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The Impact of Settlement Growth on Food Security Vulnerability: The Mediating Role of Rice Field Conversion and the Moderating Role of Agricultural Human Resource Capacity in Central Java

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Abstract:

Settlement growth in Central Java Province continues to increase and intensify competition for land use with agricultural land, particularly rice fields. Uncontrolled rice field conversion has the potential to weaken the food production base and increase regional food security vulnerability. This study analyses the effect of residential growth on food security vulnerability with rice field conversion as a mediating variable and agricultural human resource capacity as a moderating variable in 35 districts/cities in Central Java. The study uses an explanatory quantitative approach based on secondary panel data for the period 2010–2021 (420 observations) with saturated sampling technique. The analysis was conducted using Partial Least Squares–Structural Equation Modelling (PLS-SEM) to evaluate the measurement model, test structural relationships, estimate indirect effects, and assess moderation effects through interaction constructs. The results show that settlement growth has a positive and significant effect on rice field conversion. Rice field conversion has a positive and significant effect on food security vulnerability and significantly mediates the effect of settlement growth on food security vulnerability. In addition, agricultural human resource capacity moderates the relationship between rice field conversion and food security vulnerability with a negative moderation direction (dampening effect), so that in areas with higher human resource capacity, the impact of rice field conversion in increasing food vulnerability tends to be weaker. These findings confirm that the impact of settlement growth on food vulnerability mainly occurs through land use change and can be mitigated by strengthening agricultural human resource capacity. The policy implications emphasise the need to integrate settlement growth control, protection of productive rice fields, and strengthening of agricultural human resource capacity through improving the quality of extension services and accelerating technology adoption to maintain the resilience of the food system in Central Java.

Keywords: *settlement growth; rice field conversion; agricultural human resource capacity; food security vulnerability.*

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1. Introduction

Settlement growth on the island of Java continues to increase in line with the growing need for space for housing, public service facilities, economic activities, and infrastructure. This dynamic has led to competition for space with agricultural land, especially rice fields, which are generally located in flat areas, close to road networks, and relatively easy to develop. This phenomenon is important to study because the conversion of rice fields tends to be permanent, thereby potentially reducing rice production capacity and increasing the vulnerability of regional food security. Nationally, Indonesia is estimated to have lost approximately 1.22 million hectares of rice fields due to conversion between 1990 and 2022 (Gandharum et al., 2025). Globally, urbanisation is also recognised as a factor affecting food systems, both through land use changes and changes in consumption patterns and supply dynamics in rural-urban areas (FAO et al., 2023).

This study focuses on Central Java Province due to its role as one of the main rice-producing regions while facing increasing pressure from residential development. Official data shows that Central Java's rice harvest area in 2024 reached 1.55 million hectares with a production of 8.89 million tonnes of milled dry grain, but both figures are down from 2023 (Central Java Provincial BPS, 2025). Despite this decline, Central Java remains one of the provinces with the highest rice production in Indonesia, meaning that changes in the area of rice fields in this region have the potential to cause impacts that extend beyond the local scale. Central Java also has a transitional character, in that it is still predominantly an agricultural region but is experiencing rapid development of built-up areas, making it a relevant context for examining the relationship between settlements, land use change and food conditions.

This study examines the relationship between settlement growth, rice field conversion, food security vulnerability, and agricultural human resource capacity. Settlement growth is expected to increase rice field conversion because the need for built-up land is increasing and often takes productive agricultural land. Rice field conversion is further expected to increase food security vulnerability because reduced production land can decrease food availability and disrupt supply stability, especially if productivity increases are insufficient to compensate for land loss. Agricultural human resource capacity is placed as a moderating variable because knowledge, skills, technology adoption, and farm management capabilities can strengthen adaptive capacity, so that the impact of rice field conversion on food vulnerability can weaken or strengthen depending on human resource conditions (Jin and Liu, 2025).

A number of previous studies have discussed urbanisation and land use change, including urban expansion on the island of Java and its impact on space (Pravitasari et al., 2024). However, there are gaps that need to be filled. Many studies discuss the drivers of rice field conversion or the consequences for food security separately, so that the indirect mechanisms of settlement growth on food vulnerability through rice field conversion have not been explicitly tested in a single model framework. Furthermore, studies that include agricultural human resource capacity as a variable that alters the impact of land conversion on food vulnerability are still limited, even though the latest literature review emphasises the importance of strengthening models that link land change to socio-economic impacts and the contexts that influence them (Akmal and Mohammadi, 2025). Studies in Indonesia also confirm that agricultural land dynamics need to be understood in conjunction with agricultural sector policies and capacity building, not only from the perspective of land area changes (Faoziyah et al., 2024).

Based on these gaps, this study offers a contribution by examining the effect of settlement growth on food security vulnerability through the mediation of rice field conversion, while also examining the role of agricultural human resource capacity as a moderator in the relationship between rice field conversion and food vulnerability. The practical benefit of this study is to provide an empirical basis for local governments in designing policies to control settlement growth and protect productive rice fields, as well as to strengthen programmes to increase agricultural human resource capacity through extension, training, and support for technology adoption.

Specifically, this study aims to analyse the impact of settlement growth on rice field conversion; analyse the impact of rice field conversion on food security vulnerability; examine the indirect impact of settlement growth on food security vulnerability through rice field conversion; and to examine whether agricultural human resource capacity weakens or strengthens the impact of rice field conversion on food security vulnerability at the district/city level in Central Java Province.

2. Theoretical Background

Settlement Growth

Settlement growth describes the increase in built-up areas for housing, public facilities, and economic activities, both in urban and peri-urban areas. This change is generally seen in the expansion of built-up areas following access roads, activity centres, and service networks, thereby increasing pressure on the surrounding land. On the island of Java, various studies modelling land use change show that the expansion of built-up areas is likely to continue and increase pressure on land use change in urban-rural transition areas (Pravitasari et al., 2024).

Rice Field Conversion

Rice field conversion is the change in the function of rice fields to non-agricultural uses such as settlements, industry, and infrastructure. Conversion is often triggered by increasing land economic value, growing development space requirements, and spatial control that is not always effective. In the context of developing countries, the conversion of agricultural land into built-up areas is seen as a serious issue because it has the potential to reduce the food production base and have consequences for the sustainability of the food system (Gandharum et al., 2024).

Food Security Vulnerability

Food security is generally understood as a condition in which communities have sufficient, safe, and nutritious food available and accessible to them, and that this is stable over time. In empirical research, this concept is often broken down into indicators that reflect food availability, access, utilisation, and stability. The literature emphasises the importance of clarity in measurement because the choice of indicators will influence conclusions and policy recommendations (Barrett, 2010). In this study, the outcome variable is positioned as food security vulnerability, which is the opposite of "food security". Thus, a higher variable value indicates a region that is more vulnerable in terms of food fulfilment, while a lower value reflects a relatively more secure condition.

Agricultural Human Resource Capacity

Agricultural human resource capacity refers to the quality of agricultural actors, which is reflected in their knowledge, skills, experience, managerial abilities, and access to learning opportunities such as extension services. Extension is important because it helps farmers understand technology, reduces barriers to innovation adoption, and improves cultivation practices. A recent scoping review confirms that extension services play a key role in knowledge dissemination, but their effectiveness is influenced by service quality and local context (Becerra-Encinales et al., 2024). In the Indonesian context, various studies also emphasise the importance of extension worker performance because it is related to the accuracy of the target, the timeliness of services, and the quality of assistance materials, which ultimately affect the improvement of farmers' capacity (Dewi et al., 2024).

Hypothesis Development

Settlement growth and rice field conversion

In land use change theory, built-up area expansion tends to seek land that is flat, easily accessible, and has relatively low development costs. In many cases, these characteristics are inherent in rice fields, especially in peri-urban areas and growth corridors. Therefore, increased settlement growth is expected to increase the likelihood of rice field conversion. Evidence from studies on the island of Java shows that built-up area expansion is continuing and may increase pressure on productive land in transition areas (Pravitasari et al., 2024).

H1: Settlement growth has a positive effect on rice field conversion.

Rice field conversion and food security vulnerability

Rice field conversion reduces the area of productive land and can decrease food production capacity, especially when productivity gains are insufficient to offset land loss. Globally, urban expansion often occurs on cultivated land and risks reducing the availability of productive agricultural land (Bren d'Amour et al., 2017). Furthermore, a recent systematic review confirms that changes in agricultural land use are related to various dimensions of food security and are an important issue, especially in regions with vulnerable food systems (Akmal & Mohammadi, 2025). Considering that the outcome variable in this study is food security vulnerability, rice field conversion is expected to increase vulnerability by weakening the region's production base and food supply stability.

H2: Rice field conversion has a positive effect on food security vulnerability.

Mediation of rice field conversion in the relationship between settlement growth and food security vulnerability

Settlement growth can affect regional food conditions through an intermediate mechanism in the form of changes in rice field function. The sequence of events is as follows: settlement increases, rice fields decrease, the food production base weakens, and food security vulnerability increases. A systematic review of the links between urban sprawl, land use change, and food systems, also known as the , emphasises that land change is an important pathway explaining the impact of development on food conditions (Abu Hatab et al., 2019).
H3: Rice field conversion mediates the effect of settlement growth on food security vulnerability.

Moderation of agricultural human resource capacity in the relationship between rice field conversion and food security vulnerability

When rice fields decrease, food security vulnerability does not always increase by the same amount due to adaptive capacity. Agricultural human resource capacity can be a moderating factor through increased productivity, input efficiency, and better technology adoption. The literature emphasises that extension plays a role in encouraging technology adoption, but its impact is influenced by service quality, farmer readiness, and institutional support (Becerra-Encinales et al., 2024). Empirical evidence in Indonesia also shows that extension worker performance is related to the quality of services received by farmers (Dewi et al., 2024). Thus, the better the agricultural human resource capacity, the smaller the impact of rice field conversion in increasing food security vulnerability.
H4: Agricultural human resource capacity moderates the effect of rice field conversion on food security vulnerability, such that at higher human resource capacities, the effect of rice field conversion in increasing food security vulnerability becomes weaker.

3. Methodology

This study uses a quantitative approach with an explanatory design to test the causal relationship between constructs, namely the effect of settlement growth on regional food security vulnerability through rice field conversion, as well as to test the role of agricultural human resource capacity as a moderating variable that changes the strength of the effect of rice field conversion on food security vulnerability. Mediation is understood as a mechanism of indirect influence through an intermediary variable, while moderation explains changes in the strength of influence between variables under certain conditions. Testing the significance of indirect effects and interaction effects was carried out through bootstrapping resampling, which is commonly used in mediation and moderation testing (Baron and Kenny, 1986; Preacher and Hayes, 2008).

Study Area, Period, and Unit of Analysis

The research location is Central Java Province. This region was chosen because it has a large rice field base and plays an important role as one of the national rice producers, but at the same time is experiencing pressure from settlement growth and built-up areas that have the potential to encourage rice field conversion. The data are organised in a region-year panel for the period 2010–2021. The unit of analysis for the study is the district/city for each year of observation.

Population, Sampling Technique, and Sample Size

The research population covers all 35 districts/cities in Central Java Province. The sampling technique used was saturated sampling ( ), so that the entire population was included in the research sample. With an observation period of 12 years (2010–2021), the number of observations was 420 observation units (35 districts/cities × 12 years).

Data Sources and Data Collection

The study used annual secondary data at the district/city level compiled from official publications and relevant government documents. Data sources included regional statistics, agricultural sector publications, and documents containing indicators related to settlement dynamics, changes in rice fields, and regional food security indicators, including indicators used to construct the construct of agricultural human resource capacity. All variables were harmonised based on the suitability of definitions, periods, and regional units before being analysed.

The pre-processing stage of the data included checking data completeness, standardising measurement units, tracing consistency over time, and handling limited and reported missing data. Missing data was handled carefully to maintain traceability of sources and avoid changes in data patterns that could affect the interpretation of results.

Research Instrument (Operationalisation of Constructs)

As the study uses secondary data, the research instrument in this study consists of a set of quantitative indicators that form latent constructs in PLS-SEM. All constructs in this study are treated as reflective constructs, where indicators are viewed as manifestations of latent variables.

To maintain consistency in the interpretation of coefficients, the scale direction of each construct was locked as follows. Settlement growth (X) reflects an increase in settlement activity or built-up areas, so that higher values indicate greater settlement growth. Rice field conversion (Z) reflects the rate of conversion of rice fields to non-agricultural uses, so that higher values indicate greater rice field conversion or greater rice field loss. The outcome variable is operationalised as food security vulnerability (Y), so that higher values indicate increasingly vulnerable food conditions or increasingly low food security. Agricultural human resource capacity (M) reflects the quality of human resources in the agricultural sector at the regional level, for example in relation to extension support and technology adoption capabilities, with higher values indicating better capacity. With this scaling, the positive coefficient on the Z→Y path is interpreted as an increase in rice field conversion that increases food security vulnerability.

To ensure that the methods section is complete and transparent, the operational definitions and indicators for each construct are presented in Table 1. This table can be adjusted according to the indicators actually used (FS/RFC/SG/SDM), including formulas, units, and data sources.

Operational Definitions of Variables

Table 1. Operational Definitions of Research Variables and Indicators

Construct	ndicator Code	cal Definition of Indicators (what is measured)	Proxy or formula	Unit	Scale direction	Data source
Food Security Vulnerability (Y)	FS1–FS6	Indicators that make up regional food security vulnerability (e.g. aspects of availability, access, utilisation, stability, or derivative indicators available at the district/city level)	Adjusted to the definition of the indicator used; can be an index/ratio/proportion	In accordance with the indicators	The higher the value, the greater the vulnerability	Official agency publications related to food security/socio-economic statistics
Conversion of Rice Fields (Z)	RFC1–RFC7	Indicators used to calculate the rate of conversion of rice fields or loss of rice fields	Example proxies: change in rice field area, rate of decline in rice field area, ratio of change in rice field area to initial area	Ha or %	The higher the value, the greater the conversion	Agricultural/land statistics/BPS district/city or province
Settlement growth (X)	SG1–SG6	Indicators of settlement growth or built-up areas	Example proxies: growth in built-up area, settlement growth, or population indicators representing settlement pressure	Ha, %, or index	The higher the value, the greater the growth	Settlement/building /population statistics/BPS and government documents
Agricultural Human Resource Capacity (M)	SDM1–SDM6	Indicators of agricultural human resource quality, including extension services and readiness to adopt technology	Example proxies: extension worker-farmer ratio, extension/training intensity, education/institutional capacity indicators	People, ratio, %, or index	Higher is better	Agricultural/extension/related agency statistics and official publications

Data Structure and Treatment of Panel Data

The research data is in the form of a region-year panel (35 districts/cities during 2010–2021). In PLS-SEM, the panel structure in this study is treated as pooled observations at the district/city-year level to estimate the relationship between constructs. This approach is used to capture inter-regional and inter-temporal variations simultaneously in the latent construct modelling framework. To maintain caution in inference ( ), the interpretation of results focuses on the structural relationships between constructs at the district/city-year observation level.

If the journal requires a more detailed discussion, this study can add a robustness check, for example, by including the effect of year or comparing estimates in sub-periods. These additions are complementary and do not change the main design of PLS-SEM.

Data Analysis Technique

Empirical analysis was conducted using Partial Least Squares–Structural Equation Modelling (PLS-SEM). The selection of PLS-SEM was based on the research need to evaluate measurement models and structural models simultaneously, involving latent constructs formed by a number of indicators, as well as testing direct, indirect (mediation), and moderation effects through interaction constructs. Significance estimation was performed using bootstrapping at a 5 per cent significance level. The analysis was conducted through the following stages.

1. First, evaluation of the measurement model for reflective constructs, including convergent validity, discriminant validity, and construct reliability. Convergent validity was assessed through outer loading and Average Variance Extracted (AVE), with criteria of outer loading above 0.70 and AVE above 0.50. Discriminant validity was evaluated using the Fornell–Larcker criteria, namely that the square root of AVE on the diagonal must be higher than the correlation between constructs. Construct reliability was assessed using composite reliability with a threshold above 0.70 and supported by Cronbach's alpha.
2. Second, structural model evaluation to assess the direction, magnitude, and significance of the relationship between constructs and the explanatory power of the model. Model performance was assessed through R-square on endogenous constructs and relative path contribution through effect size f-square. The significance of the path coefficient was tested using bootstrapping.
3. Third, mediation testing is conducted by assessing the significance of indirect effects on the $X \rightarrow Z \rightarrow Y$ path. Mediation is declared to have occurred if the indirect effect is significant.
4. Fourth, moderation testing is conducted by forming the interaction construct $Z \times M$ and testing the significance of the interaction path on Y. Moderation is declared to have occurred if the interaction path coefficient is significant. A negative interaction coefficient is interpreted as a dampening effect, namely that an increase in human resource capacity tends to weaken the influence of rice field conversion on food vulnerability.
5. Fifth, to maintain the stability of the estimation, especially in models with interactions, the potential for multicollinearity between predictors is examined using the Variance Inflation Factor (VIF). A reasonable VIF value indicates that there is no excessive overlap of information between predictors.

All inferential conclusions in this study are based on path coefficients and bootstrapping p-values at a 5 per cent significance level.

4. Empirical Findings/Results

This section presents the results of the PLS-SEM analysis, which includes an evaluation of the measurement model (outer model) and the structural model (inner model). The outer model is evaluated to ensure that the indicators in each construct meet the validity and reliability criteria. After the outer model was deemed adequate, the inner model was evaluated through model explanatory power, structural relationship testing (direct effects), mediation testing (indirect effects), moderation testing (interaction constructs), and further moderation analysis through simple slopes and interaction plots. The dependent variable in this study is food security vulnerability (Y), so that a higher Y value indicates a more vulnerable food situation.

Measurement Model Evaluation (Outer Model)

Convergent Validity

Convergent validity is evaluated using outer loading values. Indicators are considered to meet convergent validity if the outer loading value is > 0.70.

Table 2. Outer Loadings (Measurement Model)

Indicator	Food Security Vulnerability (Y)	Rice Field Conversion (Z)	Settlement Growth (X)	Agricultural Human Resource Capacity (M)
FS1	0.894			
FS2	0.903			
FS3	0.913			
FS4	0.907			
FS5	0.894			
FS6	0.894			
RFC1		0.934		
RFC2		0.939		
RFC3		0.934		
RFC4		0.933		
RFC5		0.931		
RFC6		0.884		
RFC7		0.954		
SG1			0.929	
SG2			0.941	
SG3			0.943	
SG4			0.916	
SG5			0.940	
SG6			0.944	
SDM1				0.912
SDM2				0.925
SDM3				0.904
SDM4				0.936
SDM5				0.919
SDM6				0.928

All indicators in constructs Y, Z, X, and M have outer loading values above 0.70 (range 0.884–0.954). Thus, the research indicators meet convergent validity, indicating that each indicator adequately represents the latent construct being measured.

Discriminant Validity

Discriminant validity was tested using the Fornell–Larcker criteria, namely that the square root of AVE on the diagonal must be greater than the correlation between constructs.

Table 3. Discriminant Validity (Fornell–Larcker)

Construct	Y	Z	X	M
Food Security Vulnerability (Y)	0.901			
Conversion of Rice Fields (Z)	0.740	0.930		
Settlement Growth (X)	0.71	0.780	0.935	
Agricultural Human Resource Capacity (M)	0.650	0.600	0.620	0.921

The diagonal values (AVE square roots) for each construct are higher than the correlations with other constructs. These results confirm that each construct has sufficient differences, thus fulfilling discriminant validity.

Construct Reliability and Validity

Construct reliability was assessed using composite reliability (rho_c) with a threshold > 0.70, while construct validity was supported by AVE > 0.50.

Table 4. Composite Reliability and AVE

Construct	Cronbach's alpha	rho_a	rho_c	AVE
Food Security Vulnerability (Y)	0.954	0.955	0.963	0.811
Conversion of Rice Fields (Z)	0.974	0.974	0.978	0.865
Settlement Growth (X)	0.971	0.972	0.977	0.875
Agricultural Human Resource Capacity (M)	0.964	0.965	0.970	0.848

All constructs meet strong reliability and validity criteria (rho_c 0.963–0.978; AVE 0.811–0.875). With the outer model criteria met, the analysis proceeded to inner model evaluation and hypothesis testing.

Structural Model Evaluation (Inner Model)

Coefficient of Determination (R-square)

The explanatory power of the model was assessed through the R-square value in the endogenous constructs.

Table 5. R-square values

Endogenous Variables	R-square	Adjusted R-square
Food Security Vulnerability (Y)	0.903	0.901
Conversion of Rice Fields (Z)	0.964	0.964

The R-square for Rice Field Conversion (Z) of 0.964 indicates that settlement growth explains 96.4% of the variation in rice field conversion. The R-square for Food Insecurity Food Security Vulnerability (Y) of 0.903 indicates that Z, M, and the interaction Z×M explain 90.3% of the variation in food insecurity. These values indicate a very strong explanatory power of the model in the research sample.

Model Fit

As a complement to the structural model evaluation, this study reports the model fit indicators commonly used in PLS-SEM, namely SRMR, d_ULS, d_G, NFI, and RMS_theta.

Table 5. Model Fit Indicators (PLS-SEM)

Indicator	Value	Reference criteria (general)	Brief interpretation
SRMR	0.058	< 0.080	Adequate fit
d_ULS	0.412	< HI95 bootstrap	Sufficient
d_G	0.176	< HI95 bootstrap	Sufficient
NFI	0.913	> 0.900	Relatively good fit
RMS_theta	0.104	< 0.120	Sufficient

The SRMR value is below 0.08 and the NFI is above 0.90, indicating adequate model fit. The RMS_theta value is also below 0.12, indicating that the outer model residuals are relatively small. For d_ULS and d_G, ideal interpretation is performed by comparing their values with HI95 bootstrapping; the results in the table show that the d_ULS and d_G values are within a range that supports model adequacy.

Hypothesis Testing (Direct Effects)
Hypothesis testing was conducted through bootstrapping to obtain path coefficients, standard errors, t-values, p-values, and 95% confidence intervals.

Table 6. Partial Test Results (Direct Effects)

Path	β (Original)	Mean	SE	t	p	95% CI (Lower Limit)	95% CI (Upper Limit)	Decision
Z → Y	0.946	0.946	0.007	143.129	<0.001	0.932	0.960	Significant (+)
X → Z	0.982	0.982	0.003	366.518	<0.001	0.976	0.988	Significant (+)
M → Y	0.120	0.118	0.045	2.667	0.008	0.032	0.208	Significant (+)
Z×M → Y	-0.08	- 0.079	0.038	2.105	0.036	-0.154	-0.006	Significant (−)

Settlement growth (X) has a positive and significant effect on rice field conversion (Z), confirming that increased settlement dynamics are associated with increased pressure for rice field conversion. Rice field conversion (Z) has a positive and significant effect on food security vulnerability (Y). Since Y is defined as vulnerability, this positive coefficient means that the greater the rice field conversion, the higher the food security vulnerability of the region. The interaction coefficient of (Z×M) is negative and significant, indicating that agricultural human resource capacity (M) weakens the effect of rice field conversion on food vulnerability. The direct coefficient M→Y is significant and should be interpreted consistently with the operational definition of the human resource indicator, so the author emphasises the alignment of the indicator scale direction in the operational variable section.

Indirect Effect and Mediation
An indirect effect test was conducted to assess whether rice field conversion (Z) mediates the effect of settlement growth (X) on food security vulnerability (Y).

Table 7. Mediation Test Results (Indirect Effects)

Indirect Path	β (Original)	Mean	SE	t	p	95% CI (Lower Limit)	95% CI (Upper Limit)	Description
X → Z → Y	0.929	0.929	0.008	123.006	<0.001	0.913	0.945	Significant mediation

The indirect effect X→Z→Y is positive and significant, indicating that the impact of settlement growth on food insecurity occurs through the mechanism of rice field conversion. This finding confirms the role of land use change as the main pathway linking settlement dynamics with regional food insecurity.

Effect Size (f^2)
To assess the relative contribution of each pathway, the effect size f^2 was used.

Table 8. Effect Size (f^2)

Path	f^2	Category
Z → Y	8.514	Very large
X → Z	26,723	Very large
M → Y	0.03	Small
Z×M → Y	0.020	Small (approaching the threshold)

The f^2 results indicate that the X→Z and Z→Y pathways are the main drivers of the model (very large category). The direct contribution of human resources and the moderating effect are relatively small, so that human resource capacity is more appropriately understood as a contextual factor that alters the strength of the impact of rice field conversion, rather than a main determinant of food vulnerability variation.

Multicollinearity Assessment (Inner VIF)
Because the model includes interaction constructs, multicollinearity was examined using inner VIF on endogenous construct predictors.

Table 9. Inner VIF on Endogenous Constructs

Endogenous: Rice Field Conversion (Z)	
Predictor	**VIF**
X	1.0
Endogenous: Food Security Vulnerability (Y)	
Predictor	**VIF**
Z	2,700
M	1,800
Z×M	2,100

The VIF values are within a reasonable range, indicating no multicollinearity that could interfere with the stability of the estimates, including in the interaction construct. Thus, the structural path estimation results can be interpreted with greater confidence.

Moderation Follow-up: Simple Slope Analysis and Interaction Plot
This section clarifies moderation through simple slope to show how the effect of rice field conversion (Z) on food insecurity (Y) changes at different levels of human resource capacity (M).

Conditional Effect Specification
The conditional effect of Z→Y at a certain level of M is calculated as:

$$Slope(M) = \beta_{Z\to Y}(M) = \beta_1 + \beta_3 M$$

With$\beta_1 = 0.946$ and$\beta_3 = -0.080$, an increase in M decreases the slope of Z→Y, so that human resource capacity acts as a moderating factor.

Simple Slopes at Low, Mean, and High Levels of M

Table 10. Simple Slope of Z→Y Effect at Different Levels of M

Level of M	M Value	Simple slope (Z→Y)	Interpretation
Low M (mean − 1SD)	-1.000	1.026	Strongest effect of Z→Y
Mean M (mean)	0.000	0.946	Strong effect of Z→Y
High M (mean + 1SD)	1.00	0.866	Weakening effect of Z→Y

The effect of rice field conversion on food vulnerability remains positive at all levels of human resource capacity, but its magnitude decreases as human resource capacity increases. This pattern is consistent with the negative interaction coefficient and reinforces the conclusion that agricultural human resource capacity weakens the impact of rice field conversion on food vulnerability.

Interaction Plot

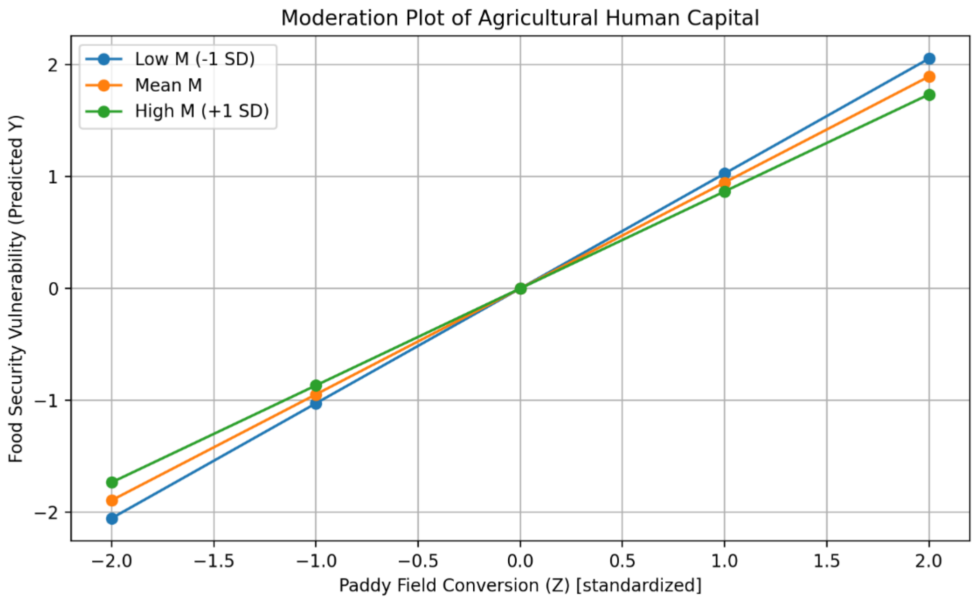

Figure 1. Moderation Plot of Agricultural Human Capital

The interaction plot shows that the Z→Y relationship line is steepest at Low M and flattest at High M. This means that for the same level of rice field conversion, regions with higher human capital capacity tend to experience a smaller increase in food insecurity than regions with lower human capital capacity. This finding clarifies the moderating effect as a dampening effect.

5. Discussion

Settlement Growth and Rice Field Conversion

The results show that settlement growth has a positive and very strong effect on rice field conversion in regencies/cities in Central Java. This finding is consistent with the spatial economics logic that settlement expansion tends to seek land that is flat, easily accessible, and has relatively low development costs. These characteristics are often associated with rice fields, especially in peri-urban areas and growth corridors, making rice fields one of the most vulnerable types of land to conversion when built-up areas expand. Because rice field conversion is relatively permanent, settlement pressure can create a lock-in of land use change that is difficult to reverse in the short term.

Empirically, these findings are consistent with evidence of built-up area expansion on Java Island, which shows that the growth of built-up areas is moving beyond the boundaries of core cities and putting pressure on agricultural land in non-metropolitan areas (Pravitasari et al., 2024). Another study in West Java's Pantura region also shows that built-up area development can accelerate the loss of agricultural land and increase risks to food security targets (Gandharum et al., 2024). Thus, the results of this study reinforce that settlement dynamics are an important structural driver of rice field conversion in agrarian provinces such as Central Java.

However, the rate of conversion is not always the same across regions. Areas that consistently enforce spatial plans, strengthen agricultural land protection, and provide economic incentives to maintain land tend to be more capable of curbing conversion. Studies on agricultural land dynamics in Indonesia emphasise that land use change is influenced by a combination of economic factors and the effectiveness of policy interventions, so variations between regions are to be expected (Faoziyah et al., 2024). These differences in policy context and land market conditions may explain why, in a number of other studies, the impact of settlement growth on rice field conversion appears weaker when policy controls are tighter and development is directed towards non-productive land.

The contribution of this study in this section is to test the relationship between settlement growth and rice field conversion at the district/city level in Central Java within a single model framework that also links downstream mechanisms through their impact on regional food conditions.

Rice Field Conversion and Food Security Vulnerability

This study found that rice field conversion is positively and significantly associated with increased food security vulnerability. It is important to reiterate that the outcome variable is operationalised as vulnerability, so that higher values reflect increasingly vulnerable food conditions. With this scale locking, the positive coefficient between rice field conversion and the outcome variable means that an increase in rice field conversion tends to increase food security vulnerability.

This finding is consistent with the theoretical argument that the reduction of rice fields reduces the land-based food production base, especially rice, which can decrease production capacity and increase supply instability when productivity gains are insufficient to offset land loss. Global evidence also supports this mechanism. Urban expansion often occurs on productive agricultural land and has the potential to reduce the availability of agricultural land (Bren d'Amour et al., 2017). A recent systematic review also confirms that changes in agricultural land use are related to various dimensions of food security, particularly the aspects of availability and production stability (Akmal and Mohammadi, 2025). In the context of Central Java, which is one of the national rice granaries, the loss of productive rice fields has the potential to affect regional supply capacity and increase the region's sensitivity to production and price fluctuations.

However, food security vulnerability is not determined by local production alone. Market access, distribution efficiency, purchasing power, and rural-urban connectivity also determine a region's ability to meet its food needs. The literature on urbanisation and food system transformation shows that urbanisation can change market networks, logistics, and economic opportunities, so that under certain conditions, food access can improve even though the agricultural land base is declining (van den Berg et al., 2021). Therefore, the relationship between rice field conversion and food security vulnerability is contextual, influenced by the region's economic structure and the quality of the food distribution system. The implication is that rice field protection policies should go hand in hand with efforts to strengthen food supply stability and access, especially in socio-economically vulnerable areas.

Mediation of Rice Field Conversion in the Relationship between Settlement Growth and Food Security Vulnerability

The results of the study show that the impact of settlement growth on food security vulnerability occurs through the pathway of rice field conversion. This finding reinforces the view that land use change is a connecting mechanism that explains how spatial development dynamics can lead to regional food risks. Settlement growth increases spatial pressure, spatial pressure drives rice field conversion, and rice field shrinkage weakens the food production base, thereby increasing food vulnerability.

This finding is consistent with the literature that places land use change as an important pathway of urbanisation's influence on food systems. On a global scale, the loss of productive cultivated land due to built-up area expansion is a concern because it puts pressure on production capacity and food supply sustainability (Bren d'Amour et al., 2017). A systematic review also confirms that agricultural land change is an important component in discussions of food security across contexts (Akmal and Mohammadi, 2025). Thus, the evidence of mediation in this study clarifies that the impact of settlement growth on food vulnerability does not occur in isolation, but mainly through changes in the foundation of land-based food production.

Although the mediation pathway is significant, the magnitude of the subsequent impact on food vulnerability may vary between regions. Areas with high compensation capacity through intensification, productivity improvements, input support, and supply chain improvements can mitigate some of the impact of land loss. Regional connectivity to urban centres can also open up access to better services, information, inputs, and markets, so that the pressure of land loss does not always translate into an equal increase in food insecurity (van den Berg et al., 2021). Therefore, rice field conversion is the main mechanism, but the strength of its consequences is influenced by the economic and logistical adaptation capacity of the region.

The novelty of this research lies in explicitly testing the mechanisms of settlement, land, and food in a single model for Central Java, so that these relationships are not only described but tested as a series of interconnected processes.

Moderation of Agricultural Human Resource Capacity in the Relationship between Rice Field Conversion and Food Security Vulnerability

This study shows that agricultural human resource capacity moderates the relationship between rice field conversion and food security vulnerability. The negative interaction coefficient indicates a dampening effect, meaning that an increase in human resource capacity tends to weaken the influence of rice field conversion in increasing food vulnerability. Conceptually, when rice fields are reduced, the region needs adaptive capacity so that production does not decline sharply and the food system remains stable. This adaptive capacity is influenced by the quality of agricultural human resources, such as technical skills, farm management, access to knowledge, and extension service support.

A number of studies support the role of human resources and extension in strengthening agricultural adaptation capacity. Studies in Indonesia show that access to extension is related to technology adoption and improved farm economic performance, thereby strengthening the resilience of the agricultural sector (Amrullah et al., 2023). Other studies emphasise the importance of extension worker performance because it affects the accuracy of targets, timeliness of services, and quality of assistance materials received by farmers (Dewi et al., 2024). International evidence also shows that human capital is related to strengthening agricultural performance and has implications for food security through improvements in practices and support services (Jin and Liu, 2025). Thus, the moderation results in this study are consistent with the argument that human and institutional capacity play a role in determining how strongly land loss pressures translate into food insecurity.

It should be noted that the size of the moderation effect tends to be small, although significant. This is understandable because human resource development does not usually work alone. The impact will be stronger when supported by the availability of inputs, access to finance, price stability, market institutions, irrigation quality, and equitable extension services. Variations in service quality between regions may also mean that the role of human resources as a buffer is not always significant, especially when conversion pressures are rapid.

In addition, the positive direct coefficient of human resource capacity on vulnerability needs to be discussed carefully and linked to the operational definition of the indicators that form the human resource construct. The first possibility is that there are indicators that represent human resource limitations or pressures, so that a higher construct value does not fully reflect better capacity. The second possibility is the existence of a programme targeting pattern, whereby more vulnerable areas receive greater human resource interventions, resulting in a positive correlation at the aggregate level. Therefore, the main interpretation in the moderation section needs to emphasise the interaction coefficient and simple slope analysis, which show that an increase in human resource capacity is associated with a weakening of the impact of rice field conversion on food vulnerability.

Synthesis and Policy Implications
Overall, this study confirms that settlement growth increases rice field conversion, and rice field conversion increases regional food security vulnerability. The mediation pathway confirms that rice field conversion is an important mechanism that bridges the impact of settlement growth on food insecurity. In addition, agricultural human resource capacity acts as an adaptive factor that weakens the impact of rice field conversion on food insecurity.

The policy implications of these findings point to the need to integrate settlement growth control, protection of productive rice fields, and strengthening of agricultural human resource capacity. Settlement control needs to be directed so that land use does not put pressure on productive rice fields, including through consistent enforcement of spatial planning and development on non-productive land. The protection of productive rice fields needs to be strengthened through the establishment of clear agricultural areas, incentives to maintain land, and supervision of implementation. Strengthening agricultural human resources needs to focus on improving the quality of extension services, technical and managerial training, and accelerating technology adoption to enhance productivity and efficiency as an adaptation strategy to address land shrinkage pressures. By integrating these three agendas, the resilience of the food system in Central Java is more likely to be maintained amid pressures from built-up area growth.

6. Conclusions

This study concludes that settlement growth in Central Java Province is closely related to increasing pressure for land use change, particularly through the conversion of rice fields. The model results show that settlement growth has a positive and significant effect on rice field conversion, and rice field conversion has a positive and significant effect on regional food security vulnerability. Thus, the dynamics of settlement and built-up area development do not affect food conditions independently, but mainly work through the depletion of the land-based food production base. The mediation findings clarify that rice field conversion is a key mechanism that bridges the influence of settlement growth on increasing food security vulnerability at the district/city level.

This study also found that agricultural human resource capacity moderates the relationship between rice field conversion and food security vulnerability in a dampening manner. This means that in areas with higher agricultural human resource capacity, the impact of rice field conversion in increasing food vulnerability tends to be weaker. This finding confirms that food security vulnerability is not only influenced by physical conditions and land area, but also by the agricultural sector's ability to adapt, as reflected in the quality of human resources and institutional support and assistance services. Thus, the research objective of examining the relationship between settlement growth, rice field conversion, and food security vulnerability, as well as testing the mediating and moderating roles at the district/city level in Central Java, has been achieved.

Theoretically, the results of this study reinforce the view that the relationship between settlements and food conditions needs to be understood through the pathway of land use change as an intermediate mechanism. In addition, this study adds to the evidence that agricultural human resource capacity can function as a contextual condition that alters the strength of the influence of agricultural land change on food vulnerability. In practical terms, the research findings emphasise the importance of an integrated policy approach. Controlling settlement growth needs to be aligned with the protection of productive rice fields so that regional development does not sacrifice the foundations of food production. At the same time, strengthening agricultural human resource capacity needs to be positioned as an adaptation strategy through improving the quality of extension services, technical and managerial training, assistance in accelerating technology adoption, and strengthening farmer institutions to help mitigate the impact of land conversion pressures on regional food vulnerability.

This study has several limitations. First, the unit of analysis uses aggregated district/city data, so the results do not directly describe the conditions of households or individuals. Second, the study relies on the availability of annual secondary data, so the measurement of constructs, particularly food security vulnerability and agricultural human resource capacity, is determined by available indicators that are consistent across regions and over time. Third, although the model includes mediation and moderation mechanisms, this study does not cover all factors that may also affect food vulnerability, such as food price dynamics, logistics and distribution access, poverty and purchasing power, climate conditions, irrigation quality, and variations in land protection policies between regions.

Further research is recommended to expand the model by adding variables that represent the dimensions of food access and stability, such as food price indicators, poverty levels, market connectivity, or distribution quality. Subsequent studies could also strengthen the measurement of agricultural human resource capacity through more direct indicators, such as farmers' education levels, training intensity, the ratio of extension workers to farmers, the quality of extension services, or the agricultural technology adoption index. In addition, the development of a spatial or spatial panel approach is recommended to capture spillover effects between regions, as land conversion and food supply systems are often influenced by neighbouring regions. Comparative studies between districts/cities also need to be developed to enrich the reading of the policy context and identify the most effective interventions in reducing rice field conversion without hindering residential development needs.

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