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ASSESSMENT OF DROUGHT IN THE SOUTHERN SUB-REGION OF THE RED RIVER DELTA FOR AGRICULTURAL DEVELOPMENT

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Abstract. The southern sub-region of the Red River Delta possesses favorable natural conditions for agricultural development and plays an important role in the country's agricultural output. Nevertheless, this region is highly vulnerable to natural disasters, particularly droughts, which pose significant challenges to agricultural productivity. This study applies a combination of statistical and spatial analysis methods to examine drought characteristics in the Southern Subregion of the Red River Delta. The research methodology included: (i) calculation of the K drought index, (ii) estimation of drought and extreme drought frequency, (iii) application of simple linear regression analysis, and (iv) interpolation using the Inverse Distance Weighting (IDW) method. Monthly precipitation and evapotranspiration data from 1991 to 2020 were utilized. The results show that droughts occurred in almost all months, except August and September, with the most severe events concentrated in December, January, and February. Although the region is relatively homogeneous, spatial variations are apparent. Ha Nam Province consistently recorded the lowest drought severity across all indicators, including drought frequency, extreme drought frequency, and the annual drought index. In contrast, a prominent elongated zone (or "trough") with a high frequency of severe drought months is evident in the spatial distribution maps. Additionally, a drought tongue with increasing severity extends from Ha Nam in a northeast–southwest direction toward Van Ly (Nam Dinh). These findings provide critical insights for disaster risk reduction and serve as a scientific basis for agricultural planning and sustainable development in the region.

Keywords: natural disasters, drought, K drought index, drought frequency, dry seasons, Red River Delta.

1. Introduction

According to the World Meteorological Organization (WMO), drought is defined as a prolonged dry period within the natural climate cycle that can occur anywhere in the world [1]. The main causes of drought are extended periods of low precipitation and high potential evapotranspiration. Meteorological drought is considered a primary factor contributing to the emergence of hydrological, agricultural, economic, and socio-economic droughts [2], [3]. Among natural disasters, drought causes the most significant economic damage globally [4]. In the context of climate change, particularly during El Niño events, droughts have become more widespread and intense [5], increasing the risk of damage from natural hazards [6], [7]. Currently, drought results in economic losses of approximately 9 billion euros annually in the United Kingdom and the European Union [8]. In Asia, between 1970 and 2019, 138 drought-related disasters were recorded over a 50-year period, with estimated losses reaching USD 72 billion [9].

To support drought-related research, the WMO published a drought handbook introducing 50 different drought indices [10]. Wanders et al. [11] analyzed the strengths and limitations of 18 key drought indices, providing a basis for researchers to select appropriate indices tailored to specific geographical contexts. Depending on geographic conditions and research objectives, different drought indices may be employed. For example, the use of the PED index in Serbia from 1949 to 2016 showed a spatial trend of decreasing drought severity from west to east, later shifting from north to south [12]. In southern Iran, application of the RDI index revealed significant increases in drought severity over time, particularly in regions characterized by normal to extremely dry conditions [13]. A study using the SPI index in the Yazd-Ardakan Plain showed that the lowest SPI values were found in the central, northern, and southeastern areas, while higher values were associated with elevated terrains in the west [14].

Agriculture plays a critical role in Vietnam’s economy, with the agriculture, forestry, and fisheries sector accounting for 8.84% of GDP in 2023 [15]. Most studies on drought in Vietnam focus on temporal variability and spatial distribution to support agricultural development. The K drought index has shown that the most drought-prone areas include the Mekong River Delta, South Central Coast, and Central Highlands [16]. In the Tien River estuary, the RIDst [17] and PED indices [18] have been used to identify increasing inland drought severity and significant risks of severe to extreme drought during the dry seasons of 2019–2035 and 2046–2065, respectively [17], [18]. The SWSI hydrological drought index has been evaluated as suitable for drought monitoring and forecasting in the Red River Delta region. In Hai Duong province, the K drought index revealed that from 2021 to 2050, droughts occurred between December and February, ranging from moderate to severe [20]. The SPI, PED, and D drought indices were used to assess drought trends and severity in Ninh Binh Province for the period 1980–2010. The results indicate that, under the influence of climate change, drought frequency and intensity have markedly increased in both lowland and mountainous areas of the province [21].

Drought indices such as RDI, PED, and SPI are typically designed to evaluate drought severity in a specific year relative to long-term averages. These indices are suitable for temporal assessments at individual meteorological stations but are less effective for spatial comparisons across regions. For spatial drought assessment, especially in terms of meteorological drought, the K drought index is considered the most appropriate and simplest option.

The southern Red River Delta sub-region is a major agricultural area, particularly for rice cultivation, contributing 6.1% of Vietnam's rice production in 2023 [22]. Drought zoning for the study area serves as a critical source of information for policymakers and farmers to use land resources efficiently and implement effective disaster prevention measures, thereby supporting sustainable agricultural development at the local level.

2. Content

2.1. Study Area, Data Sources, and Research Methods

2.1.1. Study Area

The southern sub-region of the Red River Delta, located within the Red River Delta region, includes the provinces of Ninh Binh and the south of Hung Yen province. It lies between 19°55'–20°44' North latitude and 105°32'–106°39' East longitude. It shares borders with the provinces of Hanoi, Hai Phong, Phu Tho, and Thanh Hoa (Figure 1). The natural area covers approximately 552.7 km², accounting for 1.7% of the total national land area and 26% of the Red River Delta. In 2023, the population reached 5.672 million people, with a population density of 1,026 people/km² [23].

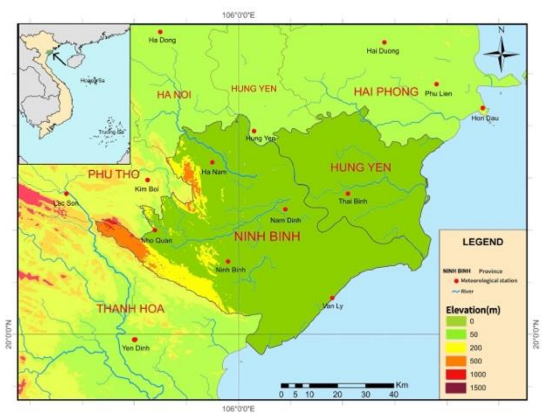
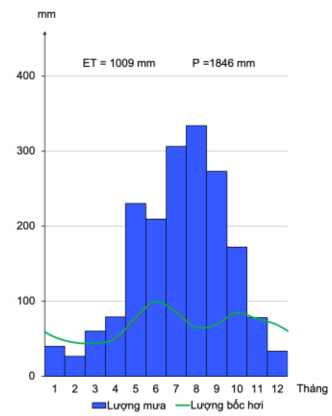


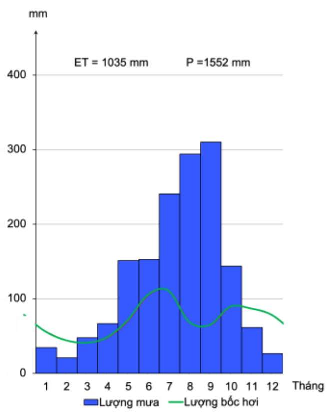
Figure 1. Topographic map of the study area

The southern sub-region of the Red River Delta has a tropical monsoon climate with a cold winter [24]. The average annual temperature ranges from 23.6°C to 24°C. Annual precipitation ranges between 1552 and 1846 mm, and the annual potential evapotranspiration is between 1004 and 1035 mm (Figure 2). However, due to substantial intra-annual variability in precipitation, from December to February of the following year, evaporation consistently exceeds precipitation by a significant margin, leading to the onset of the dry season in the study area.. The average monthly relative humidity exceeds 80%, except in December at the Ninh Binh meteorological station, where the average relative humidity is 79% [25]. The seasonal characteristics of the region's climate are particularly evident in rainfall distribution, with three consecutive months (December, January, February) receiving very low rainfall—below the temperature curve—thus defining the dry season for the study area. Seasonal variability of relative humidity is also observed, with the lowest monthly averages (79–84%) occurring during October, November, and December, and relatively low humidity is also recorded in June and July [25].

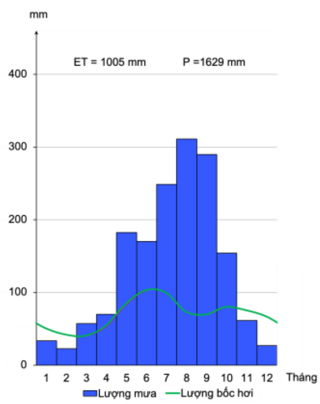
The southern sub-region of the Red River Delta is undergoing significant development. In 2023, the Gross Regional Domestic Product (GRDP) reached 224 trillion VND, with growth rates across the study provinces ranging from 7.37% to 10.19%. In terms of economic structure, agriculture, forestry, and fishery account for 14%, industry and construction for 47.8%, services for 31.9%, and taxes, less subsidies for products account for 6.3% [15]. Within the agriculture–forestry–fishery sector, agriculture is the most developed sub-sector due to the region's natural potential, yet it is also the most negatively affected by drought compared to other sectors.



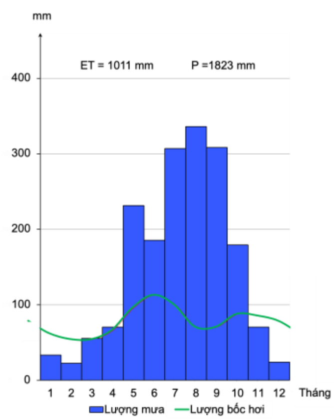
(a) Phu Ly meteorological station



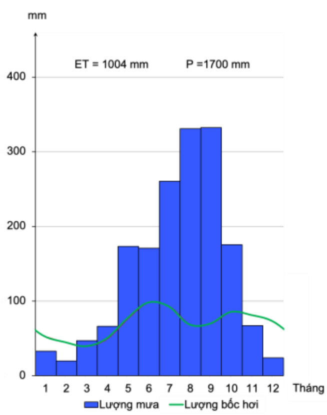
b) Thai Binh meteorological station



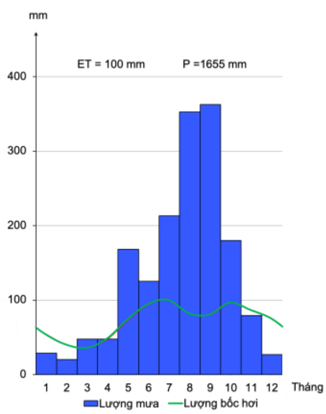
(c) Nam Dinh meteorological station



(d) Nho Quan meteorological station



(e) Ninh Binh meteorological station



(f) Van Ly meteorological station

Figure 1. Annual variation chart of monthly precipitation and evaporation

Source [25]

2.1.2. Research Methods

**** Calculation of the K Drought Index***

The K drought index [26] used in this study is calculated using the following formula (1):

$$K_t = \frac{E_t}{P_t} \quad (1)$$

where E_t is evaporation for the time period t (t is month, season, year); P_t is precipitation for the time period; K_t is the drought index for the time period t.

Drought classification is presented in Table 1.

Table 1. Classification of drought levels based on the K drought index

Drought severity level	K drought index range
Wet	K < 1,0
Slightly dry	1 ≤ K < 2
Dry	2 ≤ K < 4
Severely dry	K ≥ 4

Source: [27]

**** Drought and severe drought frequency***

Drought severity at specific locations is determined by calculating the frequency of drought and severe drought. These are calculated using the following formulas:

$$f_{dry} = \frac{Number\ of\ drought\ months\ over\ 30\ years}{Total\ months\ in\ 30\ years} * 100\% \quad (2)$$

$$f_{Severely\ dry} = \frac{Number\ of\ severely\ drougth\ months\ over\ 30\ years}{Total\ months\ in\ 30\ years} * 100\% \quad (3)$$

f_{dry}: drought frequency (1991–2020);

$f_{severely\ dry}$: severe drought frequency (1991–2020) [27].

**** Simple linear regression method***

The annual K drought index values constitute a time series of the observed random variable K, which may exhibit a trend. To identify trends over time, a simple linear regression model is applied using the formula (4):

$$K = a * T + b \quad (4)$$

K: Drought index;

a: Slope coefficient, representing the average change in K per unit increase in T;

b: Intercept, representing the predicted value of K when T = 0 (Taylor, 1997) [28]. The value of *a* indicates the trend of drought index variation.

- Inverse Distance Weighted (IDW) Interpolation Method

The study applies the Inverse Distance Weighted (IDW) interpolation method using values from six known points within the study area and six points from surrounding areas to estimate unknown values at other locations.

The weight calculation formula is as follows:

$$Z_0 = \frac{\sum_{i=1}^{N} Z_i \, . \, d_i^{-n}}{\sum_{i=1}^{N} d_i^{-n}} \quad (5)$$

Z_i: Value at the known point;

d_i: is the distance to the unknown point;

Z_0: Estimated value at the unknown point;

N: Number of known points.

n: Power parameter [29].

This method supports the generation of isopleth (contour) maps used in this study.

2.1.3. Data Sources

The study uses monthly average temperature, monthly precipitation, and monthly of potential evapotranspiration data for the period 1991–2020 from the meteorological stations in Ha Nam, Thai Binh, Nam Dinh, Nho Quan, Ninh Binh, and Y Yen, as well as from surrounding stations including Ha Dong, Hai Duong, Phu Lien, Kim Boi, Lac Son, and Yen Dinh (Figure 1). These data were provided by the Vietnam Center of Hydro-Meteorological Data [25].

2.2. Research Results

2.2.1. Annual Drought Variation

Based on formula (1), monthly K values were calculated for the period 1991–2020 for six meteorological stations within the study area and six surrounding stations.

According to Figure 3 and the calculation results, the annual drought variation in the Southern Subregion of the Red River Delta is as follows: At the Ninh Binh meteorological station, drought events did not occur in three consecutive months: July, August, and September. Months with over 50% drought occurrence include November, December, January, and February (four consecutive months). The drought frequency was 26%. Very severe droughts did not occur during the six consecutive months: April to September. December was the only month with over 50% very severe drought occurrence. The frequency of very severe drought was 15% (Figure 3). At the Nho Quan station, drought events did not occur in two consecutive months: August and September. Months with over 50% drought occurrence were November to February (four consecutive months). The drought frequency was 29%. Very severe droughts did not occur in five consecutive months: May to September. December had over 50% very severe drought occurrences. The frequency of very severe drought was 16%.

At the Ha Nam station, drought events did not occur in three consecutive months: July to September. Months with over 50% drought occurrence were December to February (three consecutive months). The drought frequency was 21%. Very severe droughts did not occur in seven consecutive months: March to September. No month had more than 50% very severe drought occurrence from 1991 to 2020. The frequency of very severe drought was 11%.

At the Nam Dinh station, drought events did not occur in two consecutive months: August and September. Months with over 50% drought occurrence were December to

February. The drought frequency was 23%. No month had over 50% very severe drought occurrence. The frequency of very severe drought was 13%.

At the Van Ly station, drought events did not occur in two consecutive months: August and September. Months with over 50% drought occurrence were December, January, and March. The drought frequency was 27%. No month had over 50% very severe drought occurrence. The frequency of very severe drought was 16%.

At the Thai Binh station, drought events did not occur in June, August, and September. Months with over 50% drought occurrence were November to February (four consecutive months). The drought frequency was 26%. Very severe droughts did not occur in four consecutive months: June to September. December had over 50% very severe drought occurrences. The frequency of very severe drought was 14%.

Thus, in all stations within the study area, drought did not occur in August and September. In the remaining months, drought and very severe drought risks were present. Drought frequency exceeding 50% across the entire study area was observed in December, January, and February.

Năm	TT	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1991	NinhBinh	3,9	6,3	0,6	1,5	0,6	1,0	0,4	0,3	0,7	5,0	3,2	1,5
1992	NinhBinh	1,3	1,4	0,8	0,8	0,7	0,2	0,3	0,5	0,3	10,0	3,7	0,9
1993	NinhBinh	5,8	4,6	3,0	1,1	0,6	0,7	1,2	0,2	0,1	3,5	1,4	15,1
1994	NinhBinh	7,5	0,8	0,3	2,3	0,2	0,2	0,2	0,1	0,1	0,3	2,7	2,0
1995	NinhBinh	1,9	2,2	0,5	2,0	0,3	0,3	0,3	0,2	0,2	0,9	1,2	8,1
1996	NinhBinh	4,7	2,1	0,3	0,8	0,6	0,9	0,5	0,1	0,1	1,0	0,2	25,6
1997	NinhBinh	1,0	1,8	0,7	0,2	2,3	1,1	0,3	0,2	0,3	0,2	5,0	2,1
1998	NinhBinh	2,0	1,3	1,0	0,9	0,4	0,3	1,0	0,3	0,5	0,5	5,3	19,4
1999	NinhBinh	2,5	20,6	3,6	0,9	0,2	0,5	1,7	0,2	0,6	0,2	0,9	1,1
2000	NinhBinh	71,9	5,0	0,7	0,5	1,0	0,6	0,2	0,4	0,1	0,3	23,2	53,1
2001	NinhBinh	65,3	4,4	0,9	0,4	1,0	0,5	0,2	0,4	0,1	0,3	22,9	32,3
2002	NinhBinh	9,7	3,0	4,0	1,5	0,2	0,8	0,5	0,4	0,6	0,5	1,7	1,2
2003	NinhBinh	1,7	2,3	1,2	1,9	0,9	0,4	0,7	0,2	0,1	4,7	89,9	40,6
2004	NinhBinh	4,7	1,1	1,5	0,6	0,7	0,6	0,5	0,4	0,2	5,0	3,8	33,8
2005	NinhBinh	5,4	1,4	2,4	0,8	1,3	1,1	0,4	0,2	0,1	3,3	0,4	5,2
2006	NinhBinh	49,1	1,4	1,0	3,7	0,3	0,7	0,4	0,2	0,5	1,5	2,5	1044,0
2007	NinhBinh	129,7	0,9	0,7	1,7	0,5	0,9	0,5	0,3	0,4	0,4	13,1	10,3
2008	NinhBinh	0,9	4,9	2,2	1,2	0,4	0,3	0,5	0,2	0,2	0,2	0,4	2,7
2009	NinhBinh	10,6	9,2	0,5	0,3	0,2	1,5	0,3	0,3	0,2	0,7	29,4	2,4
2010	NinhBinh	0,4	6,4	5,2	0,5	0,9	2,7	0,4	0,1	0,3	0,6	25,8	7,1
2011	NinhBinh	7,6	8,6	0,4	3,2	0,3	0,3	0,3	0,3	0,2	0,4	1,0	4,6
2012	NinhBinh	0,6	1,3	1,2	1,1	0,2	1,0	0,3	0,2	0,2	0,4	0,3	2,3
2013	NinhBinh	3,2	1,3	2,1	0,9	0,4	0,4	0,1	0,2	0,2	0,6	1,1	8,0
2014	NinhBinh	23,0	1,2	0,3	0,3	0,5	0,4	0,3	0,3	0,4	0,4	0,4	3,5
2015	NinhBinh	1,7	0,5	0,4	1,9	2,2	0,5	0,4	0,3	0,1	0,8	0,3	0,9
2016	NinhBinh	0,2	8,5	0,6	0,3	0,5	0,8	0,2	0,1	0,3	0,9	3,3	0,8
2017	NinhBinh	0,3	4,3	0,3	0,7	0,9	0,4	0,2	0,3	0,2	0,1	1,7	2,3
2018	NinhBinh	1,6	5,1	1,6	0,6	0,4	1,1	0,2	0,2	0,4	0,2	3,6	0,8
2019	NinhBinh	3,3	1,7	1,0	1,2	0,2	2,8	1,0	0,2	0,7	0,2	1,4	5,3
2020	NinhBinh	0,3	2,5	0,4	0,9	1,3	1,0	0,4	0,2	0,4	0,3	0,8	5,6

Color code	Drought severity level	K drought index range
0,5	Wet	K<1
1,0	Slightly dry	1≤K<2
3,0	Dry	2≤K<4
5,0	Severely dry	K≥4

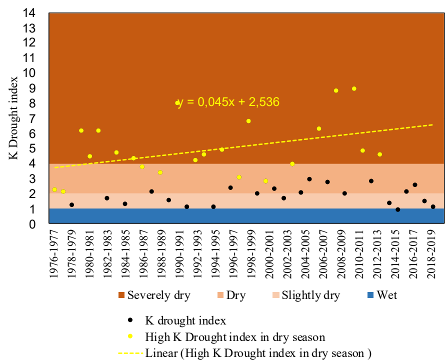
Figure 2 Monthly K Drought Index values for the period 1991–2020 at the Ninh Binh station

2.2.2. Temporal variation of the drought index in the dry season

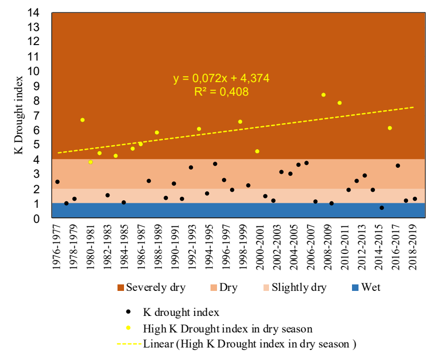
In addition to intra-annual variation, drought severity also changes over the years. This study analyzed the variation of high K Drought Index values across 44 dry seasons (1976–2020) at six stations within the study area (Figure 4). The High K Drought Index is defined as instances where the K value exceeds that observed in adjacent years. The dry season here refers to December of the previous year to February of the following year.

To identify trends in the most severe drought season, the study selected dry seasons with high K values and examined their variation over time.

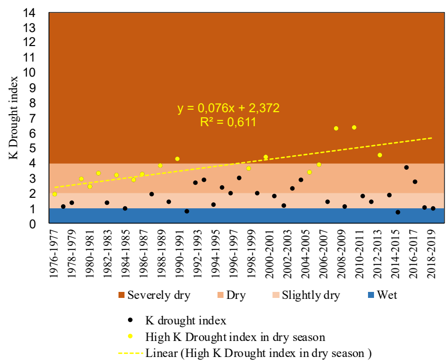
At the Phu Ly station, the K index trend was 0.045/year, meaning it increased by approximately 1.3 over 29 years. At the Ninh Binh station, the trend was 0.078/year—seven times higher than Phu Ly, an increase of 2.3 over 29 years. At the Nho Quan station, the trend was 0.078/year, five times higher than Phu Ly, an increase of 2.3 over 29 years. At the Nam Dinh station, the trend was 0.076/year, also about seven times higher than the Phu Ly increase of 2.2 over 29 years.



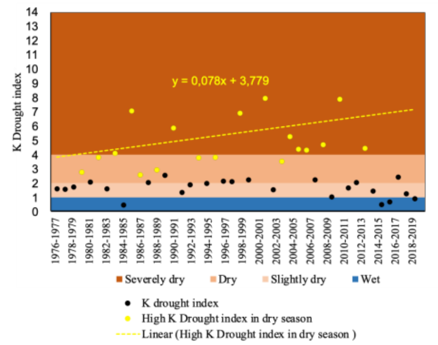
a) Phu Ly



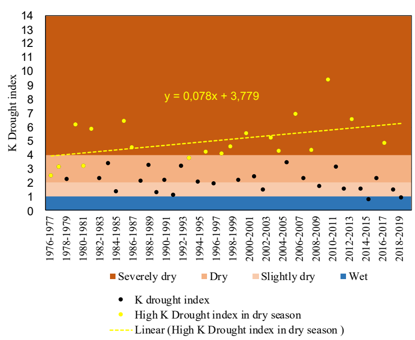
b) Thai Binh



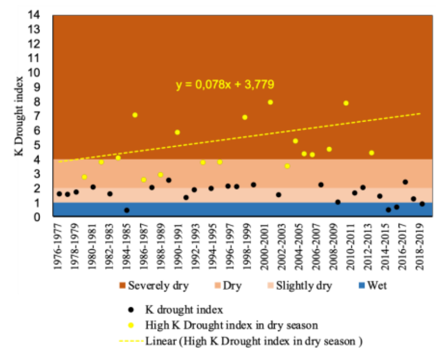
c) Nam Dinh



d) Ninh Binh



e) Nho Quan



f) Van Ly

Figure 3. Long-term trend and variation of the K drought index at meteorological stations in the Southern subregion of the Red River Delta, 1976 - 2020

Hence, the high K Drought index in the dry season shows an increasing trend across all stations. The lowest trend was at Phu Ly. Ninh Binh, Nho Quan, Nam Dinh, Thai Binh, and Van Ly stations had similar trends, all approximately seven times higher than Phu Ly.

2.2.3. Spatial differentiation of monthly drought frequency

To construct the zoning map, the Inverse Distance Weighted (IDW) interpolation method was employed, integrating expert knowledge and topographic factors. In this study, drought frequency is defined as the proportion of drought months within the 12 months of a year during the period 1991–2020. To improve reliability, data from six meteorological stations located within the study area, along with six surrounding stations, were used to calculate drought indices and construct contour lines.

In the Southern Subregion of the Red River Delta, the spatial trend of drought frequency generally follows a northwest–southeast axis. Ha Nam Province exhibits the lowest drought frequency, which increases sharply toward the north and south of Ha Nam, and more gradually toward the east–southeast, particularly in Nam Dinh. In Thai Binh Province, however, spatial variation in drought frequency is less clearly defined.

In Hung Yen province, spatial variation in drought frequency is not clearly defined.

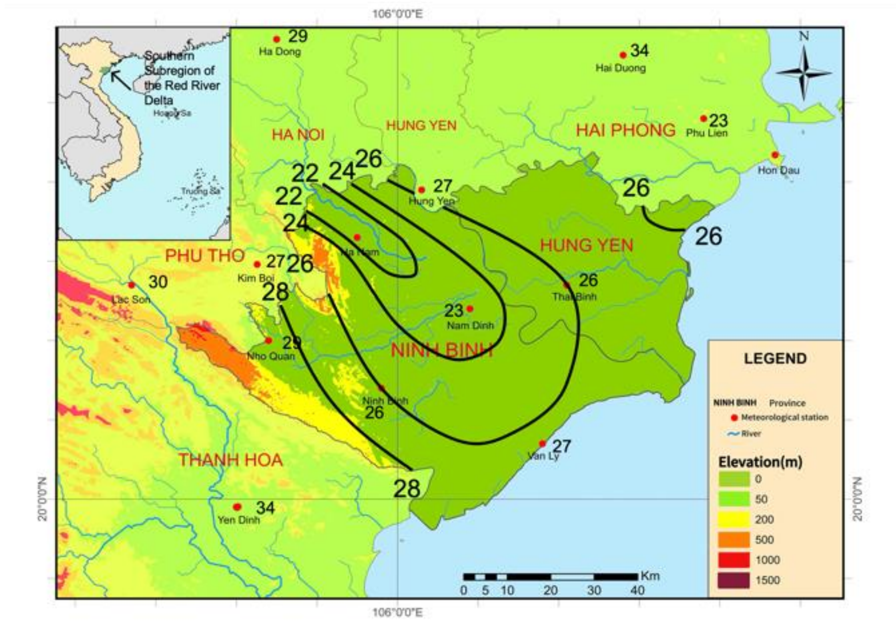


Figure 5. Spatial distribution of the frequency of drought months per year in the Southern subregion of the Red River Delta, 1991 - 2020

2.2.4. Spatial differentiation of very severe drought frequency during the dry season

The spatial distribution of very severe drought frequency also follows a northwest–southeast trend. The lowest frequency was in Ha Nam (11%), increasing rapidly north and south of Ha Nam and more slowly southeastward toward Van Ly (16%).

In Hung Yen province, spatial variation in very severe drought frequency is not pronounced.

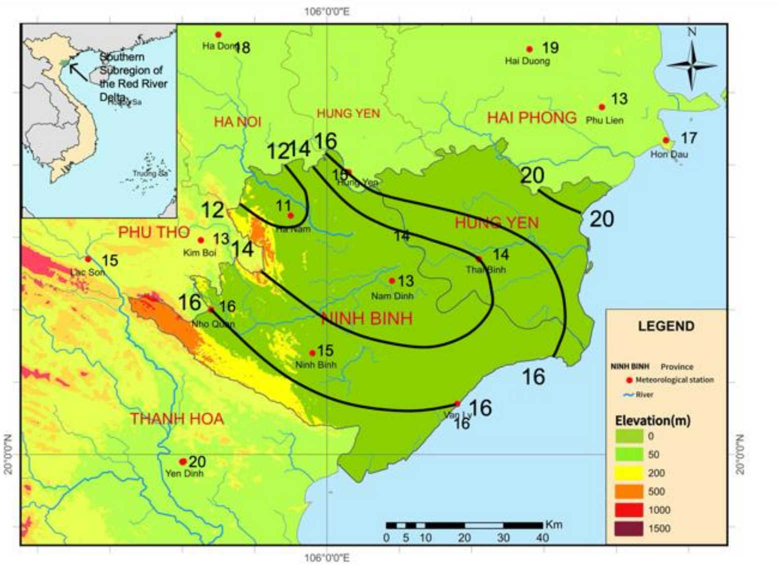


Figure 6. Spatial distribution of the frequency of severe drought months per year in the Southern Subregion of the Red River Delta, 1991 - 2020

2.2.5. Spatial Differentiation of Annual Drought Severity

Annual drought severity was calculated as the ratio of total evaporation to total precipitation over 1991–2020.

The spatial trend of annual drought severity also follows a northwest–southeast direction. The lowest index was in Ha Nam (0.4), increasing rapidly toward the north and south of Ha Nam, and more gradually southeastward toward Van Ly (0.5).

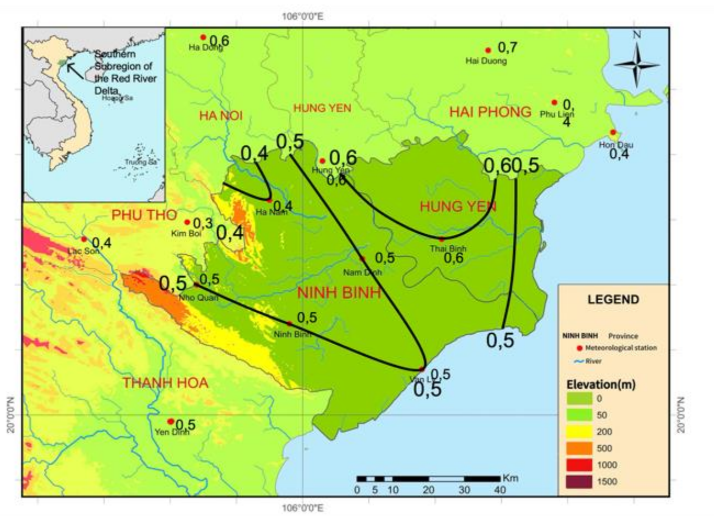


Figure 7. Spatial distribution of annual drought severity in the Southern Subregion of the Red River Delta, 1991 - 2020

2.3. Discussion

2.3.1. Temporal and spatial variation of drought

The results show that in the Southern Subregion of the Red River Delta, drought occurred in almost all months during 1991–2020, except for August and September, likely due to these months having the highest average rainfall.

Focusing on December, January, and February (the dry season) for drought analysis is scientifically meaningful, as this period corresponds to the lowest rainfall levels in northern Vietnam and aligns with the findings in Section 2.2.1. During this period, the highest K values exhibit an increasing trend across all stations, with the lowest at Phu Ly (Ha Nam) and the highest at Van Ly (Nam Dinh). Western Ha Nam features mountainous terrain, favoring orographic rainfall, contributing to higher precipitation and lower K values. In addition, Ha Nam also records the lowest monthly evaporation rates among the stations.

2.3.2. Significance of temporal and spatial drought analysis

Mapping and charting drought variation over space and time in the context of climate change is both scientifically and practically important: Provides baseline data for developing drought forecasting models for early warning and adaptation planning; Aids in building drought risk maps for disaster management with a regional focus; Enhances disaster risk management capacity, aiming for water security and sustainable livelihoods; Identifies vulnerable areas for prioritizing resource allocation (e.g., reservoir discharge, irrigation infrastructure, flow regulation); Serves as a basis for water resource planning and coordination during the dry season, especially for the winter–spring rice crop; Helps localities select suitable crop calendars, adapt cropping patterns, or reduce planting areas in high-risk zones; Guides irrigation planning to reduce water waste and improve water use efficiency in agriculture. The evaluation results are also consistent with actual conditions. For example, the droughts shown in Figure 3 during the 2009–2010 and 2010–2011 dry seasons correspond to the most severe drought events recorded in the Red River Delta. In the 2009–2010 dry season, the water level of the Red River in Hanoi continuously dropped to historically record lows (November 2009: 0.76 m; February 2010: 0.10 m; March 2010: 0.40 m). During the 2010–2011 winter–spring crop, widespread water shortages occurred, with dry-season flows in the lower reaches of the Red–Thai Binh river system falling 30–40% below the long-term average [30].

2.3.3. Relevance of drought research for agricultural production in the southern subregion of the Red River Delta

Focusing on drought conditions between December and February is particularly critical for agricultural production, as this period coincides with the preparation for the winter-spring rice crop, the principal crop with substantial economic importance for local communities.

In 2023, the four provinces of the Red River Delta, Thai Binh, Ha Nam, Nam Dinh, and Ninh Binh (according to their administrative names before July 1, 2025) accounted for 44.8% of the region's winter–spring rice cultivation area and 46.6% of its output [22]. These provinces make significant contributions to the regional food supply (e.g., rice), agricultural products (such as vegetables, meat, poultry, and aquatic resources), and ornamental plants for northern provinces, particularly urban centers like Hanoi.

The agriculture–forestry–fishery sector, which is highly dependent on natural and climatic conditions, continues to play a major role in the provincial economies, contributing 23.3% of GRDP in Thai Binh and 20.8% in Nam Dinh (according to administrative divisions before July 1, 2025) [31], [32]. Therefore, identifying drought patterns and developing appropriate strategies and solutions to mitigate their impacts are essential not only for this subregion but also for the entire Red River Delta.

3. Conclusions

Global climate change has resulted in increasingly frequent and severe natural disasters, with droughts being among the most significant. Drought exerts substantial impacts on socioeconomic activities, particularly agricultural production.

In the study area, drought was absent only in August and September; in all other months, drought conditions occurred to varying degrees, with the most severe events typically observed in December, January, and February. Despite the area's relative homogeneity, notable spatial differences in drought intensity were evident. Ha Nam exhibited the lowest severity across all indicators—including drought frequency, frequency of extreme drought, and the annual drought index. From Ha Nam, drought severity increased progressively along a northwest–southeast axis toward Van Ly (Nam Dinh).

Drought zoning for the Southern Subregion of the Red River Delta represents a critical step toward understanding both the spatial distribution and the intensity of drought. Such analysis provides the basis for developing appropriate technical measures, policy interventions, and integrated water resource management strategies aimed at disaster prevention and ensuring water security.

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