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Research Article

Potential risks of climate variability on small-scale sugarcane farmers in the Cu Lao Dung Isle of Soc Trang Province, Vietnam

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Abstract
This study aims to assess the potential risks of climate variability on small-scale sugarcane farmers in Cu Lao Dung Isle, Soc Trang Province, Vietnam. The study used the standardized precipitation index (SPI) to analyze the drought conditions in the area from 1986 to 2022. The results showed that the SPI3, SPI6, and SPI12 values indicate a range of drought conditions, from near normal to extreme drought. The trend of increasing drought severity in recent years suggests that the area may be more vulnerable to drought events in the future. The findings suggest that sugarcane farmers in Cu Lao Dung Isle should apply adaptive solutions to reduce the impacts of drought and salinity intrusion. This solution may include using drought-tolerant sugarcane varieties, implementing efficient irrigation systems, and adopting climate-resilient agricultural practices. Additionally, farmers should have based on reliable climate information to make informed decisions about crop planting calender and irrigation management. The study also highlights the importance of climate change adaptation and mitigation measures for small-scale sugarcane farmers in Cu Lao Dung Isle.

Keywords: *Climate variability, Drought, Salinity intrusion, Sugarcane, Rainfall.*

1. Introduction
Climate change and its associated impacts pose significant challenges to agricultural systems worldwide, particularly in coastal cultivation regions [1, 2, 3]. Among these challenges, small-scale sugarcane farmers in coastal areas face unprecedented threats from rising sea levels, saline intrusion, and irregular weather patterns [4, 7, 13]. The vulnerability of coastal cultivation systems to climate variability manifests through multiple interconnected factors [5, 6, 7]. Global warming has accelerated the frequency and intensity of extreme weather events, leading to significant changes in temperature patterns, precipitation distribution, and evapotranspiration rates [7, 8, 9]. These changes particularly affect coastal cultivation regions, where rising sea levels exacerbate saline intrusion and create persistent irrigation water deficits [5, 15, 21]. Recent studies indicate that coastal regions experience temperature increases at nearly twice the global average rate, resulting in more frequent heat extremes and altered rainfall patterns [6, 10, 21]. The direct negative impacts of climate change on agricultural systems that serve as the major livelihood with limited ability to adapt aggravate their vulnerability [6, 16, 17]. Consequently, small-scale farmers, in general, are often negatively impacted mainly due to their dependence on rain-fed agriculture and natural resources, restricted financial capacity and low adaptive capacity as well as an inability to detect the likelihood of extreme climatic events as such drought, salt instrusion occurrence due to lack of climate information and skills as well as low technology adoption [12, 19, 20].

These environmental pressures are especially pronounced in Vietnam's Mekong Delta, specifically in the Cu Lao Dung Isle of Soc Trang Province, where sugarcane cultivation represents a crucial economic activity for local communities. Small-scale farmers, who constitute the majority of agricultural producers in Cu Lao Dung Isle, face disproportionate impacts from these environmental changes [6, 11, 21]. Their vulnerability stems from multiple factors, including limited access to resources, infrastructure constraints, and restricted adaptive capacity [6, 14]. With approximately 6,500 hectares of sugarcane cultivation, the isle's agricultural community has already experienced significant losses due to climate variability [6, 21]. For instance, in 2016, severe drought and saline intrusion damaged over 30% of the sugarcane area, while subsequent years continued to witness crop losses due to environmental stressors. Typically, during the drought period of 2014-2016, most of the irrigation canals in Cu Lao Dung Isle were heavily contaminated with salt, with the lowest salinity reaching more than 12‰. Due to the effects of heat and saltwater intrusion, more than 38 hectares of sugarcane were completely damaged, and more than 34 hectares were severely damaged [6, 16]. The challenges facing sugarcane cultivation in Cu Lao Dung Isle are compounded by the region's unique geographical characteristics and changing climatic conditions. Traditional farming practices, which relied on predictable weather patterns and freshwater availability, are becoming increasingly unreliable. Salinity levels in agricultural fields have reached critical levels, often exceeding the sugarcane's tolerance threshold of 4‰, with some areas recording levels between 6-8‰ during peak intrusion periods.

This study aims to assess the potential risks of climate variability on small-scale sugarcane farmers in Cu Lao Dung Isle and evaluate the effectiveness of adaptive strategies. Understanding these dynamics is crucial for developing sustainable agricultural practices that can support the livelihoods of local farmers while maintaining agricultural productivity in the face of increasing environmental challenges.

2. Materials and Method

2.1 Study Area

Cu Lao Dung Isle, situated at the terminus of the Hau River between Tran De and Dinh An estuaries in Vietnam's Mekong Delta, encompasses approximately 26,000 hectares of land intersected by numerous waterways (Figure 1). This unique agricultural region is characterized by a tropical monsoon climate, with average daily temperatures ranging from 25.7-28.8°C, mean daily sunshine of 6.7 hours, and annual rainfall of approximately 1900 mm (Figure 2).

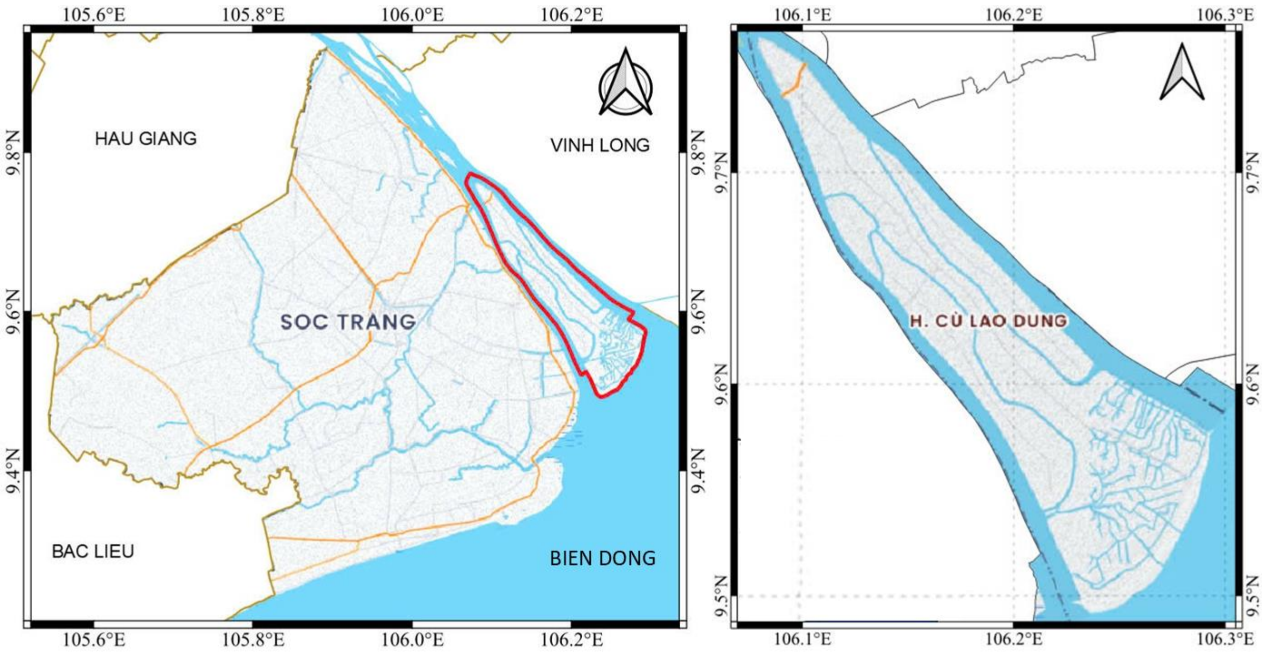

Figure 1: Illustration of the study area

Despite substantial annual precipitation, its uneven distribution throughout the year poses challenges for agricultural activities [13, 21]. Sugarcane cultivation dominates the agricultural landscape, occupying 85% of the farming area with an impressive average yield up to 100 tons per hectare. The traditional growing cycle begins in late January with harvest occurring in September. The isle's agricultural system primarily relies on rain-fed for irrigation, with the majority of precipitation (95%) concentrated between May and November, creating distinct challenges for water management during the dry season (Figure 2).

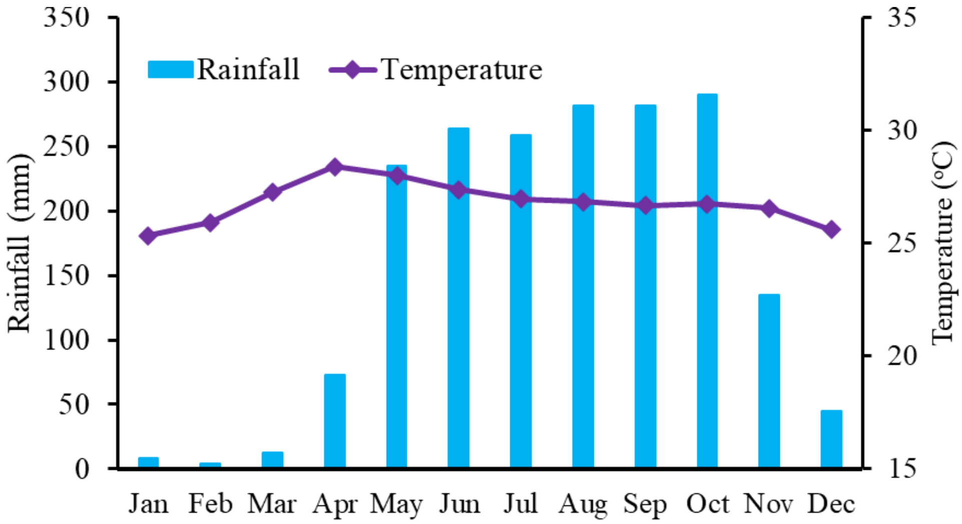

Figure 2: Distribution of rainfall and temperature across the Cu Lao Dung Isle

According to statistics from Cu Lao Dung district, in the 2015-2016 sugarcane crop year, the entire Cu Lao Dung district had nearly 6,700 hectares of sugarcane. Heat and saltwater intrusion completely damaged nearly 180 hectares of sugarcane; more than 500 hectares were severely damaged, from 50% to 70%; more than 1,230 hectares were damaged from 30% to 50%; about 4,700 hectares were damaged under 30%. Sugarcane productivity decreased by about 28%, equivalent to 34 tons/ha (Figure 3). In the 2016-2017 sugarcane crop year alone, drought and saltwater intrusion damaged nearly 100 hectares, of which dozens of hectares were completely damaged (Source: Nhan Dan news on March 20, 2016).

Source: Vietnam News Agency, March 2016

Source: Thanh Nien new, March 2016

Figure 3: Sugarcane fields dried up due to the lack of irrigation fresh water during the 2016 drought event across the Cu Lao Dung Isle of Soc Trang province

2.2 Approach methods

The standardized precipitation index (SPI) is commonly used for forcasting meteorology drought [11]. The SPI provides information on drought events, helping to assess their severity, duration, and intensity [11]. SPIs of different time scales are likely tied to stream flows, reservoir levels, and even groundwater levels at longer time scales [11]. The SPI methodology involves fitting a probability distribution function, such as the Gamma or Pearson Type III distributions, to historical precipitation data. This probability distribution function is then standardized to a normal distribution, allowing precipitation values to be expressed as standardized anomalies from the mean. By transforming the data in this manner, the SPI offers a consistent metric for comparing precipitation deviations across different regions and timeframes [11]. The probability distribution function representation is defined by formula 1 to facilitate the standardization process and enhance the comparability of precipitation anomalies [11].

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

Where, β and α in formula 1 are the scale and shape parameters, x is the rainfall amount and Γ(α) is a Gamma function.

When the cumulative distribution function G(x) is calculated by integrating the probability distribution function as given in formula 2.

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

In the process of calculating SPI, we use the gamma function to describe the probability distribution of precipitation. However, since the range of the gamma function is defined as values greater than zero, in the data we can find m precipitation values equal to zero. The probability that this value occurs is m/n, where n is the number of years being evaluated. This probability is called q. To adjust for the case where one or more precipitation values equal to zero are found, a special correction is made, expressed as:

$$H(x) = q + (1 - q)G(x) \qquad (3)$$

The SPI values, for the normal distribution function with zero mean and one variance, are defined by ormula 4 and 5.

$$SPI = -\left(t - \frac{C_0 + C_1 + C_2 t^2}{1 + d_1 t + d_2 t + d_3 t}\right), 0 < H(x) \leq 0.5 \qquad (4)$$

$$SPI = -\left(t - \frac{C_0 + C_1 + C_2 t^2}{1 + d_1 t + d_2 t + d_3 t}\right), 0 < H(x) \leq 1.0 \qquad (5)$$

SPI has been applied in many studies and applications in the fields of meteorology, hydrology, and water resources. It provides crucial information on factors affecting the stability of the water system and helps policymakers and developers make informed and effective decisions.

The SPI values calculated are classified based on Table 1.

Table 1. Classification of the standardized precipitation index [11]

Interval	Intensity
> 2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-l.00 to -l.49	Moderately dry
-1.50 to -1.99	Severely dry
<-2.00	Extremely dry

3. Results and discussion

Based on the SPI3 values analyzed in Table 2, we can analyze the drought conditions in the Cu Lao Dung Isle of Soc Trang province from 1986 to 2022. From 1986 to 1995, the SPI3 values were mostly near normal, indicating a stable and moderate climate. However, there was a slight increase in the number of extremely wet and severely dry events in the period of 1989-1992. From 1996 to 2005, the SPI3 values showed a trend of decreasing drought severity, with a higher number of moderately dry to severely dry events (SPI3 = -1.82 at 2004). From 2006 to 2015, the SPI3 values showed a decrease in drought severity, with two times extremely dry events (Figure 4A). This period was marked by a return to normal climate conditions, with some areas experiencing moderate drought. From 2016 to 2022, the SPI3 values showed a trend of increasing drought severity, with a higher number of severely dry and extremely dry events. This period was characterized by a prolonged drought, experiencing severe dryness (SPI3 = -1.87 in April 2016) and extreme drought conditions (SPI3 = -2.26 in May 2020). Overall, the SPI3 values indicate that the Cu Lao Dung Isle of Soc Trang province has experienced a range of drought conditions over the past 37 years, from near normal to extreme drought. The trend of increasing drought severity in recent years suggests that the area may be more vulnerable to drought events in the future.

Table 2: Analysis results of weather scales based on the standardized precipitation index (SPI) across the Cu Lao Dung Isle

Weather scales	SPI3	SPI6	SPI12
Extremely wet	13	9	14
Very wet	10	11	4
Moderately wet	48	45	38
Near normal	48	295	296
Moderately dry	20	53	56
Severely dry	5	27	31
Extremely dry	13	4	5

For the SPI6 (six months scale drought), from 1986 to 1995, the SPI6 values showed a moderate drought trend, with a higher number of near normal and moderately dry events (Figure 4B). However, there was a slight increase in the number of severely dry events (27 times) during this period. From 1996 to 2005, the SPI6 values showed a trend of decreasing drought severity, with a higher number of near normal to moderately dry events (Figure 4B). This period was mainly characterized by near normal weather. From 2006 to 2015, the SPI6 values showed an increase in drought severity, with a lower number of severely dry events (SPI6 = -1.84 in March 2014 and SPI6 = -1.90 in December 2015).

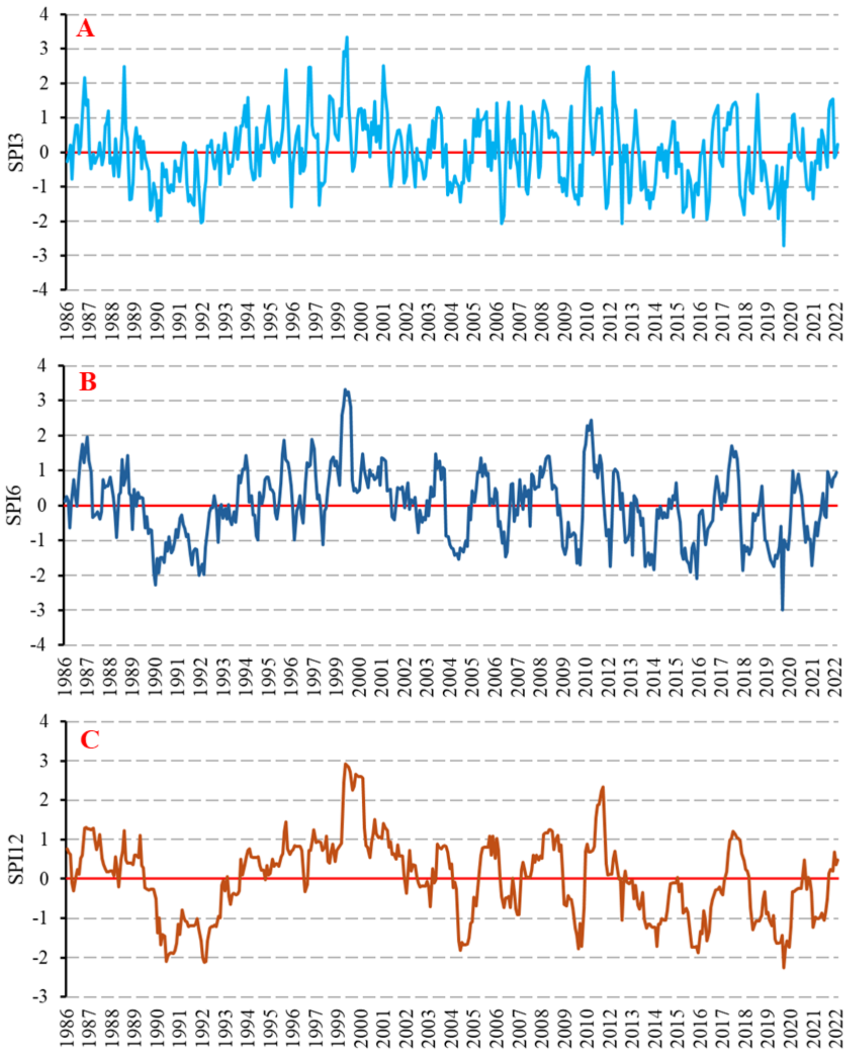

Figure 4: Simulated results of the drought timescales (SPI3, SPI6 and SPI12) across the Cu Lao Dung Isle

This period was marked by a return to severe climate conditions. From 2016 to 2022, the SPI6 values showed a trend of increasing drought severity, with a higher number of severely dry and extremely dry events. This period was characterized by a prolonged drought, with experiencing extreme drought conditions with the maximum SPI6 value down to -3.00 in May 2020. Overall, the values of the SPI6 values indicate that the Cu Lao Dung Isle has experienced a range of drought conditions over the past 37 years, from near normal to extreme drought. The trend of increasing drought severity in recent years suggests that the area may be more vulnerable to drought events in the future.

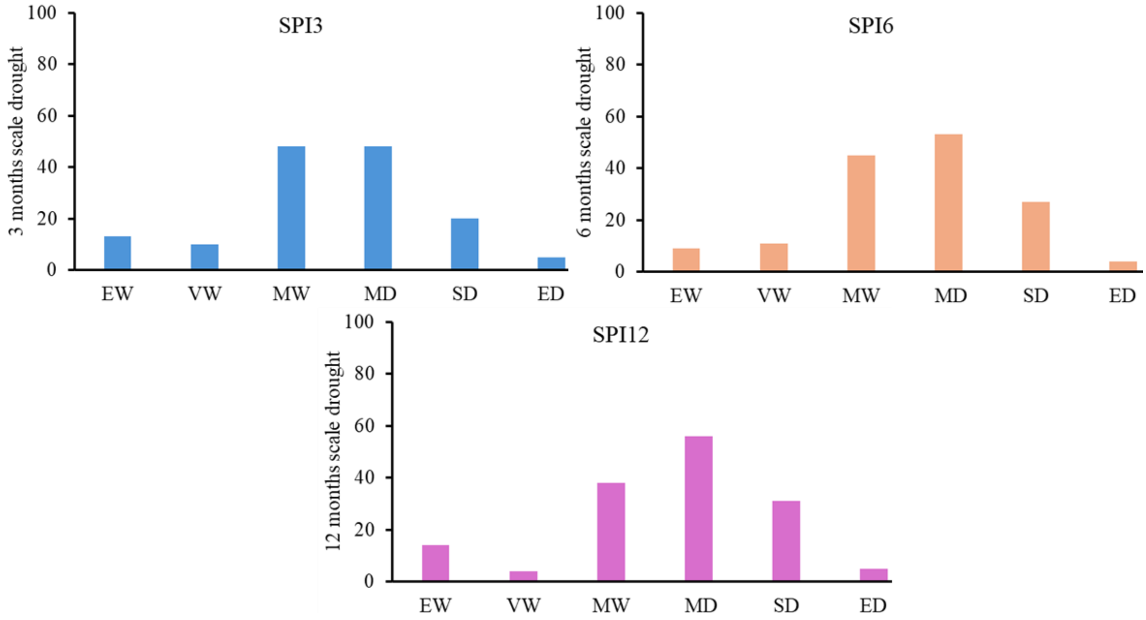

Figure 5: Drought events at timescales of 3, 6 and 12 months across the Cu Lao Dung Isle

For the SPI12 (12 months scale drought), from 1986 to 1995, the SPI12 values showed a moderate drought trend, with a higher number of severely and extremely dry events (Figure 4C). However, there was a slight increase in the number of moderate dry events (56 times) during this period (Figure 5). From 1996 to 2005, the SPI12 values showed a trend of increasing drought severity, with a higher number of severely dry events (SPI12 = -1.82 in November 2004) (Figure 4C). This period was mainly characterized by near normal weather. From 2006 to 2015, the SPI6 values showed an increase in drought severity, with a lower number of severely dry events (SPI12 = -1.73 in July 2010).

4. Conclusion

The study used the standardized precipitation index (SPI) to analyze the drought conditions in the area from 1986 to 2022. The results showed that the SPI3, SPI6, and SPI12 values indicate a range of drought conditions, from near normal to extreme drought. Based on the analysis, it is evident that the region's increasing susceptibility to drought events poses a significant threat to small-scale sugarcane farmers. To mitigate this risk, sugarcane farmers in the Cu Lao Dung Isle must implement proactive measures to adapt to the changing climate conditions. This can be achieved by adopting drought-resistant sugarcane varieties, optimizing irrigation systems, and incorporating climate-resilient agricultural practices into their operations. Furthermore, farmers should have access to accurate and timely climate information, enabling them to make informed decisions regarding planting, harvesting, and irrigation management.

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