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Evaluating the Impact of Drought on Palm Oil Productions in Malaysia: Insights for Agricultural Modernization

Halimatun Sa'adiah Md Salehan, Noor Elidawati Bahari, Mazliana Mohamad and Nurafzan Muslim

[1]*Fakulti Sains Sosial dan Teknologi Maklumat, Kolej Universiti Agrosains Malaysia, Lot 2020, Ayer Pa'abas, 78000 Alor Gajah, Melaka.*

Corresponding author: hsaadiah5@gmail.com

RESEARCH ARTICLE

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Abstract

This study investigates the impact of drought on palm oil production in Malaysia, focusing on Melaka. Using the six-month Standardized Precipitation-Evapotranspiration Index (SPEI-6), it quantifies drought severity and its influence on yields. Malaysia, as a major palm oil producer, faces challenges from climate variability, particularly during dry periods. Statistical analysis reveals a correlation coefficient (R) of 0.725, demonstrating a strong positive relationship between SPEI-6 values and palm oil yields, where wetter conditions correspond to higher yields. The study evaluates the effects of six-month drought intervals, detailing the statistical models and variables analyzed. These findings highlight patterns that can enhance agricultural resilience and resource management in the palm oil sector, particularly in Melaka. By addressing climate-related vulnerabilities, this research provides actionable insights for mitigating climate impacts and strengthening adaptive strategies within Malaysia's key agricultural sectors.

Keywords: Agricultural Adaptation, Climate Resilience, Drought Impact, Palm Oil Yields, SPEI-6.

1. Introduction

Palm oil production is a key pillar of Malaysia's economy, closely linked to environmental factors. As one of the leading producers globally, Malaysia's agricultural output is highly sensitive to weather changes, particularly extended periods of drought (Basiron, 2007). This study investigates the relationship between drought severity, measured using the six-month Standardized Precipitation-Evapotranspiration Index (SPEI-6), and palm oil yields per hectare. The goal is to provide a clearer understanding of how climate variability influences palm oil productivity, offering insights to ensure the long-term sustainability of this critical sector.

Palm oil, derived from the *Elaeis guineensis* species, plays a significant role in Malaysia's economy, contributing substantially to the country's Gross Domestic Product (Yusoff, 2006). It also serves as a primary source of income for a large portion of the population. However, palm oil plantations are highly vulnerable to environmental stressors, with prolonged droughts being a significant challenge. Understanding how water deficits affect yield per hectare is crucial. Previous studies highlight that drought—characterized by variations in rainfall and evapotranspiration—can significantly impact the growth and fruit production of oil palm trees (Feintrenie et al., 2010; Wahid et al., 2005). This research seeks to analyze the connection between SPEI-6 (a measure of medium-term drought) and historical palm oil yield data. By identifying patterns and trends in how drought affects palm oil productivity, this study aims to inform and refine agricultural strategies and resource management. Such measures are especially critical as climate change continues to influence palm oil output (Sarkar et al., 2020).

2. Literature Reviews

Climate change poses a major challenge to agriculture in Malaysia, with rising temperatures, unpredictable rainfall, and more frequent extreme weather events putting significant pressure on the sector (Abubakar et al., 2021). As an essential contributor to the national economy, the agricultural sector must adapt to these evolving conditions to maintain productivity and sustainability. Crops like palm oil are particularly sensitive to environmental stress, making them vulnerable to the challenges brought about by climate change (Abubakar et al., 2021).

Palm oil, extracted from the *Elaeis guineensis* species, plays a critical role in Malaysia's economy by contributing to GDP and providing income for a substantial portion of the population (Alam et al., 2015). However, environmental challenges—particularly drought—pose significant risks to oil palm cultivation. Periods of drought, defined by a drop in rainfall and heightened evapotranspiration, can weaken the vitality of palm oil trees, hinder their growth, and decrease fruit output, ultimately lowering the industry's total production capacity (Oettli et al., 2018).

To address the impact of drought, tools like the Standardized Precipitation-Evapotranspiration Index (SPEI) were created to evaluate drought conditions. The SPEI-6 index, designed to capture medium-term droughts, combines both rainfall and evapotranspiration data, providing a robust method to evaluate the severity and duration of drought events (Sein et al., 2021). For agricultural research, SPEI offers valuable insights into the temporal variability of drought and its effects on crop performance.

Studies across different regions and crops have used SPEI values to investigate the relationship between drought conditions and agricultural yields, revealing key trends through statistical analysis (He et al., 2021). These studies confirm that medium-term droughts, measured using SPEI-6, can significantly reduce crop productivity, including palm oil yields (He et al., 2021).

In palm oil cultivation, drought-induced stress is known to slow growth and reduce fruit yield. Additionally, the delayed effects of drought—where the impact on yields becomes evident only after a certain period—highlight the intricate relationship between environmental factors and agricultural output. This underscores the need to understand these dynamics for developing strategies to minimize the harmful effects of drought on palm oil production (Silva et al., 2017).

Although many studies have examined agriculture's response to climate change, drought measurements, and palm oil yields, only a limited number have specifically explored the connection between SPEI-6 values and yields in Melaka. This emphasizes the need for targeted research to understand the effects of moderate-duration drought on palm oil production. This study aims to fill that gap by analyzing the relationship between SPEI-6 data and palm oil yields, offering insights that can support the creation of adaptive agricultural practices and effective resource management strategies to address changing climate conditions.

3. Methodology

This study investigates the relationship between drought severity and palm oil production in Melaka using a combination of climate data and statistical modeling. The research follows a structured methodology, comprising data collection, calculation of the Standardized Precipitation-Evapotranspiration Index (SPEI-6), statistical analysis, and interpretation.

Key climate data, including monthly rainfall and temperature records, were obtained from the Malaysian Meteorological Department (MyMet). These datasets serve as the foundation for calculating SPEI-6, a widely used drought index. Historical palm oil yield per hectare data was sourced from the Department of Statistics Malaysia (DOSM), ensuring accuracy and reliability in evaluating the impact of drought on production.

The SPEI-6 values were calculated using the Thornthwaite equation to estimate potential evapotranspiration (PET), which is a key component in the index computation. The formula for PET is:

$$PET = 16 \times \left(\frac{10 \times T}{I} \right)^{a} \quad (1)$$

where T is the mean monthly temperature (°C), I is the heat index calculated as the sum of monthly heat indices, and a is a calibration coefficient based on I. The heat index I is computed as:

$$I = \sum \left(\frac{T}{5} \right)^{1.514} \quad (2)$$

and the calibration coefficient a is given by:

$$a = 6.75 \times 10^{-7} \times I^{3} - 7.71 \times 10^{-5} \times I^{2} + 1.79 + 10^{-2} \times I + 0.49239 \quad (3)$$

Once PET values were computed, they were combined with precipitation data to calculate the climatic water balance (P−PET). These water balance values were then normalized using a log-logistic probability distribution to derive the SPEI values. The SPEI-6 integrates temperature and rainfall over six-month periods, enabling a comprehensive assessment of medium-term drought conditions. The calculations were performed using R statistical software, which was chosen for its ability to process large datasets efficiently. Assumptions such as the stationarity of climate data and normal distribution were considered to ensure accuracy and reproducibility.

After computing the SPEI-6 values, drought conditions were categorized based on a standardized classification system. Table 1 provides a detailed breakdown of these categories, ranging from extremely wet to extremely dry, which is critical for systematically analyzing the severity and duration of drought conditions in this study. For instance, SPEI values below -2.0 indicate extreme drought conditions, which are likely to have the most severe effects on palm oil production.

Table 1. Classification of SPEI

Index	Classification
> 2.0	Extremely wet
1.5 – 2.0	Very wet
1.0 – 1.5	Moderately wet
-1.0 – 1.0	Near Normal
-1.5– -1	Moderately dry
-2.0 - -1.5	Severely dry
< -2.0	Extremely dry

The relationship between SPEI-6 values and palm oil yields was examined using various statistical techniques. First, Pearson’s correlation analysis was conducted to measure the strength and direction of the relationship between SPEI-6 values and palm oil production. A correlation coefficient of R = 0.725 indicates a strong positive correlation, suggesting that higher SPEI-6 values (wetter conditions) are associated with increased palm oil yields.

A linear regression model was then applied to quantify the impact of drought severity on palm oil production. The regression model is formulated as:

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad (4)$$

where Y represents palm oil yield (tons per hectare), X denotes SPEI-6 values, β_0 is the intercept, β_1 is the regression coefficient, and ε is the error term. The results indicate that 52.6% of the variation in palm oil yields can be explained by changes in SPEI-6 values, as reflected in the R-squared value (R^2 = 0.526).

To further explore the temporal effects of drought, a time series analysis was conducted. The study examined long-term trends and seasonal variations in both SPEI-6 values and palm oil yields. Delayed effects of drought were also assessed by incorporating lag variables, as previous research suggests that the impact of drought on palm oil production may manifest several months after the initial drought event (Silva et al., 2017).

To ensure the robustness and reliability of the statistical models used, several diagnostic tests were conducted. The normality of residuals was checked using the Shapiro-Wilk test, while homoscedasticity was verified using the Breusch-Pagan test. Multicollinearity among predictor variables was assessed through the Variance Inflation Factor (VIF) to confirm that independent variables did not distort the regression analysis. By incorporating these validation techniques, the study ensures that the statistical models are accurate, reliable, and generalizable for understanding the impact of drought on palm oil production.

By incorporating these validation techniques, the study ensures that the statistical models are accurate, reliable, and generalizable for understanding the impact of drought on palm oil production. The research framework follows a structured process that integrates climate data processing, SPEI-6 computation, statistical modeling, and validation. This approach ensures a comprehensive evaluation of how drought affects palm oil yields in Melaka, providing valuable insights for developing adaptive agricultural strategies in Malaysia’s palm oil sector.

4. Results and Discussion

The results from this research demonstrate a significant relationship between the six-month Standardized Precipitation-Evapotranspiration Index (SPEI-6) and palm oil yields in Melaka. The linear regression analysis reveals that fluctuations in SPEI-6 values are closely associated with variations in palm oil production, indicating that changes in drought severity impact on agricultural productivity.

As shown in Figure 1, the scatter plot with a fitted regression line illustrates the relationship between SPEI-6 and palm oil yields. The R-squared (R^2) value of 0.526 suggests that 52.6% of the variability in palm oil yields can be attributed to changes in SPEI-6 values. These findings align with Leng and Hall (2019), who also reported that drought conditions significantly affect agricultural productivity, reinforcing the importance of water availability for stable crop yields.

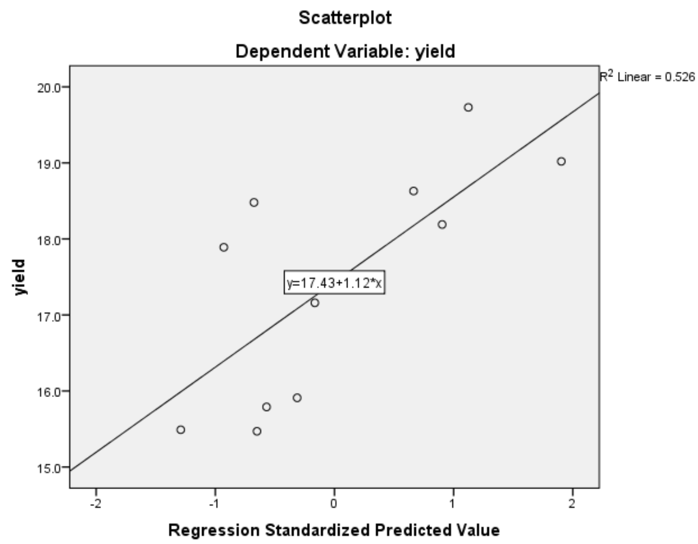

Figure 1: Scatterplot with a fitted regression line

To further examine drought trends in Melaka, a heatmap of SPEI-6 values over the years (Figure 2) visually represents the variations in drought severity across time. This visualization provides a clearer picture of prolonged dry periods and their potential impact on agricultural output. The approach used in this study is consistent with Mokhtar et al. (2021), who applied similar techniques in climate research.

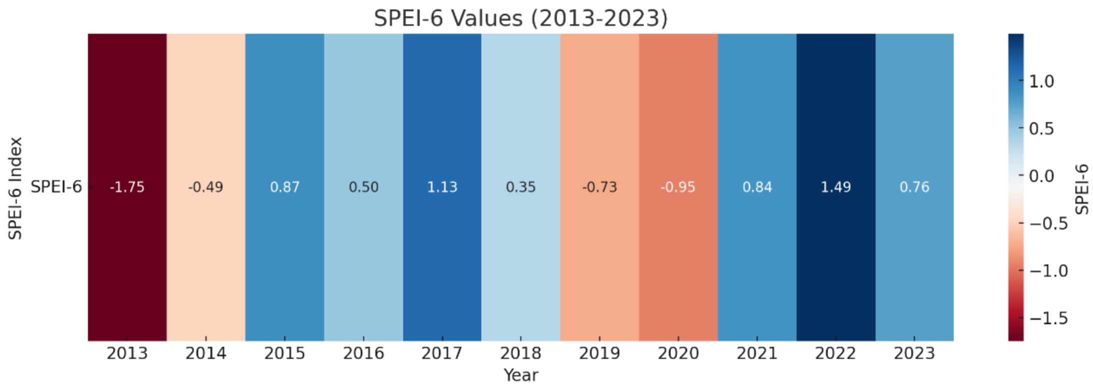

Figure 2. Heatmap of SPEI-6

Additionally, the time series graph with a trend line (Figure 3) illustrates the changes in drought intensity over time, showing patterns of fluctuations in moisture availability that could affect palm oil yields. The findings in this study correspond with Hasan et al. (2023), who also identified seasonal variations in drought severity over the years in their research.

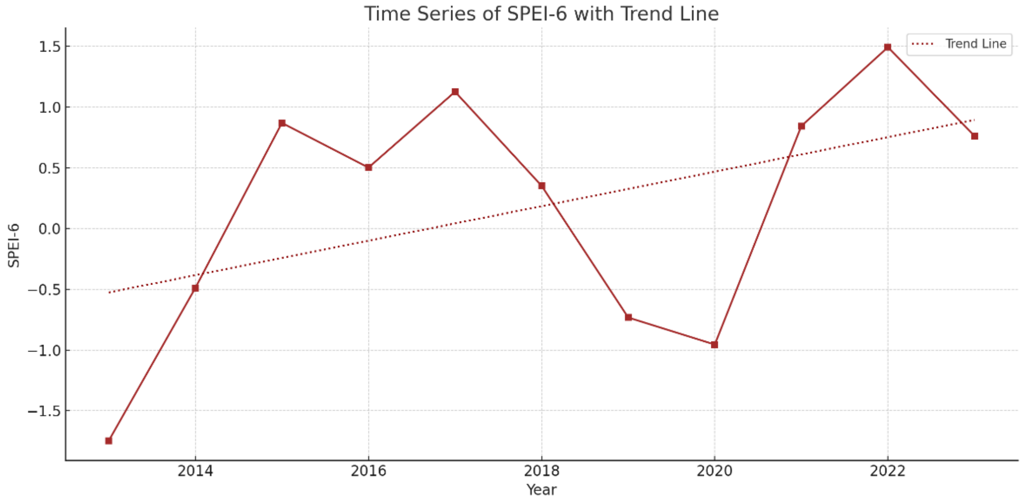

Figure 3: Time series of SPEI-6 with trend line

Table 2: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.725[a]	.526	.473	1.1208

a. Predictors: (Constant), spei 6

b. Dependent Variable: yield

Table 2 presents a detailed overview of the statistical relationship between the SPEI-6 index and palm oil yields. The correlation coefficient (R) of 0.725 indicates a strong positive relationship, meaning that higher SPEI-6 values (wetter conditions) are associated with higher palm oil yields. This confirms that palm oil production is highly influenced by climate factors, particularly rainfall and evapotranspiration levels, as captured by SPEI-6 values. The R-squared (R^2) value of 0.526 suggests that 52.6% of the changes in palm oil yields can be explained by fluctuations in SPEI-6, highlighting the importance of water availability in maintaining successful palm oil cultivation.

However, the Adjusted R-squared value of 0.473 and the Standard Error of the Estimate at 1.1208 indicate that some variability in palm oil yields remains unexplained by this model. This suggests that other factors, such as soil quality, palm tree age, fertilizer application, and plantation management practices, may also influence yield outcomes (Huth et al., 2014).

The heatmap and time series graph provide clear insights into the temporal variations in drought conditions and how these changes align with yield variations over time. While Figure 1 (scatter plot) and correlation values quantify the statistical relationship between drought conditions and palm oil yields, the time series graph and heatmap illustrate long-term trends in drought intensity and their impact on agricultural production in Melaka.

The standard error of the model suggests that yield variability is influenced by factors beyond SPEI-6 values, pointing to the complexity of agricultural systems and the potential interactions between climate and non-climatic factors (Ferchichi et al., 2024). Future research should consider incorporating additional environmental variables, such as soil moisture levels, temperature variations, and farm management techniques, to refine yield prediction models further.

The findings of this study provide valuable insights into the palm oil industry in Malaysia. Understanding how drought impacts palm oil yields can help stakeholders develop adaptive strategies to mitigate climate-related risks. Key recommendations include:

- Optimizing irrigation systems to ensure efficient water distribution during dry seasons.
- Introducing drought-resistant palm oil varieties to enhance plantation resilience to climate variability.
- Implementing climate monitoring systems to provide early warnings for potential drought periods, allowing proactive decision-making in plantation management.
- Enhancing water management policies by integrating SPEI-6 drought monitoring tools to support sustainable palm oil production (Zaib et al., 2023).

Additionally, these findings can assist policymakers in formulating long-term strategies for water resource management and climate adaptation initiatives. By leveraging climate data and predictive models, decision-makers can implement agricultural policies that ensure stable palm oil production despite fluctuating weather patterns (Abubakar et al., 2022).

5. Conclusion

This research investigates how drought, measured using the six-month Standardized Precipitation-Evapotranspiration Index (SPEI-6), influences palm oil production in Melaka, Malaysia. The findings emphasize the significant role of medium-term drought in determining palm oil yields, highlighting the importance of water availability and the effects of shifting climate patterns on agricultural performance. The correlation analysis, supported by linear regression, scatter plots, and heatmaps, confirms that SPEI-6 variations are strongly linked to changes in palm oil yields. The results indicate that higher SPEI-6 values, representing increased moisture availability, correspond with improved yields, demonstrating the sensitivity of palm oil production to climate variability.

By integrating climate data with palm oil yield statistics, this study provides a structured framework for understanding the relationship between drought and agricultural productivity. Utilising advanced statistical methods, the study not only examines the direct influence of drought on palm oil yields but also develops a predictive model to estimate future yield trends based on climate conditions. These predictions are crucial for developing proactive strategies to mitigate climate-related risks and ensuring the long-term sustainability of the palm oil industry.

While the model explains a substantial portion of yield variability, the adjusted R-squared value (0.473) suggests that additional environmental, biological, and management factors contribute to yield fluctuations. Future research should consider variables such as soil fertility, palm tree age, genetic variation, irrigation efficiency, and agricultural practices to refine predictive models further. By incorporating these additional parameters, researchers can gain a more comprehensive understanding of palm oil yield determinants and improve strategies to enhance climate resilience in industry.

This study provides valuable insights into the agro-environmental impact of climate variability and underscores the importance of integrated resource management to mitigate the adverse effects of drought on palm oil yields. The findings offer a solid foundation for policymakers and industry stakeholders to develop sustainable, climate-resilient agricultural systems in Malaysia and other palm oil-producing regions. As climate change continues to pose challenges to global agriculture, research like this is essential for informing adaptive strategies, promoting sustainable farming practices, and ensuring the resilience of critical food and commodity industries.

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