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Research Article

Investigating Meteorological Drought Characteristics in Nghe An based on Standardized Precipitation Index in the period 1998-2020

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Abstract

Drought is one of the most severe natural disasters worldwide, affecting millions of people and causing significant economic losses. Studies on droughts have been conducted globally, but there are still many challenges to be addressed. The objective of this study is to evaluate and analyze the drought situation in Nghe An Province, Vietnam, using the Standardized Precipitation Index (SPI). The study used rainfall data from four observation stations in Nghe An Province, including Do Luong, Dua, Nam Dan, and Yen Thuong. The data were analyzed using the SPI method to evaluate the drought situation.

The results of the study show that Nghe An Province has experienced several droughts during the period 1998-2020. The drought situation was evaluated using the SPI index, indicating that Nghe An Province experienced two severe droughts during this period. The findings of this study will contribute critical information for drought management and prevention in Nghe An Province.

Keywords: *SPI, Timescale, Meteorology drought, Agriculture, Ecosystem.*

1. Introduction

Droughts are a significant natural disaster that affects millions of people worldwide, causing widespread damage to agriculture, ecosystems, and economies [1-3]. Drought is a complex and multi-faceted phenomenon that can be caused by a combination of factors, including climate change, land use changes, and water management practices [4, 5, 7]. According to the Food and Agriculture Organization (FAO) [5], drought is one of the most significant natural disasters in the world, affecting millions of people and causing significant economic losses. Studies on droughts have shown that climate change is a major contributor to droughts, with rising temperatures and changing precipitation patterns leading to more frequent and severe droughts [6, 8, 9]. Researchers have also identified the importance of soil moisture, vegetation, and water storage in mitigating drought impacts. Additionally, the role of human activities, such as over-extraction of groundwater and deforestation, has been recognized as a significant factor in exacerbating droughts [7, 9, 11].

Global research on droughts has led to the development of various drought indices, such as the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI) [10, 12, 15]. These indices have been widely used to monitor and predict droughts, providing valuable information for water resource management and drought mitigation strategies [6, 8, 14]. Furthermore, research on droughts has also highlighted the need for a multi-disciplinary approach to address this complex issue [6, 7, 14]. Collaboration between hydrologists, climatologists, ecologists, and social scientists is essential to develop effective drought management strategies that take into account the social, economic, and environmental impacts of droughts [8, 9]. Overall, research on droughts has made significant progress in recent years, but there is still much to be learned about this complex and multifaceted issue [1, 8, 9]. In Vietnam, drought has been a recurring problem in Nghe An province [7, 13]. The Standardized Precipitation Index (SPI) is a widely used drought index that can be used to measure the severity and duration of drought [6, 15]. The SPI takes into account the amount of precipitation relative to the long-term average, and it can be used to classify drought into different categories, including mild, moderate, severe, and extreme [10, 15].

The aim of this study is to investigate the meteorological drought characteristics in Nghe An province, Vietnam, using the SPI. The study will analyze the drought characteristics across the study area during the period 1998-2020. The study hopes to contribute to the understanding of drought characteristics in Nghe An province, Vietnam, and it will provide valuable information for water resources management and agricultural planning in the region.

2. Materials and methodology

2.1 Study Area and data collection

Nghe An Province is a vast and diverse land region located in the North Central region of Vietnam (18°33'-20°01'N and 103°52'-105°48'E), spanning a total area approximately of 16,400 km^2 (Figure 1). Nghe An is bordered by Thanh Hoa province to the north, Ha Tinh province to the south, the East Sea to the east, Huaphanh province of Laos in the northwest, Xiengkhuang province in the west, and Borikhamxay province in the southwest [16]. The province's unique geography and climate make it an important region for agriculture, forestry, and tourism, with a rich cultural heritage and a long history of human habitation.With a population of approximately 3,419,989 people, the province is characterized by a unique geography, featuring mountains, hills, and plains with elevation fluctuations ranging from below 10 to over 1,500 meters above mean sea level (Figure 1). The province's terrain is gradually tilted from north to south and from west to east, with a diverse range of topographic conditions, from flat plains to steep terrain [13, 16].

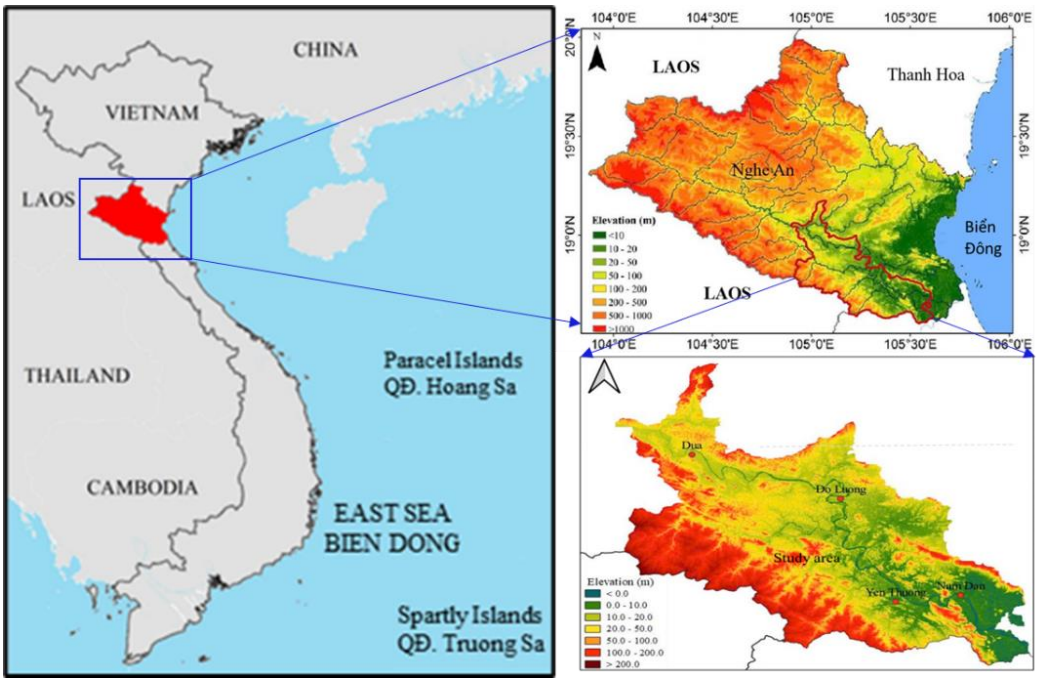

Fig. 1 The study area with rainfall observation stations is marked by the red circles

Nghe An is situated in the tropical monsoon climate zone, marked by four distinct seasons: spring, summer, autumn, and winter [13, 16]. During the summer months (April to August), the area experiences hot and dry southwesterly winds, while in winter (December to February), it is affected by cold and humid northeasterly winds. The average annual temperature is approximately 23-24°C, with significant temperature fluctuations between the months [16]. The province receives an average annual rainfall of between 1,200 to 2,000 mm per year, with the majority of rainfall concentrated in August, September, and October (Figure 2). The rainfall distribution varies spatially, with different areas receiving varying amounts of rainfall [13].

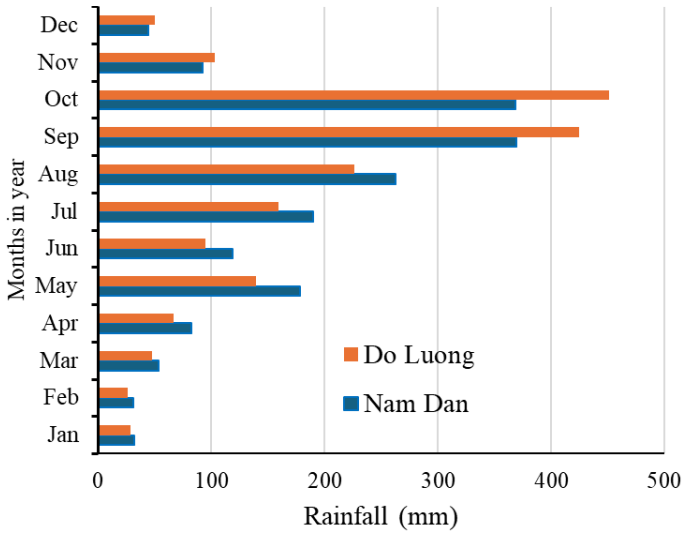

Figure 2: Distribution of monthly rainfall at Do Luong and Nam Dan stations during the period 1998-2020

Rainfall data series from 4-gauge stations were obtained from the Southern Regional Hydro-meteorological Center of Vietnam, which were representative of the study area as shown in Fig. 1. The collected rainfall data were then processed using Excel software to derive catchment representative monthly rainfall values.

2.2 Standardized Precipitation Index

Standardized Precipitation Index (SPI) is a widely used indicator for predicting and monitoring meteorological drought [8, 10]. The concept of meteorological drought was first introduced by McKee et al. (1993), who defined it as a rainfall shortfall event of a certain magnitude and duration [10]. The SPI has been successfully applied in many regions worldwide, including the United States, Australia, and Asia [4, 8, 10].

One of the advantages of the SPI is its ability to be used for different time scales and input data, requiring only precipitation data [8, 10, 17]. In 2009, the World Meteorological Organization (WMO) recommended the use of SPI as a tool for monitoring meteorological droughts [1, 2, 8] . The SPI is a precipitation-based index that transforms rainfall data series into a standardized normal distribution [8, 10]. Assume that the amount of precipitation in a given time period is a random variable x, and when x is not 0 (x > 0), the probability density function of its gamma distribution is given by:

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

The cumulative distribution function G(x) is obtained integrating formula (2)

$$G(x) = \int_0^x g(x)\, d = \int_0^x \frac{x^{\hat{\alpha}-1}\, e^{-x/\hat{\beta}}}{\hat{\beta}^{\hat{\alpha}}\, \Gamma(\hat{\alpha})} dx \qquad (2)$$

Where the parameter $\hat{\alpha}, \hat{\beta}$ in the formula (2) are given by formula (3) and formula (4)

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

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (4)$$

The factor A in formula (3) is defined by formula (5)

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad (5)$$

In the formula (5), n is number of precipitations measured and $\bar{x}$ refers to the sample mean of the data series. While the SPI dimensionless function is defined by formula (6)

$$SPI = \Psi^{-1}[G(x)] \quad (6)$$

A station will be given as drought if the SPI meets a value of 1.0 or less (Table 2).

Table 1: Standardized Precipitation Index classification [10]

Values	Category classes	Abbreviation
≥ 3.00	Extremely wet	EW
2.00 to 2.99	Very wet	VW
1.00 to 1.99	Moderately wet	MW
0.50 to 0.99	Slightly wet	SW
-0.49 to 0.49	Near normal	NN
-0.99 to -0.50	Slightly dry	SD
-1.99 to -1.00	Moderately dry	MD
-2.99 to -2.00	Severely dry	SED
≤ -3.0	Extremely dry	ED

3. Results and discussion

The SPI is a widely used indicator to measure drought events, with values ranging from EW to ED. Simulation results of meteorology drought time scales based on the SPI at four representative stations across the study area during the period 1998-2021 were presented in Table 2. Based on Table 1, we can analyze the meteorological drought events with a time scale of 6 months (SPI6) at the Do Luong, Dua, Nam Dan, and Yen Thuong observation stations. The mean values for the four stations are also presented in Table 2, with SPI6 timescale, a mean of 2 EW and 12 VW events, 33 MW events, 174.7 near-normal conditions, 34.5 MD events, 12.2 SD events, and 7.5 ED events. These values indicate that the four stations generally experienced a similar pattern of drought and precipitation during the 1998-2020 period. Specifically, an examination of the data reveals that the Do Luong station experienced a total of 3 extremely EW, 13 very VW, 36 MW events, and 180 NN conditions during the period 1998-2020. The number of MD and SD events were 28 and 14, respectively, while the number of extremely ED was only 2. This suggests that the Do Luong station generally experienced a relatively high level of precipitation during the 1998-2020 period, with a majority of the time being near-normal or moderately wet.

Table 2: Simulated results of meteorology drought time scales based on the SPI during the period 1998-2021

SPI	EW	VW	MW	NN	MD	SD	ED
SPI6-6 months drought time scale							
Do Luong	3	13	36	180	28	14	2
Dua	6	13	27	178	34	13	5
Nam Dan	1	20	28	178	29	18	2
Yen Thuong	1	14	41	168	30	20	2
Mean	2.7	15	33	176	30.2	16.2	2.7
SPI12-12 months drought time scale							
Do Luong	1	13	34	176	33	11	8
Dua	2	17	25	179	36	9	8
Nam Dan	2	10	31	178	31	16	8
Yen Thuong	3	8	42	166	38	13	6
Mean	2	12	33	174.7	34.5	12.2	7.5

EW is extremely wet; VW is very wet; MW is moderately wet; NN is near normal; MD is moderately dry; SD is severely dry; ED is extremely dry

In contrast, the Dua station experienced a higher number of MD and SD events, with 34 and 13 occurrences, respectively. The number of extremely ED was 5, which is more than double the number at the Do Luong station. This indicates that the Dua station experienced a higher frequency of drought events during the 1998-2020 period, with a greater proportion of time being moderately dry or severely dry. The Nam Dan station had a similar pattern to the Dua station, with 20 MD events and 18 SD events, and 2 ED events. However, the Nam Dan station had a slightly higher number of NN weather conditions with 178 occurrences. This suggests that the Nam Dan station experienced a mix of drought and normal conditions during the 1998-2020 period. The Yen Thuong station had the highest number of MW events with 41 occurrences, and the lowest number of ED events with only 2.

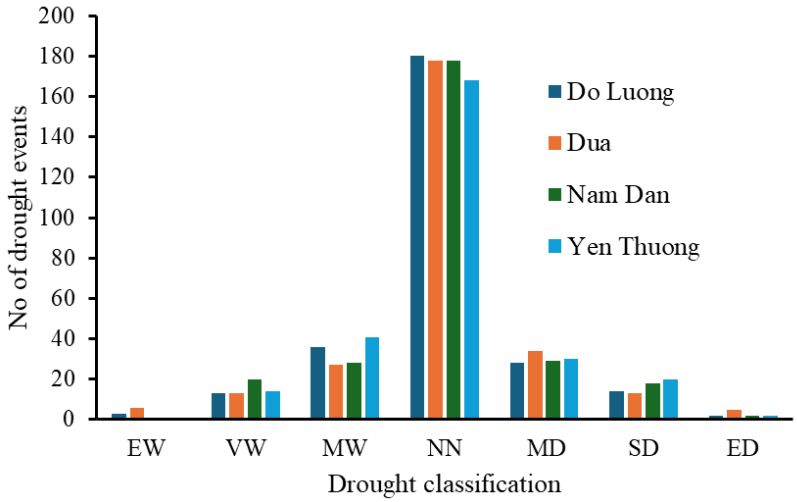

Fig.3 The number of drought events at 6-month drought timescale

The number of NN weather conditions was 168, which is the highest among the four stations. This indicates that the Yen Thuong station experienced a relatively high level of precipitation during the 1998-2020 period, with a majority of the time being near-normal or moderately wet (Figure 3).

In overall, the simulated results of the SPI6 drought timescales from the four observation stations reveals a diverse range of drought conditions during the 1998-2020 period. While the Do Luong station experienced a high level of precipitation, the Dua and Nam Dan stations experienced a higher frequency of drought events. The Yen Thuong station had the highest level of precipitation and the lowest number of drought events. These findings highlight the importance of monitoring drought conditions in different regions to develop effective strategies for managing water resources and mitigating the impacts of drought on agriculture and ecosystems.

With SPI12 timescale, the mean values for the four stations are also presented in Table 2, with a mean of 2 EW and 12 VW events, 33 MW events, 174.7 near-normal conditions, 34.5 MD events, 12.2 SD events, and 7.5 ED events. These values indicate that the four stations generally experienced a similar pattern of drought and precipitation during the 1998-2020 period. Specifically, an examination of the data reveals that the Do Luong station experienced a total of 1 EW, 13 VW events, and 34 MW wet events during the period 1998-2020. The number of NN weather conditions was 176, with 33 MD and 11 SD events. The number of ED events was 8 (Table 2). This suggests that the Do Luong station generally experienced a relatively high level of precipitation during the 1998-2020 period, with a majority of the time being near-normal or moderately wet.

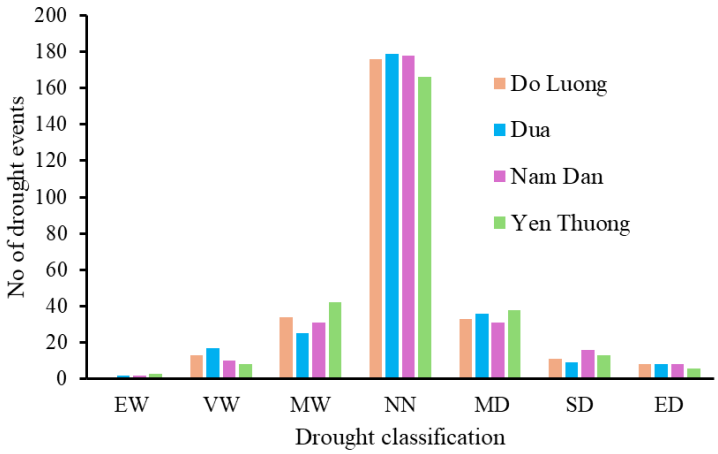

Figure 4: The number of drought events at 12-month drought timescale

In contrast, the Dua station experienced a higher number of MD and SD events, with 36 and 9 occurrences, respectively. The number of ED events was 8, which is the same as the Do Luong station. The number of near-normal conditions was

179, with 2 EW and 17 VW events. This indicates that the Dua station experienced a higher frequency of drought events during the 1998-2020 period, with a greater proportion of time being moderately dry or severely dry. The Nam Dan station had a similar pattern to the Dua station, with 31 MD and 16 SD events, and 8 ED events. The number of near-normal conditions was 178, with 2 EW and 10 VW events. This suggests that the Nam Dan station experienced a mix of drought and normal conditions during the 1998-2020 period (Figure 4). The Yen Thuong station had the highest number of MW events with 42 occurrences, and the lowest number of ED events with 6. The number of near-normal conditions was 166, with 38 MD and 13 SD events. This indicates that the Yen Thuong station experienced a relatively high level of precipitation during the 1998-2020 period, with a majority of the time being near-normal or moderately wet.

In overall, the analysis of the SPI12 timescale during the 1998-2020 period reveals that the Do Luong station experienced a high level of precipitation, the Dua and Nam Dan stations experienced a higher frequency of drought events. The Yen Thuong station had the highest level of precipitation and the lowest number of drought events. These findings confirmed the importance of monitoring drought conditions in different regions to develop effective strategies for managing water resources and mitigating the impacts of drought on ecosystems.

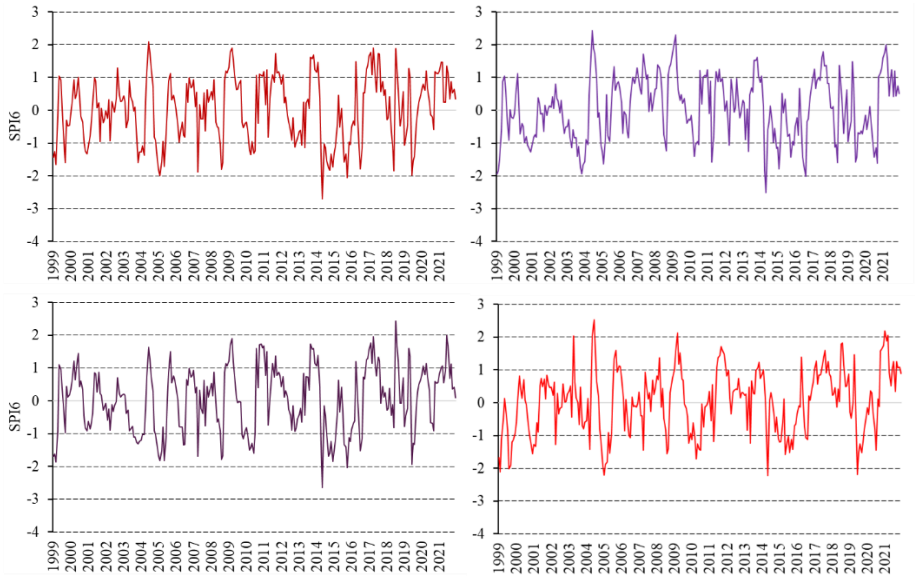

Figure 5: Simulated results of SPI for 6-month time scales at a) Yen Thuong, b) Do Luong, c) Nam Dan and d) Dua station in the period 1989 to 2021

Table 3 presents the simulated results of the 6 months drought timescales (SPI6) at four weather stations in Nghe An Province, Vietnam, from 1998 to 2020. The overall trend of SPI6 values at the four weather stations shows a mix of positive and negative values, indicating a relatively balanced distribution of wet and dry periods (Figure 5). However, a closer examination of the data reveals some interesting patterns. Specifically, the SPI6 values at the Do Luong station tend to be more positive during the months of April to September, indicating above-average rainfall during this period. In contrast, the values at the Dua station show a more pronounced negative trend during the same period, suggesting below-average rainfall. The Nam Dan station exhibits a relatively stable SPI6 trend, with only minor fluctuations throughout the year. The Yen Thuong station shows a mix of positive and negative values, with a slight bias towards positive values during the months of June to September. In addition, the analysis also highlights several extreme events that occurred at the four weather stations. The Do Luong station experienced a significant drought during the 2000-2001 period, with SPI6 values dropping to -2.5. Conversely, the Dua station saw severe wet weather during the 2010-2011 period, with SPI6 values reaching 2.5. The Nam Dan station experienced a moderate drought during the 2015-2016 period, with SPI6 values dropping to -1.5. The Yen Thuong station record a moderate wet weather during the 2017-2018 period, with SPI6 values reaching 1.5.

In overall, the analysis of the SPI6 at weather stations in Nghe An Province from 1998 to 2020 reveals a complex and dynamic pattern of meteorological events. While the overall trend is relatively balanced, the data highlights several extreme events, including severe droughts and wet weather, that occurred during the study period.

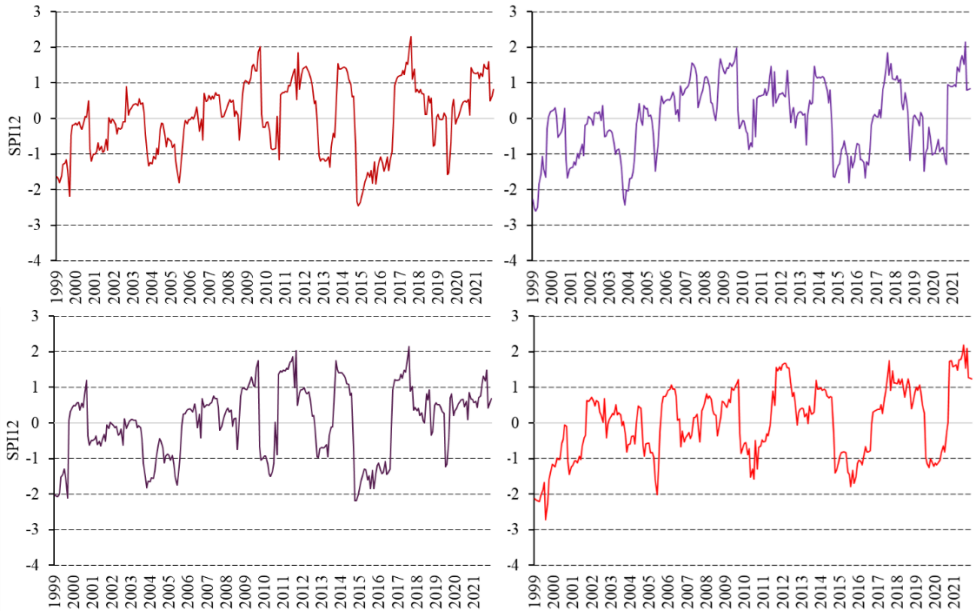

Figure 6: Simulated results of SPI for 12-month time scales at a) Yen Thuong, b) Do Luong, c) Nam Dan and d) Dua station in the period 1989 to 2021

Figure 6 3 also provides valuable insights into the SPI12 at four weather stations in Nghe An Province, Vietnam, from 1998 to 2020. The overall trend of SPI12 values at the four weather stations also records a mix of positive and negative values. Specifically, at Do Luong station, the SPI12 values tend to be positive during the period from 1998 to 2005, indicating above-average rainfall during this period. However, from 2006 onwards, the values become more negative, indicating below-average rainfall. The most significant negative SPI12 value was recorded in 2015, with a value of -1.33, indicating a severe drought. At Dua station, the SPI12 values tend to be negative during the period from 1998 to 2002. However, from 2003 onwards, the values become more positive, indicating above-average rainfall. The most significant positive SPI12 value was recorded in 2017, with a value of 1.46, indicating severe wet weather. At the Nam Dan station, the SPI12 values tend to be positive during the period from 1998 to 2004, indicating above-average rainfall during this period. However, from 2005 onwards, the values become more negative, indicating below-average rainfall. The most significant negative SPI12 value was recorded in 2019, with a value of -1.49, indicating a severe drought. At the Yen Thuong station, the SPI12 values tend to be negative during the period from 1998 to 2001 and the SPI12 values become more positive, indicating above-average rainfall. The most significant positive SPI12 value was recorded in 2018, with a value of 1.08, indicating severe wet weather. In overall, the analysis of the SPI12 at weather stations across Nghe An Province from 1998 to 2020 reveals a complex and dynamic pattern of meteorological events.

4. CONCLUSION

The results of this study provide valuable insights into the characteristics of meteorological drought in Nghe An Province, Vietnam, during the period 1998-2020. The analysis of SPI6 and SPI12 values at four weather stations revealed a complex and dynamic pattern of meteorological events, with several extreme events, including severe droughts and wet weather, occurring during the study period. The results highlighted the vulnerability of the region to droughts, particularly during the dry season. The findings of this study have significant implications for drought management and mitigation strategies in Nghe An Province. The study emphasizes the importance of monitoring drought conditions and developing effective strategies for drought management and mitigation. By using the results of this study, drought management and mitigation strategies can be improved, and the resilience of agriculture and ecosystems to droughts can be enhanced.

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