 3 (moderate drought). Except for the southeastern part of the province, an additional peak appears around June (Figure 2).

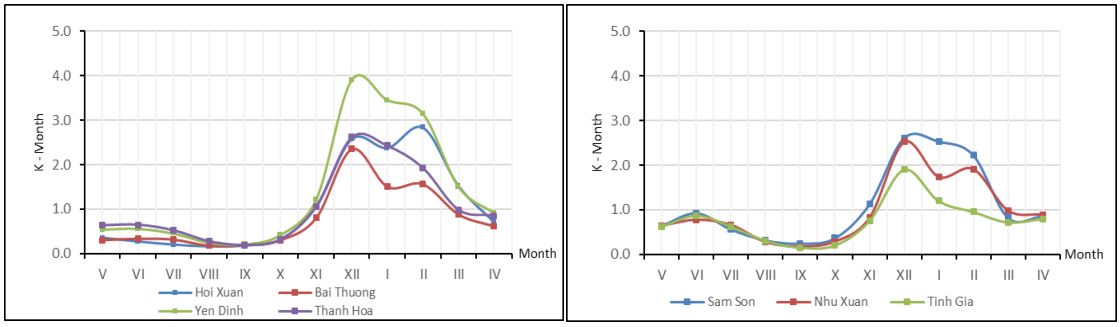

Figure 2. The monthly drought variation in Thanh Hoa province

From May to October, generally, the monthly drought value reaches its lowest level of the year, commonly fluctuating between 0.2 and0.6.or areas with an additional sub-minimum peak, this value can be up to 0.8- 0.9. September is the month with the lowest K_{th} value, with K_{th} value = 0.2 (Figure 2).

2.2.3. Monthly drought frequency

The drought degree was determined by the number of months (n) with significant drought frequency (> 30%). The drought degree in Thanh Hoa province is divided into 3 classes: mild drought (n ≤ 2 months of significant drought); moderate drought (n = 3-4 months of significant drought), and extreme drought (n ≥ 5 months of significant drought (Table 3).

Table 3. Monthly drought frequency at the monitoring stations (%)

No.	Station	Month												Frequency ≥ 30%
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	Hoi Xuan	57	48	48	7	5	2	0	2	0	11	20	48	***4***
2	Bai Thuong	20	15	33	10	2	7	2	0	2	8	15	31	***2***
3	Yen Dinh	44	36	57	21	20	15	15	2	2	5	18	43	***4***

4	Thanh Hoa	39	26	43	21	28	20	16	3	3	3	13	38	***3***
5	Sam Son	48	38	48	41	41	41	17	7	0	7	14	31	***7***
6	Nhu Xuan	25	28	44	21	25	16	15	2	2	7	11	30	***1***
7	Tinh Gia	11	11	20	23	31	28	30	5	0	3	7	25	***1***
8	Cam Thuy	44	27	42	12	8	2	2	0	2	10	25	52	***3***
9	Chuoi	43	33	43	16	34	30	25	2	2	3	21	33	***5***
10	Cu Thon	53	44	58	29	32	17	14	3	0	3	18	47	***5***
11	Cua Dat	11	4	24	9	2	2	0	0	0	7	11	18	***0***
12	Giang	56	35	53	26	14	26	14	0	0	7	23	58	***4***
13	Kim Tan	53	53	53	22	14	11	11	0	0	14	33	53	***5***
14	Lang Chanh	38	21	50	12	0	5	0	2	0	10	31	39	***4***
15	Len	53	37	47	37	21	16	5	5	0	5	16	58	***5***
16	Ly Nhan	54	42	58	19	14	5	10	5	3	9	21	50	***4***
17	Muong Lat	73	68	65	12	20	18	3	5	2	23	47	72	***5***
18	Ngoc Tra	26	12	30	16	21	33	26	7	2	2	7	21	***2***
19	Quang Chau	52	38	41	28	31	31	10	3	0	3	10	48	***6***
20	Thach Quang	48	37	47	17	13	12	7	3	2	15	32	60	***5***
21	Xuan Khanh	53	33	51	16	16	12	9	2	0	9	19	49	***4***

The dry season coincides with the Northeast monsoon season. The territory has the greatest drought frequency during the period from December to March. The frequency is not only high in the winter months but also in the late winter and spring months. In the summer and autumn months, there is very little drought, even almost no drought, because this period belongs to the rainy season in the territory (Table 3).

Winter months (from November to February of the following year) except for November at the beginning of winter, usually have a drought frequency ranging from 35-60%. The highest drought frequency was recorded in Muong Lat Station, located in the Ma River valley (reaching over 70% in December and January).

In spring months (March, and April), the drought frequency usually fluctuates between 40 and55% in March, and rapidly decreases in April, with drought frequency in this month usually fluctuating between 15 and 30%; in Sam Son alone, the drought frequency in this month remains high, reaching over 40%.

Summer months (from May to August) are the rainy periods in Thanh Hoa province. In the early summer months, May and June, usually the drought frequency is below 25%; however, these months, there is still a possibility of drought occurring in the southeastern coastal areas of the province (Sam Son, Tinh Gia, Chuoi, Ngoc Tra, Quang Chau). Drought frequency decreases rapidly in July and August, reaching the lowest value in August, with the monthly drought frequency ≤7%. Drought events during this period mainly appear during El Nino years. The reason is partly due to the decrease in tropical cyclones. The results of calculating the storm wind field using Tacasaki's semi-realistic model, using best track data in the Western North Pacific Region show that the number of tropical cyclones during Neutral years (Figure 3b) in comparison with El Nino years (Figure 3a) in coastal areas decreases by an average of 24.5% for the whole Vietnam and particularly 25% for Thanh Hoa province. Meanwhile, the proportion of rainfall during tropical cyclones is very high, with an average of about 10% of the annual rainfall [20].

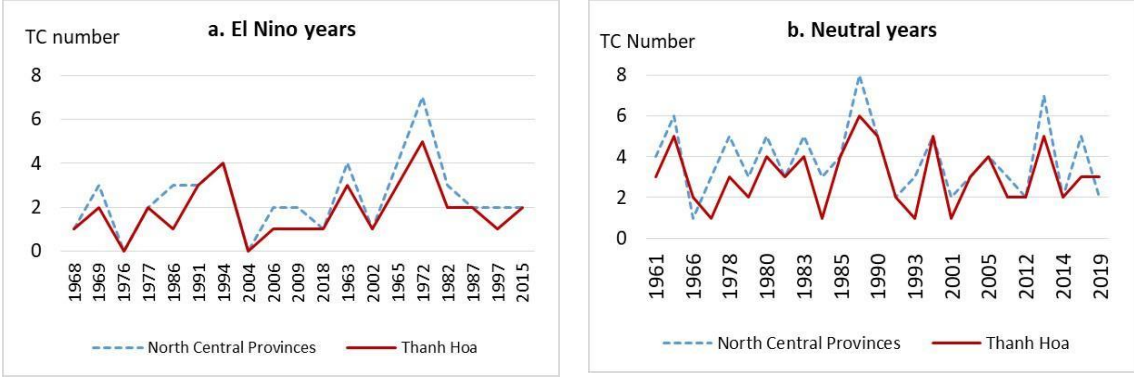

Figure 3. Graphs of the Tropical Cyclone activities over coastal zones in the El Nino and Neutral years

At the beginning of the autumn months (September to October), which is still the rainy season in the area, the possibility of drought is very low, with the lowest monthly drought frequency of the year (September) below 3-4%. The drought frequency increases in October, with the drought frequency ≤10% (Table 3).

The spatial distribution of drought classes is shown in Figure 4.

- Mild drought class: this occupies the area of mild hills and low mountains in the southern province, mainly belonging to Thuong Xuan, Nhu Thanh, Nhu Xuan, and Tinh Giadistricts and Nghi Xuan town. On the other hand, the area also receives the highest

rainfall compared to the province's territory. So, the drought effect is little eliminated but should be taken into account of the ecosystem ranges: Ben En National Park, protective forests, planted and regenerated forests, and annual crops.

- Moderate drought class: this occupies a large area in the central region and the northwest of the province, typically with r mountains at medium-low altitudes, and the hills and the plains, mainly belonging to Muong Lat, Lang Chanh, Quan Hoa, Ba Thuoc, Tho Xuan, Ngoc Lac, Yen Dinh, Thieu Hoa districts, and Thanh Hoa City. Local ecosystems, those likely to be affected by drought range, are paddy rice, other annual crops, Pu Luong nature reserve ecosystem, other forest ecosystems, and perennial industrial crops.

- Extreme drought class: this is located in two separate parts, the northeast coastal part (belonging to Thach Thanh, and Ha Trung Districts, a coastal district from Nga Son to Quang Xuong); and the other part upstream of Ma River valley in the mountainous region, mainly belonging to Muong Lat, Lang Chanh, and Quan Hoa Districts. Ecosystems that may be affected by drought range from annual crops to aquaculture, and mangroves.

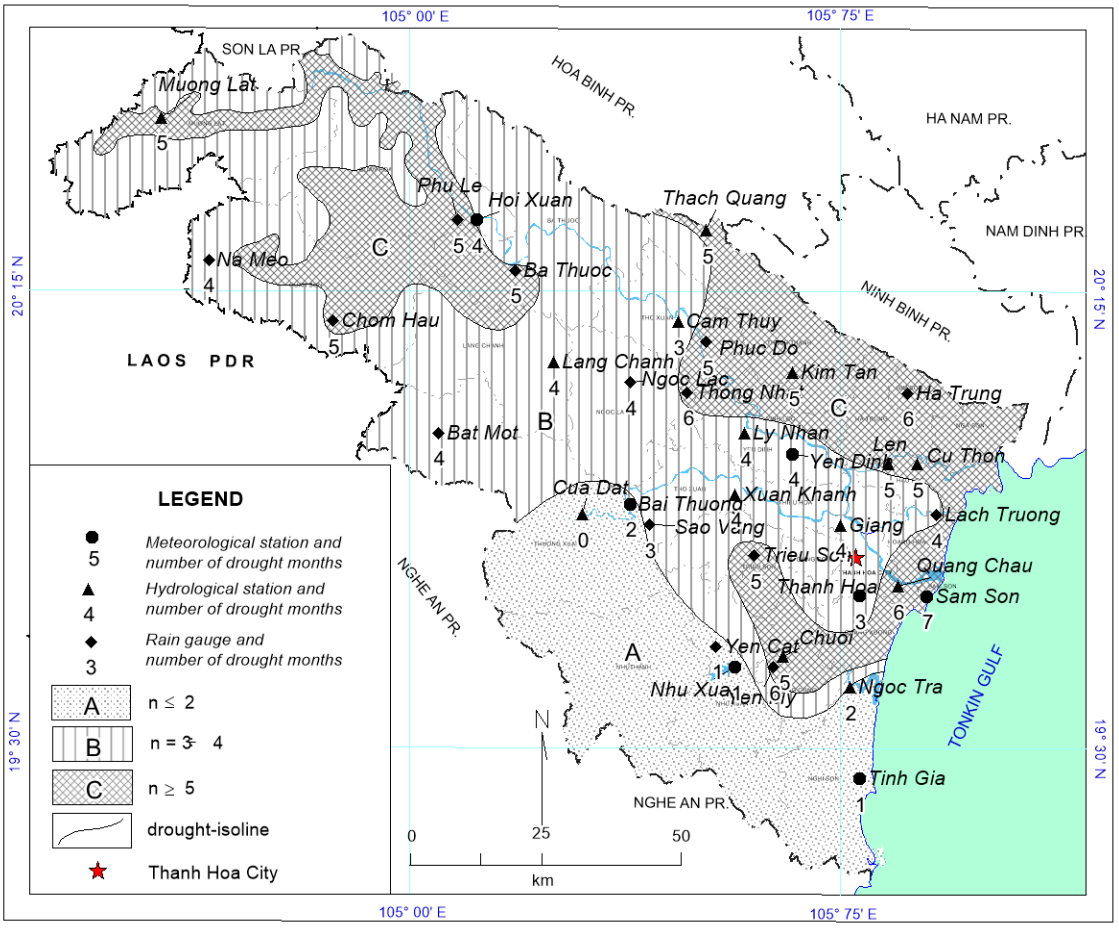

Figure 4. Drought map at Thanh Hoa Province (downscaling from 1/100.000)

Table 4. Characteristics of the drought areas

Drought class	Drought duration			Number of months with drought frequency ≥ 30%	Drought intensity	Geographical location
	Start month	***Highest month***	***Finish month***			
A	Dec	Dec	Feb, Mar	≤ 2	Mild drought	Mainly distributed in the low hill-mountain areas in the southern part of the province.
B	Nov	Dec, Feb	Feb	3÷4	Moderate drought	Mainly distributed in the downstream delta of the Ma River, and the middle-low mountainous area in the northwest of the province.
C	Nov	Dec	Feb	≥ 5	Extreme drought	Mainly distributed in valleys in the northwest mountainous area, and the coastal zone in the northeast of the province.

3. Conclusions

The results of the calculation of the K drought index show that the K_n value ranges from 0.4 to 0.6. That means Thanh Hoa province is humid for the whole year. However, in more detail for each month, most areas of Thanh Hoa province have a drought period ($K_{th} > 1$) lasting from November, December to February or March of the following year, with 4-5 drought months.

The monthly drought value (K_{th}) of Thanh Hoa province has a very large variation ($K_{th} = 0.2 \div 3.9$), much larger than the yearly drought value K_n. Thanh Hoa province has a high drought frequency throughout most of the winter (from December to February of the following year), and reaches its highest value in December. Drought frequency is high not only during the winter months but also in the spring months. In summer and early autumn, the drought frequency is smaller and drought does not even occur in many places.

According to the significant drought frequency (≥30%), Thanh Hoa province is divided into 3 drought classes (mild drought, moderate drought, and extreme drought), of which the moderate drought class accounts for the majority part of the province; extreme class is mainly distributed in the northeast coastal area of the province, and the other part along the valley in the northwest of the province. Mild drought class is located in mild hills in the southern part of the province.

The results of assessing the degree of meteorological drought in Thanh Hoa province provide a scientific basis for the reasonable arrangement of crop structure and conversion of crop structure, contributing to effective drought management, prevention, and mitigation of damage caused by drought.

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