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ASSESSING THE METEOROLOGICAL DROUGHT LEVEL IN THAI NGUYEN PROVINCE

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Abstract. The study aims to assess the degree of drought in Thai Nguyen province by using two indices including (i) the *K* drought index, and (ii) the Sazonov drought index (*Sa.I*). According to the value of K_n, the north of the province is sufficiently moist, while the plain region (the center and the south of the province) is dry (K_n = 2.6). The *Sa.I* index is used to assess the evolution of the drought levels in the region in the period 1961 - 2020. Drought tends to increase throughout the region. The value of *Sa.I* index fluctuates from -4 to 3 with the year frequency of drought occurrence accounting for 27.5%, of which 12.5% is severe. The assessment results on the degree of meteorological drought in Thai Nguyen province are the scientific basis for the arrangement and restructuring of the crop in agricultural production and making important contributions to the prevention and mitigation of drought natural disasters.

Keywords: Meteorological drought, Thai Nguyen province, drought index, drought frequency.

1. Introduction

Presently, there is no consistent definition of drought and criteria for identifying drought because the occurrence of drought in different parts of the world is different in terms of drought nature and impact. In general, the definitions are given based on the lack of rain for a relatively long time. According to Vietnam Standard TCVN 8643:2011 [1], drought is defined as "a type of natural disaster that describes a temporary shortage of water or soil moisture below a level in a specific period of time, affecting the water supply capacity of the irrigation system or affecting the normal growth of plants".

Droughts are divided into the following categories:

Meteorological drought: The lack of rainfall and moisture compared to the average value of multiple years in a specific period (day, month, season, year, etc.) of the area. Meteorological drought is characterized by rainfall and moisture.

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Hydrologic drought: The shortage of water resources compared to the mean value of many years in the specific period (day, month, season, year, etc.) of the area. Hydrological droughts are characterized by water level, discharge, and total water volume. For the irrigation system, hydrological drought is characterized by the water source coming to the focal work of the system, including the water level, flow, and total water volume compared to the designed criteria [2].

Agricultural drought: A phenomenon in which the amount of available moisture in the soil falls below the allowable level of the plant during each growth stage, resulting in poor plant growth, reduced yield, or death. Agricultural drought is a consequence of meteorological or hydrological drought that directly affects agricultural production. Agricultural drought is characterized by the change in shape and color of trees and leaves (wilted, dry, dead) for vegetation; by soil moisture for arable land.

Drought affects many aspects of the ecological environment, socio-economic conditions, and human health. Asia is the region most affected by natural disasters, the damage caused by drought ranks third after floods and storms. In recent years, climate change has affected the frequency and severity of meteorological droughts, with severe meteorological droughts occurring more frequently in multiple regions of Vietnam [3]. Meteorological drought causes a shortage of groundwater and surface runoff, lack of water in soil; seriously affects production and social life.

In the world, many drought indices have been developed and used such as Selyaninov hydrothermal coefficient (1937), Ivanov moisture index (1948), Budyko dry index (1955), Penman dry index (1948), global monsoon index GMI, standardized precipitation index *SPI*, Sazonov index, Koloskov index (1925), Palmer index (PDSI), crop moisture index (CMI), surface water supply index (SWSI), Reconnaissance drought index (RDI), dry coefficient [2]. However, no single index has outstanding advantages over others in all conditions. Therefore, the use of these indices depends on the specific conditions of each area and the available meteorological data.

Drought is increasing in frequency, duration, and intensity globally, especially in recent decades. Analysis of drought indicators based on historical rainfall, temperature, and humidity data to assess drought on a global [4, 5] regional and local scale [6, 7] shows that the number of droughts, duration, frequency, and intensity of droughts in some regions of the world has increased significantly.

Thai Nguyen is a province located in the northeastern mountainous and midland region of Vietnam. Thai Nguyen has a natural land area of 3566.63 km^2. The geographical position of the territory, natural conditions, and especially topographical conditions are important prerequisites that make the province suffer from many types of natural disasters such as floods, flash floods, erosion, landslides, soil cracking, and drought. The topography of Thai Nguyen province is mainly low hills and mountains. The area of hills and mountains over 100 m high accounts for two-thirds of the province's area, the rest is areas with elevations below 100 m. The terrain slopes in the north-south direction which matches the flow direction of the Cau River. The right bank of the Cau River has a northwest-southeast slope. The left bank of the Cau River (except for the southeast part of Vo Nhai district) slopes in a northeast-southwest direction. The mountains of Thai Nguyen are the southern part of the Ngan Son and Bac Son mountain ranges. The highest

part is Tam Dao mountain range, with the highest peak of 1590 m; The eastern slope of Tam Dao mountain range in the southwestern part of Thai Nguyen province has an altitude of about 1000 m and then rapidly decreases to the Cong River valley and Nui Coc lake area. In the eastern part of the province, the terrain is only 500 m - 600 m high, mostly limestone blocks with the same elevation. In the southern part of the province, the terrain is much lower, with some low mountains rising out of the low hills. The midland hills in the south and the alluvial plains of the rivers are below 100 m high [8].

This paper aims to determine drought by using typical drought indicators (*Kth*, *Kn*, and *Sa.I*) and frequency of drought occurrence (*Pth*) according to monthly rainfall value. Based on the results of calculating the number of drought months with frequency ≥ 30%, the distribution map of meteorological drought severity in Thai Nguyen province has been established.

2. Content

2.1. Data usage and methodology

2.1.1 Data usage

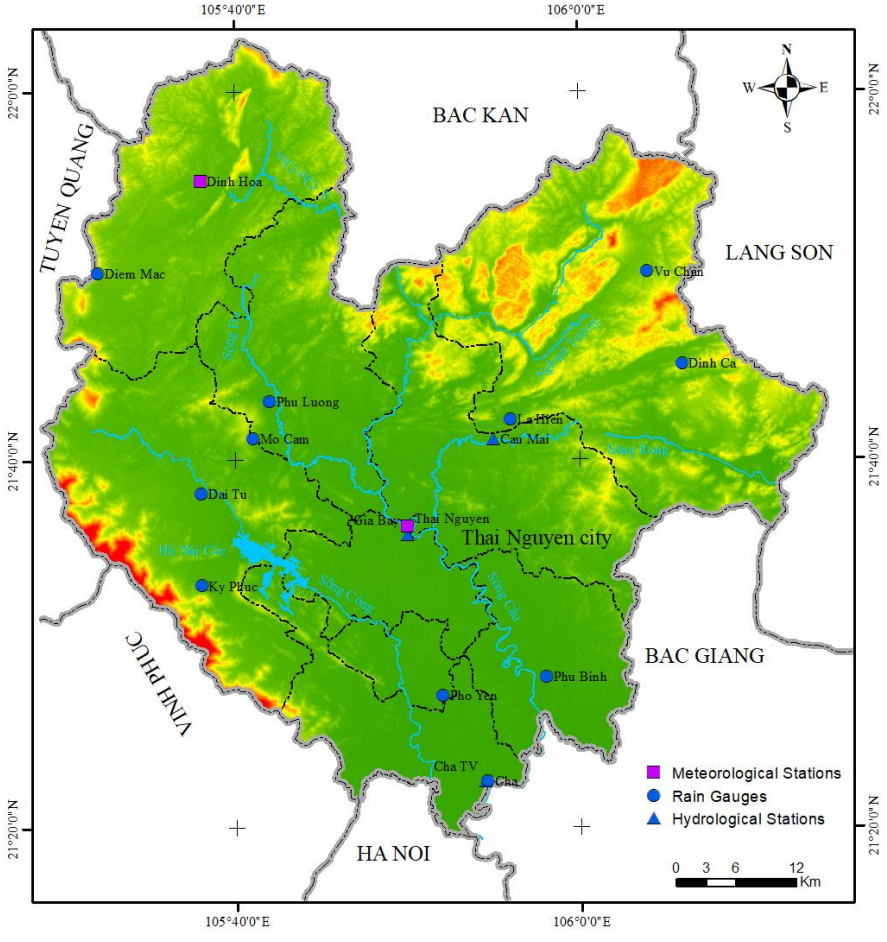

Figure 1. Meteorological stations of Thai Nguyen province

Data on mean temperature, monthly and yearly rainfall in the period from 1961 to 2020 of 2 meteorological stations of Dinh Hoa and Thai Nguyen were used. Rainfall data were collected from 10 rain gauges and 2 hydrological stations with data series lengths ranging from 25 years to 60 years [9].

2.1.2. Methodology

**** Method of drought indicators***

The drought status of Thai Nguyen Province is assessed by using specific indicators of drought severity, including drought index *K*, drought index *Sa.I.*

- *The drought index* is the ratio between the main inflows and the main outflows of the water balance.

The monthly drought index (K_{th}) is calculated as follows:

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

in which, E_{th} is the monthly mean Piche evaporation (mm), R_{th} is the monthly mean rainfall (mm);

The yearly drought index (K_n) is calculated as follows:

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

in which, E_n is the yearly mean Piche evaporation, R_n is the yearly mean rainfall.

Monthly drought is categorized into 5 levels: very wet ($K < 0.5$), wet (K: 0.5 - 1.0), slightly wet (K: 1.0 - 2.0); dry (K: 2.0 - 4.0); very dry ($K > 4.0$) [2].

- *Monthly drought frequency*

The drought level of different places is identified by monthly drought frequency (P_{th}):

$$P_{th} = \frac{m(H_{th})}{n(H_{th})} * 100 \quad (3)$$

where P_{th} is the monthly drought frequency; H_{th} is the monthly drought event; m(H_{th}) is the number of years in which monthly drought occurs; $n(H_{th})$ is the number of years in which monthly drought is monitored.

The monthly drought event is determined from the R_{th} monthly rainfall series. Depending on the climatic season, there are different criteria for monthly drought. The authors use the criterion of monthly drought in different seasons by Nguyen Duc Ngu (2002) [2].

Monthly drought in winter (from November to February next year): $R_{th} \leq 10$ mm

Monthly drought in spring (March and April) and Autumn (September and October): $R_{th} \leq 30$ mm.

Monthly drought in summer (from May to August): $R_{th} \leq 80$ mm.

The degree of drought in the province during the study period is determined by the number of months with significant drought frequency (≥ 30%).

- *The temperature – moisture balance index (Sa.I)*

The degree of drought in a territory is reflected through the temperature-moisture balance. The change in temperature-moisture balance is the imbalance between precipitation and temperature compared to the standard over a certain period. To determine the temperature-moisture balance of a certain region, many authors have used the Sazonov index, abbreviated as *Sa.I* (Sazonov Index). This coefficient is calculated as follows [10]:

$$Sa.I = \frac{\Delta T}{\sigma T} - \frac{\Delta R}{\sigma R} \quad (4)$$

in which, ΔT and ΔR are standard errors of temperature and precipitation; σT and σR are the standard deviations of temperature and precipitation.

The *Sa.I* index allows for assessing the degree of water shortage, drought as well as the level of excess water and inundation of a territory. *Sa.I* is categorized into 5 levels as shown in Table 1.

Table 1. drought classification by Sa.I index

No.	Value	Degree
1	Sa.I < -2	Inundated
2	-2 ≤ Sa.I < -1	Water redundant
3	-1 ≤ Sa.I ≤ 1	Non-drought
4	1 < Sa.I ≤ 2	Drought
5	Sa.I > 2	Severe drought

**** Methodology of mapping drought***

The map of drought severity distribution in Thai Nguyen province was established by the number of drought months (n) with frequency ≥ 30%. Based on the differentiation of the terrain elevation and the number of drought months, the territories with different drought levels are demarcated by the isolines of the drought month (n). The map of Thai Nguyen province shows 3 areas with drought levels: slight drought (n = 1 - 2 months of drought); moderate drought (n = 3 - 4 months of drought) and severe drought (n ≥ 5 months of drought).

2.2. Result and discussion

2.3.1. Drought severity of Thai Nguyen province by *K* index

The results of calculating the drought index *K* showed that: the K_{th} value at the stations did not change much, ranging from 0.2 to 3.7; K_n value ranges from 0.4 to 2.6.

In Thai Nguyen, there is a dry period (K_{th} > 1), lasting 4-5 months (from November to February-March next year). According to the K_n index, the northern mountainous areas of the province (K_n = 0.4) are sufficiently moist, while in the plain region (the central and

southern regions of the province) the drought index K_n is equal to 2.6, indicating drought in the region (Table 2).

Table 2. Yearly and monthly drought index of Thai Nguyen province

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	Drought period
Thai Nguyen	2.6	2.0	1.1	0.6	0.5	0.3	0.2	0.2	0.4	0.8	1.8	3.7	2.6	XI-III
Dinh Hoa	2.0	1.7	0.9	0.6	0.4	0.3	0.2	0.2	0.4	0.6	1.4	3.0	0.4	XI-II

2.3.2. Monthly drought of Thai Nguyen province by monthly rainfall

The data presented in Table 3 shows the following:

- Winter months (from November to February next year): The frequency of drought ranges from 25 to 53%. This time coincides with the dry season in the province. The highest frequency of drought was recorded at the Phu Luong rain gauge station (62%).

- Spring months (March and April): The frequency of drought is from 9 to 31%. The highest value (45%) is at the Phu Luong rain gauge station. The frequency of drought in March is higher than in April.

- Summer months (from May to August): The common drought frequency is 0 - 14%. At Phu Luong station, the frequency of drought in May reached the highest value of 22%. The frequency of drought in May, June, and August is higher than in July. In these summer months, in many places, the frequency of drought is 0%.

- Autumn months (September and October): The frequency of drought in September reaches the lowest value of the year (3%). October has a drought frequency in the range of 10 - 30%. The frequency of drought was highest at La Hien and Vu Chan stations (38%).

On the basis of counting the number of drought months with drought frequency ≥ 30% presented in Table 2, the province's drought severity is divided into 3 levels: Slight drought (n = 1 - 2 months of significant drought months); Moderate drought (n = 3 - 4 months of significant drought) and Severe drought (n ≥ 5 months of significant drought). The spatial distribution of drought severity in Thai Nguyen province is shown in Figure 2.

As in Figure 2, severe drought is concentrated mainly in the low hilly areas of Phu Luong and Dong Hy districts and the southeastern plain of Phu Binh district. Moderate drought occurs in the central plains and eastern mountainous areas of the province. Slight drought occurs in mountainous areas in the west and northeast of the province.

Table 3. Monthly drought frequency in monitoring stations (%)

No.	Station	Period	Month											Frequency ≥ 30%	
			1	2	3	4	5	6	7	8	9	10	11	12	
Meteorological station															
1	Thai Nguyen	1961 - 2020	25	12	28	2	2	0	2	0	0	12	25	42	1
2	Dinh Hoa	1961 - 2020	28	22	27	2	5	3	0	3	0	18	35	53	2
Rain gauges															
1	Dai Tu	1960 - 2017	22	16	19	9	7	3	0	0	2	14	22	38	1
2	Diem Mac	1985 - 2017	15	27	9	9	3	3	3	9	0	12	15	21	0
3	Dinh Ca	1961 - 2017	38	29	22	16	14	9	7	5	2	28	36	38	3
4	Mo Cam	1985 - 2017	30	21	24	12	3	6	0	0	3	15	45	52	2
5	Ky Phu	1960 - 2017	36	26	28	10	12	5	2	5	3	21	29	47	2
6	La Hien	1992 - 2017	50	27	31	12	4	8	0	4	4	38	38	46	5
7	Pho Yen	1960 - 2017	38	31	28	10	16	7	2	9	0	19	28	47	3
8	Phu Binh	1960 - 2017	41	31	40	17	12	12	3	7	0	21	31	50	5
9	Phu Luong	1960 - 2017	52	41	45	28	22	7	3	7	9	24	40	62	5
10	Vu Chan	1992 - 2017	27	19	19	4	4	0	0	4	4	38	15	42	2
Hydrological stations															
1	Gia Bay	1961 - 2020	27	0	17	10	7	3	0	0	0	7	22	45	1
2	Cha	1985 - 2020	22	25	31	14	17	0	3	6	3	19	28	53	2

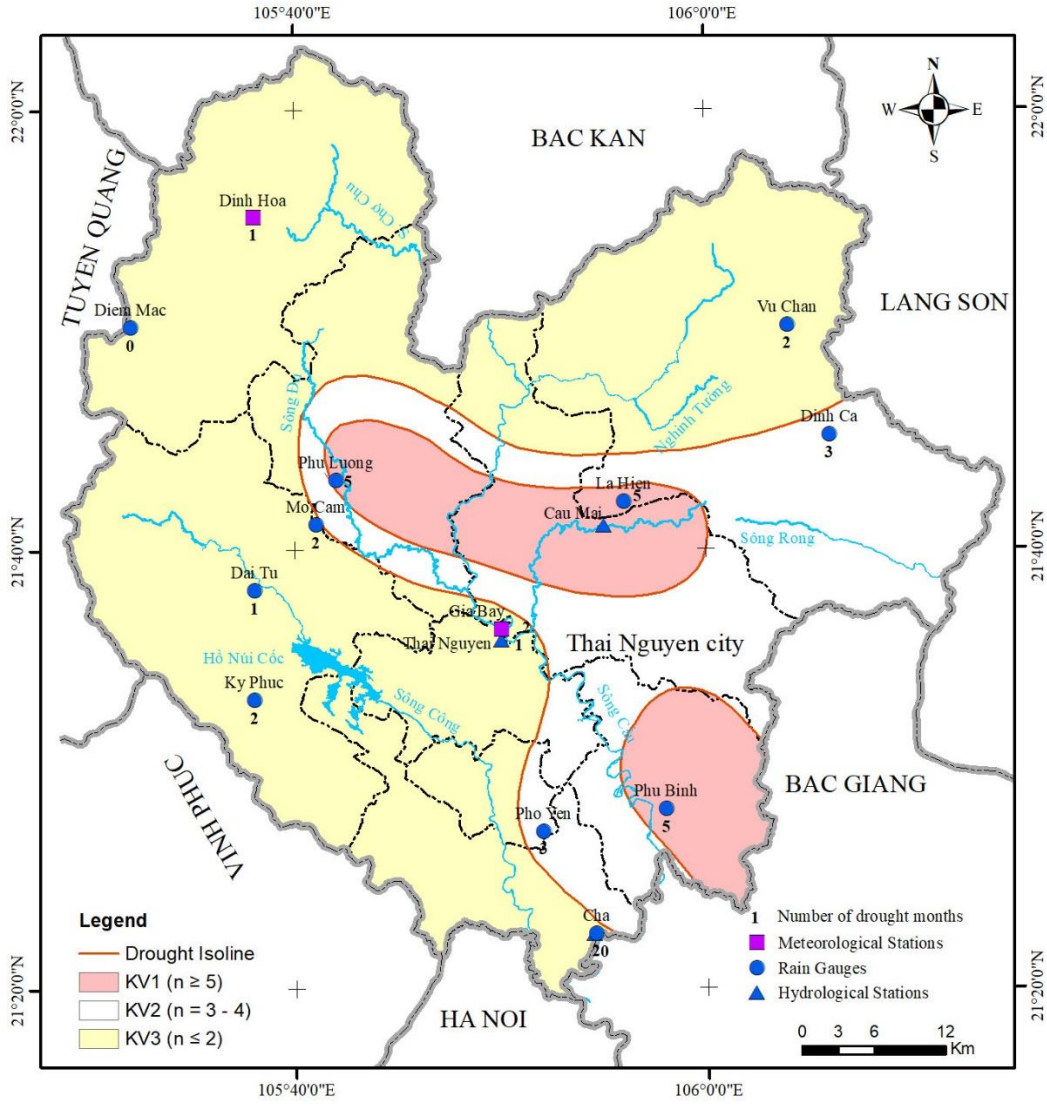

Figure 2. Meteorological drought map of Thai Nguyen province (downscaled from 1/100.000)

2.3.3. Drought severity in Thai Nguyen province by Sazonov

The results of calculating the level of drought by the *Sa.I* index (Table 4) shows that the province has 3 drought months on average, of which 2 months are moderate and 1 month of severe drought. However, the monthly and yearly *Sa.I* calculated data showing that the number of drought months has great variation from year to year.

During the study period, there were 17 years of drought at Thai Nguyen station, 11 of which were severe droughts. At Dinh Hoa station, there were 16 years of drought and 4 years of severe drought. The probability of drought in the province is 27.5%, of which 12.5% is a severe drought.

Thus, the number of years of severe drought in the lowlands (plain) of Thai Nguyen province occurs with a significantly higher frequency than in the mountainous areas, although the number of drought years is almost the same.

Table 4. Drought level of Thai Nguyen province by Sazonov index

No.	Station	Drought by a number of months			Drought by a number of years	
		Drought (Sa.I > 1)	Moderate drought (1 < Sa.I ≤ 2)	Severe drought (Sa. I > 2)	Drought (Sa.I > 1)	Severe drought (Sa.I > 2)
1	Thai Nguyen	3.0	2.0	1.0	17	11
2	Dinh Hoa	2.8	2.1	0.7	16	4
Mean					16,5	7,5
					27,5%	12,5%

Figure 3 shows the evolution of the *Sa.I* index over the years during the evaluation period. Analysis of the *Sa.I* index (years) in the period 1961 - 2020 shows that at 2 stations of Thai Nguyen and Dinh Hoa, the number of drought years tends to increase, of which the years of severe drought at Thai Nguyen station are 1997, 2002 - 2003, 2007, 2010, 2014, 2016, 2019 - 2020. At Dinh Hoa station, the years of severe drought were 1961, 1998, 2003, 2007, and 2020.

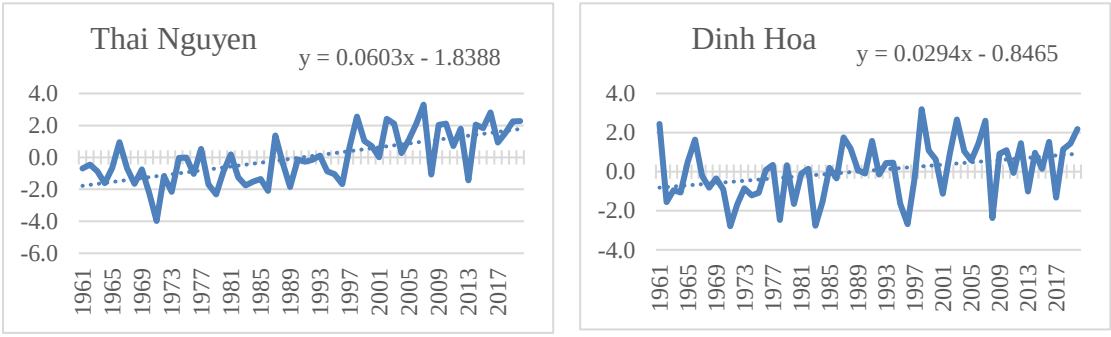

Figure 3. Change of Sa.I index in some stations in the period 1961 - 2020

3. Conclusions

- The *K* index (month, year) and *Sa.I* (year) shows that in the central plain, drought occurs more severely than in the mountainous areas of the province.

- The frequency of monthly drought (*Pth)* ranges from 25 to 53% in the winter months, corresponding to the dry season of the province. In other months, the frequency of monthly drought is negligible.

- During the study period, there were 17 years of drought in the central plain, and 11 years of severe drought. In the mountainous areas, there are 16 years of drought and 4 years of severe drought. The probability of drought and severe drought in the province is 27.5% and 12.5% respectively. The number of years of severe drought in the lowlands (plain) of Thai Nguyen province occurs with a significantly higher frequency than in the mountainous areas, although the number of drought years is almost the same.

- The annual variation of the *Sa.I* index shows that the trend of drought occurrence in the province is increasing, in which the increase in the plain is higher than in the mountainous areas. In recent years, drought is more common in the lowlands than in the mountainous areas.

- The assessment results of meteorological drought extent in Thai Nguyen province provide a scientific basis for the arrangement and change of the crop structure, contributing to effective drought management, prevention, and control of drought to mitigate the damage caused by drought.

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