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# Analysis for the Agricultural Study of Sugarcane Commodities on Papua Island

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**Abstract**

The cultivation of sugarcane for the national sugar industry necessitates a comprehensive site suitability evaluation, particularly in potential regions such as Papua Island, owing to rising domestic demand and constrained land availability in traditional producing areas. This study seeks to assess the spatial and temporal appropriateness of land for sugarcane agriculture on Papua Island by integrating Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP) methodology. This model assesses climatic (precipitation, temperature, solar radiation) and edaphic (soil pH) variables during historical (1970–2000) and contemporary (2021–2025) periods. The spatial evaluation results indicate a complete predominance of the S1 (Highly Suitable) land classification in coastal lowland regions. The exceptional adaptability is attributed to the ideal synergy between ample yearly precipitation and steady solar radiation, with well-drained soils in Papua transforming excessive rainfall into an agricultural benefit. Highland and transitional locations predominantly fall into the S2 (Moderately Suitable) classification, which is moderately constrained by a reduction in temperature and an elevation in soil acidity. The primary conclusion from this modelling is the lack of regions designated as N (Not Suitable) or S3 (Marginally Suitable), indicating outstanding ecological integrity devoid of any irreversible constraints. Moreover, cross-temporal analysis substantiates the presence of climate stationarity, demonstrating that the Papuan landmass retains its biophysical stability and functions as a climate refuge impervious to global weather anomalies. These findings establish a scientific basis indicating that agricultural expansion in Papua constitutes a vital, low-risk food estate plan.

**Keywords:** Geographic Information System (GIS); Land Suitability; Papua Island; Sugarcane (*Saccharum officinarum*); Weighted Overlay Analysis

## 1.Introduction

Sugarcane (*Saccharum officinarum*) is a vital commodity that significantly contributes to the provision of sugar raw materials and the advancement of the national agroindustry. It is the focal point of land suitability assessments in several tropical areas owing to its influence on productivity and land utilization (Neswati *et al.*, 2016; Purnamasari, 2023). With the rise in domestic sugar consumption and the limitation of land in conventional production regions, it is essential to extend and enhance sugarcane cultivation in new prospective locations. Papua Island possesses extensive land resources and a tropical climate, rendering it a viable region for sugarcane cultivation. Nonetheless, spatial data regarding the appropriateness of sugarcane cultivation in Papua, particularly in relation to temporal climate variations, is insufficient (Haq *et al.*, 2025). This scenario signifies the necessity for a more extensive investigation to comprehend the viability of land in Papua for sugarcane development.

The appropriateness of sugarcane cultivation is significantly affected by climatic conditions and soil characteristics, namely yearly precipitation, mean air temperature, solar irradiance, and soil pH (Abubakar *et al.*, 2023). Appropriate annual precipitation varies from 1,500 to 2,500 mm with a very uniform distribution

(Chen *et al.*, 2023). The ideal temperature for sugarcane is between 24 and 30 °C (Hakim, 2010). Furthermore, solar radiation is crucial for facilitating photosynthesis and biomass buildup, whereas soil pH influences nutrient availability and root development (Dumipto *et al.*, 2019). Spatial and temporal fluctuations in these characteristics can result in disparities in land suitability across regions and across time.

Global climate change may modify precipitation patterns, temperatures, and solar radiation, potentially impacting the viability of agricultural land. Consequently, a land suitability study must be performed both spatially and temporally by evaluating climatic conditions throughout several periods. This methodology is crucial for determining whether climate change enhances or diminishes the viability of sugarcane cultivation in a certain area.

Advancements in Geographic Information System (GIS) technology facilitate the amalgamation of climate and soil data from many temporal contexts for thorough analysis. Raster-based GIS analysis allows for the reclassification and overlay of factors such as rainfall, temperature, solar radiation, and soil pH to provide maps depicting sugarcane land suitability for historical eras (1970–2000) and the current time (2021–2025). This study seeks to analyze the suitability of land for sugarcane cultivation on Papua Island across two periods to identify alterations in land suitability patterns and ascertain the time exhibiting more favorable conditions for sugarcane development.

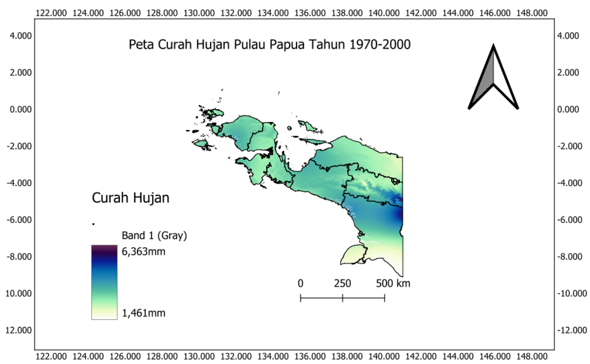
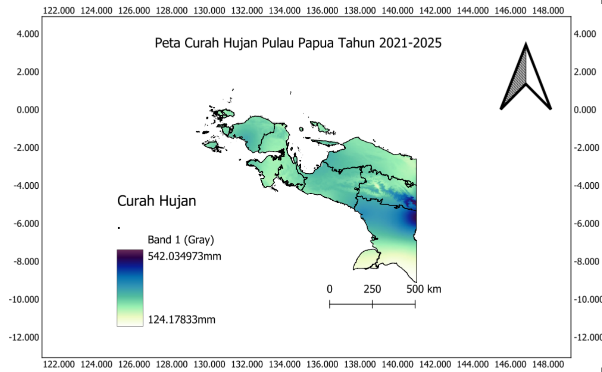
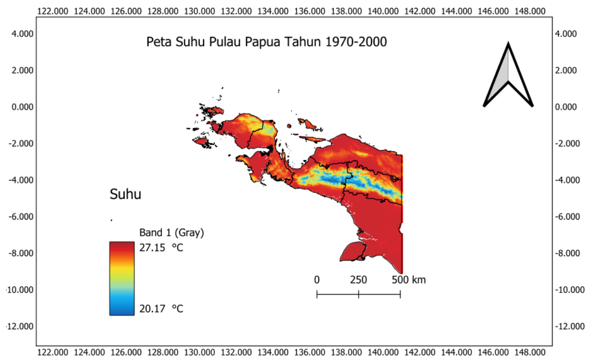
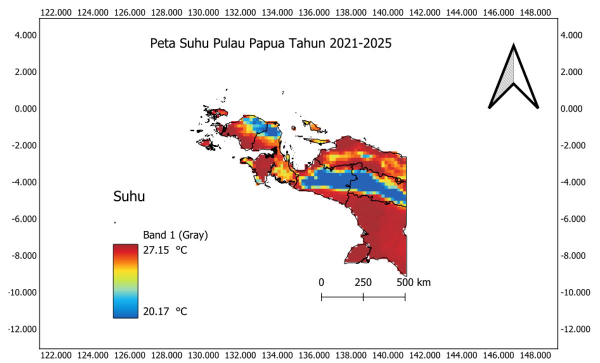
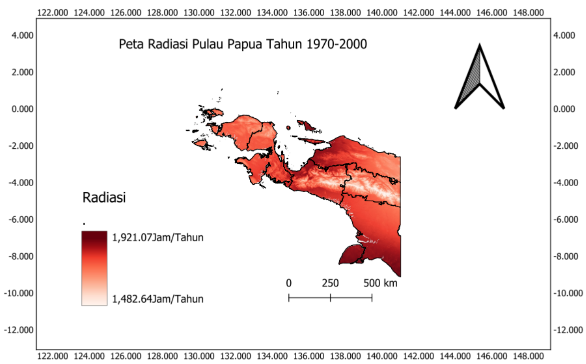
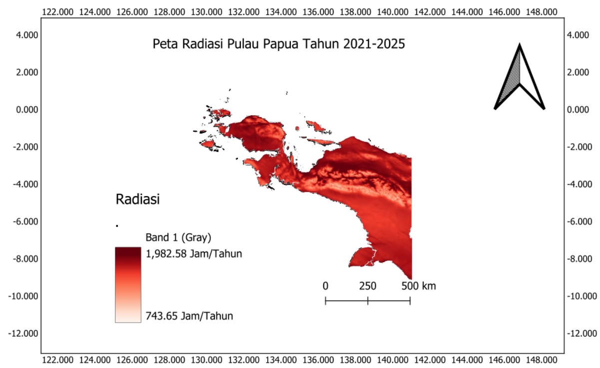
## 2. Materials and Methods

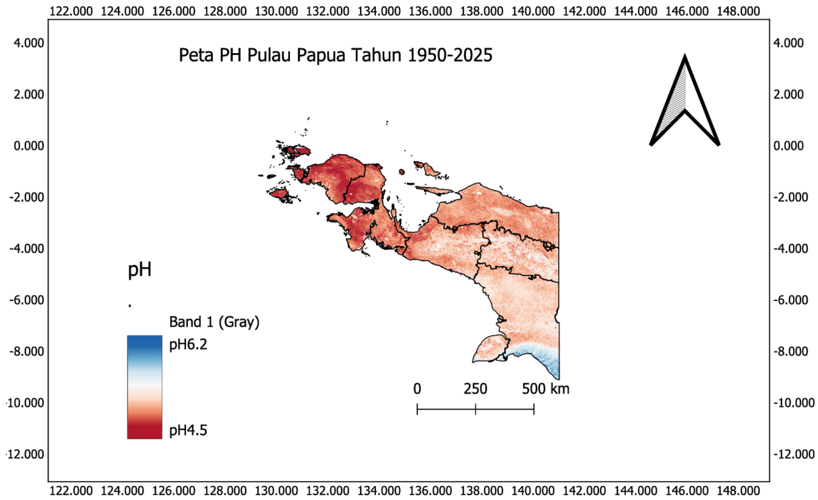
This regional evaluation was performed on Papua Island, concentrating on the biophysical and climatic factors necessary for the cultivation of sugarcane (Saccharum officinarum). The research approach incorporated Geographic Information Systems (GIS) for spatial analysis utilising QGIS software, alongside the Analytic Hierarchy Process (AHP) for multi-criteria decision-making. The assessment included two primary categories of environmental variables: climatic and edaphic. Climatic geographical data, including annual precipitation, average air temperature, and solar radiation, were obtained from the NASA POWER database. To examine temporal climate fluctuations, data were gathered from two separate intervals: a historical baseline (1970–2000) and a present period (2021–2025). Soil pH data were obtained to reflect long-term soil conditions. The AHP approach was utilised to methodically establish the hierarchy and weight of each parameter according to its ecological importance. The climatic macro-group constituted the evaluation framework with a total weight of 80%, comprising rainfall (30%), temperature (20%), humidity (20%), and sun radiation (10%). The edaphic group, only indicated by soil pH, comprised the remaining 20% of the model's weight. Subsequent to the weight assessment, a spatially weighted overlay analysis was conducted. This integration produced a continuous Land Suitability Index (LSI) with values between 2.6 and 3.7. Utilising this LSI range, the land pixels were classified into four distinct suitability categories: S1 (Highly Suitable), S2 (Moderately Suitable), S3 (Marginally Suitable), and N (Not Suitable).

## 3. Results

A regional analysis of climatic and edaphic factors on Papua Island indicates diverse geographical distributions throughout two observation periods: the baseline period (1970–2000) and the modern period (2021–2025). The raster data processing for each essential growth parameter of sugarcane exhibits distinct output dynamics. The rainfall map extraction indicates a significantly elevated annual precipitation distribution from 1970 to 2000, with geographic values between 1,461 mm and 6,363 mm. The spatial value range underwent a variation in water distribution from 2021 to 2025, changing from 124.17 mm to 542.03 mm. The temperature value signifies a remarkably constant thermal condition in this area. The average temperature distribution in Papua Island remains consistent during both times, precisely ranging from 20.17 °C to 27.15 °C. The minimum temperature concentration of 20.17 °C prevails in the middle mountainous region (intermontane). Coastal and lowland regions consistently register the maximum temperature of 27.15 °C. The distribution of solar radiation exposure exhibits a variable shift across different times. The radiation intensity varied between 1,482.64 and 1,921.07 hours per year from 1970 to 2000. The radiation exposure increased to between 743.65 and 1,982.58 hours per year during the 2021–2025 period. The general rise in maximum irradiation intensity can effectively enhance the biomass accumulation process in plants, although a reduction in the lower limit of irradiation in certain specific regions. The composite map illustrates long-term edaphic conditions (1950–2025) via the soil acidity (pH) parameter. The soil pH across much of Papua Island ranges from 4.5 to 6.2, categorising it as acidic to somewhat acidic (Table 1).

**Table 1.** Spatial distribution of land suitability parameters in Papua Island for two periods (1970–2000 and 2021 2025), including annual rainfall, temperature, solar radiation, and soil pH.

| **Land Suitability Parameters** | **Period** | |
|---|---|---|
| | **1970–2000** | **2021–2025** |
| **Annual Rainfall (mm)** |   |   |
| **Temperature (°C)** |   |   |
| **Solar Radiation (J/m²)** |   |   |

| Land Suitability Parameters | Period | |
|---|---|---|
| | 1970–2000 | 2021–2025 |
| Soil pH |  | |



The development of a land suitability map for sugarcane agriculture combines Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP). The AHP approach is employed to establish the priority scale and weight of each climatic and edaphic parameter according to its ecological relevance to the target crop. This spatial weighting model integrates all characteristics to produce continuous Land Suitability Index (LSI) values, ranging from 2.6 to 3.7 (Figure 1). The LSI range provides the mathematical foundation for categorising land pixels into classifications S1 (Highly Suitable), S2 (Moderately Suitable), S3 (Marginally Suitable), and N (Not Suitable).

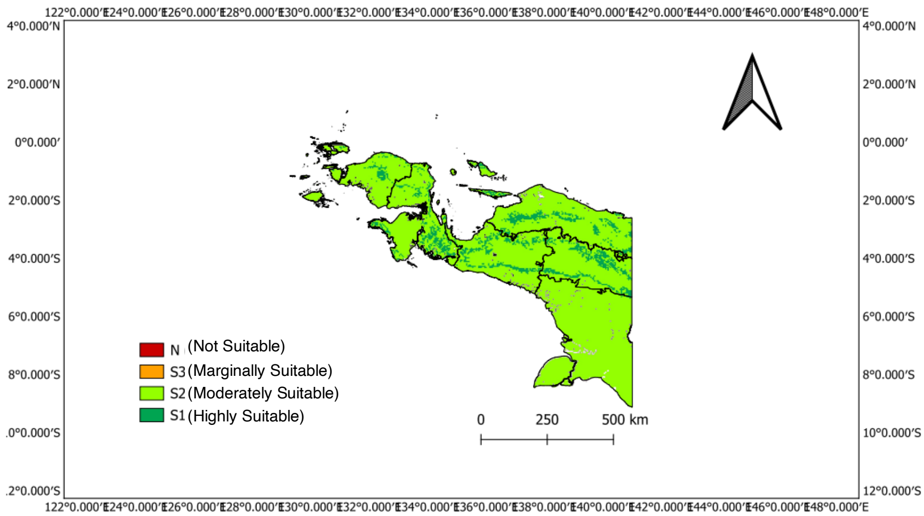



**Figure 1.** Sugarcane Land Suitability in Papua Island (1970–2000)

Spatial land suitability mapping for sugarcane during the historical base period of 1970–2000 indicates the predominance of classes S1 and S2 throughout nearly the whole land area of Papua Island. Class S1 prevails in coastal lowland ecosystems and intermontane valleys due to the reliable presence of accumulated thermal units. Topographic elevation variables that decrease air temperature, together with changes in soil acidity, diminish the viability of adjacent regions into expanses of class S2. The findings from spatial observations throughout this decade confirm the nonexistence of land classified as N or S3. This spatial data substantiates the dependability of Papua's biophysical land potential for optimal sugarcane cultivation (Figure 1).

The landscape assessment for the current period 2021–2025 indicates a geographical arrangement that closely aligns with earlier mapping results. Low-elevation areas persist in exhibiting a concentrated distribution of lands classified as very appropriate. The highlands significantly illustrate the persistence of areas classified as moderately suitable owing to natural constraints, particularly a reduction in climatic temperature. Temporal dynamics have been demonstrated not to induce spatial degradation into the marginally acceptable or unsuitable classifications throughout the full study region (Figure 2). The occurrence of enduring climate stationarity is unequivocally validated through interperiod geographical analysis. Decades of global weather anomalies have demonstrated an inability to diminish the ecological viability of Papua Island as a sustainable, critical food source.

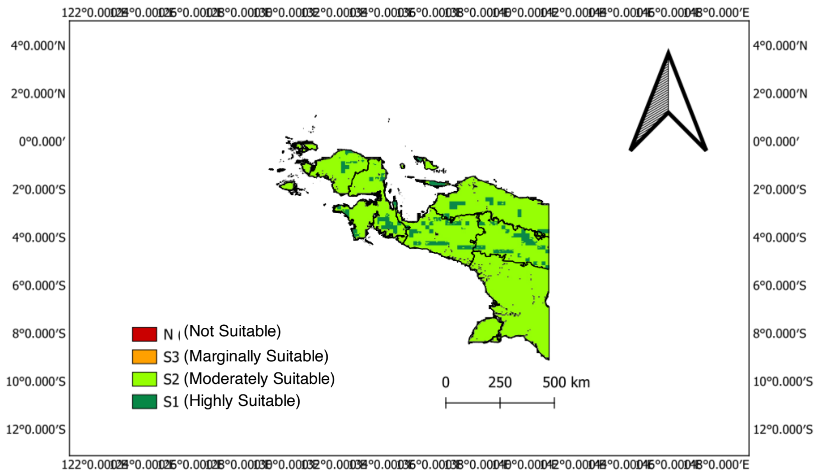



**Figure 2.** Sugarcane Land Suitability in Papua Island (2021–2025)

## 4. Discussion

This study's spatial modelling produces reliable forecasts and precisely verifies the biophysical compatibility of the Papuan landmass with the ecophysiological requirements of the target crop. The land suitability assessment was conducted by integrating Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP), a multi-criteria decision-making method that decomposes problems by structuring their components hierarchically (Saaty, 1990). The AHP model categorises the determining parameters into two primary groups: climate and soil, in alignment with the global agroclimatic land suitability evaluation framework (Ostovari *et al*., 2019). The climate group dominates the spatial evaluation structure with an accumulated weight reaching 80 percent. The rainfall variable occupies the highest hierarchical position with an individual weight of 30 percent (0.3). The humidity and temperature parameters each hold an equivalent weight proportion of 20 percent (0.2). The solar radiation variable completes the climate elements with a weight contribution of 10 percent (0.1). The soil group occupies the remaining proportion of the model with an accumulated weight of 20 percent. The soil acidity (pH) parameter acts as the constituent component of the edaphic group with a weight portion of 20 percent (0.2).

The prevalence of Class S1 (Highly Suitable) in the coastal lowlands and intermontane valleys of Papua Island is chiefly influenced by the synergistic interplay of substantial yearly precipitation and steady sun radiation in these areas. Rainfall in the Papuan lowlands typically meets or above the ideal range of 1,500–2,500 mm annually necessary for effective sugarcane farming (Chen et al., 2023), thereby ensuring that soil moisture remains at or near field capacity during the crop's growth cycle. Unlike traditional land suitability models that often disadvantage high-rainfall areas due to potential nutrient leaching or waterlogging, the well-drained alluvial and fluvial soils prevalent in the coastal lowlands of Papua alleviate these concerns, enabling high rainfall to serve as an agronomic benefit rather than a constraint. This interpretation is consistent with the findings of Neswati et al. (2016), which indicate that humid tropical areas with well-draining soils regularly yield high sugarcane productivity, even when total rainfall surpasses conventional limits. Concurrently, solar radiation levels in the Papuan lowlands—despite the reduction in minimum radiation noted during the current period (2021–2025)—continue to be adequate to support the net photosynthetic rates and biomass accumulation necessary for commercially viable sucrose yields. The convergence of these two environmental advantages in the same geographical area elucidates the broad geographical scope of the S1 classification and differentiates Papua from other tropical locations where sugarcane suitability is limited by one or both of these factors.

The spatial distribution of Class S2 (Moderately Suitable) land, concentrated in highland transition zones, illustrates the combined effect of two moderate limiting factors: the reduction in temperature resulting from the elevation gradient and the rise in soil acidity. The mean air temperature in the intermontane highlands of Papua nears or descends below 20 °C, which is below the optimal thermal range of 24–30 °C designated for S. officinarum (Hakim, 2010), leading to a reduction in the rate of enzymatic activity linked to sucrose synthesis and impeding overall plant growth. The prevalence of highly weathered tropical soils, such as Ultisols and Oxisols, in these elevated regions, with pH levels nearing 4.5, results in diminished availability of phosphorus, calcium, and molybdenum, potentially constraining root growth and nitrogen fixation efficacy (Dumipto et al., 2019; Ostovari et al., 2019).

Nonetheless, neither of these constraints attains an irreversible threshold. The temperature deficit in highland locations, while considerable, does not fully inhibit cultivation; it just diminishes the productivity potential to the level indicated in the S2 classification. Analogously, the soil pH constraints observed in Papua can be effectively alleviated through the application of agricultural lime, an economical measure demonstrated to elevate soil pH from the 4.5–5.0 range to the ideal range of 6.0–7.5 within a single planting season in similar tropical environments (Purnamasari, 2023). The soil pH's contribution of merely 20% in the AHP model mitigates its restrictive influence on the overall LSI value, as the elevated scores from rainfall and temperature variables counterbalance its potential to classify an area as N (Not Suitable).

The most notable discovery in this study is the considerable lack of N (Not Suitable) and S3 (Marginally Suitable) classifications. The minimum index value of 2.6 signifies that no area on Papua Island has irreversible constraints that would make farming impractical. This event acts as a significant indicator of Papua Island's potential as a strategic "food estate." The lack of the N class indicates that the region possesses remarkable biophysical integrity; the reported limiting constraints are modest, including changes in soil pH and temperature declines at certain altitudes. Nevertheless, while the climatic variables (precipitation and radiation) persist at optimal score levels (3 and 4), they function as ecological compensators that elevate the entire index value beyond the critical category. This verifies that Papua is both agronomically feasible and possesses a little probability of production failure stemming from natural limitations.

The implementation of the AHP approach offered a benefit in reducing subjectivity via consistency ratios, which is essential for assessing the particular soil and climatic attributes of Papua. In the context of global climate change, tropical areas such as Papua are anticipated to encounter irregular precipitation patterns. This mapping indicates that the existing weight structure allows the land in Papua to exhibit significant buffering capacity against such oscillations. The consistent temperature and humidity of Papua, relative to other tropical areas that have experienced significant land degradation, establish the island as a climate refuge for commodities vulnerable to global temperature fluctuations. The edaphic properties (soil pH), serving as the only minor limitation, offer prospects for precision fertilization technologies to transform S2 locations into S1 in the future. This analysis presents a persuasive case for policymakers that agricultural investment in Papua is based on sound scientific principles to guarantee sustainable national food security.

A comparison analysis of historical climate baselines and contemporary data (2020–2025) demonstrates a notable consistency in land suitability trends throughout Papua Island. The absence of a substantial change—commonly termed 'climatic stationarity'—indicates that although worldwide anomalies are present, the fundamental equatorial climate of Papua exhibits considerable stability. The use of the latest datasets (NASA POWER 2025) aims not to reveal significant changes, but to confirm the current reliability of these suitability zones in the context of global climate variability. The temporal stability indicates that the S1 and S2 zones found are not transient but signify enduring critical agricultural resources. Moreover, utilizing contemporary data eradicates the 'temporal bias' sometimes associated with land assessments reliant on outdated 20th-century averages, thereby assuring that food security recommendations are congruent with present atmospheric CO2 concentrations and contemporary heat conditions.

## 5. Conclusions

This study finds that spatial modelling, utilising Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP), effectively confirms the high biophysical suitability of Papua Island for sugarcane development. The spatial evaluation results indicate a clear predominance of the S1 (Highly Suitable) land class in coastal lowland regions, attributed to the favourable combination of abundant rainfall and steady solar radiation. Highland and transitional locations predominantly fall within the S2 (Moderately Suitable) classification due to moderate constraints characterised by reduced environmental temperatures and elevated soil acidity (pH) levels. The primary conclusion from this modelling is the lack of regions classified as N (Not Suitable) or S3 (Marginally Suitable), indicating outstanding ecological integrity devoid of any irreversible constraints. The lack of these definitive limits establishes the Papuan landmass as a food estate area with minimal risk of failure. Moreover, cross-temporal comparison research substantiates the presence of climate stationarity, indicating that this region can function as a climate refuge resistant to global weather anomalies. The biophysical and climatic stability offers a robust scientific basis for policymakers, indicating that the increase of agricultural investment on Papua Island is a crucial sustainable strategy to ensure national food security.

**References**


Abubakar, A., *et al.* (2023). Geospatial simulation and mapping of climate suitability for oil palm (Elaeis guineensis) production in Peninsular Malaysia using GIS/remote sensing techniques and analytic hierarchy process. *Modelling Earth Systems and Environment*, 9: 73-96. https://doi.org/10.1007/s40808-022-01465-9.

Chen, S., *et al.* (2023). Cultivation suitability in Guangxi Province, China, Based on Multi-Source Data. *MDPI*, 13(5): 988-100. https://doi.org/10.3390/agriculture13050988.

Dumipto, P. K., *et al.* (2019). Evaluasi kesesuaian lahan untuk tanaman tebu pada lahan karst formasi Wonosari (TMWL) Kecamatan Gedangan Kabupaten Malang. *Jurnal Tanah dan Sumberdaya Lahan*, 6(2): 1361-1375. https://doi.org/10.21776/ub.jtsl.2019.006.2.17.

Hakim, M. (2010). Potensi sumber daya lahan untuk tanaman tebu di Indonesia. *Jurnal Agrikultura*, 21(1): 5-12.

Neswati, R., *et al.* (2016). Land suitability index for estimating sugar cane productivity in the humid tropics of South Sulawesi. *Indonesia. Journal of Tropical Soils*, 21(2): 115–122. https://doi.org/10.5400/jts.2016.21.2.115.

Ostovari, Y., Honarbakhsh, A., Sangoony, H., Zolfaghari, F., Maleki, M., & Ingram, B. (2019). GIS and multi-criteria decision-making analysis assessment of land suitability for sugarcane bagasse in Khuzestan province, Iran. Theoretical and Applied Climatology, 135(1-2), 1-15.

Purnamasari, R. A. (2023). Land suitability evaluation for sugarcane cultivation based on agroecological zoning system in East Java, Indonesia. *Buitenzorg: Journal of Tropical Science*, 1(2): 42-50. https://doi.org/10.70158/buitenzorg.v1i2.12.

Saaty, T. L. (1990). How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research, 48: 9-26. https://doi.org/10.1016/0377-2217(90)90057-I.