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Spatial Land Suitability for Paddy Cultivation: Empirical Analysis of Its Impact on Export Volume and Exchange Rates Behavior in Indonesia

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Abstract:

This study explores the linkages between geographical land suitability for rice cultivation and fluctuations in the Rupiah to US Dollar (IDR/USD) exchange rate in Indonesia's macroeconomic context. Combining qualitative and quantitative approaches, the study involved stakeholder interviews and regression analysis of national economic time series data from 1994 to 2024. Spatial analysis using the Multi-Criteria Decision Analysis (MCDA) approach was used to assess land suitability, considering legal restrictions on conversion of paddy fields and conservation forests. Results show that land suitability-based rice production has a statistically significant effect on exchange rate at the 10% level ($p = 0.0883$), with a positive coefficient of 0.0499, indicating that increased production is associated with Rupiah depreciation. In contrast, GRDP shows a significant negative effect on the exchange rate ($p < 0.05$), indicating its contribution to currency appreciation. Mediation analysis revealed that although rice production significantly increased export volume ($p = 0.0053$), the relationship between export and exchange rate did not prove significant ($p = 0.3962$). This suggests that increased production does not automatically strengthen the exchange rate without effective integration into the trading system. The qualitative interviews highlighted the importance of adaptive strategies by stakeholders in food security management. The findings emphasize the need for synchronization between agricultural expansion policies and macroeconomic strategies to sustainably achieve exchange rate stability and national food security.

Keywords: *Agricultural Policy, Exchange Rate, Food Security, Land Suitability, Spatial-Macroeconomics.*

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1. Introduction

Indonesia, as an agrarian nation, relies heavily on rice as a staple commodity central to its food security agenda. Despite stable domestic production, fluctuations in the Import Dependency Ratio (IDR) reveal growing concerns over reliance on external rice supplies. As reported by Central Statistics Agency (BPS) (2024), the IDR surpassed the critical 2% threshold, rising to 8.14% in 2023. Simultaneously, the Self-Sufficiency Ratio (SSR) declined from 98% to 91.86%, approaching the FAO's

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warning level of 90%. This trend underscores vulnerabilities in national rice production, demanding more resilient and location-specific strategies. The government's decision in late 2024 to suspend rice imports in 2025 exemplifies a bold move toward food sovereignty (BPMI Setpres, 2024). This national commitment emphasizes the need for sustainable, productive, and export-ready rice cultivation frameworks.

Aligned with Indonesia's long-term goal to become a global food estate by 2045, the Astacita program, initiated by President Prabowo, prioritizes agricultural self-reliance as a pillar of national resilience. The program outlines annual targets of developing 1 million hectares of rice fields from 2025 to 2029 (Ministry of Agriculture, 2024). However, past attempts such as the Food Estate in Central Kalimantan encountered significant setbacks. The mega-project's failures stemmed from land misclassification, ecological mismatch, and inadequate irrigation infrastructure World Resources Institute (WRI) (2022). Specifically, the conversion of peatlands under the Ex-Mega Rice Project resulted in massive financial losses, with only 110,000 hectares realized out of the 1.45 million planned. These past shortcomings reveal the necessity of spatially informed land use policies for paddy expansion. Accurate land evaluation methods are thus integral to the current policy's success.

The integration of spatial land suitability analysis with macroeconomic policy is increasingly critical in the context of volatile global trade and exchange rate dynamics. Recent studies highlight how agricultural outputs, particularly rice, affect currency strength through export flows (Laksono, 2023). Depreciation of the Rupiah can increase export competitiveness, but it also elevates the cost of agricultural inputs. Empirical data between 1997 and 2020 show a strong relationship between GDP growth and rice export performance, suggesting that macroeconomic variables are closely tied to land-based production capacity (Yusiana et al., 2022). Additionally, the impact of regional paddy production on the IDR/USD exchange rate remains underexplored, particularly in relation to specific land suitability parameters. This underscores the need to connect agricultural planning to broader economic stabilization goals. A comprehensive model linking land use and monetary stability is thus essential.

Spatial and geospatial methodologies are capable of identifying highly suitable lands for agriculture using multiple parameters such as slope, soil type, rainfall, flood hazard, and elevation (Choudhary, 2023). GIS-based Multi-Criteria Decision Analysis (MCDA) allows for classification into land suitability categories, which can enhance decision-making in food estate planning. For example, in East Kalimantan, slope and rainfall data are crucial determinants for assessing paddy feasibility (Setyanto, 2023). These spatial indicators provide a structured framework for visualizing the potential of new rice fields. In particular, East Kalimantan especially Kutai Kartanegara has emerged as a key candidate for food estate development, backed by complete spatial data availability. Such spatial modeling not only enhances location accuracy but also aligns agricultural expansion with environmental regulations and economic goals. This scientific foundation can reduce policy failures experienced in previous national projects.

Moreover, empirical evidence supports the integration of land suitability outputs with economic variables such as exchange rates, inflation, and GDP. The Structural Vector Autoregression (SVAR) model, along with mediation analysis, provides a robust framework for examining how agricultural outputs influence currency behavior (Yusiana et al., 2022). Export volumes, when treated as mediating variables, allow a nuanced exploration of how production capacity impacts macroeconomic stability. For example, increased paddy output may reduce import needs, strengthen trade balances, and stabilize the Rupiah. However, without adequate export infrastructure and post-harvest processing, production surpluses may not convert into foreign exchange gains. Hence, production estimation must be accompanied by a realistic export integration model. This study bridges land suitability insights with economic outcomes through integrated regression and mediation frameworks.

The lack of up-to-date, high-resolution geospatial datasets in Indonesia has long hampered evidence-based policymaking. Institutions like Barrakusuma Spatial Teknologi have started addressing these gaps by deploying satellite imagery and radar for land classification and rice field distribution. These technologies have been applied in Kutai Kartanegara to develop a robust geospatial baseline. Furthermore, stakeholder interviews confirm that Central Kalimantan's previous failures were due in part to mismatched land types, especially peatland unsuitability and inconsistent policy implementation (Azkiya et al., 2024). As such, a focus on regions with complete data and high land suitability becomes crucial for future success. Stakeholder-informed spatial assessment can therefore improve policy feasibility and financial planning. The convergence of spatial science and economic modeling marks a new frontier for Indonesia’s food resilience agenda.

The Indonesian government's ambition to position agriculture as both a driver of domestic food security and a foreign exchange earner demands a strategic and data-driven approach. Through the Astacita initiative, food estate development is now envisioned as an engine of macroeconomic stabilization, not merely subsistence. This vision necessitates reliable estimates of regional production potential, particularly from locations like Kutai Kartanegara that offer optimal land conditions. Understanding how much rice can be produced and how that volume affects trade balances and the Rupiah requires integrating agricultural planning with economic forecasting. If successfully implemented, the program could reverse trends in rice imports and enhance Indonesia’s standing in the global rice market. Yet, this is contingent on ensuring ecological compatibility, infrastructure readiness, and export facilitation. It is within this complex but critical intersection that this research is situated.

Thus, this study aims to evaluate land suitability for paddy production in one of food estate location propose, in Kalimantan based on the suitably potential location, Kutai Kartanegara using spatial analysis and examine its predicted macroeconomic impact through exchange rate behavior. Employing both GIS-based MCDA and time-series econometric models, the research establishes empirical connections between production potential and economic outcomes. Specifically, it tests whether export

volume mediates the relationship between land suitability-based paddy production and exchange rate changes over a 26-year period. The findings are expected to inform future national policy in food estate development, including spatial prioritization, investment decisions, and financial modeling. By providing a robust framework grounded in empirical data and multi-level analysis, this study offers a replicable model for agricultural-economic policy integration. Its relevance extends beyond academic contribution to practical application in national food sovereignty planning. In this context, the research is both timely and aligned with Indonesia's long-term development agenda.

2. Theoretical Background

Land Suitability for Agriculture: The suitability of land for rice cultivation is crucial in optimizing agricultural productivity and ensuring food security. Methods such as the Multi-Criteria Decision Analysis (MCDA) are commonly employed to evaluate land suitability by considering various factors like soil characteristics, climate conditions, and legal constraints on land use. In Indonesia, regulations that restrict the conversion of rice paddies to non-agricultural purposes are essential for sustaining rice production, which is vital for both local food supply and export markets.

Agricultural Production and Exchange Rates: Rice production, as a key agricultural activity, plays a role in influencing exchange rate movements through its effect on the trade balance. Higher rice output typically leads to increased exports, which can drive demand for the domestic currency and potentially result in an appreciation of the exchange rate. However, the link between rice production and exchange rate behavior is influenced by several factors, including export competitiveness, global market conditions, and broader macroeconomic policies.

Macroeconomic Factors Influencing Exchange Rates: Macroeconomic variables such as Gross Regional Domestic Product (GRDP) significantly affect exchange rate fluctuations. The economic principle known as the Balassa-Samuelson effect suggests that growth in productive sectors, including agriculture, can contribute to a stronger currency. However, in economies like Indonesia, where agriculture remains an important sector, the relationship between rice production and exchange rates is shaped by a wider range of economic factors, including inflation, interest rates, and international trade dynamics.

Food Security and Exchange Rate Stability: Food security is inherently linked to agricultural productivity, with rice playing a central role in Indonesia's food system and rural economy. Proper management of rice

production and its integration into domestic and global markets is essential for ensuring food security and stabilizing the exchange rate. Aligning agricultural policies with macroeconomic strategies ensures that increased rice production contributes to broader economic stability, emphasizing the importance of coordinated efforts between stakeholders and adaptive policy frameworks.

3. Methodology

This study adopts a mixed-methods approach, integrating qualitative insights from stakeholder interviews with quantitative analyses involving spatial modeling and time-series regression. The methodological framework is structured to assess how spatial land suitability for rice cultivation can influence macroeconomic variables such as exchange rates. Interviews with stakeholders provide qualitative insights into the challenges and potential of the Food Estate program in Kalimantan, including geographical issues, financial constraints, government policy, and the economic impact on rupiah appreciation. The findings reveal that 67% of Pulang Pisau in Central Kalimantan consists of swampy, acidic land, making intensive rice cultivation difficult. However, a lack of post-harvest infrastructure, such as milling factories, forces farmers to sell raw paddy to other provinces, reducing prices and farmer profitability. Economic data, including exchange rates, rice export volumes, inflation, and GDP, will be collected from official publications and online platforms such as Bank Indonesia and FAOSTAT. Geospatial data will be used for spatial modeling and analyzing rice production volume at the study location.

Table 1. Economic and geospatial data resources (2024)

No	Data	Resources	Data Format	Resolution (Spatial data only)
1	Land Elevation	21AT+SRTM	Raster	30-50cm + resampling int 3m
2	Slope	21AT+SRTM	Raster	30-50cm+resampling int 3m
3	Annual Rainfall	https://chrsdata.eng.uci.edu	Raster	4km
4	Soil Type	FAO	Vector	1:3.000.000
5	Flood Risk	BNPB	Raster to Vecto	100m
6	Land cover data	KLHK	Vector	1:50.000
7	Land use data	ATR/BPN	Vector	1:50.000
8	Actual Productio of Paddy in Kuta Kartanegara 1997-2024	BPS Kabupaten Kutai Kartanegara	Web API, Document Publication	N/A
9	GRDP Kutai Kartanegara 1997-2024	BPS Kabupaten Kutai Kartanegara	Web API, Document Publication	N/A
10	Indonesian GDI 1997-2024	Worldbank	Web API	N/A
11	Exchange rates 1997-2024	Statista & Worldbank	xlsx	N/A
11	Rice Exports 1997-2024	FAO	xlsx	N/A

The spatial analysis was performed using Geographic Information Systems (GIS), particularly the Multi-Criteria Decision Analysis (MCDA) technique, which accounts for multiple environmental parameters. These include slope, elevation, soil type, rainfall, flood hazard, and existing land use, derived from diverse sources such as the Ministry of Agriculture, FAO, and national mapping agencies (Table 1). The output of this stage was a raster-based classification map that segments land into suitability classes: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), and Not Suitable (N), using weighted overlay modeling. The classification system and scoring criteria used were adapted from Setyanto (2023), as summarized in Table 2. The analytical process was operationalized in QGIS, utilizing raster calculator tools and reclassification modules for spatial accuracy.

Table 2. Indicators for land suitability for rice production by Setyanto, 2023

No	Indicators	Categories	Score	Amount
1	Land Elevation	S1	5	0-1500 masl
		S2	3	1500-2000 masl
		S3	1	2000-3000 masl
		N	0	>3000 masl
2	Slope	S1	5	0-15%
		S2	3	15%-30%
		S3	1	30%-45%
		N	1	>45%
3	Annual Rainfall	S1	5	1500-2000mm
		S2	3	1000-1500mm or 2000-2500mm
		S3	1	500-1000mm or 2500-3000mm
		N	0	0-500mm or >3000mm
4	Soil Type	S2	3	Acrisols, histosols, fluvisols, nitisols, cambisols
		S3	1	Arenosols
5	Flood Hazards	S1	5	Low risk
		S2	3	Moderate risk
		S3	1	High risk

To identify the most appropriate location, this research applies the theory of location intelligence, which integrates spatial data such as slope, rainfall, soil type, elevation, and production rates into a geospatial overlay analysis. The criteria are assessed using Multi-Criteria Decision Analysis (MCDA), which enables the integration of qualitative and quantitative data and considers multiple key parameters that influence land suitability.

Overlay analysis, a core component of Geographic Information Systems (GIS), combines multiple spatial datasets based on predetermined criteria. This method is effective in evaluating land suitability and identifying optimal locations for agricultural development (Malczewski, 2004). The spatial analysis framework (Figure 1) employed in this study is GIS-based MCDA, incorporating criteria derived from the literature. The land suitability classification is conducted using a weighted overlay model, with scoring references adapted from relevant literature. The classification

results are visualized through a grid-based map, and rice production volumes are subsequently estimated using raster statistics.

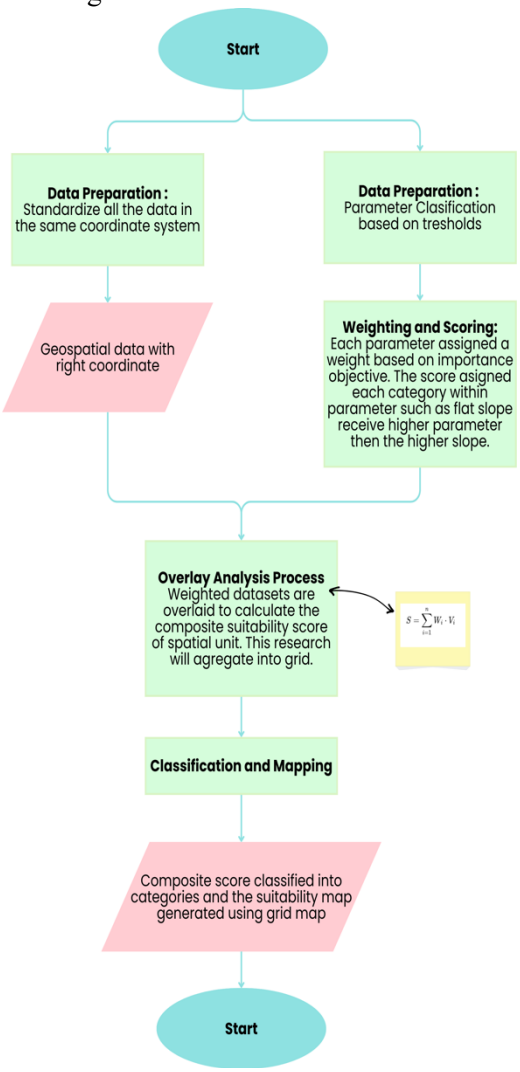

Figure 1. Flowchart of Spatial Analysis

Based on the literature, variables influencing agricultural land suitability include slope, elevation, land use, soil texture, precipitation, temperature, soil moisture, and road distance. These are calculated using the Analytical Hierarchy Process (AHP), a structured technique for analyzing complex decisions (Choudhary, 2023). Choudhary's findings categorize land suitability as: highly suitable (27.5%), moderately suitable (42.8%), marginally suitable (17.6%), and not suitable (12.1%). According to Setyanto (2023), land suitability for rice production in East Kalimantan, particularly near the new capital city, is influenced by elevation, slope, annual rainfall, soil type, and flood risk. The suitability classification is as follows: The following table presents the tools used in the land suitability analysis (Table 3):

Table 3. Software/Tools for Land Suitability Analysis

Stages	Process	Software
Data Preparation	Standardize coordinate system, preproces raster and vector data.	Quantum GIS (QGIS) (for geospatial processing).
Parameter Classification	Define thresholds for land suitability parameters (e.g., slope, elevation, soil texture, rainfall).	QGIS (vector classification, attribute analysis).
Weighting and Scoring	Assign weights based on Analytical Hierarchy Process (AHP) or expert-base criteria. Flat slopes get higher weights.	QGIS (Raster Calculator, Weighted Overlay Tool).
Overlay analysis an aggregation	Combine weighted datasets to compute composite suitability scores using a grid-based approach.	QGIS (Multi-Criteria Decisio Analysis - MCDA).
Land suitability classification	Apply Grid Analysis System for hierarchical classification (Highly Suitable, Moderately Suitable, Marginall Suitable).	QGIS

The analysis begins with Digital Elevation Model (DEM) data processing (combination part of high resolution and medium 30 m resolution). From DEM, two critical variables elevation and slope are extracted. Elevation indicates land height, while slope assesses steepness, which can affect erosion and suitability for farming (Figure 2). Environmental factors such as rainfall and flood risk are also considered. Rainfall data (originally 4 km resolution) and flood risk data (100 m) are resampled to 30 m to align with DEM resolution. This ensures consistent pixel size across all datasets, enabling precise spatial overlay. Soil type data, initially in vector format, is rasterized into 30 m resolution to enable raster-based analysis.

Each parameter is reclassified with scores representing agricultural suitability. For example, flatter terrain and optimal rainfall receive higher scores. These scored layers are then overlaid to create a preliminary suitability map, identifying regions with high, moderate, and low agricultural potential. Before finalizing potential development areas, land cover data (existing rice fields, protected forests) are filtered out to ensure that only new, permissible areas are considered. The result is a land suitability map highlighting areas with high potential for rice field development, based on elevation, slope, rainfall, flood risk, and soil type while also adhering to land-use regulations.

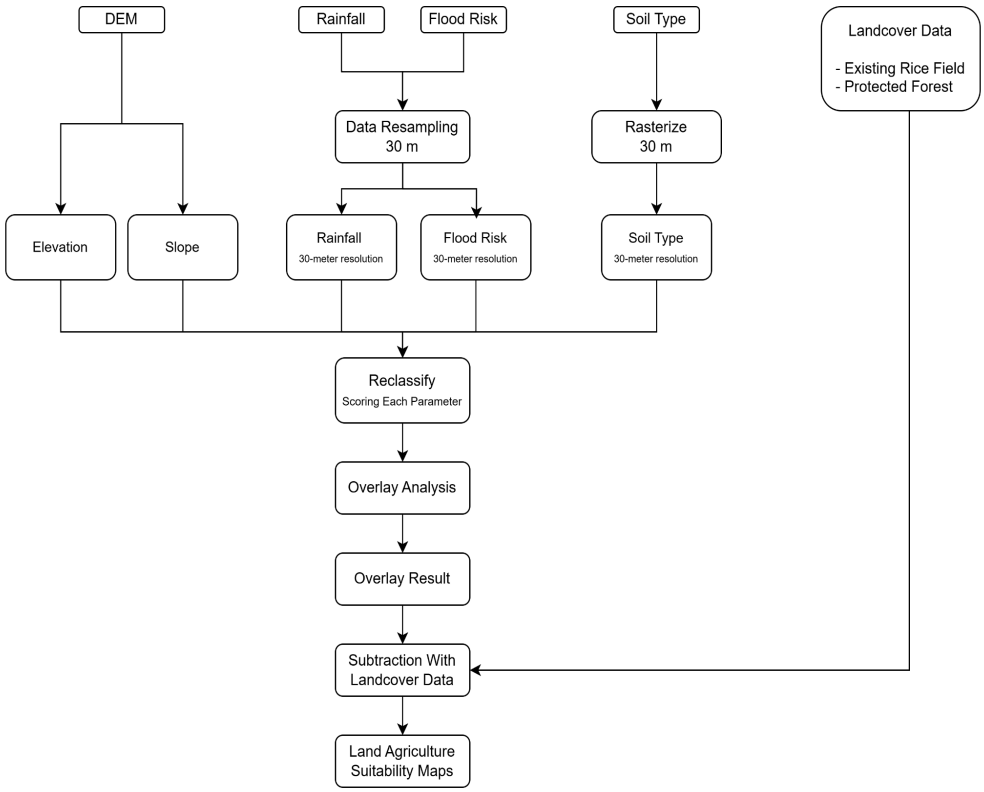

Figure 2. Workflow for land suitability analysis

To complement the spatial analysis, a quantitative econometric analysis is conducted using time-series regression data from 1997 to 2024 (26 observations). The relationship between land suitability–based rice production and macroeconomic indicators is examined. The variables include:

a. Average exchange rate (1997–2024)
b. GDP growth (1997–2024)
c. Inflation (1997–2024)
d. Rice exports (1997–2024)
e. Paddy production from land suitability projections (1997–2024)
f. GRDP growth (1997-2024)

4. Empirical Findings/Result

The spatial analysis conducted in this study identified significant areas in Kutai Kartanegara Regency as suitable for paddy cultivation. Based on the GIS-based Multi-Criteria Decision Analysis (MCDA), suitability was categorized into four classes: Highly Suitable, Suitable, Marginally Suitable, and Not Suitable. Parameters included in the analysis were slope, land elevation, rainfall, flood hazard, and soil type. These were weighted and reclassified into standardized scores, producing a composite land suitability map. The classification map is presented in Figure 3, which displays spatially distributed suitability across the region. This foundational analysis provided

the empirical base for calculating potential paddy production in accordance with national agricultural development plans. The outcome highlights the potential to expand rice cultivation in high-scoring zones.

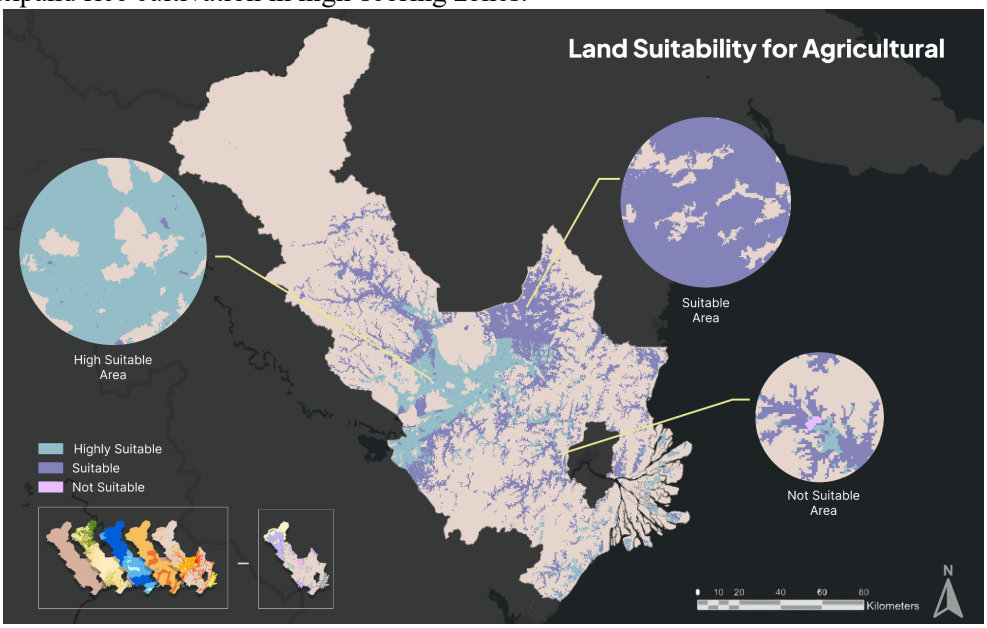

Figure 3. The GIS results on land suitability analysis.

To refine the accuracy of the analysis, existing land use constraints were applied to the suitability results. Areas designated as protected forests and existing rice fields were excluded from the model to ensure legal and spatial relevance. This refinement was performed using vector masking and raster subtraction techniques in QGIS. The outcome of this exclusion process which compares the land area before and after filtering. After removing restricted zones, a total of 629,791.29 hectares remained suitable for paddy expansion. The most promising classification, “Highly Suitable,” retained 239,029.2 hectares after exclusion. These findings underscore that even a single regency can contribute significantly to the national target of 1 million hectares per year. Using regional yield data, production potential was projected based on the area classified as Suitable and Highly Suitable. Kutai Kartanegara's 2023 yield of 4.34 tons per hectare (dry milled grain) served as the conversion factor. This figure was multiplied by the total eligible area to estimate the expected rice output. The results show an estimated total production of 2.73 million tons, broken down into 1.70 million tons from Highly Suitable land and 1.03 million tons from Suitable land (Table 4). This projection is significantly higher than the actual 2024 production of 106,553 tons, indicating large-scale underutilization. These projections form the empirical basis for testing production-output elasticity and trade effects on macroeconomic indicators.

Table 4. The areas of highly suitable and suitable at Kutai Kartanegara

Class	Estimated Production Yield (tons of GKG)
Highly Suitable	1.695.907,4706
Suitable	1.037.386,7280
Total	**2.733.294,1986**

To establish the reliability of economic data, stationarity testing was conducted using the Augmented Dickey-Fuller (ADF) test. The test was applied to five variables: Exchange Rate, Export Volume, Land Suitability-Based Paddy Production (LSU_PADDY_PROD_TREND), GDP Growth, and Inflation. Four of these variables showed statistical stationarity at the 5% significance level, while the Exchange Rate variable was found to be non-stationary. As a result, the Exchange Rate series was log-transformed and differenced once to ensure stationarity. The graphical comparison of the original and differenced series is shown in Figure 4, validating the stability of transformed variables. These transformations allowed the regression models to satisfy the assumptions of classical time-series econometrics.

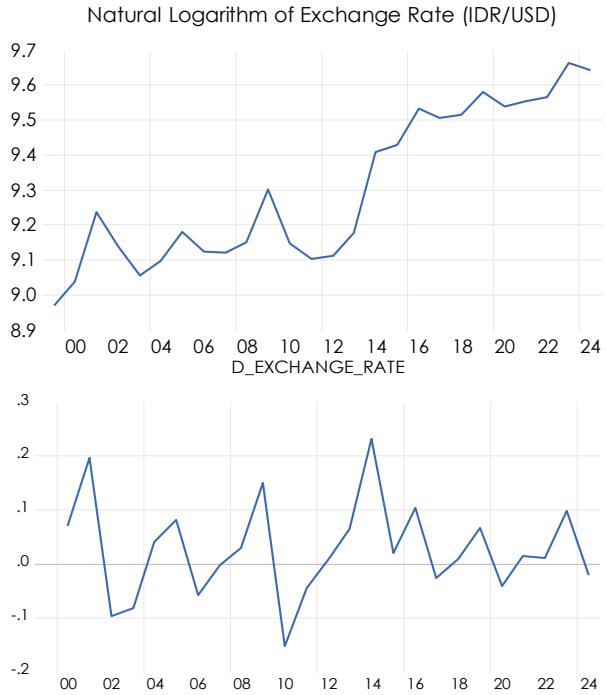

Figure 4. The graph of variables shows (a) the exchange rate variable before differencing and (b) the exchange rate variable after first differencing.

After confirming stationarity, multicollinearity analysis was conducted using the Variance Inflation Factor (VIF). This step was critical to ensure that the independent variables in the regression model did not inflate standard errors or distort coefficient estimates. The correlation matrix revealed low to moderate relationships among predictor variables, with no coefficients exceeding 0.80. For example, the correlation between LSU_PADDY_PROD_TREND and Export Volume was -0.161, indicating a weak inverse relationship. VIF values for all variables remained below the critical threshold of 10, confirming the absence of problematic collinearity. These findings are visually summarized in Figure 5. This diagnostic strengthens the internal validity of the regression analysis.

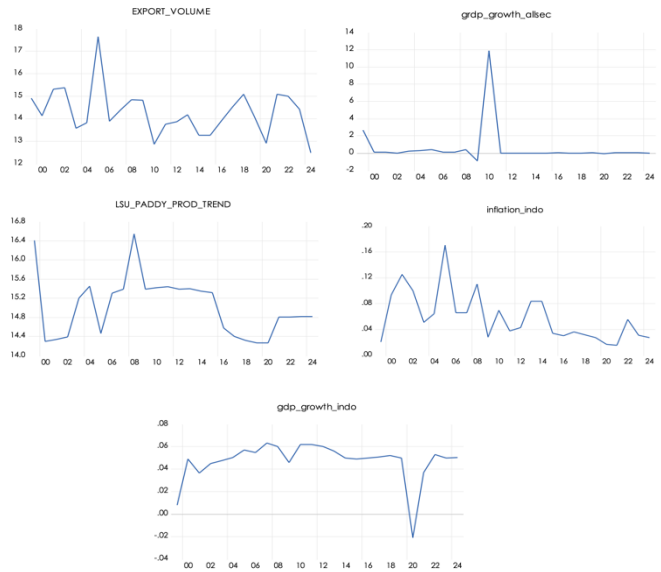

Figure 5. The graph of the variable shows all variables on the VIF test.

The first regression model testing the direct effect of lagged LSU-based paddy production on exchange rate behavior together with control variable, shows that the result rejects the null hypothesis. The model estimates the effect of LSU-based paddy production, GDP growth both national and regional, and inflation on changes in the rupiah exchange rate. Using 25 observation after adjustment on differencing the model yields meaningful insights into how macroeconomic and spatial agricultural variables contribute to currency movement dynamics. The model's R-squared value is 0.3667, indicating that combining the four independent variables explain approximately 36.7% of the variation. In the exchange rate changes. The adjusted R-squared of 0.2401 reflects a moderate explanatory power, adjusted for the number of predictors. The F-statistic of 2.8957 with a p-value of 0.0484 suggests that the model is statistically significant at the 5% level, indicating that the independent variables collectively have a critical explanatory effect on exchange rate behavior. Among the predictors, GRDP is statistically significant at the 5% level with p-value 0.0171 with a negative coefficient implying that higher sectoral economic growth tends to be associated with a depreciation of rupiah. These results suggest that production effects on currency behavior may be more complex or delayed. The model specification aligns with the lagged effect theory proposed by Barro (1990) and Gujarati (2003).

To test the mediation hypothesis, a two-step regression was employed. The first regression analyzed the relationship between LSU_PADDY_PROD_TREND and Export Volume. Results showed a positive and statistically significant coefficient of 0.3646 ($p = 0.0053$), indicating that paddy production based on land suitability strongly influences export volumes. The model's R^2 of 0.3646 demonstrates that 36.5% of the variance in exports is explained by spatially determined production levels. This confirms the first condition in Baron and Kenny's mediation framework (1986). It also supports the hypothesis that production capacity is a key driver of trade performance. The implication is that suitable land is not just agriculturally viable but economically significant.

The second mediation regression tested the effect of Export Volume on Exchange Rate behavior. In this model, the coefficient for export volume was -0.0009, but it was not statistically significant ($p = 0.3962$). The low R^2 of 0.0352 indicated minimal explanatory power. This result weakens the case for a strong indirect effect through exports. Despite production increasing exports, the latter does not significantly influence exchange rates within the timeframe studied. Factors such as input costs, import dependency, and price volatility may have confounded the expected transmission. The null result in this pathway reflects the complexity of trade-currency interactions.

A third regression tested both LSU-based production and Export Volume as predictors of exchange rate changes. The coefficient for production remained positive (0.0494), with a marginal significance at the 10% level ($p = 0.0830$), while Export Volume remained statistically insignificant ($p = 0.4091$). The combined model had an R^2 of 0.0986, indicating limited but consistent explanatory contribution. These results suggest partial mediation, where paddy production directly affects the exchange rate but is not fully transmitted through exports. This model aligns with the partial mediation typology described in the conceptual framework. It suggests that trade performance, although influenced by production, does not serve as a dominant conduit to currency shifts.

Graphical representations of all regression outcomes were plotted to assess trends and variable behavior. These plots include exchange rate fluctuations, paddy production over time, and export volume trends. The graphs reinforce the statistical findings, especially the divergence between production and exchange rate trends. While paddy production rises, exchange rate appreciation does not consistently follow, confirming the regression's modest significance. Descriptive statistics further support the conclusions, indicating that production variance is much higher than exchange rate variance. These patterns emphasize the limitations of assuming linear causality in agriculture–currency dynamics. The full set of descriptive statistics is provided in the appendix.

In terms of spatial policy implications, the findings validate the prioritization of Kutai Kartanegara as a pilot location for food estate expansion. With over 629,000 hectares of land classified as suitable or highly suitable, the region can realistically contribute to annual national targets. The estimated production capacity more than 25 times the current output reinforces the need for land-based productivity optimization. This empirical result aligns with the Ministry of Agriculture's spatial policy targets outlined in RPJMN 2020–2024. A spatially informed approach can address past failures in location mismatches and low yield returns. Thus, the GIS outputs serve both scientific and operational value.

The analysis also highlights infrastructure and institutional gaps that may impede the realization of estimated yields. Interview data revealed that farmers in previous food estate locations lacked post-harvest facilities, such as drying and milling units. Without these, production surpluses may not translate into export volumes or currency

gains. The regression's partial mediation result reflects this bottleneck in the value chain. Policy interventions must go beyond land classification and target logistical support and price guarantees. Stakeholder interviews emphasized the need for inter-ministerial coordination to align production, trade, and currency strategies. These qualitative insights explain some of the statistical anomalies observed in the regression models.

Another significant observation is the limited macroeconomic impact of export volumes alone on the Rupiah. Although production boosts exports, these volumes do not significantly move the exchange rate in the studied period. This suggests that external trade dynamics, such as global prices, exchange volatility, and input cost structures, must be integrated into future models. The current model may underestimate lagged or structural effects not captured in annual data. This underscores the importance of incorporating international rice market behavior and price elasticity into extended analyses. Future research may benefit from panel data or higher-frequency (e.g., quarterly) data structures. It also signals the need to consider commodity-specific terms of trade effects.

Overall, the findings confirm that spatially determined paddy production is economically significant but only partially translated into macroeconomic benefits through exports. The role of land suitability in enhancing regional production potential is strongly supported by the spatial models and yield estimates. However, the regression and mediation results caution against over-simplified assumptions about direct causality between agriculture and currency strength. The findings highlight the need for integrated agricultural, infrastructural, and monetary policies. This also points to the necessity of spatial planning in national food estate strategies. The study provides a robust empirical foundation for prioritizing regions like Kutai Kartanegara, not only based on land but also on economic leverage. These results lay the groundwork for a more systemic and evidence-based approach to agricultural policy design.

5. Discussion

The spatial analysis results underscore the critical role of land suitability in driving agricultural production efficiency, particularly in the context of rice cultivation. Kutai Kartanegara emerges as a high-potential zone, with over 629,000 hectares deemed viable for rice expansion, of which 239,000 hectares are classified as highly suitable. These findings affirm the assertion by Setyanto (2023) that land elevation, slope, and rainfall are pivotal determinants for rice farming potential in East Kalimantan. The classification and scoring system employed also align with prior studies on GIS-based MCDA for agricultural planning (Choudhary, 2023). The considerable discrepancy between estimated and actual production volumes in the region reflects the underutilization of agricultural land. This spatial production gap presents a substantial opportunity for strategic intervention. By mobilizing this untapped potential, Indonesia could make meaningful progress toward food self-sufficiency and export competitiveness.

Despite the production potential, the regression results demonstrate that land suitability-based paddy output has only a modest and statistically weak significant effect on exchange rate behavior. These finding challenges initial assumptions that increased agricultural output would directly appreciate the Rupiah through reduced import dependence or enhanced trade balances. The lack of a strong significant relationship suggests that other factors such as trade infrastructure, input costs, or commodity prices moderate the impact. As noted by (Laksono, 2023), currency movements are influenced by a wider macroeconomic ecosystem beyond domestic production metrics. Additionally, the positive coefficient implies a depreciation effect, which may be explained by surplus-induced price drops or increased input imports. This complexity reinforces the importance of multi-variable modeling in agricultural economics. It also suggests that production alone is insufficient for macroeconomic impact without systemic support mechanisms.

The mediation analysis provides further insight into the transmission mechanism between agriculture and currency outcomes. While the relationship between paddy production and export volume is strong and significant, the export volume itself does not significantly influence the exchange rate. This breaks the hypothesized chain of causality and indicates partial mediation. The result supports Gatawa and Mahmud (2017), who emphasized that trade volumes must be matched with export readiness and supportive fiscal conditions to influence macroeconomic indicators. The export volume's weak effect on exchange rates may be attributed to inefficiencies in logistics, limited international market access, or volatility in global rice prices. Therefore, while increasing rice production is necessary, it is not sufficient for economic gains unless the trade system is equally optimized. The result calls for a holistic policy approach that includes logistics, storage, marketing, and trade agreements.

Another key insight is that spatial prioritization should be integrated into the national food estate agenda to avoid repeating the failures of past initiatives. The Central Kalimantan food estate, built on peatlands, exemplified the consequences of ecological misalignment (Azkiya et al., 2024; World Resources Institute (WRI), 2022). In contrast, the Kutai Kartanegara case demonstrates how spatial analysis can preemptively identify suitable zones with biophysical compatibility. This not only improves agricultural productivity but also mitigates ecological and economic risk. Land use regulations must also be aligned with this spatial prioritization, as shown in the exclusion process that removed protected and unsuitable areas from the suitability maps. This ensures legal compliance and avoids conflicts with conservation and forestry agendas. Such data-driven targeting enhances the credibility and feasibility of agricultural expansion policies. Connecting with how GRDP has a significance level for rupiah depreciation as one of the control variables supporting the LSU-paddy production shows that regional trade strength might have an effect not only on national food security but also on rupiah appreciation.

Institutional gaps remain a major barrier to translating land potential into economic gains. Interviews reveal that poor post-harvest infrastructure and weak coordination

between ministries hinder local farmers from maximizing value chains. As noted in previous studies (AJMRD, 2024; Pakpahan, 2020), the absence of drying and milling facilities forces farmers to sell raw paddy, reducing profit margins and regional competitiveness. This disconnect between production and processing undermines the economic value of increased cultivation. The regression results echo this by showing limited macroeconomic impact despite large spatial gains. Addressing this requires not just investment in farming inputs, but also in value-chain infrastructure and farmer training. These findings support a shift from output-oriented to outcome-oriented agricultural policy frameworks.

The choice of a one-year lag in modeling reflects institutional practice and theoretical logic in agricultural economics (Barro, 1990; Gujarati, 2003). Given the seasonal nature of agricultural production, its impact on macroeconomic variables like exchange rate is rarely immediate. Delayed effects through trade flows, policy feedback, and market adjustments are well-documented in the literature. This lagged relationship, although modestly supported in this study, indicates that agricultural policy must consider delayed payoffs. The use of lag also aligns the study with national practices in modeling agricultural scenarios and predicting inflationary effects (Central Statistics Agency (BPS), 2024; Kementan, 2022). However, the absence of significant results may also reflect the annual frequency of data, which masks intra-annual fluctuations. Future research could benefit from higher-frequency data to better capture short-term dynamics.

The findings also emphasize the utility of spatial analytics in national economic planning, particularly for food security. By combining DEM data, climate variables, and land cover classifications, the study generates a replicable model for agricultural site selection. These tools allow policymakers to move beyond political or administrative criteria and adopt data-driven land use decisions. Moreover, the ability to estimate output volumes spatially enhances planning for national reserves, price stabilization, and export strategy. This confirms the relevance of geospatial intelligence in integrated agricultural and financial policy. Spatial analytics, therefore, represent not only a technical tool but a strategic enabler for national development goals.

In summary, the discussion reveals both the strengths and limitations of land suitability analysis in predicting macroeconomic outcomes. While Kutai Kartanegara holds exceptional potential for rice production, the economic conversion of this potential depends on institutional capacity, infrastructure readiness, and global trade dynamics. The partial mediation observed calls for stronger linkages between spatial planning, production systems, and trade mechanisms. Importantly, the results challenge linear assumptions about agriculture and macroeconomics, urging multidimensional models that incorporate social, ecological, and financial variables. The role of land remains fundamental, but its economic value is contingent upon integration across the entire value chain. As Indonesia strives toward food sovereignty and currency stability, this study offers a replicable framework and critical insights

for future policy refinement. The findings ultimately call for an ecosystem-based approach to agricultural development.

6. Conclusions

This research delved into the dynamic relationship between paddy production based on land suitability and fluctuations in Indonesia's exchange rate, incorporating GDP (regional and national) and inflation as controlling variables. It further examined whether rice exports serve as a mediating factor in this relationship. Findings indicate that land suitability-driven paddy output has a statistically significant and positive correlation with the IDR/USD exchange rate, particularly when macroeconomic controls are accounted for. The delayed effect of paddy production (with a one-year lag) proved significant at the 10% level, pointing to a modest but noteworthy depreciation of the Rupiah together with GRDP that proved significant at the 5% level, challenging initial expectations that increased agricultural output would bolster currency strength through improved trade balances. This outcome suggests inefficiencies in integrating surplus production into domestic consumption or international trade frameworks. Mediation analysis revealed that although paddy production significantly influences export volume, the link between export volume and exchange rate remains statistically weak. Hence, the direct influence of production on currency fluctuations appears stronger than its indirect, trade-mediated impact.

These findings expose limitations in Indonesia's current export infrastructure, especially in agricultural zones prioritized through spatial planning. Stakeholder insights highlighted the importance of first securing regional food security before pursuing exports, pursuing the larger area harvest for greater production, and increasing demand to buy the regional production to meet the goals of stopping the import of rice commodities. Advocating for innovations in distribution, post-harvest management, and local manufacturing through BUMD and BULOG initiatives. National policymakers emphasized the need to reduce dependence on the USD and enhance bilateral trade partnerships, particularly within alternative global blocs like BRICS, which they recommend for future research. Recommendations include strengthening trade infrastructure, empowering regional economic systems, expanding spatial policy tools, and improving incentive frameworks for farmers and exporters. Future studies are encouraged to integrate broader external variables, explore spatial heterogeneity, and adopt longer observation models to better understand policy impacts on macroeconomic stability.

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