



Deconstructing National Food Security: A Spatial Analysis of Paddy Field Conversion and Rice Production Volatility Based on Area Frame Sampling (AFS) Data

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ABSTRACT

This study analyzes the structural vulnerability of national food security by examining the spatial impact of paddy field conversion on rice production volatility. Production instability is influenced by several key factors, including land-use change, climate-related harvest failures, and the degradation of primary irrigation infrastructure. Using the Area Frame Sampling (AFS) approach from 2020 to 2024, this research integrates remote sensing data with field observations to measure the loss of productive agricultural land. The results reveal a 4.22% decline in the national harvest area. In Java, the conversion of technically irrigated paddy fields leads to an estimated loss of 11.4 tons of Milled Dried Grain (MDG) per hectare annually, reflecting a significant reduction in production capacity due to the disappearance of multi-cropping systems. Spatial regression analysis shows a strong relationship ($R^2 = 0.78$) between infrastructure expansion and rice supply instability. This finding indicates that irreversible land-use change, rather than yield fluctuation, is the primary driver of production volatility. The results suggest that national food security is approaching a critical threshold. Therefore, the study recommends implementing a moratorium on paddy field conversion, strengthening field-level spatial monitoring, integrating food security policies, and providing fiscal incentives to protect remaining agricultural land.

Keywords: Area Frame Sampling (AFS); Food Security; Land-Use Conversion; Paddy Field; Production Volatility; Spatial Analysis

1. Introduction

National food security serves as a fundamental pillar for economic stability and sovereign resilience, yet it currently faces an existential threat from aggressive spatial pressures [1].

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Within a volatile global landscape, a nation's capacity to safeguard domestic food supplies has become a primary metric of national robustness. Indonesia, as a leading global rice producer, encounters a paradoxical challenge where the ambition for food self-sufficiency frequently clashes with unbridled urbanization [2]. To mitigate this, it is necessary to empower the community in the village through participatory agricultural management to strengthen local resilience against land-use shifts.

The significance of this study lies in the urgent requirement to deconstruct prevailing food security narratives that have historically relied on administrative production figures while overlooking the spatial erosion of the land resource base [3]. This research is further necessitated by the alarming rate of paddy field conversion, particularly in Indonesia's primary rice-producing hubs such as Java, South Sulawesi, and North Sumatra, which threatens the long-term sustainability of the national caloric supply [4]. Furthermore, the implementation of regulations that prevent land conversion, such as Law No. 41 of 2009 concerning the Protection of Sustainable Food Agricultural Land (locally known as LP2B), is crucial to provide a legal shield for productive zones.

The current state of research in this field reflects a significant methodological evolution. Over the past decade, scholarly and policy debates regarding the precision of Indonesian land area and rice production statistics have been highly contentious. Discrepancies between subjective "eye estimate" data and empirical field realities have historically undermined the credibility of national food statistics [5]. However, the adoption of the Area Frame Sampling (AFS) methodology by Statistics Indonesia (SI) has established a new, more objective consensus. By integrating remote sensing technology with Geographic Information System (GIS) coordinates to monitor paddy growth phases in real-time, the AFS method has drastically corrected previously over-optimistic harvest area estimates.

Despite this progress, conflicting hypotheses persist regarding the efficacy of the Sustainable Food Agricultural Land (SFAL) policy; some scholars argue that this regulation has failed to deter land conversion due to insufficient economic incentives for farmers, while others contend that the failure stems from jurisdictional overlaps between central and regional governments [6].

The primary objective of this study is to perform a rigorous spatial analysis of paddy field conversion phenomena and their correlation with rice production volatility utilizing AFS-based secondary data. This research seeks to map the geographic distribution of conversion hotspots and quantify the extent to which the loss of land assets contributes to fluctuations in grain output across various provinces [7].

By employing a deconstructive approach, this study aims to unravel the complexities of food land management that are often obscured by aggregate national data. The principal



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conclusions of this work highlight that rice production volatility in Indonesia is driven more by the irreversible loss of effective harvest areas due to land conversion than by fluctuations in per-hectare productivity [8]. Consequently, this study emphasizes the necessity for a more rigid reorientation of spatial policies to guarantee the integrity of paddy fields as a strategic national asset. Specific spatial policies needed to ensure the integrity of rice fields include the mandatory integration of AFS-based spatial data into Regional Spatial Plans (locally known as RTRW) and the establishment of a "Green Zone" permanent status for technically irrigated fields to prevent any future non-agricultural development.

2. Materials and Method

This section delineates the systematic procedures employed to examine the correlation between land-use transformation and rice production instability. This research utilizes a national-scale secondary data approach, with a specialized analytical focus on regions experiencing the most acute conversion pressures.

2.1 Study Site and Sampling Population

The scope of this study encompasses the entire sovereign territory of the Republic of Indonesia, with strategic analytical weighting applied to the eight primary rice-producing provinces (North Sumatra, South Sumatra, Lampung, West Java, Central Java, East Java, South Sulawesi, and West Nusa Tenggara).

The sampling population within the Area Frame Sampling (AFS) framework analyzed in this study consists of observation segments proportionally distributed across the National Paddy Field Map (locally known as LBS). Based on recent figures, the total sampling population routinely monitored by Statistics Indonesia (SI) involves approximately 217,513 segments (each measuring 300 X 300 meters), covering the complete spectrum of paddy field ecosystems, including both technical irrigation and rain-fed areas. Of the total national paddy field area, technically irrigated fields account for approximately 58%, while rain-fed areas and other types of paddy fields comprise the remaining 42%, reflecting the spatial diversity of Indonesia's rice production base [9].

Data Sources and Materials

All research materials consist of official secondary datasets that can be verified and traced via digital identifiers or authoritative state publications:

- Production Statistical Data: Monthly harvest area and milled dry grain (MDG) production data derived from AFS observations for the 2020–2024 period and sourced from Statistics Indonesia (SI).



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- Spatial Land Data: National Paddy Field Map (LBS) data from the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (MAASP/NLA). This data is verified through Ministerial Decree No. 1/2019 and was updated in 2023 [10].
- Environmental Parameters: Land cover data from the Geospatial Information Agency (BIG) is used to identify and classify transitions in non-agricultural land use.

2.2 AFS (Area Frame Sampling) Collection Protocol

The AFS methodology replaces traditional "eye estimate" techniques with a more rigorous scientific procedure. Field enumerators perform verification of rice growth phases at fixed coordinate points within each sample segment using GPS-enabled mobile applications. Nine distinct growth stages ranging from land preparation and vegetation to harvest are photographed and uploaded to the SI central server for cross-validation with high-resolution satellite imagery [11]. These nine stages consist of (1) land preparation, (2) initial vegetative/planting, (3) late vegetative, (4) generative (flowering), (5) Ripening (milky grain), (6) Harvesting/Mature, (7) Post-harvest (stubble), (8) Fallow/Ploughed land, and (9) Non-paddy use/Other crops. This protocol minimizes data manipulation and provides rice production volatility figures rooted in empirical field facts.

2.3 Data Analysis and Volatility Modeling

We process the datasets using spatial regression analysis to determine the impact of land conversion on output decline. Production volatility is measured using temporal variability indicators to evaluate the extent of production fluctuations in regions with substantial paddy field loss. A production density formula is applied to calculate the level of food insecurity resulting from conversion:

$$DP = \frac{\sum \text{Rice Production}}{\text{Administrative Land Area}}$$

This analysis serves to test the hypothesis that every 1% decrease in the National Paddy Field Area due to conversion in Java triggers higher supply volatility compared to the opening of new agricultural frontiers outside of Java (Irawan et al., 2023). In this context, a supply volatility coefficient (CV) exceeding 0.05 (5%) is required to indicate significant supply instability, where Java's conversion specifically threatens to push this coefficient beyond 0.08 in key industrial corridors.



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2.4 Data Transparency and Ethical Considerations

This research relies entirely on public datasets that are anonymized and do not identify individual land ownership; consequently, no specific ethical approval was required.

3. Result

The deconstructive analysis of the Area Frame Sampling (AFS) datasets exposes alarming fluctuations within the national rice production foundation. Key findings indicate that the degradation of production capacity is not merely a gradual process but is undergoing rapid acceleration in strategically vital regions. The speed of this acceleration is characterized by a steady increase in the annual conversion rate, which has now reached an average national decline of 1.1% to 1.5% in productive land assets per year, significantly outpacing previous decades.

3.1 NPFA Spatial Expansion and the Erosion of the National Paddy Field Map (NPFM)

Integrated data from the Ministry of Agrarian Affairs and Spatial Planning (MAA and SP) and Statistics Indonesia (SI) reveals that the total national paddy field area (NPFA), recorded at 7,463,948 hectares in 2019, has faced intense conversion pressures, causing real harvest areas to fluctuate sharply. At the provincial level, West Java recorded the highest rate of land-use transition, with an average loss of 12,500 hectares per annum during the 2020–2024 period. Spatial analysis demonstrates that 68% of these converted lands were technically irrigated fields with a cropping index (CI) exceeding 2.0; consequently, the loss of a single hectare in these zones is equivalent to forfeiting a production potential of 11.4 tons of milled dry grain (MDG) per year.

3.2 Quantitative Findings on Production Volatility via AFS

The AFS methodology provides high-fidelity data regarding "lost harvest areas" resulting from crop failures and land conversion. In 2023, total national rice production was documented at 53.98 million tons of MDG, reflecting a decrease of 1.40%, or approximately 0.77 million tons, compared to the preceding year. This finding is critical, as this production slump occurred precisely while consumer rice prices reached historic peaks [9].

Table 1: Comparative Analysis of Harvest Area and Production Volatility

Province / Region	2020 Harvest Area (Million Ha)	2023 Harvest Area (Million Ha)	Percentage Change (%)	Production Coefficient of Variation (CV)
West Java	1.58	1.52	-3.79%	0.084



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Central Java	1.67	1.61	-3.59%	0.071
East Java	1.75	1.69	-3.42%	0.065
South Sulawesi	0.98	0.96	-2.04%	0.042
South Sumatra	0.55	0.51	-7.27%	0.112
National	10.66	10.21	-4.22%	0.076

Data Source: Independently processed (2025) based on secondary data from Statistics Indonesia (SI): National AFS Rice Reports 2020-2024 and the Ministry of Agrarian Affairs and Spatial Planning (MAA and SP): National Paddy Field Area Statistics.

The data above illustrates that South Sumatra experienced the highest volatility, driven by a heavy reliance on swamp and rain-fed lands highly susceptible to climate anomalies. Conversely, Java exhibits volatility triggered by a consistent and systemic shrinkage of harvest areas. In contrast, North Sumatra shows a relatively lower percentage of change compared to South Sumatra; this is primarily caused by more rigid local land-protection zoning in several regencies and the ongoing rehabilitation of primary irrigation channels, which has temporarily stabilized the harvest area despite urban pressure. Conversely, Java exhibits volatility triggered by a consistent and systemic shrinkage of harvest areas.

3.3 The Impact of Industrial Agglomeration on Conversion Rates

Spatial regression findings indicate a significant positive correlation $R^2 = 0.78$ between the development of new industrial estates in the Rebana corridor (West Java) and the decline in rice harvest areas in surrounding territories. Every 1% increase in industrial land use within fertile zones correlates with a 2.4% reduction in local rice output over a three-year period. This is exacerbated by land fragmentation, where average farm ownership has dwindled to less than 0.3 hectares, thereby diminishing the economic incentives for farmers to maintain agricultural operations.

3.4 Yield Gap and Productivity Stagnation Analysis

Beyond conversion factors, AFS data reveals that national productivity has stagnated at 5.2 tons/ha. Spatial deconstruction reveals that regions with high volatility tend to have degraded irrigation infrastructure. About 42% of primary and secondary irrigation networks outside Java are in mild-to-severe disrepair, which directly contributes to harvest uncertainty during the dry season.



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4. Discussion

The interpretation of these research findings validates the working hypothesis that rice production volatility in Indonesia is a direct consequence of spatial failures in safeguarding the national food land base. The following discussion dissects these results through the lenses of land-use competition theory, the validity of data methodologies, and strategic policy implications.

4.1 Causal Analysis of Land Conversion and Production Erosion

The empirical finding that West Java loses approximately 12,500 hectares per annum serves as a robust confirmation of land-use competition theory. The coherence between this specific figure and the national output decline of 0.77 Milled Dried Grain (MDG) in 2023 underscores that land conversion is not merely an administrative issue but a physical threat to caloric availability. The industrial land rent dominating Java's primary corridors creates a severe disincentive for paddy field conservation. The documented 4.22% national contraction in harvest area over the last three years demonstrates that Sustainable Food Agriculture Land (SFAL) regulations have been insufficient in countering real economic pressures, where liquidating land assets becomes a rational economic choice for farmers facing land fragmentation now averaging below 0.3 hectares [12].

4.2 Methodological Significance of AFS for Volatility Interpretation

The alignment between the AFS methodology and the observed national production Coefficient of Variation (CV) of 0.076 provides a new dimension to food risk assessment. The elevated CV in South Sumatra (0.112), which correlates directly with harvest area fluctuations, confirms that dependence on non-irrigated lands exacerbates supply instability. AFS data successfully deconstructs past "statistical optimism" by revealing that production volatility in Java (exemplified by a CV of 0.084 in West Java) is primarily triggered by the permanent loss of 11.4 tons of GKG potential per hectare due to the conversion of technically irrigated fields rather than mere yield fluctuations. To reduce this potential loss of MDG, strategic actions must include the intensification of existing land through the optimization of irrigation networks, the implementation of "incentive-disincentive" mechanisms for landowners to prevent conversion, and the acceleration of land redistribution programs to maintain viable farm sizes. [9] This supports the assertion by Statistics Indonesia (SI) that spatial grid-based data accuracy enables the precise identification of critical points where production loss becomes irreversible.



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4.3 Policy Implications and Long-Term Food Sovereignty

The spatial regression findings, with an R^2 value of 0.78 linking infrastructure development to a 2.4% output decline in industrial peripheries, necessitate a fundamental reorientation of national development strategies. Extensification efforts via "food estates," which maintain a cropping index of only 1.2, are quantitatively proven to be incapable of compensating for the loss of Javanese lands that boast a CI of up to 3.0. National food security has reached a critical juncture. Without a total moratorium on the conversion of remaining fertile irrigated lands, production volatility will continue to escalate alongside the rising logistical costs of distributing food from less productive extensification zones. This escalation is further supported by literature stating that uncontrolled land conversion in high-productivity zones leads to a "spatial mismatch" between food production and consumption centers, thereby increasing price volatility [4, 1].

4.4 Limitations and Future Research Directions

While this study successfully proves a strong correlation between AFS spatial data and production volatility, limitations remain regarding the analysis of agricultural input cost variables. Future research should integrate AFS datasets with more dynamic climate change variables and the sociological aspects of farmers' decision-making processes. Furthermore, data synchronization between the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (MAASP/NLA) and SI must be deepened to a micro-parcel level to ensure that legal enforcement against spatial planning violations can be executed in real-time [13].

5. Conclusions

5.1 Article's Conclusion

Drawing from the spatial analysis and deconstruction of Area Frame Sampling (AFS) data, this research concludes that Indonesia's national food security is currently characterized by significant structural vulnerability. The study's findings indicate that the 4.22% contraction in the national harvest area and the loss of production potential amounting to 11.4 tons of Milled Dried Grain (MDG) per hectare per year in Java's technically irrigated regions are not merely statistical artifacts; rather, they represent a permanent erosion of assets that triggers supply volatility. A critical application of the AFS methodology demonstrates that current fluctuations in rice production are driven more by the spatial shrinkage of the land base than by declines in individual farmer productivity.

This research has advanced the body of scientific knowledge by integrating grid-spatial remote sensing data to empirically validate land-use competition theory. While the results



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must be generalized with caution, noting that land conversion is most aggressive in Java while volatility in outer islands is dominated by irrigation infrastructure and climatic variables, the study underscores a critical reality. Without rigid spatial interventions, Indonesia faces chronic food instability due to the irreversible loss of highly productive paddy fields.

5.2 Research Limitations

The primary limitation of this study lies in its reliance on aggregate secondary datasets at the provincial and regency levels. This analysis does not fully encompass microeconomic variables, such as individual farmer opportunity costs or the psychological impacts of industrial agglomeration on farming intent. Furthermore, the spatial synchronization between the National Paddy Field Map (NPFM) from the Ministry of Agrarian Affairs and Spatial Planning / National Land Agency (MAASP/NLA) and the AFS data from SI still encounters challenges regarding satellite imagery resolution in regions with extreme land fragmentation.

Suggestions and Recommendations

Based on the aforementioned findings, the author proposes the following strategic recommendations:

1. **Total Moratorium:** The government must implement an absolute moratorium on the conversion of technically irrigated paddy fields across Java and other national food hubs.
2. **Fiscal Incentives:** There is a critical need for competitive economic incentive schemes for farmers within protected zones (locally known as LP2B) to ensure the economic value of paddy farming remains competitive against industrial land rents.
3. **Spatial Digitalization:** AFS data should be integrated into the spatial licensing system (SLS) to automatically block construction permits on protected agricultural land.
4. **Future Research:** Subsequent studies should undertake longitudinal evaluations of "green incentives" for farmers and perform in-depth socio-economic analyses of the capacity of "food estates" to specifically compensate for the loss of Javanese agricultural land.

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