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Preserving Rice Fields and Domestic Rice Adequacy: A Case Study in Banyumas Regency, Central Java, Indonesia

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ABSTRACT

The destruction of rice fields due to changes in their use in various regions of Indonesia affects the national food supply. In the long term, this phenomenon will threaten efforts to fulfill the adequacy of rice and increase the potential for a food crisis. This study analyzes the decline in domestic rice sufficiency due to destroying rice fields in the Banyumas Regency. This study was conducted using spatial modeling and the Micmac method. Respondents and experts were purposively determined based on the roles of 50 respondents and seven experts. The findings revealed that, on average, 103 hectares of rice fields in the Banyumas Regency were lost annually between 2007 and 2019. In 2045, it is estimated that the area of rice fields in Banyumas Regency will be 29,160 hectares, with a conversion rate from 2019 to 2045 of 1,384 hectares. Several driving factors are distance from the district capital, distance from roads, distance from settlements, distance from the irrigation channel, and population density. The essential factors influencing rice self-sufficiency include enforcing rice field preservation regulations, incentivizing measures for protecting rice fields, comprehensive spatial data on rice fields, sufficient access to irrigation water, proactive engagement of farmer collectives, and level of rice productivity.

Introduction

Rice is a staple food for most of the population of countries in the Asian region. Ensuring equitable access to nutritious sustenance is not just a societal obligation but a fundamental duty of governance to guarantee all individuals the right to nourishment. In alignment with the Sustainable Development Goals (SDGs), striving to eradicate hunger, secure access to nourishment, enhance nutritional well-being, and foster sustainable agricultural practices is important for global development [1]. Therefore, implementing sustainable agricultural practices has emerged as a pivotal priority within the global development framework. The agriculture sector serves as a vital contributor to food providers, employment opportunities, contributing to gross domestic product (GDP), stabilizing inflation [2], generating foreign exchange [3], and a source of raw material for industries [4].

The Indonesian government has instituted a range of policies to fulfill the essential dietary requirements of rice for its populace and ensure food security and nutritional sufficiency. To pursue of this goal, its strategies encompass farming technology engineering, expansion of rice fields, diversification campaigns, and implementation of agricultural land conversion control regulations. Food self-sufficiency is reflected in one's ability to attain self-sufficiency in staple food requirements. The global food crisis and malnutrition issues occur because of several factors, including population expansion, heightened energy utilization within the

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agricultural domain, rising demand for biofuels, and shifts in consumption habits [5]. The Indonesian government is still implementing a rice import policy because of the inability of domestic production to meet national demand. Nonetheless, dependence on imported rice poses risks, particularly during disruptions to global supply chains. Challenges concerning rice production in different nations include population pressure [6], suboptimal crop growth, unfavorable land conditions, ineffective cultivation methods [7], and environmental strains exacerbated by climate change [8]. Import policies, apart from making dependence on other countries, will also affect the fall in the retail price of rice at the farmer level owing to the increase in the quantity of imported rice available in the market [9]. Hence, endeavors to uphold and bolster domestic rice production are of paramount importance in mitigating reliance on imports [10,11], although this task presents a formidable challenge [12].

The burgeoning population and rapid urban development necessitate a greater demand for residential spaces and infrastructure, exacerbating the pressure on limited land resources. This condition precipitated the conversion of land use, predominantly shifting agricultural territories into nonagricultural zones. Subsequently, a critical concern in sustainable agricultural development is the diminishing availability of agricultural land, particularly rice fields [13,14]. Rice fields tend to be more easily converted than dry land [15,16]. Existing regulations such as Regional Spatial Planning (RSP) in each district often fail to explicitly safeguard the preservation of rice fields, resulting in ongoing conversions. Between 2000 and 2015, rice fields underwent an estimated conversion rate of 96,512 hectares (ha) per year in several rice center areas in Indonesia [17]. The Ministry of Agriculture showed that in 2015, the rice fields in Indonesia were 8,092,907 ha, and in 2018, they decreased by 628,956 to 7,463,948 ha, with an average conversion rate of 157,240 ha per year [18]. Driving factors include the lower land rent of rice fields compared to other uses and weak commitment to protecting rice fields in each district in Indonesia [19,20].

The decrease in rice fields, coupled with constraints on establishing new fields due to land and infrastructure limitations, exacerbates the dwindling capacity to meet domestic rice demand. This causes the gap between the domestic rice supply and demand to widen steadily. In the context of national food security, the ongoing conversion of rice fields in every district poses a grave threat with consequences that are both permanent and cumulative. Subsequently, the diminishing contribution of domestic rice to the national food supply is driving heightened reliance on imported rice, amplifying the risk of food insecurity. This implies that national stability may be disrupted. Therefore, conducting research on rice field conversion and the intricacies of regional rice sufficiency will aid in devising diverse strategies to safeguard rice fields and sustain domestic rice self-sufficiency, thereby diminishing the reliance on imported rice.

The area of rice fields on the island of Java reaches approximately 46.54% of the national rice field area [18], contributing to national rice production reaching around 55–57% [21], making it a mainstay for meeting national rice needs. Central Java, with an area of rice fields reaching 1,049,661 ha (14.06%), is the second national rice barn after East Java. Banyumas Regency is an agropolitan area and one of the centers of development area activities in the southern part of Central Java Province, making this area prone to conversion of rice fields. Over a period of 18 years, it was reported that the conversion of agricultural land to nonagricultural land was approximately 10,768 ha, with an average of 599 ha per year [22]. The research question is: what is the rate of rice-field conversion and rice sufficiency in Banyumas Regency, and what effort should be made? This research was conducted to examine the conversion of rice fields and variables related to the existence of rice fields and rice self-sufficiency in the Banyumas Regency. The goal is to formulate actions to maintain rice supply levels. It is hoped that the results of this research can serve as a reference for formulating policies to maintain domestic rice supplies in a district area so that the contribution to the national rice supply can be maintained and sustainable.

Materials and Methods

Study Area

The research was conducted in Banyumas Regency, located in Central Java, Indonesia, from June to December 2021. The study area encompasses the southern foothills of Mount Slamet, situated geographically between 108°39'17" E to 109°27'15" E longitude and 7°15'05" S to 7°30'10" S latitude (Figure 1). Moreover, Banyumas Regency has an approximate total area of 138,916 ha, comprising 37,971 ha of wetland agriculture, 45,155 ha of dryland agriculture, 17,021 ha of settlements, 28,513 ha of forests, and 10,255 ha designated for other purposes. According to the Ministry of Agriculture Regulation No. 5 of 2012 concerning Guidenlines for Development of Agricultural Areas, rice is one of the leading commodities targeted by the national program in Banyumas Regency. Altitudes in the region range from 6 to 3,800 m above sea level, with relief ranging from flat to mountainous terrain encompassing alluvial, tectonic, and volcanic landforms [23]. The soil predominantly consists of inceptisols, andisols, alfisols, oxisols, and ultisols. Generally, soils formed on volcanic and alluvial landforms have higher levels of agricultural land productivity [24]. Temperature fluctuations span between 27.78 to 27.90 °C, while annual rainfall varies from 2,789 to 4,253 mm.

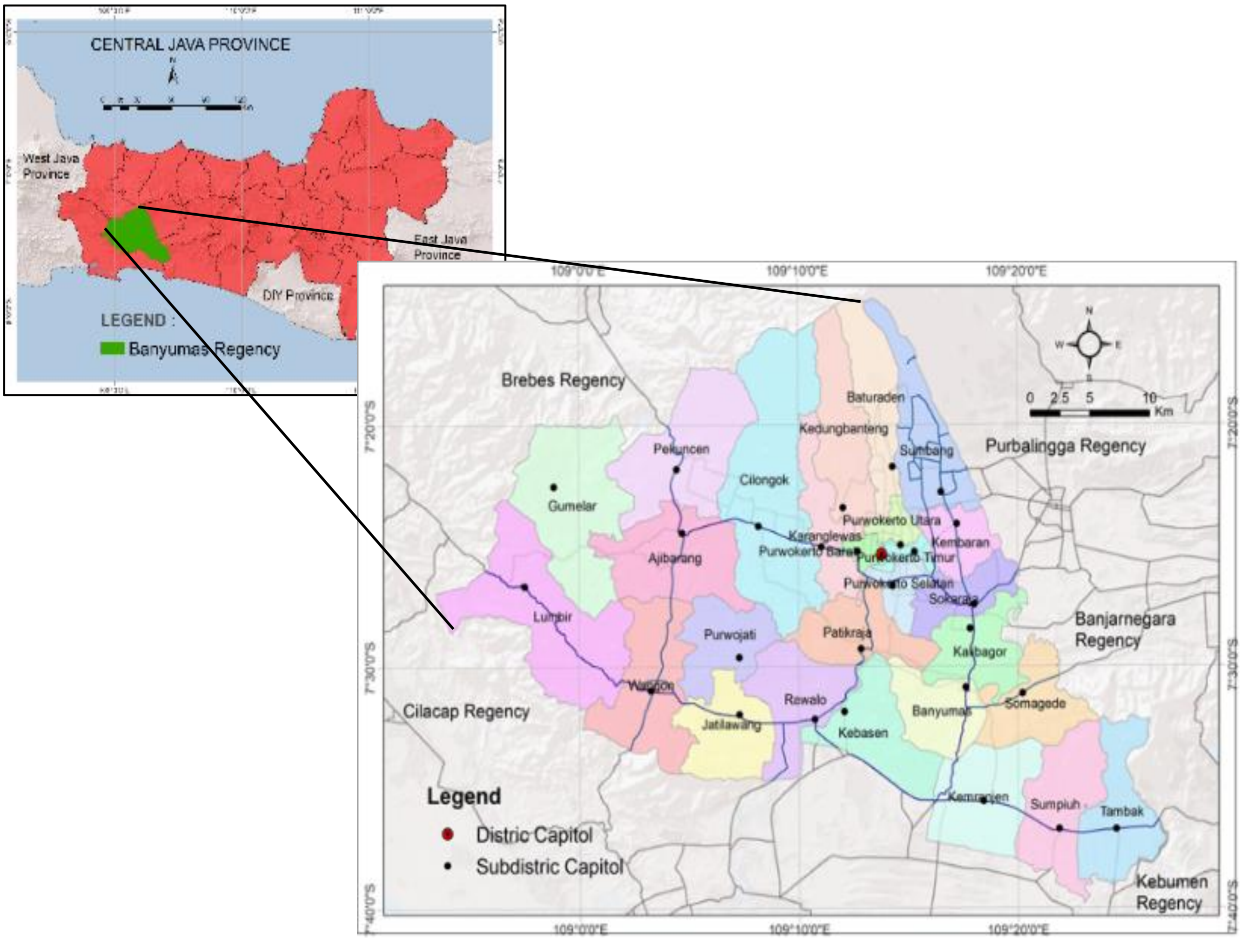

Figure 1. The study site, Banyumas Regency, Central Jawa, Indonesia.

Dataset Use Description

This research used SPOT satellite imagery to map multi-year rice fields, namely 2007, 2014, and 2019. Other datasets used in this research: Basic Rice Field Map, Topographic Map, Soil Map, variables related to rice independence, and rice production data. The Basic Rice Field Map scale 1: 50,000 from the Ministry of Agrarian and Spatial Planning/National Land Agency (ASP/NLA) 2019 validated the Rice Field Map derived from SPOT imagery.

Method

The research comprised two activities: analysis of multi-year rice fields and important variables in rice self-sufficiency. Field observations were conducted to validate the rice field map derived from SPOT satellite imagery and in-depth interviews. The dynamics of multi-year rice fields were determined based on the analysis of SPOT2 2007, SPOT5 2014, and SPOT7 2019 images sourced from the National Institute of Aeronautics and Space (NIAS) of Indonesia, in two main categories: rice fields and non-rice fields. Interpretation was carried out gradually, starting from the SPOT7 image using ArcGIS 10.8.2. This was done considering that the accuracy of the interpretation results was based on the availability of the Basic Rice Field Map from the Ministerial Decree of ASP/NLA No.686/SK-PG.03.03/XII/2019 regarding the Determination of National Basic Rice Field Areas in 2019. Then, the interpretation of the SPOT5 2014 image for rice fields in 2014 was carried out regarding the interpretation results of SPOT7 2019 and, subsequently, the interpretation of SPOT2 2007 regarding the interpretation results of SPOT5 2014.

The assessment of present-day rice field dynamics and future projections was facilitated through the utilization of the Land Change Modeler application within the TerrSet Software. The Land Change Modeler (LCM) implements a multi-layer perception algorithm that can produce a robust land change model with an accuracy rate of 81.24% [25]. In research in Iran, the use of the LCM was able to predict changes in land cover with a kappa index above 74% [26]. Predicting land cover changes with LCM is important for decision-making and implementing appropriate policy responses regarding sustainable forest resource management [27]. This application encompasses three analytical stages: change analysis, transition potential assessment, and change prediction (Figure 2).

One method for analyzing the key variables in a system is the Micmac method. Micmac analysis is conducted using a prospective analysis approach. Prospective analysis is widely used to formulate policy alternatives for natural resource management [28]. The Micmac method allows for categorizing and creating a hierarchy of strategic variables within a system and determining the level of dependency of a variable. This feature is helpful in policymaking. The variables used in this study include environmental, economic, social, technological, and institutional dimensions. The identification of various related variables was carried out by interviewing respondents who were determined purposively to include elements of local government, academics or researchers, settlement developers, the private sector, agricultural extension workers, village officials, and farmers, totalling 50 respondents. The experts were determined purposively, with seven experts consisting of elements of local government, academics or researchers, agricultural instructors, and farmers.

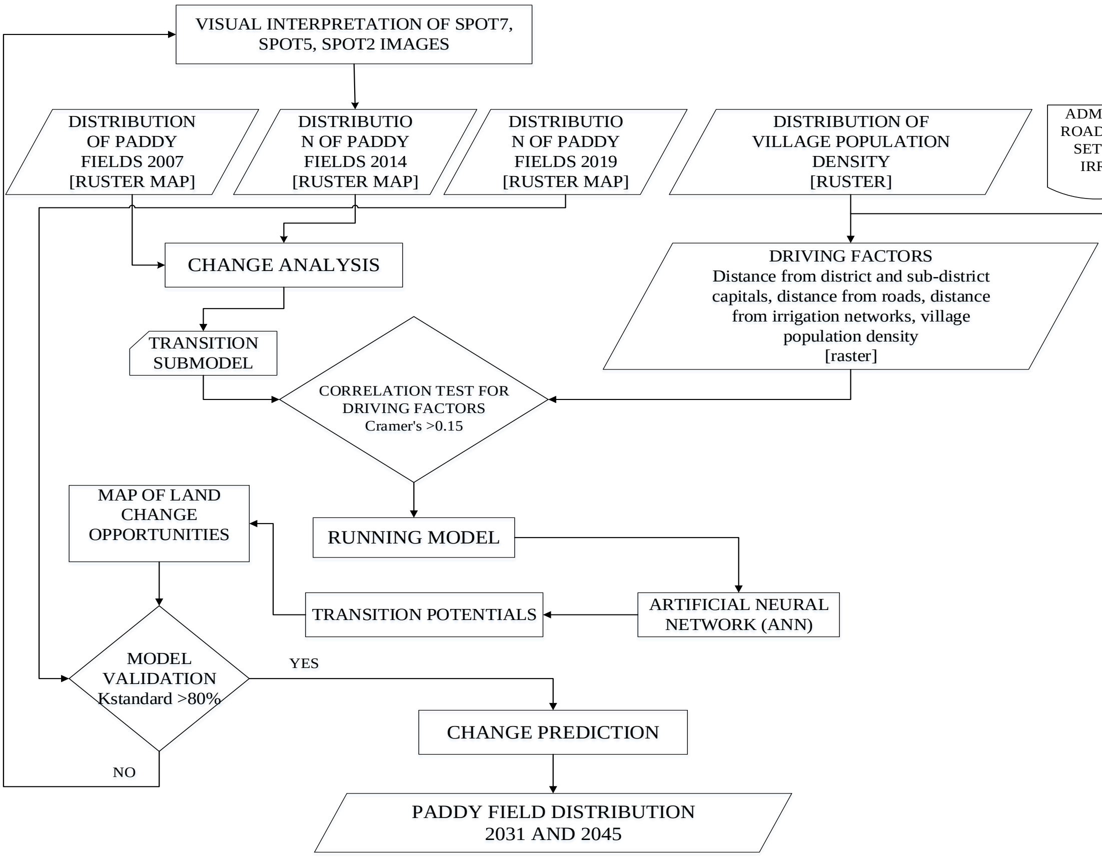

Figure 2. Stages of change analysis and prediction rice fields using the LCM TerrSet.

The stages in the Micmac method are as follows: 1) compile a list of variables, 2) describe the relationship between variables, and 3) identify the key variables [29]. Prospective analysis using Micmac essentially involves the classification analysis of influence relationships between variables identified as relevant to the issues under study and assessed by experts or stakeholders. The quantification of the relationships between variables was categorized into four categories: no influence (0), weak influence (1), moderate influence (2), strong influence (3). Based on the assessment of the relationships between these variables, the Micmac Software can map them into five groups of variable categories: sector 1 (influential variables), sector 2 (relay variables), sector 3 (resultant variables), and sector 4 (low influential). The stages of the key variable analysis using the Micmac method are presented in Figure 3.

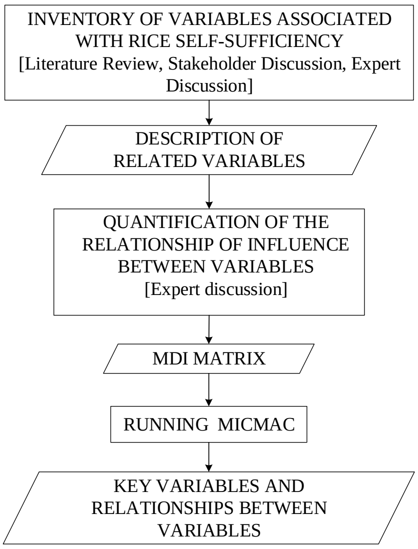

Figure 3. Flow diagram of the Micmac analysis stage.

Results and Discussion

Conversion of Rice Field

The results of the SPOT image analysis show that the area of rice fields in Banyumas Regency has decreased consistently, measuring 31,775 ha in 2007, decreasing to 31,301 ha in 2014, and further dwindling to 30,544 ha by 2019. Based on the outcomes, the transformation in rice fields within Banyumas Regency is evident: a shift of 474 ha from 2007 to 2014, equating to an annual average of 68 ha, and a subsequent increase of 151 ha per year from 2014 to 2019. The conversion rate mentioned above shows that the conversion rate increased from 2007 to 2019.

Population and economic growth will increase the demand for food and energy and dramatically increase the pressure on land [30]. The government is often faced with the dilemma of conflicting interests related to the conversion of agricultural land. The need to accelerate the economic growth rate through the development of non-agricultural sectors such as industry, services, and property conversion of agricultural land cannot be avoided. Weak government policies and supervision related to the management of paddy field resources have resulted in uncontrolled conversion of rice field functions. In its implementation, Regent's Regulation on the Banyumas Regency Regional Spatial Planning Plan has not been fully able to limit the conversion of rice fields into residential areas. The spatial information on rice fields in this Regent's Regulation is not presented in detail; therefore, in its implementation, uncertainty often arises, and settlement developments are still found by converting rice fields.

The decrease in rice fields in this research area has significant implications for rice production, exacerbating the ongoing decline in domestic rice self-sufficiency. Data sourced from the Department of Agriculture and Food Security of Banyumas Regency reveals that the region typically maintains a biannual planting index and yields average rice productivity of IDR 5,800 kg/year, so the projected loss in dry grain production amounts to 1,189,580 kg/year or equivalent to IDR 5,709,984,000. The average price of harvested dry grains in Central Java is IDR 4,800 [31].

The change of rice fields to built-up land use across diverse regions of Indonesia presents a formidable challenge in terms of prevention [32]. Conflicts of interest between individuals who want to use their land for higher economic purposes and the interest of the community and the nation in maintaining the sustainability of existing rice fields make preserving rice fields challenging [33]. It becomes even more ironic when this phenomenon is considered a logical consequence of population needs, economic development, and industrialization, which continue to increase.

The prediction of rice fields in Banyumas Regency based on the business-as-usual scenario has decreased from 30,544 ha in 2019 to 30,051 ha in 2031. The projected decrease in rice fields in the research site from 2019 to 2031 encompasses an area of 493 ha. By 2045, it is anticipated that the total area of rice fields in Banyumas Regency will decrease to 29,160 ha, indicating a cumulative conversion rate of 1,384 ha from 2019 to 2045.

Several studies have shown that the factors driving the conversion of rice fields in a region vary. The driving factors for the reduction of rice fields are internal and external factors, namely socioeconomic factors of the population [34–37], soil and land quality [38,39], accessibility [40,41], infrastructure, and policies [42]. The findings derived from the analysis of the submodel focusing on the transition in rice field land use change using the LCM TerrSet reveal that several influential factors associated with such land changes include the distance from the district capital, proximity to roads, distance from settlements, distance from irrigation channels, and population density (Table 1).

Table 1. Crammer's values for several driving factors of rice fields land use change.

Driving factors	Crammer's values
Distance from the distric capital	0.1891
Proximity to roads	0.1828
Proximity to settlements	0.2354
Proximity to the irrigation channel	0.1538
Population density	0.2229

Land use change reflects human activities that utilize and manage land resources. The transition from agricultural land to built-up areas is a phenomenon that occurs frequently in several regions owing to urban and settlement development [43–46]. The transformation of rice fields is notably concentrated in the vicinity of the urban sub-district (Purwokerto), which serves as the administrative hub of Banyumas Regency (Figure 4). This observation shows the pivotal role of regional development centers in driving the conversion of agricultural land into residential areas and complementary infrastructure. This is because of various conveniences and proximity to the center of various living needs, including economic activities, healthcare, education, and transportation accessibility [37,40–42]. This illustrates that in the absence of government intervention, the conversion of agricultural land adheres to economic principles, wherein land use transitions gravitate toward activities that yield greater economic value for land.

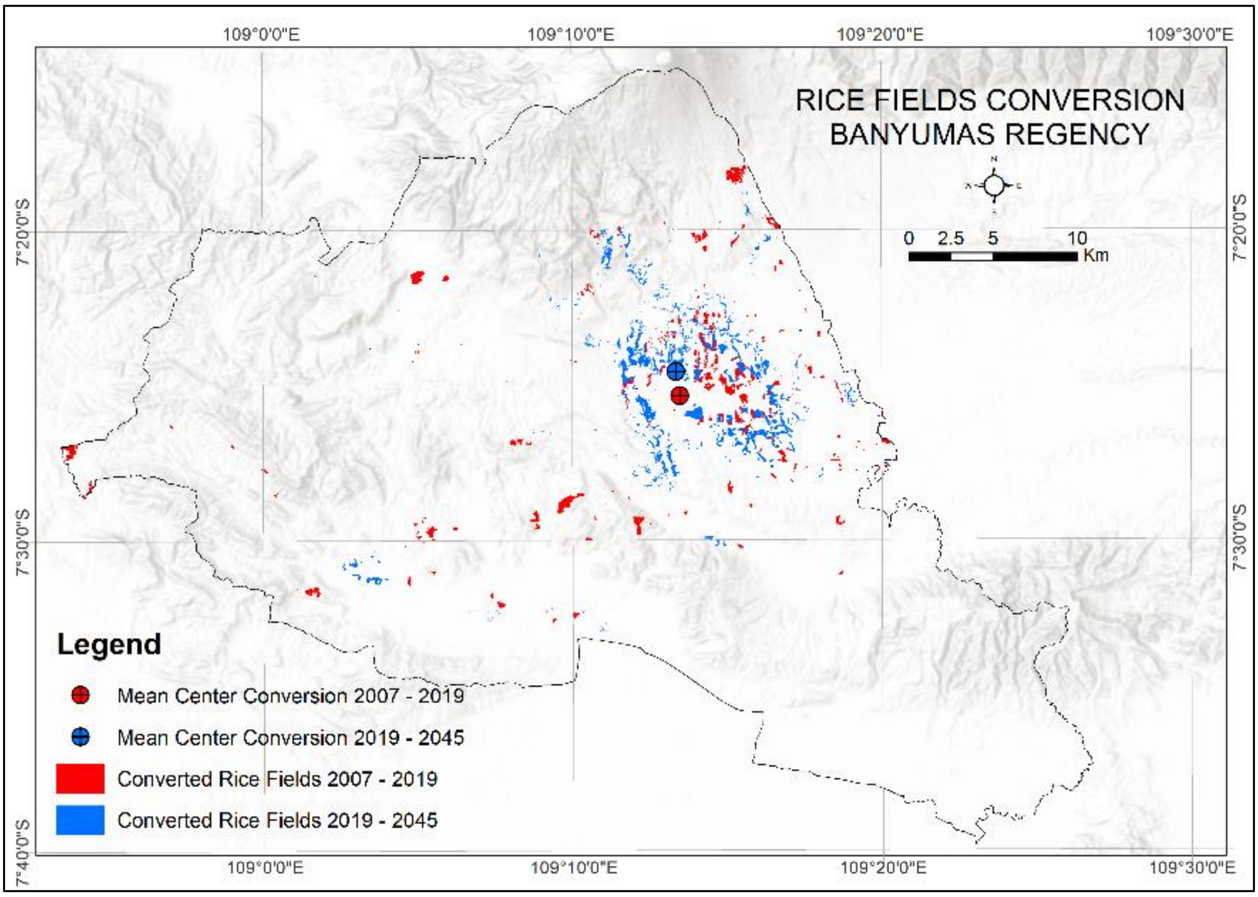

Figure 4. Distribution of converted rice fields from 2007–2019 and prediction until 2045.

In the long term, this phenomenon threatens efforts to fulfill rice sufficiency and food sovereignty. Implementing new rice field development programs is challenging because of various limitations. A more efficient action is to protect existing rice fields from being easily converted for other uses. For this reason, various efforts must be made to transform all aspects concerning policy and regulation, institutions, biophysical and socioeconomic aspects of the community, and technology. Rice fields can be preserved by making them permanent [47], improving agricultural management, increasing productivity, and optimizing the rice supply chain [48].

Key Variables Related Rice Self-Sufficiency

The variables were identified through literature review and in-depth discussions with various stakeholders. Some stakeholders who were respondents in this study included Academics, Regent, Chair of the Regional People's Representative Council (RPRC), heads of related agencies or staff assigned, agricultural extension officers, village officials, farmers' heads, farmers, fertilizer agents, rice traders, and settlement developers. The results of identifying variables related to the protection of rice fields are presented in Table 2.

Table 2. Variables related to rice self-sufficiency.

No.	Variables	Codification	Dimensions
1	Land suitability of rice fields for rice	*Keslah*	Environment
2	Distance from road	*Jarlan*	Environment
3	Distance from the city development center	*Jarkot*	Environment
4	Tendency to other uses	*Pglain*	Economy
5	Productivity and rice production	*Proddi*	Economy
6	Price stability of rice	*Stabhar*	Economy
7	Incentives for rice field protection	*Insenlin*	Economy
8	Farm income on rice fields	*Dapatan*	Economy
9	Extent of rice field ownership	*Luas*	Social
10	Population growth	*Pendu*	Social
11	Availability of agricultural labor	*Naker*	Social
12	Availability of irrigation water	*Iriga*	Technology
13	Availability of fertilizers and other production facilities	*Pupuk*	Technology
14	Availability of agricultural tools and machinery	*Alsin*	Technology
15	Active role of farmer groups	*Poktan*	Institutional
16	Regulation by the Regent regarding rice field protection	*Perbup*	Institutional
17	Detailed spatial information on protected rice fields	*Infospas*	Institutional
18	Agricultural extension activities	*Nyuluh*	Institutional

Subsequently, an assessment of the relationships between the identified variables was conducted in terms of the extent of influence between these variables. This assessment was carried out through in-depth interviews with five experts, including academics, the Department of Agriculture and Food Security, Housing and Settlements Department, Field Agricultural Instructors, and farmer groups. The results of this assessment are shown in Figure 5.

	1 : Keslah	2 : Jarlan	3 : Jarkot	4 : Pglain	5 : Proddi	6 : Stabhar	7 : Insenlin	8 : Dapatan	9 : Luas	10 : Pendu	11 : Naker	12 : Iriga	13 : Pupuk	14 : Alsin	15 : Poktan	16 : Perbup	17 : Infospas	18 : Nyuluh
1 : Keslah	0	0	0	3	3	0	1	2	0	0	0	0	0	0	0	0	0	2
2 : Jarlan	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 : Jarkot	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 : Pglain	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
5 : Proddi	0	0	0	3	0	2	0	3	0	0	0	0	0	0	3	0	0	3
6 : Stabhar	0	0	0	3	0	0	0	3	0	0	2	0	0	0	2	0	0	2
7 : Insenlin	0	0	0	2	3	0	0	3	0	0	0	2	2	2	3	0	0	3
8 : Dapatan	0	0	0	3	3	0	0	0	0	0	2	0	0	0	3	0	0	0
9 : Luas	0	0	0	1	3	0	0	3	0	0	0	0	0	0	0	0	0	0
10 : Pendu	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0
11 : Naker	0	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0
12 : Iriga	1	0	0	2	3	0	2	3	0	0	0	0	0	0	2	0	0	2
13 : Pupuk	0	0	0	2	3	0	0	3	0	0	0	0	0	0	2	0	0	2
14 : Alsin	0	0	0	2	2	0	0	3	0	0	0	0	0	0	2	0	0	0
15 : Poktan	0	0	0	1	2	3	0	3	0	0	0	1	3	2	0	0	0	2
16 : Perbup	0	0	0	3	3	1	3	2	0	0	0	2	1	1	3	0	3	3
17 : Infospas	0	0	0	3	0	0	3	0	0	0	0	2	2	1	2	0	0	3
18 : Nyuluh	0	0	0	1	2	0	0	2	0	0	0	0	0	0	3	0	0	0

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Influences range from 0 to 3, with the possibility to identify potential influences:
0: No influence
1: Weak
2: Moderate influence
3: Strong influence
P: Potential influences

Figure 5. Variable interplay assessment matrix of dynamics for rice self-sufficiency.

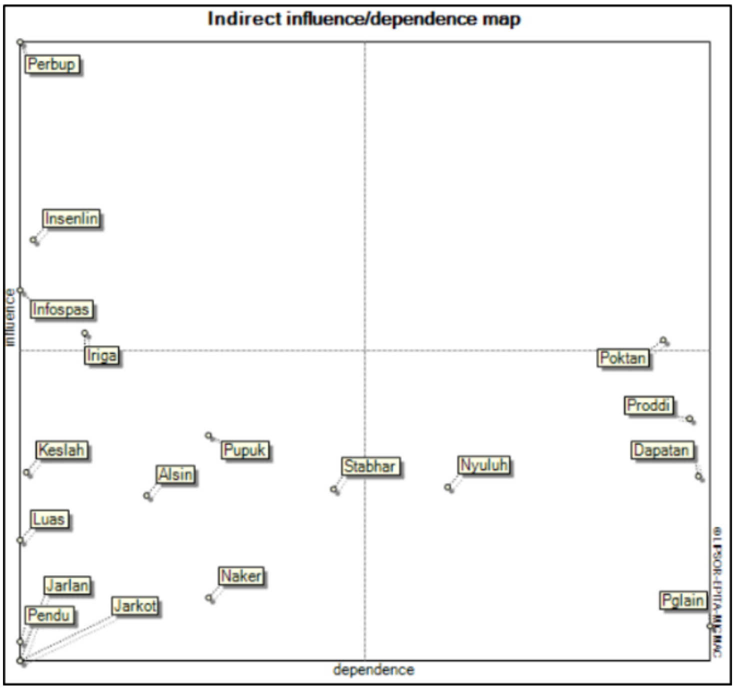

Figure 6. Position of the influence and dependency relationship between rice self-sufficiency variables.

The findings from the variable of rice self-sufficiency mapping in Banyumas Regency, conducted using Micmac software, reveal a clustering of variables categorized by their respective levels of influence and interdependence (Figure 6). Some variables were found to have a strong level of influence, thus becoming key or strategic variables in the research area. The influential variables, characterized by strong influence and low dependency, include regent's regulation on rice field protection (*Perbup*), incentives for rice field conservation (*Inselin*), detailed spatial data on protected rice fields (*Infospas*), and availability of irrigation water (*Iriga*). Variables with strong influence but high dependency (relay variables) included the dynamic engagement of farmer groups (*Poktan*). Although classified within the resultant variables sector, rice productivity (*Proddi*) emerges as a pivotal driver variable owing to its significant effect on food supply. The results of the analysis using the Micmac method, apart from showing strategic variables, can also describe the relationship between variables (Figure 7).

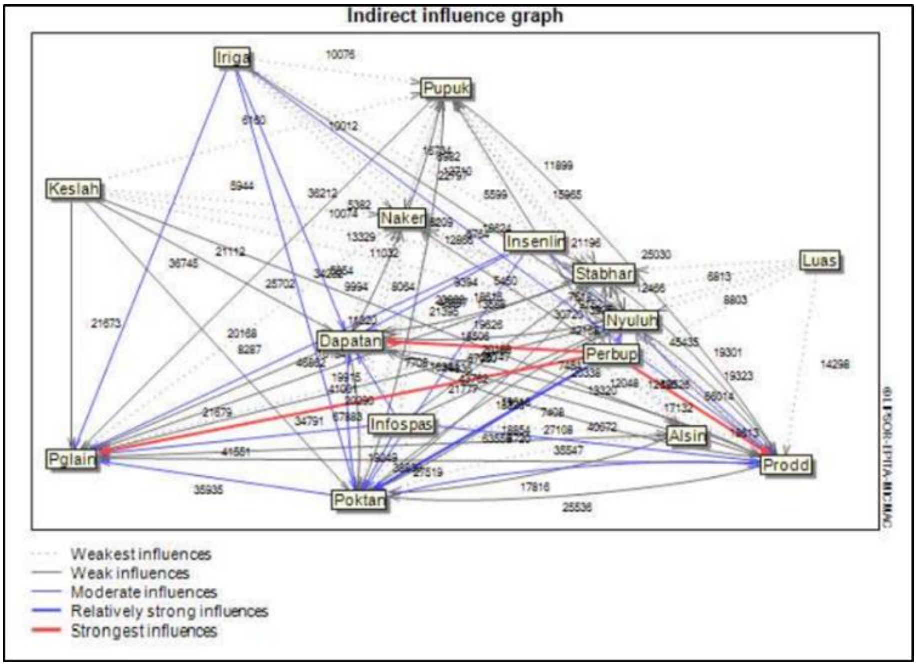

Figure 7. The relationship between variables.

Figure 7 illustrates the profound influence of the regent's regulation on rice field protection across various domains, including land use, rice production, farming income, and involvement of farmer groups. This condition indicates that regent regulation is a key variable driving the variables involved in the system. The variables of incentives for rice field conservation, detailed spatial data on protected rice fields, and the availability of irrigation water have a sufficiently strong influence on the functioning of the rice self-sufficiency system in Banyumas Regency. The relationship between these variables indicates the stages that should be undertaken to achieve an optimal system performance. In such a situation, detailed geographic information of safeguarded rice field areas that are increasingly capable of maintaining rice self-sufficiency in a region is needed. An annual rainfall between 2,789 to 4,532 millimeters, with a wet month (> 200 millimeters per month), and an average temperature of 25.78 to 27.90 °C, the rice fields in Banyumas Regency are the potential for rice production [49]. Until now, the average cropping index has been 200%, and the average productivity is 5,800 kg/ha; therefore, irrigation and cultivation technology, rice production, and productivity can still be improved. The results of a study on rice variety testing at several locations in Central Java showed varying productivity. In Sukoharjo, the productivity of rice around 6,844 kg/ha [50], and in Jepara, it also reaches 6,800 kg/ha [51].

Policy models play a crucial role in achieving goals and maintaining sustainability. Four key variables that influence several variables within the system are the establishment of the regent's regulation on sustainable food agricultural land, establishment of incentive schemes for sustainable food agricultural land protection, building detailed spatial databases of rice fields, and revitalization and development of irrigation water access, which must be executed in the initial stage, followed by the next stage of empowering farmer groups, and subsequently increasing rice crop productivity (Figure 8).

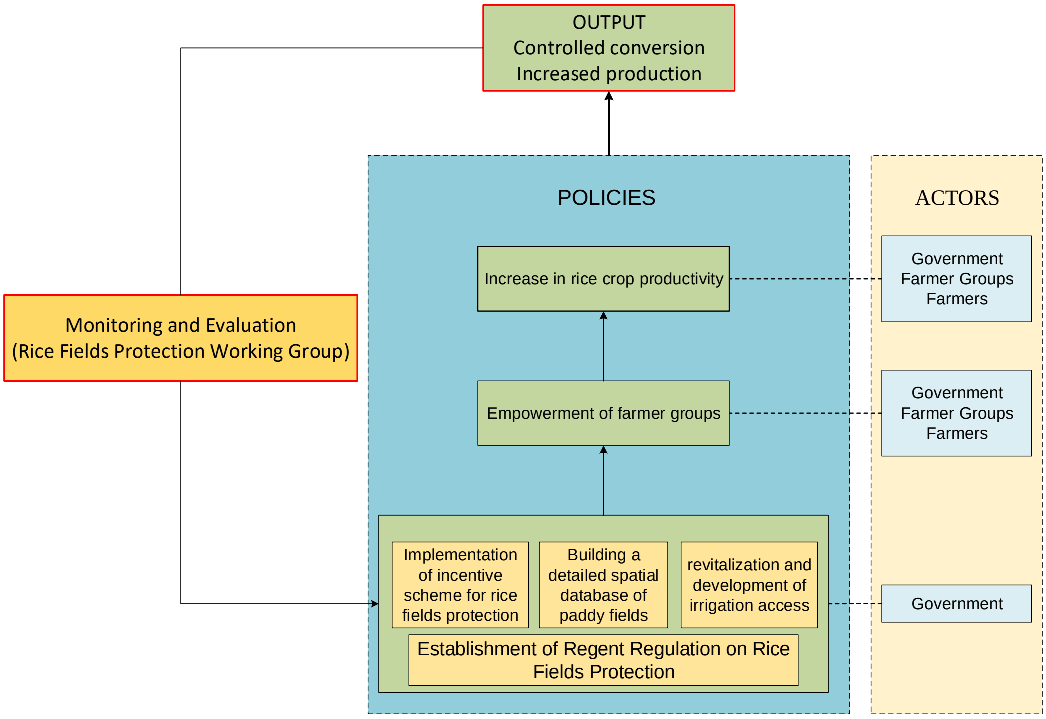

Figure 8. Conceptual model of policy in rice self-sufficiency.

The policy implementation strategy is based on the concept of system performance, which involves improving inputs and processes as well as strengthening the evaluation of outputs and outcomes. Improving inputs involves the establishment of the Regent's Regulation on Sustainable Food Agricultural Land, followed by the creation of detailed spatial databases of rice fields based on village administration, implementation of incentives for sustainable food agricultural land protection, and the development of irrigation water access. In terms of processes, collaboration among stakeholders is required to implement various programs that support input strengthening, such as empowering farmer groups and increasing productivity through cultivation technology engineering. The expected outputs of a collaborative system include controlled rice field conversion, increased rice production, effective monitoring mechanisms for rice field use, rice self-sufficiency, and the potential to control food crises.

Conclusions

Until 2045, rice fields in the Banyumas Regency still have the potential to be converted into built-up land, with an average conversion rate of approximately 38.5 ha per year. Driving factors correlated with the decline in rice fields in Banyumas Regency include population density, distance from district capital, distance from settlements, distance from roads, and distance from irrigation channels. The policies that must be implemented to prevent the continued conversion of rice fields in Banyumas Regency are based on the concept of system performance, including the establishment of a regent's regulation on the protection of rice fields, followed by the establishment of an incentive scheme for the protection of rice fields, building a detailed spatial database of rice fields, developing access to irrigation water, continuously strengthening farmer groups, and increasing rice productivity in rice fields in Banyumas Regency between 2007 and 2019, amounting to 1,231 ha. These rice fields will continue to be converted to other uses if there is no intervention in the rice field protection policies. Between 2019 and 2045, it is estimated that the decrease in rice fields in the regency will reach 1,384 ha.

Author Contributions

B: Conception and design of study, acquisition of data, analysis and interpretation data, drafting the manuscriptualization; **W**: Conception and design of study, critical review; **M**: conception of study, critical review; **KM**: Interpretation of data, critical review; and **WA**: Interpretation of data, critical review.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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