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METEOROLOGICAL DROUGHT DEVELOPMENTS IN THAI BINH PROVINCE IN THE CONTEXT OF CLIMATE CHANGE

Nguyen Thi Thu Hien* and Vu Thi Hang
Geography Faculty, Hanoi National University of Education, Hanoi city, Vietnam
*Corresponding author: Nguyen Thi Thu Hien, e-mail: hienntt@hnue.edu.vn

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Abstract. This article presents the frequency and trends of meteorological drought in Thai Binh province for the period 1991-2021 and forecasts drought trends for the period 2025-2065 based on climate change scenarios. The PED drought index is calculated using the corresponding daily temperature and rainfall data for each of these periods. The results indicate that meteorological drought in Thai Binh can occur in both the dry and rainy seasons. During the period from 1991 to 2021, medium drought occurred in the dry season nearly once every ten years. Drought occurrences in both the rainy and dry seasons show an increasing trend in intensity and the number of drought months. In the future, during the period from 2025 to 2065, dry season drought will fluctuate less under the RCP4.5 scenario but will sharply increase in frequency and intensity under the RCP8.5 scenario. In the rainy season, drought is projected to increase in both scenarios. The number of drought months is relatively high and will rise significantly in both RCP4.5 and RCP8.5 scenarios. A notable aspect of this study is the analysis of meteorological drought trends for the period 2025-2065, based on climate change scenarios.

Keywords: meteorological drought, PED drought index, Thai Binh, trend.

1. Introduction

Drought is a common natural hazard that significantly affects the natural environment, economic activities, and the social lives of people worldwide. Drought is classified into four types: meteorological drought, agricultural drought, hydrological drought, and socio-economic drought [1]. Meteorological drought specifically refers to a deficit in rainfall at a given time compared to the average rainfall over a specified period. Meteorological drought is a natural phenomenon that is primarily driven by climatic factors and is influenced by changes associated with climate change, including fluctuations in sea surface temperatures, such as those experienced during El Niño events.

Research on drought has been conducted for many years. Recently, in the context of climate change characterized by rising temperatures and more extreme precipitation

regimes, drought has garnered significant attention as one of the most relevant natural disasters [2]. The article by Jonathan S. & *et al.* presents maps of global drought frequency, duration, and severity for the periods 1951-1970, 1971-1990, and 1991-2010, to give an overview of the respective drought hot spots. The results showed that the increase in drought frequency, duration, and severity is found to be significant in Africa, Eastern Asia, the Mediterranean region, and Southern Australia, while the Americas and Russia see a decrease in each drought component [2]. The World Bank showed the intricate relationship between climate change and drought, emphasizing its global implications. The research examines how rising temperatures and altered hydrological cycles contribute to prolonged drought periods, particularly in vulnerable regions [3]. The report "Global warming and drought impacts in the EU" of the European Union showed that with global warming, droughts will happen more frequently, last longer, and become more intense in southern and western parts of Europe, while drought conditions will become less extreme in northern and north-eastern Europe. With 3 °C global warming in 2100 drought losses could be 5 times higher compared to today, with the strongest increase in drought losses projected in the Mediterranean and Atlantic regions of Europe [4].

Vietnam is one of the five countries most severely affected by natural hazards each year, including drought. Climate change, characterized by rising temperatures and alterations in rainfall patterns, has led to an increase in the frequency and complexity of droughts in our country. According to Dao N.H. & *et al.*, in the context of climate change, drought often happens, seriously affecting the local economy. This research developed a drought scenario for the future based on the results of climate change scenarios RCP4.5 and RCP8.5. The result showed over time, from 1996 to 2015 (20 years), on an annual average, the entire study area was not affected by drought. However, whether under the medium-low emission scenario or the high emission scenario, the drought level will increase over time from a slight to a high level [5]. In the study "Establishing drought maps in the Mekong Delta in the context of climate change", Tran VT & *et al.* assessed the current status of meteorological droughts and assessed the impacts of climate change on meteorological drought in the Mekong Delta, Vietnam based on Scenarios A2 and B2. Results of the SPI calculation for the period of 2015-2047 compared with those for the 1980-2012 period varied in space and timing frequency. It was also found that drought frequency would not increase, but drought severity levels (severe, moderate, mild) would change [6]. Dang Q.K. & *et al.* showed that the frequency of occurrence from mild to severe drought accounts for 57.1% to 92.9% in the dry season depending on each station in Ninh Thuan and Binh Thuan provinces from 1993 to 2020. The calculated results based on climate change scenarios showed that the duration of drought in the two provinces would not change much; however, the degree of drought tends to increase in intensity and frequency [7]. In the ref. [8] the characteristics and trends of drought in the Central Highlands were assessed using SPI and PDSI indexes. The results suggest that drought occurs with high frequency in both the dry and rainy seasons. The duration of drought tends to increase at certain stations, such as Dak Nong, Ayunpa, Pleiku, and Dak To, while it decreases at other stations [8].

Thai Binh is a coastal plain province located in the Red River Delta, covering an area of 1,584.61 km², of which agricultural land constitutes 67.11% [9]. The population of

Thai Binh province is 1,873,890, with 88.25% residing in rural areas. Additionally, 28.5% of the labor force is employed in agriculture, forestry, and fisheries [9]. Agricultural production in this region largely depends on natural conditions, making it vulnerable to significant losses from natural hazards, including drought. In the context of complex climate change, drought poses a substantial threat to the stability of the agricultural sector, which is crucial for local socio-economic development. Therefore, analyzing the developments and trends of meteorological drought in Thai Binh province over the past and the upcoming decades holds both scientific and practical significance.

Recently the issue of drought in Thai Binh Province has primarily been mentioned in studies on drought in the Northern Delta region. Le T.H. & *et al.* present a set of maps on the frequency of occurrence of heat waves and drought phenomena in the Red River for the period 1971-2015 [10]. Research by Nguyen V.T & *et al.* utilized the SWSI index to assess hydrological drought in the Red River Delta [11]. Ho V.C. & *et al.* used hydrological indices including the flow deficit (Kth) index and the surface water supply index (SWSI) to assess the hydrological drought situation in the Red-Thai Binh River Delta [12]. Thus, it is evident that there has not been a dedicated study on meteorological drought specifically for Thai Binh Province. A novel aspect of this study is the calculation and analysis of the frequency and trends of meteorological drought in Thai Binh from 2025 to 2065, based on climate change scenarios RCP4.5 and RCP8.5 built in 2020 by Vietnam of the Ministry of Natural Resources and Environment.

2. Content

2.1. Data and method

2.1.1. Data

This study was conducted based on several layers of data including:

- Daily temperatures and rainfall data for the 31 years (from 1991 to 2021) at Thai Bình station. These data are collected and updated from the Meteorological and Hydrological Data Center.

- Daily temperatures and rainfall data from 2025 to 2065 at Thai Bình station. The data come from the climate scenarios built in 2020 by the Ministry of Natural Resources and Environment.

2.1.2. Method

* *Calculating meteorological drought method*

In this article, the PED index was chosen as the basis for computing meteorological drought. The formula is calculated as follows [13]:

$$PED = \frac{\Delta T}{\delta T} - \frac{\Delta P}{\delta P}$$

where

ΔT and ΔP represent the deviations of temperature and precipitation at a specific time from the average temperature and precipitation over the entire period.

σ_T and σ_P denote the standard deviations of temperature and precipitation during the calculation period.

Classification of drought according to the PED index is given in Table 1.

Table 1. Classification of drought according to the PED index [13]

No.	PED Values	Degree of drought
1	<0	Humidity
2	0 – 0.5	Normal
3	0.5 – 1	Start drought
4	1 – 1.5	Slightly drought
5	1.5 – 2	Medium drought
6	2 – 2.5	Quite a high drought
7	2.5 – 3	High drought
8	>3	Severe drought

Drought will occur when the temperature increases, and precipitation falls sharply. The advantage of this method is its simplicity in calculation, requiring only temperature and precipitation data. These values are derived from climate change scenarios.

** Linear regression method*

The changes and trends in meteorological drought are expressed through a linear regression equation:

$$y(t) = at + b$$

The increasing or decreasing trend of y with respect to t is evaluated based on the sign and magnitude of the coefficient a.

2.2. Research results

2.2.1. Frequency of meteorological drought

The PED index was calculated for both the dry season (December, January, February) and the rainy season (May to October) over the period from 1991 to 2021. The results are presented in Figures 1 and 2.

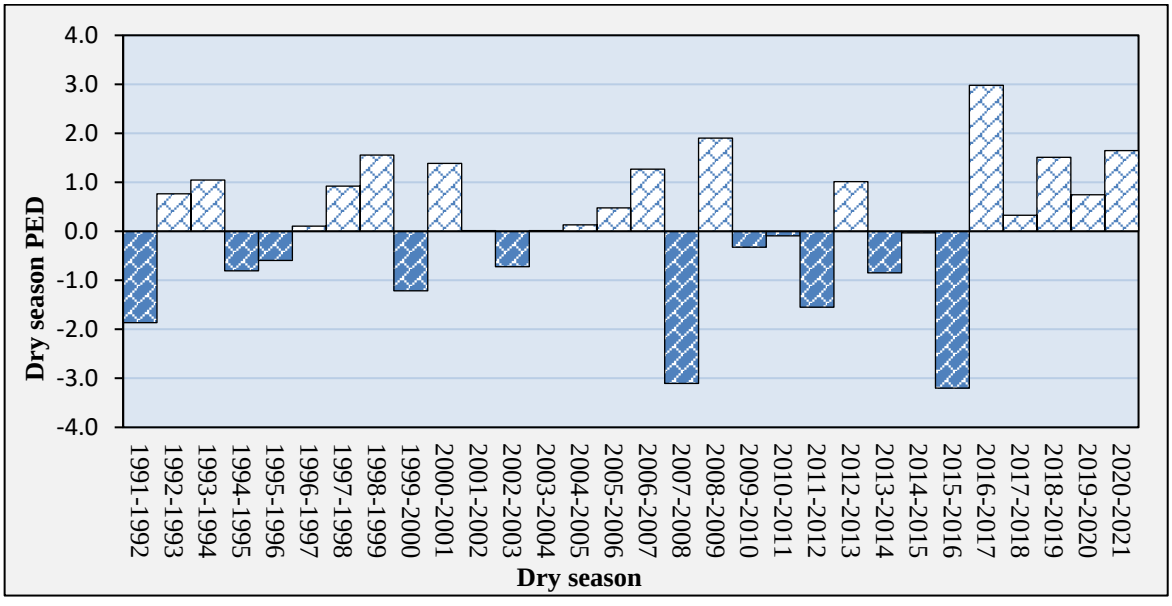

Figure 1. Dry season PED index for the period 1991-2021

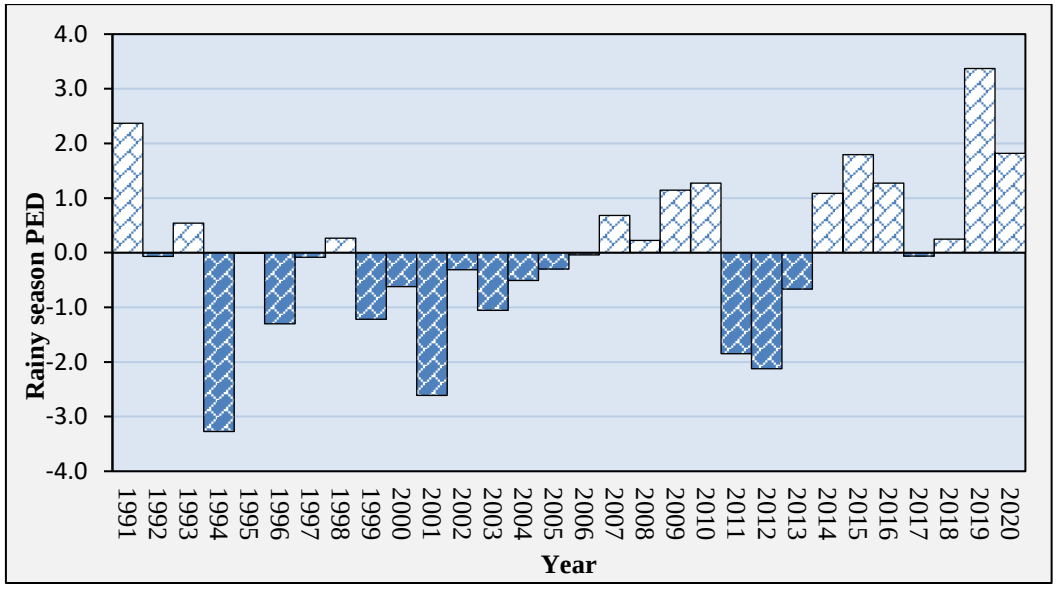

Figure 2. Rainy season PED index for the period 1991-2021

Using the PED values for the dry and rainy seasons from the years compared with Table 1, the frequency of drought is calculated. The results are presented in Figure 3.

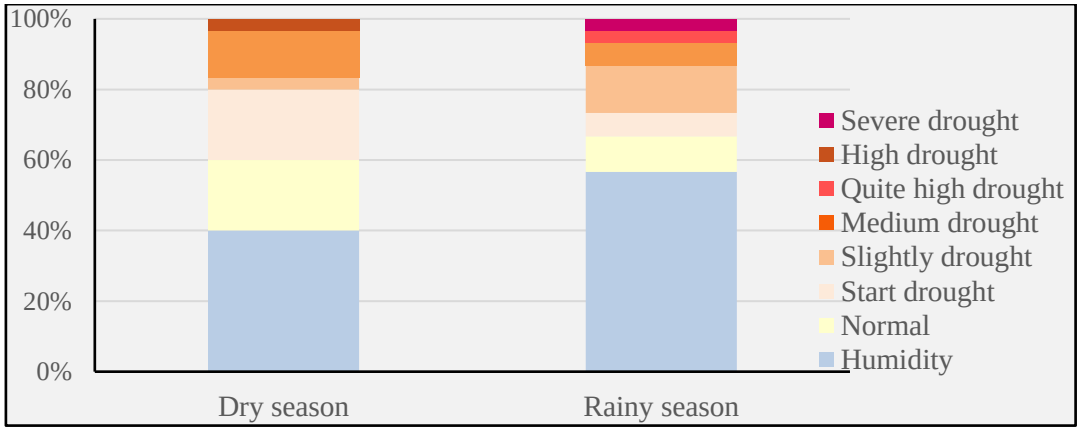

Figure 3. Frequency of drought in the dry and rainy seasons

Figures 1, 2, and 3 indicate that during the period from 1991 to 2021, the PED value in the dry season ranged from -3.1996 to 2.9771. There were 18 dry seasons classified as having humidity and normal levels , accounting for 60% of the total; 7 dry seasons categorized as starting drought and slight drought, representing 23.3%; 4 dry seasons classified as medium drought, making up 13.3%; and 1 dry season categorized as high drought, equivalent to 3.4%. In Thai Binh, although the dry season months during the winter-spring period experience low rainfall (averaging 83mm), the temperatures are also relatively low (averaging 17.3 °C), so the PED value is not high. Consequently, drought occurrences are infrequent and generally not severe. Notable dry seasons were classified as medium drought levels or above due to significant decreases in rainfall, coupled with rising temperatures. For instance, during the dry seasons of 1998 - 1999, 2008 - 2009, 2018 - 2019, and 2020 - 2021, rainfall reached only 30-75% of the average for the

period, while temperatures were 0.678 °C to 1.978 °C above the average. The PED index during these dry seasons ranged from 1.5 to 1.9. Particularly, the dry season of 2016-2017 exhibited the highest PED value, reaching 2.9771, indicating severe drought conditions attributed to low rainfall at only 44% of the average and temperatures 2.142 °C higher than the average. It can be observed that drought in the dry season in Thai Binh occurs with a frequency of nearly once every ten years at the medium drought level, with an increased frequency of drought events noted in the later years of the period.

In Thai Binh, drought occurs not only during the dry season but also in the rainy season. The rainy season lasts for six months from May to October. The calculated results indicate that the PED value in the rainy season ranges from -3.2726 to 3.3698. Specifically, in 21 out of 31 years, the PED index was less than 0.5, indicating that 67.7% of the years were drought-free (humidity or normal conditions). In 6 years, the index indicated starting drought and slight drought levels. Medium drought levels were observed in 2 years (the rainy seasons of 2015 and 2020), accounting for 6.5% of the total. Additionally, a notably high drought level occurred in the rainy season of 1991, while in 2019, the PED index reached 3.3698, corresponding to severe drought conditions.

2.2.2. Trend of drought changes for the period 1991-2021

To illustrate the variation in drought, graphs of the PED index and trend lines have been constructed for both the dry season and the rainy season (Figures 4 and 5). The increasing or decreasing trend of the PED index indicates the corresponding rise or fall in drought conditions. The graphs in Figures 4 and 5 display an upward trend line, with the linear trend equations showing positive coefficients, indicating that drought tends to increase in both the dry and rainy seasons. During the dry season, the PED value increases by 0.0218 per year, while in the rainy season, it rises at a faster rate of 0.059 per year. This demonstrates that drought conditions in the rainy season are escalating more rapidly than those in the dry season.

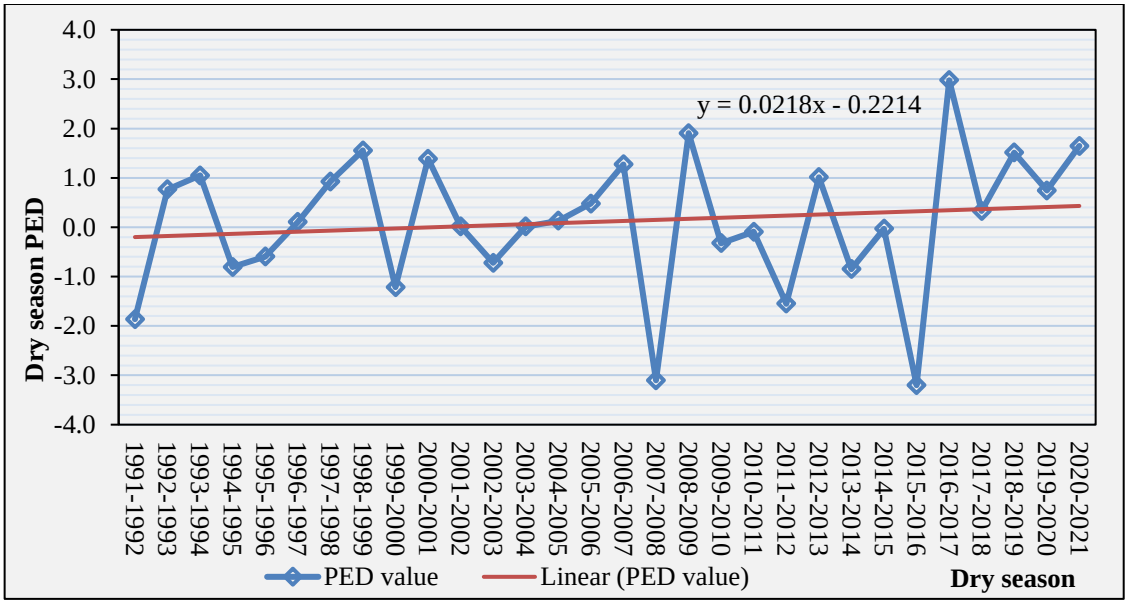

Figure 4. Change trends of the PED index in the dry season for the period 1991-2021

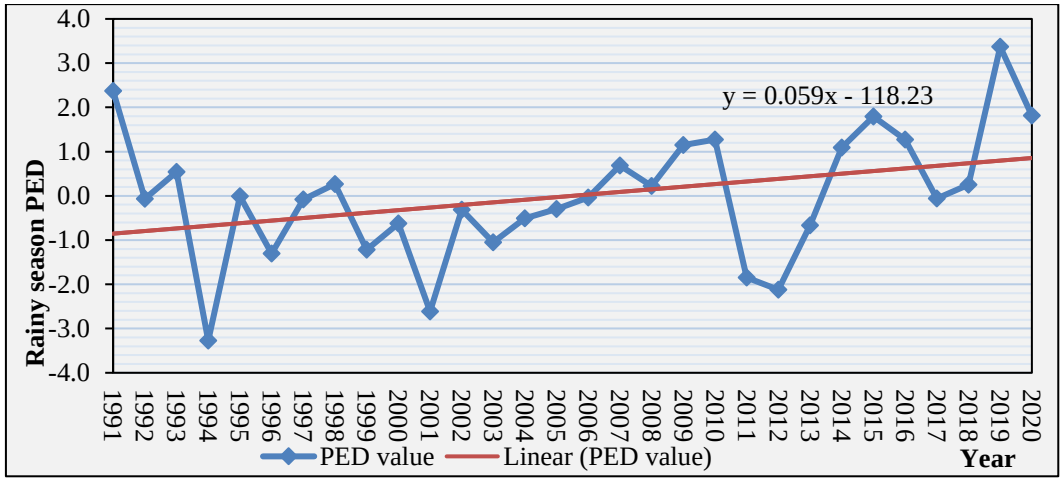

Figure 5. Change trends of the PED index in the rainy season for the period 1991-2021

The trend of drought change is also reflected in the variation in the number of drought months. By calculating the PED index for each month, we analyze the statistics on the number of months with starting drought levels (PED > 0.5) and the number of months experiencing medium drought levels or higher (PED > 1.5), as outlined in Table 1. This data is then used to construct a trend chart (Figure 6). From 1991 to 2021, only the year 1996 experienced no drought months. On average, each year had 4.5 drought months. The years 2002, 2003, 2010, 2015, 2016, 2018, 2019, and 2020 recorded between 6 and 11 drought months. Notably, the number of drought months has increased toward the end of this period. The upward-sloping trend line, with a coefficient of 0.1225, indicates an increase in the number of drought months of 0.1225 months per year, or 1.255 months per decade. The number of months at medium drought level and above follows a similar trend. From 2015 onward, this number has risen from 3 to 5 months, peaking at 7 months in 2019. The increase in the number of months at medium drought level and above is also significant, reaching 0.1159 months per year, corresponding to 1.159 months per decade.

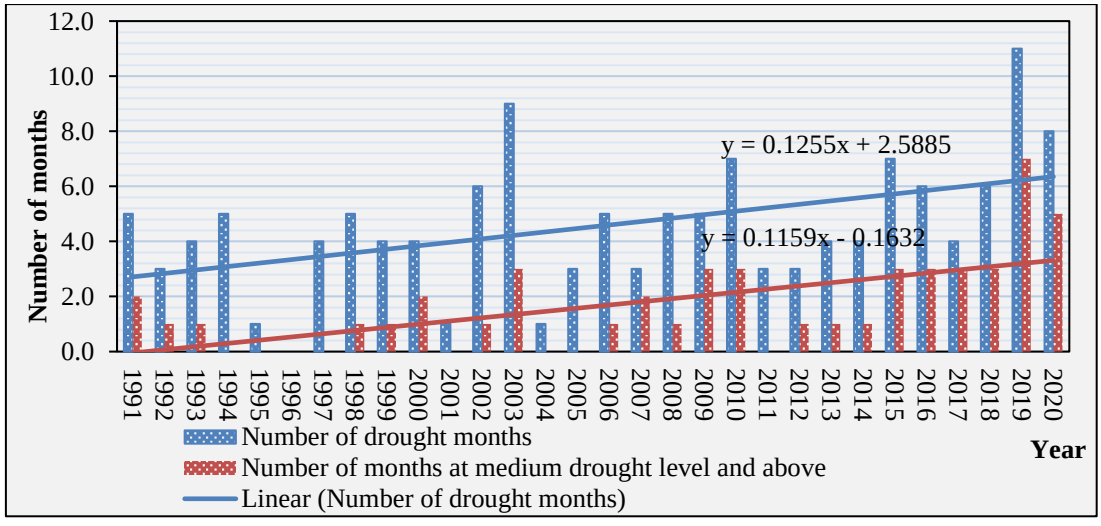

Figure 6. Change trends of the number of drought months and months at medium drought level and above for the period 1991 - 2021

2.2.3. Trend of drought changes for the period 2025-2065

The assessment of drought trends over the next 40 years, from 2025 to 2065, was conducted under both RCP4.5 and RCP8.5 climate change scenarios. The results of the PED index calculations for the dry and rainy seasons during this period are illustrated in Figures 7 and 8.

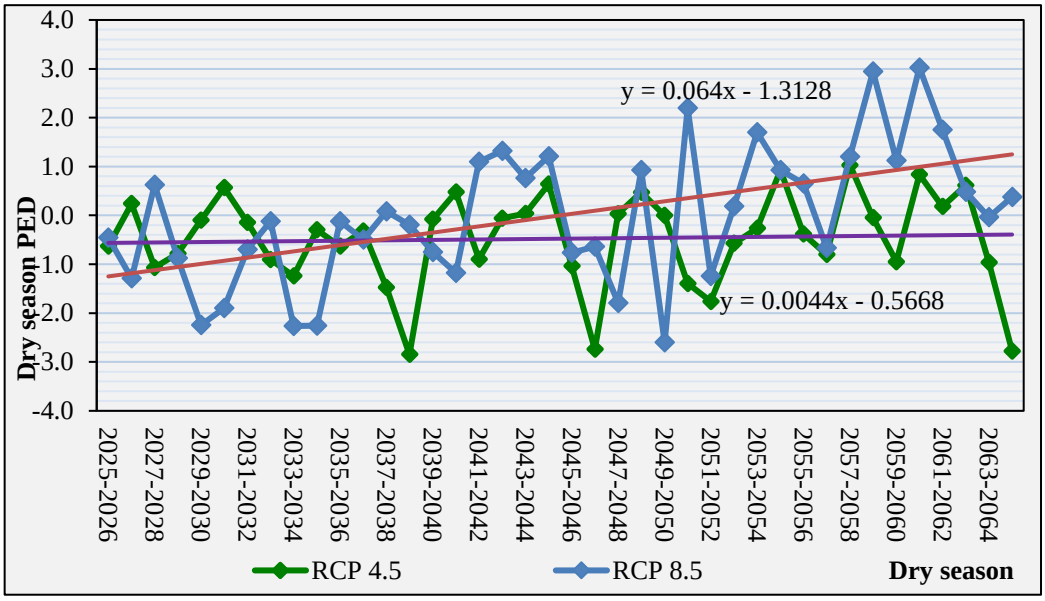

Figure 7. Change trends of the PED index in the dry season according to RCP4.5 and RCP8.5 scenarios

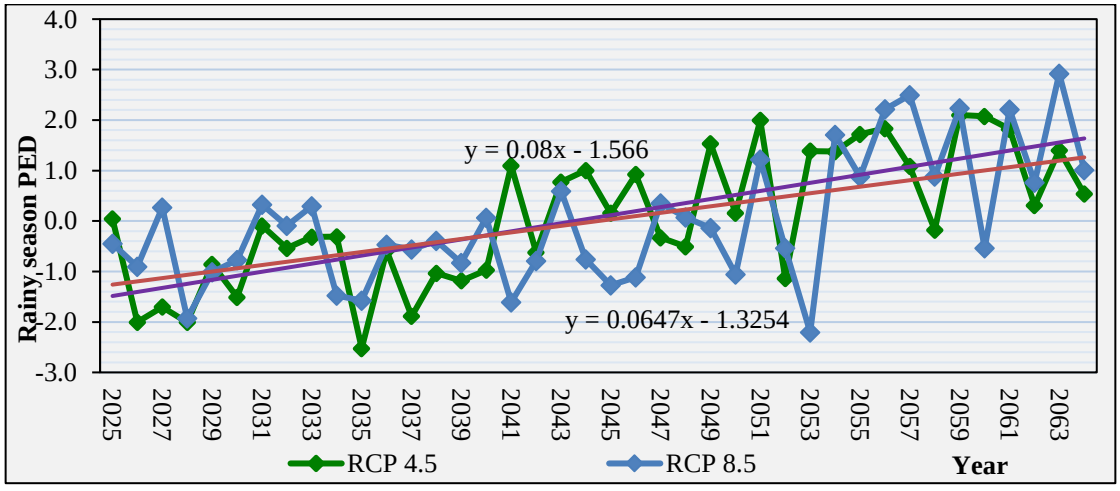

Figure 8. Change trends of the PED index in the rainy season according to RCP4.5 and RCP8.5 scenarios

Under the RCP4.5 scenario, the PED index in the dry season is less than 1 in most years, indicating that drought rarely occurs. However, there is a slight upward trend in drought occurrences, as evidenced by the positive coefficient in the trend equation (a = 0.0044). In the RCP8.5 scenario, the PED value increases significantly, with an annual increase of

0.064. The frequency of drought during the dry season rises, with 37.5% of the years experiencing drought, a notable increase compared to the period from 1991 to 2021. Medium drought, as well as quite high, high, and severe drought levels, have emerged, accounting for 12.5% of the years. The trend line indicates that the dry season drought in Thai Binh is expected to increase in the future, with an escalating severity.

During the rainy season from 2025 to 2065 drought tends to increase more significantly in both scenarios. The PED index increases by 0.08 per year in the RCP4.5 scenario and by 0.0647 per year in the RCP8.5 scenario, with the increase in the RCP4.5 scenario being greater than that in the RCP8.5 scenario. Compared to the period from 1991 to 2021, the intensity of drought in the rainy season is projected to rise in the future.

Regarding the number of drought months, the forecasted results of changes and trends in the number of drought months (at start drought level, PED > 0.5) and the months at medium drought levels and above (PED > 1.5) are presented in the graphs of Figures 9 and 10. According to forecasts for the period 2025- 2065, the number of drought months in Thai Binh will be relatively high, with an average of 4.5 drought months per year and an additional 1.5 to 2 months classified as medium drought level or higher in both scenarios. In general, the number of drought months and the number of months classified as medium drought level or higher in the RCP 8.5 scenario are greater than those in the RCP 4.5 scenario. The trend in the number of drought months is increasing in both scenarios. The coefficient of the linear trend equation is 0.2162 under the RCP4.5 scenario and 0.2586 under the RCP8.5 scenario. This represents an increase of 0.2162 months per year, or 2.162 months per decade, and 0.2586 months per year, or 2.586 months per decade, under the corresponding scenarios. Additionally, the number of months with drought levels from medium to high is also rising significantly, at 0.1179 months per year for the RCP4.5 scenario and 0.1436 months per year for the RCP8.5 scenario.

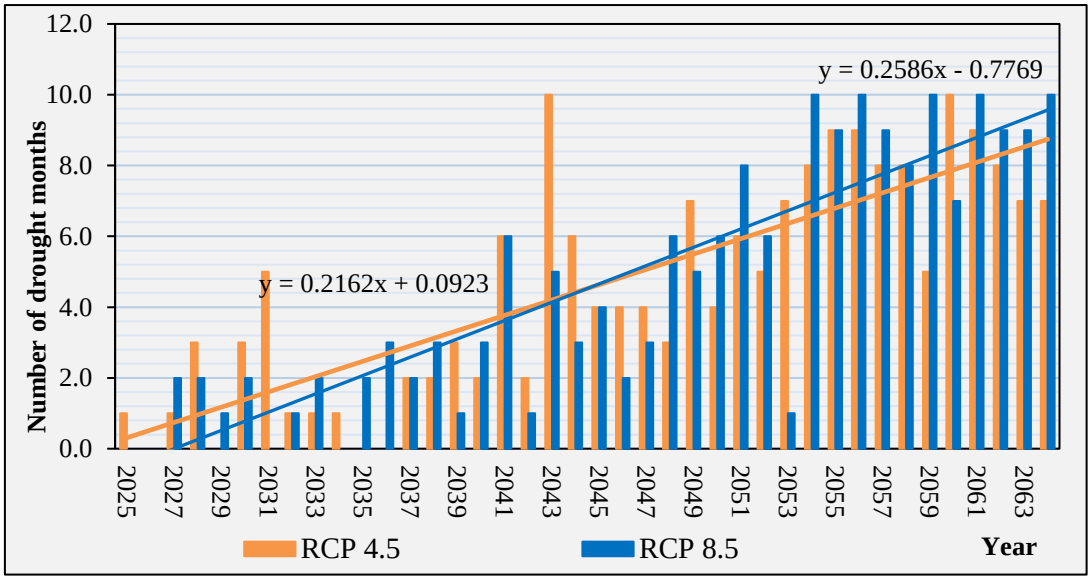

Figure 9. Forecast of changes and trends in the number of drought months (at start drought level) according to the RCP4.5 and RCP8.5 scenarios for the period 2025-2065

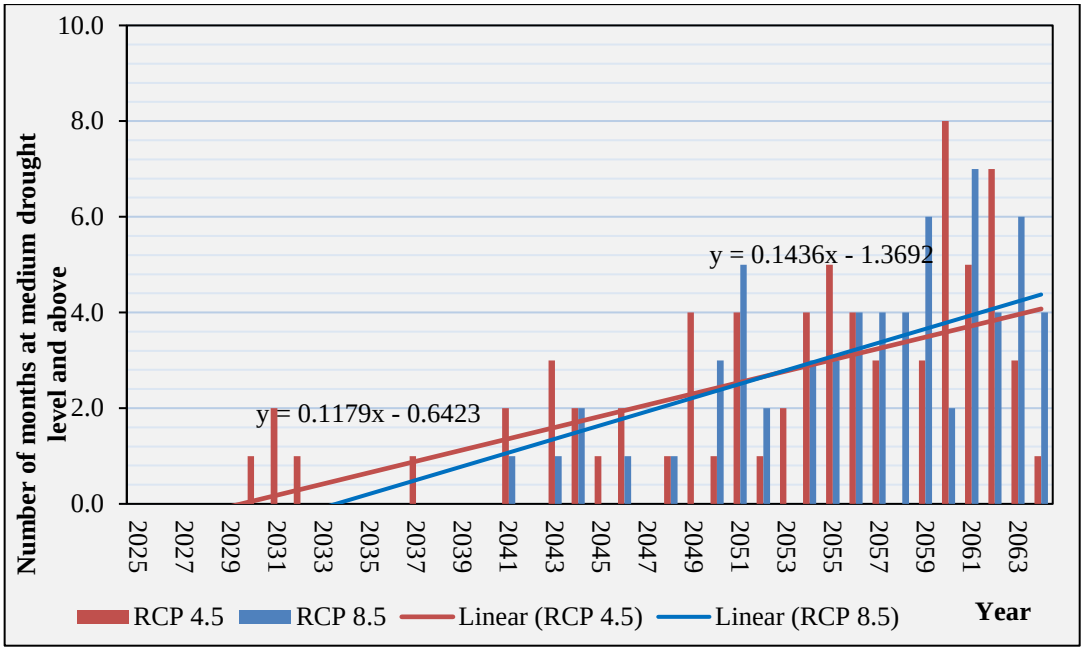

Figure 10. Forecast of changes and trends in the number of months at medium drought level and above according to the RCP4.5 and RCP8.5 scenarios for the period 2025-2065

3. Conclusions

Based on the calculations and analysis of the changing trends of the PED index in Thai Binh both in the past and future, this study draws the following conclusions:

Meteorological drought in Thai Binh can occur in both dry and rainy seasons, but the frequency is not high.

During the period from 1991 to 2021, medium drought levels occurred with a frequency of approximately once every ten years. Drought conditions in both the rainy and dry seasons exhibited an increasing trend in both intensity and the number of drought months.

In the future, during the period from 2025 to 2065, dry season drought is expected to fluctuate minimally under the RCP4.5 scenario, while it will increase sharply in frequency and intensity under the RCP8.5 scenario. Additionally, drought conditions in the rainy season are projected to increase in both scenarios. The number of drought months is already quite high and tends to rise significantly in both the RCP4.5 and RCP8.5 scenarios.

The results presented above provide an important foundation for localities to develop reasonable agricultural plans that adapt to drought conditions and enhance efficiency.

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