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Model for Determining Sustainable Food Agricultural Land through a Spatial Optimization Approach in Bantul Regency

Budiyanto[1], Cahyono Susetyo[1], Muhammad Daffa Musyary[2,*], Annisya Alifvia[2]

[1]*Urban and Regional Planning, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia*
[2]*Urban and Regional Planning,, Bandung Institute of Technology, Bandung, Indonesia*
** Corresponding Author E-mail: daffamusyary.ks@itb.ac.id*

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Abstract

Land use is a characteristic of the arrangements, activities, and contributions made by humans to either effect changes or maintain a certain type of land cover (Gregorio and Jansen, 1998). Agricultural land is a crucial resource for sustainability and food security. In an effort to control and anticipate the conversion of agricultural land, the Bantul Regency Government has issued Regional Regulation No. 10 of 2023 on the Protection of Sustainable Food Agricultural Land, with a total area of 12,831 hectares. However, the area designated for protection according to the 2021 study recommendations is 14,407.50 hectares. This represents a reduction of 1,576 hectares due to agricultural land in Sewon and Kasihan Districts being planned for non-agricultural use. Therefore, the objective of this study is to identify the modeling of sustainable food agricultural land designation in Bantul Regency, using a linear programming optimization approach with the aid of Microsoft Excel Solver. The linear programming model, with the objective function to minimize the area designated in the regional regulation, determined the need for 11,356.52 hectares of agricultural land to maintain food security in Bantul Regency over a period of 20 years.

1. INTRODUCTION

Land use is a characteristic of the arrangements, activities, and contributions made by humans to produce a change or maintain a particular type of land cover (Gregorio and Jansen, 1998). Land use includes how humans can utilize and manage land for various purposes, such as agriculture, settlement, industry, and conservation. However, the phenomenon of high urbanization rates is a problem in current land use where urbanization is one of the drivers of land use change (Grimm et al. 2008; McDonald et al. 2008). Rapid urbanization rates often come at the expense of losing agricultural land to meet the needs of urban activities. On the other hand, the continuous decline of agricultural land not only limits the potential for increasing land productivity but also affects national food security. Agricultural land is a critical resource for sustainability and food security. Farmland provides the majority of food supply and guarantees a large number of ecosystem services, such as providing food ingredients (Pereira et al., 2018; Scown et al., 2019; Stephens et al., 2018). Therefore, preserving and protecting agricultural land for now and the future is something that must be addressed immediately (Hertel, 2011; Caldwell et al., 2017; FAO, 2021), because the preservation and protection of agricultural land can provide many benefits such as maintaining local and national food security, environmental sustainability, and can control urban growth.

To address the challenges posed by rapid urbanization and agricultural land loss, innovative models for determining sustainable food agricultural land are essential. Spatial optimization techniques can be employed to identify the most suitable areas for agricultural use while considering urban encroachment and ecosystem preservation (Landis, 2001). By integrating geographic information systems (GIS) with land-use planning, stakeholders can visualize potential impacts of development and make informed decisions about land allocation (Batty et al., 2012). Moreover, using spatial analysis tools allows for the evaluation of agricultural land quality, enabling the prioritization of areas that contribute significantly to food security (Meyer et al.,

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2017). The importance of incorporating local knowledge and stakeholder engagement into land-use planning cannot be overstated. Participatory approaches ensure that the perspectives of farmers, urban planners, and community members are included, ultimately leading to more sustainable outcomes (Reed, 2008). By fostering collaboration among various stakeholders, it is possible to create a shared vision for land use that balances agricultural needs with urban development (Mastrorillo et al., 2016). Furthermore, public awareness campaigns can enhance community understanding of the value of agricultural land, promoting its conservation (López et al., 2013).

In addition, the application of environmental and economic assessment tools can support policy-making processes related to agricultural land protection (Kirkpatrick et al., 2010) . Such assessments provide evidence to justify maintaining agricultural land amidst competing urban pressures, ultimately contributing to national food security goals (Bai et al., 2019). It is crucial to adopt an evidence-based approach to land-use planning that incorporates ecological and socio-economic factors (Zhang et al., 2015). This multifaceted analysis enables the creation of adaptive strategies that are resilient to changing conditions and urban dynamics (Fischer et al., 2018). Lastly, the integration of technology in agriculture, such as precision farming and sustainable practices, can enhance productivity on existing agricultural lands (Liakos et al., 2018). By optimizing the use of resources, farmers can increase yields while minimizing environmental impacts (Kumar et al., 2019). Supporting research and development in sustainable agricultural technologies is vital for ensuring the long-term viability of food systems (Godfray et al., 2010). Ultimately, a comprehensive model that combines spatial optimization, stakeholder engagement, environmental assessments, and technological integration can pave the way for sustainable food agricultural land management (Moran et al., 2020). As such, it is imperative to continue exploring innovative frameworks that support both agricultural productivity and urban sustainability (Pérez et al., 2021).

Efforts to protect agricultural land in Indonesia are stipulated in Law No. 41 of 2009 concerning the protection of sustainable food agricultural land (LP2B), and Presidential Regulation No. 59 of 2019 concerning Control of Paddy Field Conversion, or often abbreviated as the Protected Paddy Field (LSD) regulation. These regulations aim to maintain the sustainability of national food production by protecting agricultural land from conversion to non-agricultural land. Thus, the existence of this regulation becomes the basis for the government in setting policies and supervising the use and conversion of agricultural land, especially paddy fields, in order to maintain sustainable food availability and production. However, in its implementation, there is often ineffectiveness in the implementation of laws and regulations due to the unclear objects of protected agricultural land, and the lack of public knowledge and awareness about the importance of protecting food agricultural land (Irawan, 2014; Rachmanto, 2014) [21]. This situation is evident in Sewon District, which has the largest rice harvest area in Bantul Regency, covering 2,468.6 hectares (BPS Bantul, 2021). As a result, Sewon District has been designated as the largest LP2B area in Bantul Regency. However, on the other hand, based on Bantul Regency Regional Regulation No. 8 of 2018 concerning the Detailed Spatial Plan and the Zoning Regulation for the Urban Area of Sewon for the years 2018 to 2038, all villages in Sewon District have been classified as part of the urban area. Additionally, monitoring and evaluation results of spatial utilization control activities in Sewon District for 2022-2023 indicate that there are still constructions being established in agricultural zones.

Bantul Regency is one of the four regencies in the Special Region of Yogyakarta. The land area of Bantul Regency is 50,685 ha, which is dominated by built-up land at 36.85%, irrigated rice fields 27.17% and non-irrigated rice fields 26.77%. As a result of the massive development of the city of Yogyakarta which has an impact on Bantul Regency itself, every year agricultural land shrinks, due to land conversion. Based on data from the Department of Land and Spatial Planning, agricultural land in Bantul Regency decreases by an average of 50 hectares per year, especially in the buffer zone of the city, such as Kapanewon Banguntapan, Sewon, Kasihan, and Sedayu (Lugas Subarkah, 2023, October 10). The objective of this research is to identify the extent of LP2B through a spatial optimization modeling approach in determining sustainable food agricultural land in Bantul Regency. This approach enables more integrated planning by considering both

potential and needs, allowing for a more effective and sustainable balance between agricultural land requirements and urban development.

There has been extensive research identifying sustainable agricultural land for food production. Intan Agnes Manullang et al. (2023) identified existing rice fields and analyzed the suitability of rice field areas for LP2B (Sustainable Food Agricultural Land) designation using visual/digital interpretation methods from SPOT 7 imagery in 2020. The results were then overlaid to analyze the suitability of the existing rice fields with LP2B areas. Rachman Andriawan et al. (2020) assessed the potential suitability of LP2B with the Regional Spatial Plan (RTRW). They used a spatial approach to key variables determining LP2B potential based on technical guidelines for land suitability for food crop commodities, assigning weights and scores to these criteria. However, research discussing spatial optimization modeling for determining sustainable rice field protection is still limited

2. METHODS

This research uses a quantitative approach. Quantitative research can be interpreted as research that uses a lot of numbers, starting from the data collection process, data analysis and data display (Siyoto and Sodik, 2015). This research will be more emphasized on numerical data which is then analyzed with appropriate methods. Starting from the process of identifying the minimum agricultural land area requirements in accordance with population pressure for the future, which will then be identified based on the distribution of agricultural land based on the quality of land that supports agricultural activities, to be able to formulate an optimal model for determining agricultural land protection.

This secondary data is in the form of spatial and aspatial data obtained through authorized local government agencies and other sources. Secondary data needs are Administrative Map, Land Use Map, Agricultural Land Distribution Map, LP2B Distribution Map, Food Agricultural Land Productivity of Bantul Regency, and Population of Bantul Regency.

The analysis methods used in this research are land carrying capacity analysis, land evaluation and optimization modeling through Linear Programming. The following are the stages of analysis used in this research.

a. Land carrying capacity analysis is an environmental carrying capacity analysis that serves to calculate the availability of paddy agricultural land in supporting the population needs in a certain area, using the following formula :

$$\sigma = \frac{Lp/Pd}{KFM/Pr} \quad (1)$$

where:
σ = Carrying capacity of agricultural area
Lp = Harvest area (ha)
Pd = Total population (people)
KFM = Food demand (kg/capita/year)
Pr = Average land production per hectare (kg/ha)

b. Land evaluation is a process in estimating the class of land suitability and land potential for certain uses, both for agriculture and non-agriculture. To determine the level of land suitability, the required data includes slope gradient, elevation, rainfall, geology, land use, and soil type. Each of these data points will be assigned a value according to its classification based on the Ministry of Public Works Regulation No. 20/PRT/M/2007 on Technical Guidelines for the Analysis of Physical and Environmental, Economic, and Socio-Cultural Aspects.
c. Analysis of the area of agricultural land needs in accordance with food needs for 20 years. To calculate the required land area, the following calculation is used:

$$KLP2B = \left(\frac{Kp\ x\ \Sigma Pt}{P}\right) x \frac{1}{IP} \quad (2)$$

where:
Kp = standard food requirement based on rice consumption (tons/capita/year)
ΣPt = population in year t (people)
P = productivity level in paddy fields (tons/ha)
IP = rice paddy cropping index (%)

d. Land demand optimization model with Linear Programming approach through simplex method, with the assistance of Microsoft Excel Solver software. Linear programming is well-suited for problems involving the allocation of limited resources, such as land, while satisfying multiple constraints. In spatial optimization, it helps determine the most efficient way to use land, balancing agricultural, urban, and environmental needs.

3. RESULT AND DISCUSSION

3.1 Land Support Capacity

Agricultural land carrying capacity is an important concept in maintaining the food security of a region. Agricultural land carrying capacity is an area's ability to provide land that can support agricultural activities (Moniaga, 2011). An area is able to provide a decent life for its population depending on food crops that can meet the needs of the population at a decent level, which is equivalent to 265 kilograms of rice/person/year or 2.466 times the FKM. In the last 5 years, the harvest area in Bantul Regency has experienced an increasing trend, reaching its peak in 2022, followed by a decline in 2023. Despite the fluctuations, the overall harvested area shows a positive trend until 2022 before decreasing in 2023, which is caused by the impact of land conversion in Bantul Regency.

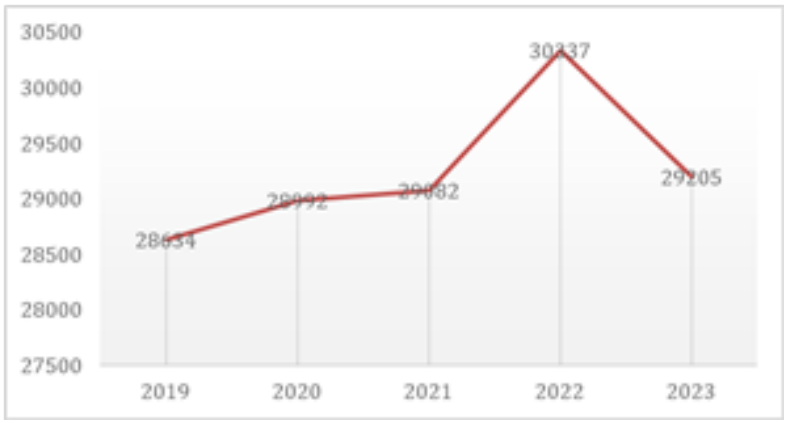


Figure 1. Figure/Diagram Illustration placement.

Based on the figure above, the average harvest area of Bantul Regency is 29,250 hectares with an average production level of 187,981 tons. The population in 2023 reached 971,161 people, it is known that currently, Bantul Regency is included in the category of areas capable of food self-sufficiency for its population in meeting their rice needs, with an σ value of 3.49 obtained from the formula calculation:

So that Bantul Regency has a high level of agricultural carrying capacity which is able to achieve self-sufficiency in terms of rice production.

Table 1. Self-sufficiency carrying capacity level of Bantul Regency

Production (tons)	Average production (kg)	Population 2023 (people)	Rata-rata Average KFM* (kg)	Agricultural Support Capacity (σ)
183.964	106.456	972.161	81,4	3,49

Efforts to ensure the sustainability and stability of food supply for the population in Bantul Regency without damaging the environment are to consider the ability of land to support food needs for the local population in Bantul Regency. The population of Bantul Regency in 2023 reached 971,161 people. By projecting over a 20 year period with an increasing population growth scenario, it is predicted that by the year 2043, the population of Bantul Regency will reach 1,116,612 people.

Table 2. Population Projections for 2023 - 2043 Bantul Regency

Total Population (people)				
2023	2028	2033	2038	2043
971.161	1.006.549	1.042.068	1.078.839	1.116.612

To calculate the food demand in Bantul Regency, a calculation based on Odum's theory was used, which stipulates that an area capable of meeting food needs is an area that can provide the minimum physical needs of the population of 1600 calories/person/day, or the equivalent of 100 kg/rice/person/year (Soehardjo and Tukiran, 1990). Thus, the food demand in 2043 in Bantul Regency is 112,661 tons. With an average cropping index of 1.6, the standard food requirement for grains according to the food agency of 100.4 kg/cap/year, a farmland area of 11,357 ha is required. This represents the minimum area of agricultural land that must be protected to avoid land conversion to non-agricultural use in order to maintain food security in Bantul Regency.

3.2 Land Evaluation

The land evaluation of Bantul Regency in this study was carried out to assess the level of land suitability based on the physical aspects of agricultural land potential and the existing conditions of agricultural land in Bantul Regency. To be able to determine the level of land suitability, the data required includes slope, altitude, rainfall, geology, land use and soil type. Each of these data will be given a value according to its class in accordance with the Regulation of the Minister of Public Works No.20/PRT/M/2007 on Technical Guidelines for Analysis of Physical and Environmental, Economic and Socio-Cultural Aspects. After all the data is given a value, an overlay process will be carried out with the aim of more in-depth analysis of different spatial information, which will produce 10 thematic maps of Land Capability Units, namely Morphological SKL, Ease of Working SKL, Slope Stability SKL, Foundation Stability SKL, Water Availability SKL, Drainage SKL, Erosion SKL, Waste Disposal SKL, and Disaster Prone SKL. The land suitability analysis process is the combined result of thematic SKLs that are overlaid and then weighted with the help of ArcGIS software. The results of the weighting will produce a level of land suitability for agricultural spatial direction with 5 categories, namely Very Low (Class A), Low (Class B), Medium (Class C), Somewhat High (Class D) and Very High (Class E).

Based on the results of the analysis of the level of land suitability based on physical aspects there are 40,503 Ha in the rather high and very high development categories. While with the current amount of agricultural land use of 14,861.03 ha, which is included in the class of agricultural land suitability high and very high amounted to 13,858 ha. While the remaining 1,000 ha is in the very low to medium development class.

Table 3. Existing Agricultural Land Suitability of Bantul Regency

Land Capability	Irrigated Rice Field	Tidal Rice Field	Rainfed Rice Field	Total (Ha)
High	4.020,35	6,36	710,41	4.737,12
Very High	7.824,21	105,10	1.192,27	9.121,57
Total	11.844,56	111,46	1.902,68	13.858,69

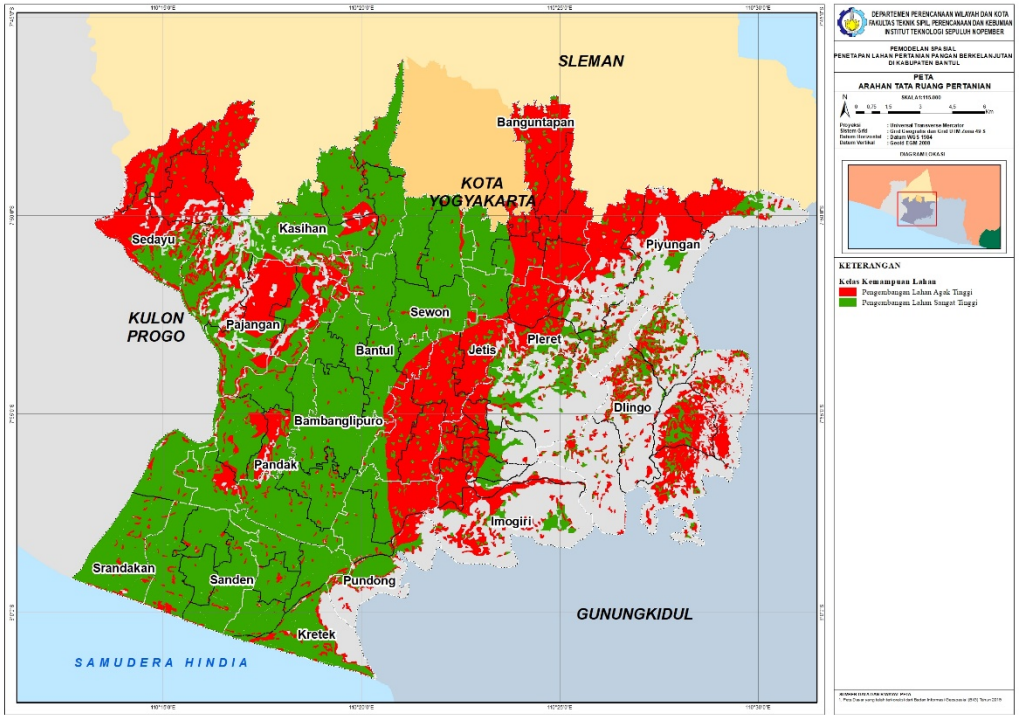


Figure 2. Land suitability map of Bantul Regency

3.3 Suitability of Sustainable Agricultural Land

Bantul Regency Regional Regulation No.10 of 2023 concerning the Protection of LP2B, that Bantul Regency has determined an area of Sustainable Food Agricultural Land of 12,831 ha. The land area that has been designated as LP2B, based on the results of the analysis, 90% is in the category of suitability for agricultural spatial direction with a rather high (Class D) and very high (Class E) development capability class, amounting to 11,666 ha, while the remaining 1,164 ha is in the very low to medium development class category.

Table 4. Land Suitability of LP2B

No	Development Direction Class	Area (ha)
1	Very Low	163,111
2	Low	226,115
3	Medium	774,875
4	High	4.111,583
5	Very High	7.555,319
	Total	12.831,003

The high composition of existing agricultural land, which in terms of land suitability is in the high capability category for agricultural development, indicates that the LP2B location has been determined in accordance with the physical potential of the region. Most of the agricultural land is located in the moderately high and very high development capability classes, which means that the land has good potential for agriculture. Although around 10% of agricultural land is in the less high development category, this is still acceptable as the land can be used as a reserve or developed gradually according to the needs and conditions of the field.

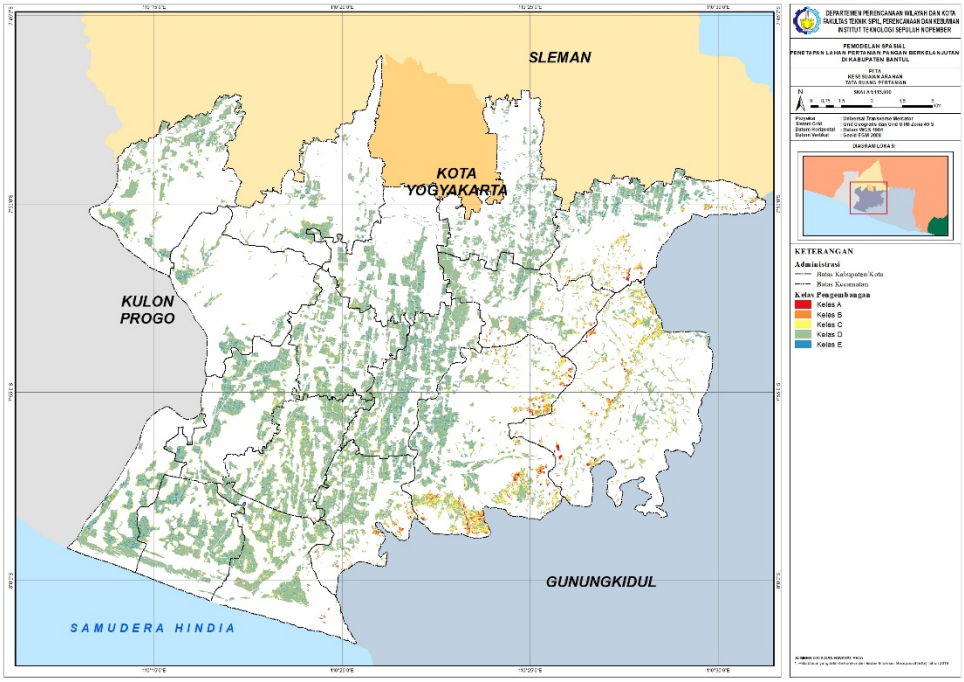


Figure 2. Land suitability class map of LP2B Bantul Regency

3.4 Optimization Model for Sustainable Food Agricultural Land Designation

Spatial Optimization Model is a mathematical tool or method used to solve problems related to space or geographic location, by utilizing spatial data and optimization techniques to find the most effective solution (Faiz and Krichen 2012; Tong and Murray 2012). In optimization modeling, there are systematic steps to find the optimal solution. Starting from object identification, objective function and determining constraints or limiters. The function of the object to be optimized in this study is to minimize the sustainable food agricultural land that has been determined by local regulations in order to meet food needs in Bantul Regency for 20 years with a land requirement of 11,356 ha.

The objective function, namely minimizing the area of agricultural land that has been determined, in order to meet food needs in Bantul Regency in the amount of 112,107 tons, so that the objective function is as in the following equation

$$Min\ Z = \sum_{i=1}^{14} x_i$$

The constraint function is a linear formula that contains decision variables that explain the limits of the decision taken. The constraint is that the land area used in each sub-district must not exceed the total available land capacity, as in the following equation

$$x_i \leq Total_i$$

The total land area needed must reach 11,356 ha from the available 12,831 ha, equation (3) and the value of x must not be negative.

$$\sum_{i=1}^{14} x_i \leq 11.356$$

After the decision variables, objective functions and constraints above are determined. The modeling process is done with Microsoft Excel software with Add-in solvers. Decision variables and constraints are entered into columns and cells in excel. As for the objective function, the equation above is entered in the cell which is the place for the optimization results. Then, the solver is activated through the Data tab, Set Objective by selecting the cell containing the objective function. By Changing Variable Cells, enter the cells that will be filled with the values to be optimized. Subject to the Constraints, add the constraints by clicking Add and entering the range of cells for the constraints and their limits. Once all parameters and constraints are added, the solver run will search for the optimal solution of the problem automatically.

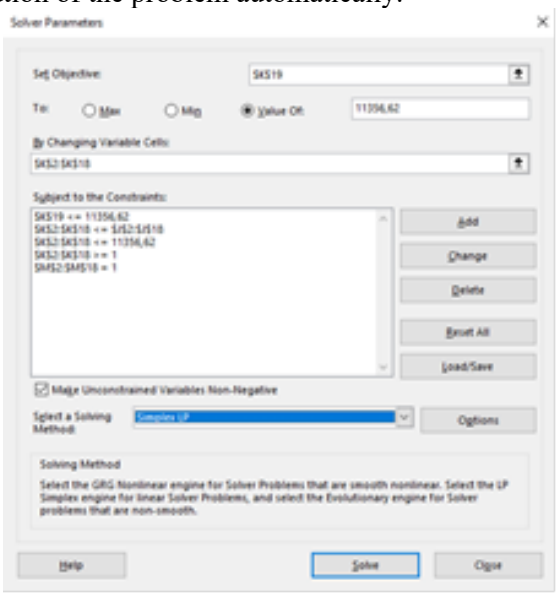


Figure 4. Solvers Add In Display

The optimal solution will be found if the solvers produce an optimal solution that meets all the constraints in the linear programming problem, this condition can be seen from the report results by giving the statement "Result: Solver found a solution. All Constraints and optimality conditions are satisfied."

The results of modeling with solvers, found that the model to minimize the area of agricultural land in Bantul Regency found an optimal solution. With the distribution of optimal land allocation in each sub-district not exceeding the predetermined constraints.

Table 6. Results of optimization of agricultural land modeling in Bantul Regency

Sub-district	LP2B area (Ha)	Optimization land (Ha)
Bambanglipuro	1.057,63	719,41
Banguntapan	560,03	560,03
Bantul	793,08	793,08
Dlingo	728,85	728,85
Imogiri	1.350,09	984,36
Jetis	1.142,98	925,29
Kasihan	341,39	341,39
Kretek	829,63	633,52
Pajangan	277,73	277,73
Pandak	800,63	800,63
Piyungan	704,95	704,95
Pleret	664,25	664,25
Pundong	786,20	666,64
Sanden	885,68	648,61
Sedayu	708,44	708,44

Sub-district	LP2B area (Ha)	Optimization land (Ha)
Sewon	625,87	625,87
Srandakan	573,56	573,56
Grand Total	12.830,99	11.356

3.5 Optimal Area of Sustainable Food Agricultural Land

The area of sustainable food agricultural land that has been designated in Bantul Regency is quite varied, ranging from 277.73 to 1,350.09 hectares. The results of optimization with solvers, it is known that the model equation (1) with the objective of minimization, can find the optimal solution and meet all the specified constraints. Of the 17 sub-districts designated as LP2B, 1,474.38 ha of agricultural land can become non-priority or reserve land from LP2B, meaning that there is agricultural land that can be removed from LP2B. Land optimization occurs in several sub-districts such as Bambanglipuro, Jetis, and Sanden which is quite significant, while most other sub-districts have reached the optimal level fully in accordance with the existing agricultural land.

Table 7. Comparison of LP2B Land Area and Optimization Results

No	**Sub-district**	**Luas (Ha)**		
		LP2B	**Optimization**	**Non-Priority**
1	Bambanglipuro	1.057,63	719,41	338,22
2	Banguntapan	560,03	560,03	0,00
3	Bantul	793,08	793,08	0,00
4	Dlingo	728,85	728,85	0,00
5	Imogiri	1.350,09	984,36	365,73
6	Jetis	1.142,98	925,29	217,69
7	Kasihan	341,39	341,39	0,00
8	Kretek	829,63	633,52	196,11
9	Pajangan	277,73	277,73	0,00
10	Pandak	800,63	800,63	0,00
11	Piyungan	704,95	704,95	0,00
12	Pleret	664,25	664,25	0,00
13	Pundong	786,20	666,64	119,56
14	Sanden	885,68	648,61	237,07
15	Sedayu	708,44	708,44	0,00
16	Sewon	625,87	625,87	0,00
17	Srandakan	573,56	573,56	0,00
	Grand Total	12.830,99	11.356,62	1.474,38

The optimization results show that the proposed reduction in agricultural land allows the Bantul district government to allocate land more efficiently without sacrificing agricultural productivity. Some sub-districts, such as Bambanglipuro and Sewon, show larger land area reductions in the optimization results, while sub-districts such as Kretek and Imogiri have smaller reductions.

4. CONCLUSIONS

In assigning sustainable food agricultural land to achieve optimal results, a mathematical approach through Linear Programming can be a solution to the problem of distributing space allocation. The optimization results provide a clear picture of how agricultural land will be allocated in the future, allowing better planning to support urban growth and agricultural needs. The optimization process successfully maintains a balance

between the potential of developed land according to the direction of agricultural spatial planning, thus meeting agricultural needs by considering existing constraints.

Based on the optimization results that the Bantul Regency Government can protect its agricultural land of 11,356.62 ha, while the remaining 1,474 ha can become non-priority land or reserve land. Each sub-district shows different optimization results. Some sub-districts such as Bambanglipuro and Sewon experienced larger land reductions, while sub-districts such as Kretek and Imogiri had fewer reductions. With optimization, the Bantul Regency Regional Government is able to improve the efficiency of agricultural land use. Overall, it can be concluded that the use of linear programming with the simplex method in assigning protected agricultural land is able to provide significant results. This method not only allows the identification of optimal land allocation but also helps in maintaining a balance between agricultural land development and other needs. The implementation of linear programming with the simplex method can provide strong guidance for the government in planning and managing agricultural land use, ensuring that existing resources are used efficiently and effectively to achieve the desired results. Thus, the Bantul Regency Government can better protect its agricultural land to support sustainable regional growth and development.

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