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Using Multiple Regression Analysis of Food Security Factors in Indonesia

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Abstract

Food security, an elemental necessity for human survival and welfare, remains an issue of universal significance. This study focuses on Indonesia, utilizing data from the Food and Agriculture Organization of the United Nations (FAO) and the World Bank database. It considers factors integral to food security such as freshwater utilization, cultivation usage, nitrogen fertilizer usage, Gross Domestic Product (GDP), and rice grain yield. A multiple linear regression model was constructed with rice production as the dependent variable to encapsulate the food security status. The study concludes that post-2017, there is a pronounced divergence between the actual and theoretical per capita rice ownership curves, with the rice supply exhibiting persistent instability. When conducting a principal component analysis, the first component (PC1) accounted for 92% of the variance, indicating its substantial role. Among the studied variables, nitrogen fertilizer use, freshwater utilization, and cultivated land area emerged as the pivotal factors influencing food security.

Keywords: Food Security; Mathematical Analysis; Influencing Factors

1. Introduction

Food security, a fundamental requirement for human life and well-being, remains a significant concern for humanity. According to the United Nations' Food and Agriculture Organization, food security is defined as the condition where "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life." Food security, a global issue of unprecedented importance, represents a fundamental aspect of human health, economic development, and social equity. The issues of food security span various intersecting domains, its relevance and urgency are magnified by global phenomena such as population growth, urbanization, cli-mate change, and conflict. Climate change and variability pose significant threats to food security worldwide, impacting all four dimensions of food security: availability, access, utilization, and stability. Hasegawa et al (2018) [1], investigate the risk of increased food insecurity under stringent climate change mitigation policy, highlighting potential ad-verse side effects of mitigation policies on global food security. Meanwhile, Rasul & Sharma (2016) [2], discuss the nexus approach to water-energy-food security as a strategy for adaptation to climate change, suggesting an

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interconnected approach to address these is-sues. Further to this, Allipour Birgani et al (2022) [3], apply analytical hierarchy process and social network analyses to prioritize indices in the context of climate change and food security. They underscore the need for a comprehensive method for ranking climate change effects and developing effective mitigation strategies. Similarly, Fujimori et al (2019) [4], offer a multi-model assessment of food security implications of climate change mitigation. The study reveals potentially significant trade-offs between food security and climate change mitigation goals, stressing the need for balanced strategies. Finally, Hall et al (2017) [5], and Li et al (2015) [6], emphasize how population growth, climate change, and uncertainties in predicting rice yield under various climatic conditions could impact African food security and global rice production, respectively. The shift from climate change brings us to the critical role of sustainable agriculture in ensuring food security. Focusing on developing countries, where agriculture is a primary economic activity, sustainable practices are imperative to meet increasing food demand efficiently and responsibly. Pawlak & Kołodziejczak (2020) [7], delve into the crucial role of agriculture in developing countries. They advocate for sustainable agricultural practices as a strategy to ensure food security. Complementing this, Kopittke et al (2019) [8], explore the role of soil science in the intensification of agriculture for global food security, emphasizing the need for improved soil management practices. Davis et al (2016) [9], explore meeting future food demand with current agricultural resources, highlighting the importance of efficiency in resource use. McKenzie & Williams (2015) [10], provide a comprehensive overview of the constraints, challenges, and choices in sustainable food production by 2050, while Bandumula (2018) [11], underscores the role of rice production in Asia as key to global food security, thus emphasizing the importance of sustainable practices in staple crop production. Statistical models and artificial intelligence tools are revolutionizing our approach to managing food systems, enabling us to devise data-driven strategies and interventions. Alam et al (2020) [12], discuss the challenges in rural riverine Bangladesh due to hazards, food insecurity, and human displacement, emphasizing the need for region-specific policies. Karabulut et al (2018) [13], propose the integration of the ecosystem-tem-water-food-land-energy nexus concept into life cycle assessment as a solution for food security, suggesting a holistic approach to address the issue. Mathematical models can generate forecasts of food production in different regions and time frames. Accurate production forecasts allow policymakers to anticipate potential shortages or surpluses and take proactive steps to ensure food security. Hou & Liang (2022) [14], the team used BP (Back Propagation) neural network to simulate China's food security early warning system, designed standardized risk prevention and control processes and classified response strategies, and provided signal guidance and reference for China's food security response and early response to risks. At the same time, mathematical models help to optimize the allocation of food production resources, determine the most effective strategy to maximize food production and improve productivity. Cowling et al. (2019) [15], shed light on the role of crop breeding in maintaining global food security amidst climate change. Through modeling analysis, they concluded that the best contribution of the economic index is to choose to satisfy the heat stress tolerance characteristics of crops first, improve grain production and avoid food crisis. The COVID-19 pandemic has disrupted the global food system in recent years, posing unprecedented challenges to food security. Fan et al (2021) [16], and Rozaki (2021) [17], both provide lessons from the Asian experience on food system resilience during COVID-19. They point to the pandemic's significant disruption to food systems and highlight the importance of system resilience. Workie et al (2020) [18], offer a broader view by examining the pandemic's impact on food security, agriculture, and livelihoods in developing countries, underscoring the necessity of

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proactive policies to address these challenges in times of crisis. In addition to the unstable factor of COVID-19 pandemic, the nexus of food security and conflict introduces yet another layer of complexity. Martin-Shields & Stojetz (2019) [19] delve into the interplay between food security and conflict. The paper points to the intricate relationships between food insecurity and various forms of conflict, emphasizing the importance of incorporating these dynamics into policy-making and interventions to ensure food security in conflict-prone areas. The shift from specific challenges to a broader global context underscores the importance of robust food security measurement tools. Cafiero, Viviani, & Nord (2018) [20], discuss food security measurement in a global context, focusing on the Food Insecurity Experience Scale. Their work underscores the importance of having reliable, globally applicable measurement tools for accurately gauging food security and making data-driven policy decisions. In conclusion, food security necessitates a comprehensive approach, especially in rice-reliant countries like Indonesia. Given that rice is vital for nutrition and food security strategies, its production variability can significantly impact food availability and affordability. Therefore, the use of mathematical models is crucial for optimizing farming practices, managing risks, and crafting policies to ensure food security.

2. Materials and Methods

The data for this investigation were sourced from the databases of the Food and Agriculture Organization (FAO) and the World Bank. The Food and Agriculture Organization and the World Bank are key global institutions, each steering unique yet intertwined paths in shaping global socio-economic and agricultural policies. The FAO focuses on combating hunger, enhancing nutrition, and promoting sustainable agriculture, while also addressing climate change impacts. In contrast, the World Bank, an influential financial body, supports developing countries across various sectors, from agriculture to education. Its extensive database provides critical insights into the economic and societal trends of its member nations. Together, the databases of both FAO and the World Bank serve as crucial resources for global policymakers and researchers. The specific data are shown in Figure 1 and Figure 2. The study focuses on rice production in Indonesia, spanning the period from 1990 to 2019. Analyzing food security requires understanding several intertwined factors. Rice Grain Yield, measured in kilograms per hectare, reflects production efficiency. Cultivated Area determines rice output, but its expansion can lead to environmental issues like deforestation. Freshwater Usage, essential for rice's growth, must be balanced with sustainability. Nitrogen Fertilizer Usage boosts yields, but its application needs careful management for soil health. Lastly, GDP, beyond its economic representation, signifies a nation's ability to support agrarian advancements and manage food price fluctuations. Together, these indicators provide a comprehensive perspective on food security, highlighting the need for sustainable practices and economic resilience. In the constructed multiple linear regression model for grain production, Rice Grain Yield serves as the dependent variable, whereas the Cultivated Area, Freshwater Usage, Nitrogen Fertilizer Usage, and Gross Domestic Product are treated as independent variables. Simultaneously, a principal component analysis was employed to meticulously examine the primary factors impacting food security in Indonesia.

Multiple linear regression basic model:

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \varepsilon_i \#(1)$$

Where i=1,2,3…;

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$\boldsymbol{y_i}$: dependent variable;

$\boldsymbol{x_i}$: intendent variable;

$\boldsymbol{\beta_i}$: parameter;

$\boldsymbol{\varepsilon_i}$: error perturbation random term;

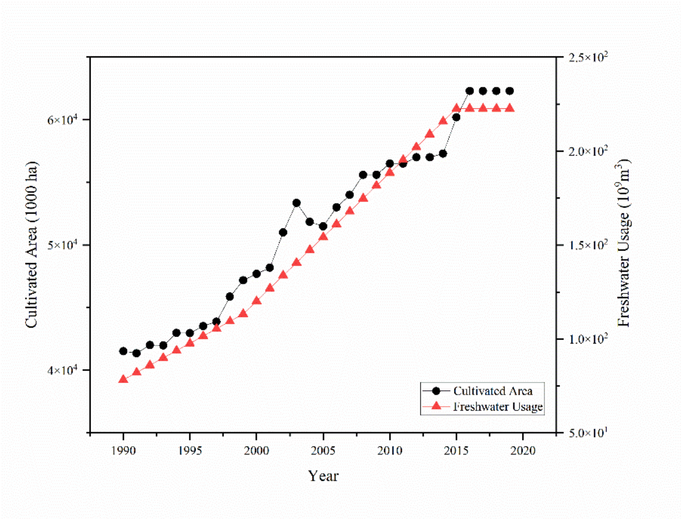

Figure 1. Cultivated Area and Freshwater Usage from 1990 to 2019

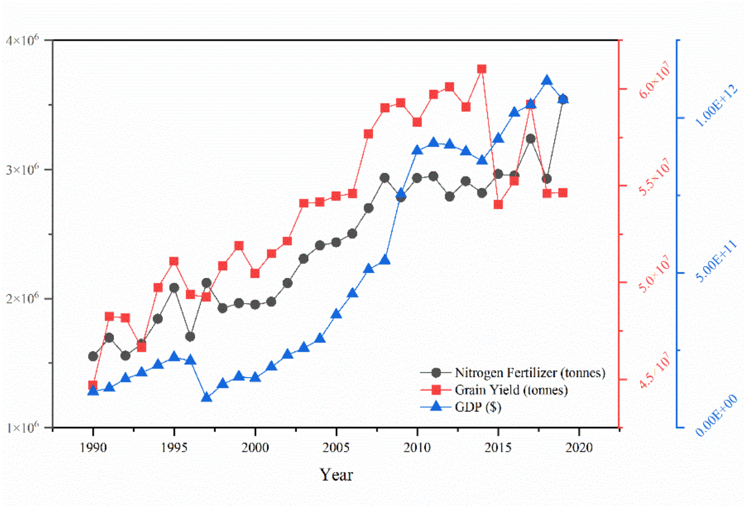

Figure 2. Nitrogen Fertilizer Usage, Grain Yield and GDP from 1990 to 2019

3. Results

3.1.1 Correlation Analysis

Taking grain yield as the dependent variable, cultivated area, freshwater usage, GDP, and nitrogen fertilizer usage were analyzed by Pearson's correlation coefficient, and the analysis results are shown in Figure 3.

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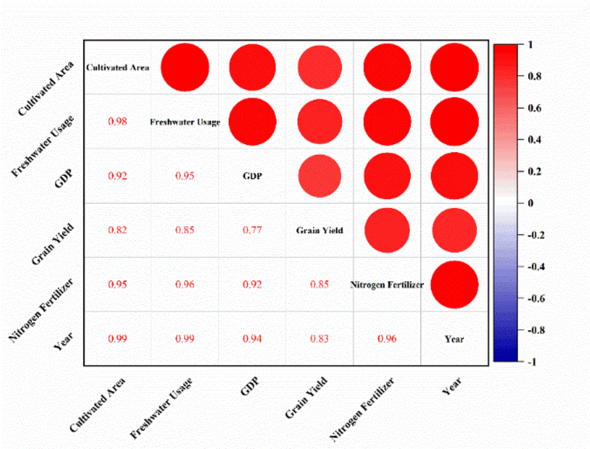

Figure 3. Correlation plot

As depicted in Figure 3, the Pearson correlation coefficients among grain yield, cultivated area, freshwater usage, and nitrogen fertilizer signify the existence of relationships between these variables and the dependent variable. Therefore, the employment of multiple linear regression modeling is justifiable for further investigation.

3.1.2 Statistical Test

Table 1. Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Nitrogen Fertilizer, GDP, Cultivated Area, Freshwater Usage[b]	.	Enter

a. Dependent Variable: Grain Yield b.All requested variables entered.

Table 2. Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.883[a]	0.779	0.744	2249254.804	1.212

a.Predictors: (Constant), Nitrogen Fertilizer, GDP, Cultivated Area, Freshwater Usage

b.Dependent Variable: Grain Yield

Table 3. ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	446282302421729.060	4	111570575605432.270	22.053	<0.01[b]
	Residual	126478679300905.330	25	5059147172036.213		
	Total	572760981722634.400	29			

a.Dependent Variable: Grain Yield

b.Predictors: (Constant), Nitrogen Fertilizer, GDP, Cultivated Area, Freshwater Usage

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Table 4. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	52529813.289	10102399.208		5.200	<0.01		
	Cultivated Area	-591.633	351.419	-0.944	-1.684	0.105	0.028	35.591
	Freshwater Usage	149495.915	63564.828	1.707	2.352	0.027	0.017	59.670
	GDP	-7.004E-6	0.000	-0.574	-1.730	0.096	0.080	12.485
	Nitrogen Fertilizer	5.156	2.682	0.644	1.922	0.066	0.079	12.727

a. Dependent Variable: GrainYield

The above results were calculated by SPSS.

$$y = 52529813.289 + 5.165 * Nitrogen\ Fertilizer + 149495.915 * Freshwater\ Usage - 591.633 * Cultivated\ Area \# \quad (2)$$

The findings presented in Table 4 reveal that all Variance Inflation Factor (VIF) values exceed 10. This indicates the presence of multicollinearity among the variables.

3.2 Stepwise Regression Analysis

Stepwise regression analysis will introduce independent variables one by one. The introduction condition is that the independent variable is significant by the F test. After each independent variable is introduced, the selected variables will be tested one by one. If it becomes no longer noticeable, it is removed. The stepwise regression analysis results are shown in Table 5 and Table 6.

$$y = 37319827.06 + 6.832 * Nitrogen\ Fertilizer\#(3)$$

Table 5. Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	37319827.060	1943339.517		19.204	<0.001		
	Nitrogen Fertilizer	6.832	0.787	0.854	8.681	<0.001	1.000	1.000

a. Dependent Variable: Grain Yield

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Table 6. Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	VIF	Minimum Tolerance
1	Cultivated Area	0.065[b]	0.198	0.845	0.038	0.092	10.856	0.092
	Freshwater Usage	0.364[b]	1.069	0.294	0.202	0.083	12.048	0.083
	GDP	-0.045[b]	-0.179	0.859	-0.034	0.161	12.048	0.161

a. Dependent Variable: Grain Yield; b. Predictors in the Model: (Constant), Nitrogen Fertilizer

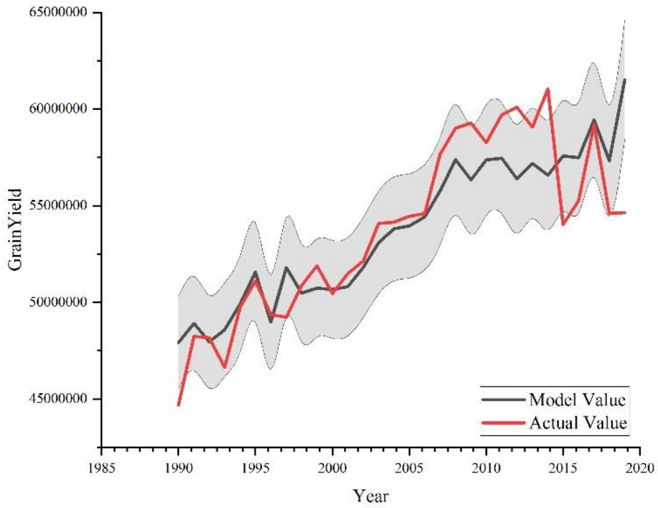

Figure 4. Comparison of Model Value and Actual Value

Figure 3 provides a comparative analysis between the predicted yield derived from Equation 3 and the actual rice grain yield. Broadly, the trajectories of the two curve align, albeit with some variations. Notably, a precipitous decline in the actual rice grain yield was observed from 2014 to 2015, and despite gradual recovery, it failed to regain parity with the theoretical yield posited by the model in subsequent years.

As illustrated in Figure 5, the population of Indonesia exhibits a consistent year-on-year increase. However, the growth rates of both theoretical and actual rice availability present substantial variability. In 2014, a precipitous drop in rice supply was observed, and a continued downward trajectory has been evident post-2017. This reduction in rice availability could potentially precipitate a crisis in food security due to the resulting rice deficiency.

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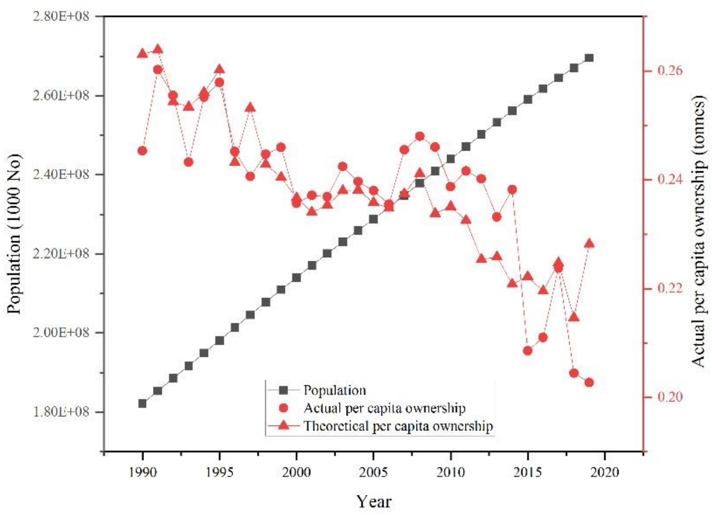

Figure 5. Population and Per Capita Rice Possession

3.3 Principal Component Analysis

Principal component analysis uses an orthogonal transformation to convert a series of possibly linearly related variables into a new set of linearly uncorrelated variables, also known as principal components, so that the new variables can be used to display the characteristics of the variables.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy returned a value of 0.811, surpassing the established benchmark of 0.8 and proving to be statistically significant at the specified level. This result decisively negates the null hypothesis, reinforcing the presence of substantial correlations among the studied variables and validating the appropriateness of employing PCA.

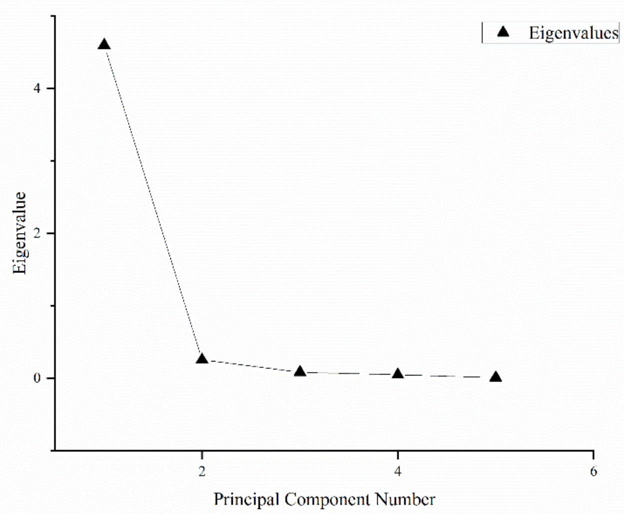

Figure 6. Scree Plot

The scree plot, a graphical representation demonstrating the degree to which each principal component accounts for the data variation, serves to ascertain the optimal number

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of principal components by analyzing the rate of eigenvalue decay. As depicted in Figure 6, the inflection point suggests the selection of two components, providing an effective balance between information retention and dimensionality reduction.

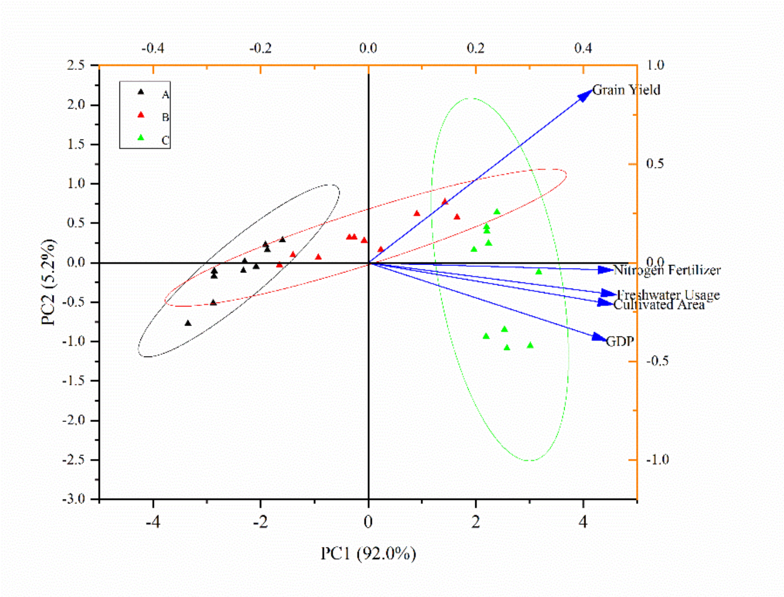

Figure 7. Biplot

The span from 1990 to 2019 was partitioned into three concurrent cohorts: A, B, and C, for the execution of a principal component analysis pertaining to food security. The subsequent analysis, as illustrated in Figure 5, resulted in the extraction of two principal components, with a cumulative explained variance of 97.2% for components 1 and 2. This substantial percentage suggests that these two principal components adequately encapsulate the essential information contained within the original dataset. The primary constituents of food security, labeled as F1 and F2, are subsequently detailed.

$$F1 = 0.45571 * Cultivated\ Area + 0.46189 * Freshwater\ Usage + 0.44489 * GDP + 0.45561 * Nitrogen\ Fertilizer\ + 0.41651 * Grain\ Yield \# (4)$$

$$F2 = -0.21214 * Cultivated\ Area - 0.16304 * Freshwater\ Usage - 0.39641 * GDP - 0.03757 * Nitrogen\ Fertilizer\ + 0.87742 * Grain\ Yield \# (5)$$

The contribution to the total variance by the first principal component (PC1) is 92.0%, which suggests that PC1 plays a pivotal role in the overall analysis and evaluation. Specifically, 'Freshwater Usage' and 'Nitrogen Fertilizer' exhibit elevated factor loadings.

In conclusion, the primary factors influencing food security within Indonesia are Nitrogen Fertilizer Usage, Freshwater Usage, and Cultivated Area. Post-2017, a significant deficiency in rice availability has been identified. The actual per capita rice ownership curve demonstrates a marked deviation from its theoretical counterpart,indicating a lack of stability in the food supply. Consequently, the resilience and overall health of the food system are subjected to instability.

4. Discussion

4.1.1 Strategies for mitigating weather-related Risks and ensuring stable rice production in Indonesia

Indonesia's rice production experienced a sharp decline in 2014-2015, attributable to suboptimal rainfall levels during the rice-planting phase, the requirement for artificial irrigation in critical growing regions, and unpredictable weather conditions, including erratic rainfall and hail. To avert a comparable downturn in future rice production, it would be prudent for Indonesian policymakers to adopt an amalgamation of short-term and long-term strategies. Establishing crop insurance programs could provide farmers with a safety net during severe weather episodes. Such programs would compensate farmers for losses incurred due to weather-related events, thereby assisting them in recuperating from production setbacks. Maintaining an efficient and stable rice market would incentivize farmers to boost yields and minimize post-harvest wastage. In addition, the implementation of effective trade policies could help stabilize rice prices during periods of production shortages, thereby safeguarding both producer and consumer interests.

4.1.2 Intensive land management to solve food security problems

Land-intensive management is closely linked to food security, as it aims to maximize agricultural production and ensure a stable food supply for a growing global population. Through intensive land use, farmers can achieve higher crop yields and increase the over-all agricultural output. This enables a more efficient utilization of available land resources, meeting the growing demands for food and reducing the risk of food shortages. While ex-pending agricultural frontiers can contribute to food security, it can also result in environmental consequences. It is crucial to balance land expansion with sustainable land management practices and the restoration of degraded lands, to minimize ecological imp-pacts and maintain long-term food security. Land-intensive management must also con-sider the impacts of climate change on food security. Increasing temperatures, erratic rainfall patterns, and extreme weather events pose significant challenges to agricultural production. Implementing climate-smart agricultural practices and improved water management, can enhance the resilience of land-intensive systems and ensure a stable food supply despite changing climatic conditions.

4.1.3 Optimizing Nitrogen Fertilizer and Water Use Efficiency to Mitigate Food Security Issues

The analysis results show that fresh water usage and nitrogen fertilizer usage are important factors affecting food security. Dinar, Tieu, & Huynh (2019) [21], their findings also show that water is a key factor affecting food security, and that water scarcity is becoming more prevalent due to factors such as climate change and overuse, posing a major threat to agricultural productivity and global food security. Water scarcity can hinder the ability to maintain or increase agricultural productivity. Optimizing nitrogen and water use efficiency provides sound strategies in the face of pressing challenges to food security. Through a combination of improved crop varieties and precision farming techniques, agricultural productivity can be increased while minimizing environmental impact. water use efficiency can be improved through genetic and agronomic interventions. Drought-resistant crop varieties, for example, can maintain productivity under water-limited conditions. On the agronomic front, efficient irrigation techniques such as drip irrigation and sprinkler systems can significantly reduce water wastage. Further, the implementation of soil moisture sensors and satellite imagery can help farmers precisely schedule irrigation, reducing excessive water use. Advances in both breeding and agronomic practices can contribute to improved nitro-gen use efficiency. Concurrently, precision agriculture techniques such as site-specific nutrient management and controlled-release fertilizers can optimize the timing, rate, and placement of nitrogen, aligning it more accurately with plant needs. He, Liu, & Cui (2021) [22]**,** their team's findings identify the potential of improving nitrogen efficiency in promoting sustainable food production, suggesting that more efficient nitrogen use can increase agricultural yields while reducing environmental degradation. The potential of these interventions to enhance global food security is significant. By in-creasing yields on existing agricultural lands, we can reduce the pressure to expand agriculture into natural ecosystems, helping to preserve biodiversity. Additionally, reducing nitrogen and water wastage can mitigate environmental pollution, promoting the long-term sustainability of farming systems. It's important to note, however, that these interventions must be coupled with supportive policies and adequate farmer training to ensure their widespread adoption and use.

4.2 Integrative Modelling: Enhancing Indonesia's Food Security Amidst Climate Challenges

Indonesia, with its unique archipelagic composition and vast biodiversity reliant on agriculture, stands distinctly exposed to the deleterious ramifications of climate change and natural calamities. Emerging research paradigms are increasingly inclined towards the deployment of sophisticated mathematical models that seamlessly integrate these environmental exigencies into food security evaluations. Anticipated models will leverage machine learning and artificial intelligence paradigms to forecast climatic event-driven impacts on crop outputs, duly factoring in determinants such as surging sea levels, evolving precipitation regimes, and escalating temperatures. Integration of remote sensing and satellite imagery is poised to amplify these models' efficacy, furnishing instantaneous insights into crop vitality and imminent natural disaster threats. Concurrently, these data streams will be synthesized with geographic information systems (GIS) for granular spatial analyses, pinpointing regions of heightened vulnerability. By elucidating the nexus between climate dynamics, natural disasters, and agricultural yield, Indonesia can fortify its food security stance amidst escalating global environmental predicaments.

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