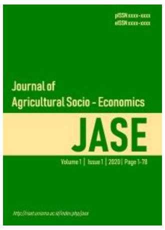

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Evaluation of Agricultural Land Carrying Capacity and Projection of Agricultural Land Requirements in Grobogan Regency Based on Geographic Information Systems (GIS)

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Abstract. Increasing population growth and agricultural land conversion pose significant challenges to food security, particularly in regions heavily dependent on agriculture. Grobogan Regency, a major rice-producing area in Central Java, has experienced a decline in harvested area alongside rising population pressure, indicating potential risks to long-term agricultural sustainability. Unlike previous studies that examine land carrying capacity, land requirements, or land use change separately, this study integrates these aspects within a Geographic Information System (GIS)-based spatial framework. The novelty of this study lies in integrating agricultural land carrying capacity, land-use requirement projections, and GIS-based land-use analysis within a multi-temporal, spatially explicit framework at the sub-district level to provide a more comprehensive understanding of agricultural sustainability and land-based food supply planning under population pressure. This study employed a quantitative, descriptive approach, combined with GIS-based spatial analysis, using secondary data on population, harvested area, rice production, and land use for 2014, 2019, and 2024. Agricultural land carrying capacity was calculated using the Suhardjo–Tukiran method, while land requirements were projected using a geometric population growth model. The results show that carrying capacity remained positive, with σ values of 3.45 in 2014, 4.62 in 2019, and 3.94 in 2024, although the number of Class I sub-districts declined from 18 in 2019 to 16 in 2024, indicating increasing localized land pressure and spatial disparities in agricultural resources. Projected land requirements increased from 46,699.19 ha in 2029 to 49,297.08 ha in 2034, while land-use analysis indicates ongoing changes in agricultural and non-agricultural land allocation. These findings highlight the importance of GIS-based spatial planning and land-use control to support sustainable agricultural development and long-term food security.

Keywords: Carrying Capacity; Land Requirement Projection; Spatial Analysis; Land Use Dynamics; Food Security.

INTRODUCTION

Food security has become a critical global issue, particularly amid rapid population growth, land conversion, and increasing pressure on agricultural resources. In Indonesia, the agricultural sector plays a vital role in supporting national food supply and rural economic stability, especially in regions where agricultural production remains the main source of livelihood. However, declining agricultural labor participation, increasing land conversion, and reduced agricultural land availability pose serious challenges to long-term agricultural sustainability (Jakapratama et al., 2021; Cahyanto, 2021).

Agricultural land is a limited and strategic resource that directly affects food production and regional food security. In Indonesia, population growth, development pressures, and policy interventions increasingly influence land-use dynamics, highlighting the importance of sustainable land management (Faoziyah et al., 2024). The theory of resource scarcity emphasizes that increasing population pressure reduces land availability per capita, which may lead to declining farm sizes, reduced farmers' income, and structural vulnerability in rural economies (Anggrasari, 2024). In this context, agricultural land carrying capacity is not only an environmental indicator but also a strategic basis for sustainable food production planning and regional food security, as land-resource limitations, population pressure, and regional differences require place-specific land management strategies (Wang, 2022).

Population growth, development pressure, and the expansion of built-up areas have intensified the conversion of agricultural land into non-agricultural uses. Such land-use changes may reduce the capacity of agricultural areas to sustain food production and create risks for regional food security, particularly in regions where food supply depends heavily on agricultural land availability (Harini et al., 2025). Grobogan Regency is one of the important agricultural regions in Central Java, where the agricultural sector plays a significant role in regional economic activity and serves as a major driver of agribusiness development, particularly through food crop commodities (Gamaputra & Nuswantara, 2023). This condition not only affects agricultural production capacity, but also influences farmers' livelihoods, agricultural income, and the economic resilience of rural communities that depend heavily on land-based activities. Declining land availability per capita may reduce farm sizes and productivity, thereby increasing socio-economic vulnerability and threatening the stability of regional food supply systems (Wang, 2025). In Grobogan Regency, a major rice-producing area in Central Java, the agricultural sector remains a key contributor to regional economic output. However, recent data indicate a decline in harvested area alongside increasing population pressure, signaling potential risks to long-term food security and regional economic stability. In this context, land-use conversion has emerged as an important driver of food security vulnerability, particularly when productive agricultural land is converted into non-agricultural uses and reduces the capacity of local areas to sustain food production (Martanto et al., 2023).

Previous studies on agricultural land carrying capacity have primarily focused on estimating land capacity, projecting land requirements, or analyzing land use change separately (Ruwanto & Banowati, 2021; Mubarokah et al., 2020). Most previous studies also tend to emphasize environmental or technical dimensions without sufficiently linking land carrying capacity and land requirements to agricultural production sustainability, regional food supply systems, and the socio-economic consequences for agricultural communities (Hidayat et al., 2025). This limitation reduces the ability to fully capture the dynamic interaction between population growth, land availability, and agricultural sustainability, particularly in terms of its socio-economic implications (Jayadi et al., 2017), Therefore, the novelty of this study lies in integrating agricultural land carrying capacity, land requirement projection, and GIS-based land-use analysis within a multi-temporal and spatially explicit framework at the sub-district level. This integration provides a broader contribution by linking agricultural carrying capacity with agricultural production sustainability, spatial inequality in land resources, and land-based food supply planning.

Furthermore, this study provides a multi-temporal assessment for 2014, 2019, and 2024, along with projections for 2029 and 2034, allowing for the identification of emerging spatial pressures and long-term trends. By combining quantitative analysis with GIS-based spatial evaluation, this study contributes to the development of more targeted, data-driven, and policy-relevant strategies for sustainable agricultural development.

Therefore, this study aims to: (1) analyze agricultural land carrying capacity in Grobogan Regency for 2014, 2019, and 2024; (2) project agricultural land requirements for 2029 and 2034 based on population growth; and (3) examine land use changes using a GIS-based approach. By integrating these analyses, this study provides a comprehensive evaluation of agricultural sustainability and offers a stronger basis for policy formulation in regions experiencing rapid demographic and land-use changes.

METHODS

Study Area

This study was conducted in Grobogan Regency, Central Java, Indonesia. Geographically, Grobogan Regency is bordered by Semarang City and Demak Regency to the west, Kudus, Pati, and Blora Regencies to the north, Blora Regency to the east, and Ngawi, Sragen, and Boyolali Regencies to the south. The regency comprises 19 sub-districts and 280 villages/urban villages, with Purwodadi serving as the administrative center. The total area of the region is approximately 197,586 hectares.

Research Design and Approach

Geographic Information Systems (GIS) were employed as the primary analytical tool to map and quantify land-use dynamics, identify spatial disparities in agricultural land resources, and support the assessment of agricultural land carrying capacity and land requirements based on population projections (Rochaida, 2016; Mulya et al., 2024).

Secondary data used in this study were obtained from official institutional sources. Population, harvested area, and rice production data for 2014, 2019, and 2024 were obtained from *Grobogan Regency in the Figures* publications issued by Statistics Indonesia of Grobogan Regency in 2015, 2020, and 2025, respectively. Additional variables, including agricultural productivity and agricultural land carrying capacity indicators, were processed based on these official statistical datasets.

Land-use data were obtained from Land Cover/Land Use (LCLU) spatial data and Digital Elevation Model Nasional (DEMNAS) provided by the Geospatial Information Agency (BIG). These spatial datasets were processed using Geographic Information Systems (GIS) through overlay techniques to identify land-use changes across different observation periods. All datasets underwent standardization and harmonization processes to ensure consistency across variables, spatial units, and observation periods.

The use of GIS in this study is particularly relevant as it allows for spatially explicit analysis of land dynamics, enabling a more accurate representation of regional disparities. Furthermore, the integration of quantitative and spatial approaches provides a comprehensive framework to assess both agricultural land capacity and socio-economic implications.

Research Variables

The independent variables include agricultural land area (ha), population size (persons), agricultural productivity (ton/ha), and land conversion. The dependent variables comprise agricultural land carrying capacity (σ) and agricultural land requirements (ha). Supporting variables include per capita rice consumption (kg/capita/year), population growth rate (%), and land use classification.

Data Analysis Methods

The analytical methods were selected to capture the relationship between land availability, population growth, and food demand. The Suhardjo–Tukiran method was used because it integrates land area, productivity, and consumption needs, making it suitable for assessing agricultural carrying capacity. The geometric population model was applied due to its simplicity and consistency in projecting population growth, while GIS analysis was employed to identify spatial disparities that cannot be captured by non-spatial methods. The population projection does not account for migration or economic changes, while the carrying capacity analysis assumes relatively stable productivity and consumption patterns. Therefore, the results should be interpreted as indicative estimates rather than absolute predictions.

Agricultural Land Carrying Capacity (DDL)

Agricultural land carrying capacity was estimated using equation (1), following Suhardjo (1990):

$$\sigma = x / K \text{..................... (1)}$$

where σ represents the agricultural land carrying capacity index (dimensionless), x denotes harvested land area per capita (ha/person), and K refers to the minimum land requirement needed to achieve food self-sufficiency (ha/person). The value of K was calculated using equation (2):

$$K = \frac{KMF}{Pr} \text{........................... (2)}$$

Where KMF represents the minimum physical food consumption requirement, standardized at 124 kg of rice per capita per year based on Regulation of the Minister of Agriculture of the Republic of Indonesia Number 16/Permentan/HK.140/4/2015, while Pr represents rice productivity measured in kilograms per hectare (kg/ha). Therefore, the resulting unit of K is hectares per person (ha/person). The value of x was obtained by dividing harvested agricultural land area (ha) by total population (persons), thereby representing land availability per capita. The DDL value (σ) indicates the comparison between available agricultural land per capita and the minimum land requirement needed for food self-sufficiency.

The carrying capacity classification follows the criteria proposed by Moniaga (2011), consisting of three categories: Class I ($\sigma > 2.47$), indicating that agricultural land is sufficient to support food self-sufficiency and provide a decent standard of living; Class II ($1 \leq \sigma \leq 2.47$), indicating that land resources are still sufficient for food self-sufficiency but have limited capacity to support broader economic welfare; and Class III ($\sigma < 1$), indicating that agricultural land is insufficient to meet minimum food self-sufficiency needs. These threshold values were used to evaluate the degree of land adequacy and socio-economic sustainability across sub-districts in Grobogan Regency.

Projection of Agricultural Land Requirements (KLPR)

Agricultural land requirements were projected using Equation (3):

$$KLPR = (KPB \times Po)(1 + r)^{n} / (Pr \times 0.632) \text{ .... (3)}$$

Where (KLPR) denotes projected agricultural land requirements, KPB denotes per capita rice consumption (114.6 kg/capita/year), Po is the base-year population (persons), r represents the annual population growth rate (%), n is the projection period (years), Pr refers to rice productivity (kg/ha), and 0.632 is the conversion factor from harvested paddy into rice. This projection assumes that rice productivity, per capita rice consumption, and the paddy-to-rice conversion factor remain constant throughout the projection period. These assumptions were applied to simplify the estimation of future agricultural land requirements and to evaluate the potential impact of population growth on land demand. However, changes in productivity, consumption patterns, technological development, or climate conditions may influence future agricultural production capacity and food supply sustainability, meaning that the projection results should be interpreted as indicative estimates rather than absolute predictions. Population projections were estimated using the geometric growth model presented in equation (4):

$$Pn = P_0(1 + r)^n \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where (Pn) represents the projected population in year (n), (P_0) denotes the base-year population, (r) refers to the annual population growth rate, and (n) indicates the projection period. In this study, the geometric population growth model was used to estimate the population of Grobogan Regency for 2029 and 2034, which was subsequently used to calculate projected agricultural land requirements.

Land Use Change Analysis

Land use change was analyzed using a GIS-based spatial overlay technique by comparing land use maps across three time periods (2014, 2019, and 2024). The land-use classification system consisted of four categories: forest, non-forest vegetation, agricultural land, and built-up areas. Spatial data were obtained from Land Cover/Land Use (LCLU) data provided by the Geospatial Information Agency (BIG) and processed using GIS through overlay techniques to identify land conversion between observation periods. Land-use change percentages were calculated by comparing the area differences of each category relative to the total regional area. All spatial data were standardized to ensure consistency across years. The overlay results were compared across the 2014–2019, 2019–2024, and 2014–2024 periods to identify the direction and magnitude of land-use conversion. This approach enables the identification of spatial patterns and the extent of land conversion over time.

RESULT AND DISCUSSION

Population Growth in Grobogan Regency

The population of Grobogan Regency increased from 1,351,790 in 2014 to 1,364,757 in 2019 and further to 1,506,374 in 2024, with an average annual growth rate of 1.09%. Based on geometric projections, the population is expected to reach 1,590,174 in 2029 and 1,678,635 in 2034 (Table 1). Purwodadi Sub-district consistently recorded the highest population density throughout the observation period, whereas Klambu Sub-district exhibited the lowest population size.

Table 1. Population and Population Projection of Grobogan Regency by District, 2014–2034

District	Population 2014 (Persons)	Population 2019 (Persons)	Population 2024 (Persons)	Growth Rate (%)	Projection 2029 (Persons)	Projection 2034 (Persons)
Kedungjati	39,834	39,820	45,199	1.27	48,147	51,287
Karangayung	90,170	91,026	104,145	1.45	111,925	120,286
Penawangan	59,081	59,169	66,655	1.21	70,799	75,200
Toroh	107,280	108,198	121,679	1.27	129,588	138,011
Geyer	60,154	60,016	68,328	1.28	72,823	77,613
Pulokulon	101,131	101,921	113,072	1.12	119,561	126,423
Kradenan	75,944	76,515	85,459	1.19	90,655	96,166
Gabus	67,883	67,850	76,438	1.19	81,112	86,071
Ngaringan	66,717	67,603	72,076	0.78	74,915	77,865
Wirosari	86,343	87,343	96,216	1.09	101,568	107,218
Tawangharjo	54,878	55,571	60,537	0.99	63,582	66,780
Grobogan	75,734	76,858	80,386	0.60	82,818	85,324
Purwodadi	135,698	138,310	143,152	0.54	147,031	151,015
Brati	46,492	47,063	52,618	1.25	55,977	59,551
Klambu	34,779	35,017	40,295	1.48	43,373	46,686
Godong	79,137	79,797	90,807	1.39	97,272	104,198
Gubug	77,074	77,741	86,974	1.22	92,391	98,146
Tegowanu	53,860	55,002	59,036	0.92	61,808	64,709
Tanggungharjo	39,601	39,937	43,302	0.90	45,280	47,349
Grobogan Regency		1,364,757	1,506,374	1.09	1,590,174	1,678,635

Source: Statistics Indonesia (BPS) of Grobogan Regency, 2024 (processed)

This continuous population growth indicates a rising demographic pressure on land resources, particularly in regions with uneven population distribution. At the sub-district level, the concentration of population in areas such as Purwodadi suggests a higher potential for localized land scarcity compared to less dense areas. This imbalance reflects spatial heterogeneity in population distribution, which plays a critical role in shaping agricultural land availability per capita.

The increasing population trend is likely to intensify competition for land between agricultural and non-agricultural uses, driven by urban expansion, infrastructure development, and economic activities (Afni, 2016). As a result, the availability of agricultural land per capita tends to decline over time, creating structural challenges for maintaining stable food production systems. This condition highlights that population growth is not only a demographic phenomenon but also a key driver influencing land resource allocation and agricultural sustainability.

These findings emphasize that the impact of population growth on agricultural systems cannot be assessed solely at the aggregate level. Instead, a spatial perspective is required to capture variations across sub-districts, where certain areas may experience significantly higher pressure than others. This spatial variation in population pressure and agricultural land availability is a key factor shaping agricultural land carrying capacity at the sub-district level (Harini et al., 2025a), which is further analyzed in the following section.

Harvested Area and Rice Productivity

The harvested area of rice in Grobogan Regency increased from 113,549 ha in 2014 to 132,155 ha in 2019, but declined to 119,068 ha in 2024. In contrast, rice productivity improved from 5,099.80 kg/ha in 2014 to 6,174.51 kg/ha in 2024, indicating increased agricultural efficiency despite the reduction in cultivated land. At the sub-district level, Godong consistently recorded the largest harvested area, while Kedungjati exhibited the smallest throughout the observation period, reflecting the uneven spatial distribution of agricultural resources.

Table 2. Results of Agricultural Land Carrying Capacity Calculation in Grobogan Regency, 2014

District	Population	Harvested Area (ha)	Rice Productivity (kg/ha)	DDL (σ)
Kedungjati	39,834	929	4,729.82	0.89
Karangayung	90,170	3,370	4,756.97	1.43
Penawangan	59,081	8,329	5,183.22	5.89
Toroh	107,280	6,312	4,963.56	2.36
Geyer	60,154	3,470	3,934.87	1.83
Pulokulon	101,131	7,292	5,067.33	2.95
Kradenan	75,944	6,063	5,631.04	3.63
Gabus	67,883	7,804	4,525.37	4.20
Ngaringan	66,717	7,888	4,868.03	4.64
Wirosari	86,343	7,590	5,440.71	3.86
Tawangharjo	54,878	5,204	5,070.71	3.88
Grobogan	75,734	4,640	5,765.95	2.85
Purwodadi	135,698	8,028	5,200.80	2.48
Brati	46,492	4,416	5,532.84	4.24
Klambu	34,779	4,430	5,157.56	5.30
Godong	79,137	12,508	5,469.06	6.97
Gubug	77,074	7,014	5,268.32	3.87
Tegowanu	53,860	6,255	4,438.05	4.16
Tanggungharjo	39,601	2,007	4,535.13	1.85
Grobogan Regency	1,351,790	113,549	5,099.80	3.45

Source: Statistics Indonesia (BPS) and Department of Agriculture of Grobogan Regency, 2015 (processed)

This contrasting trend suggests a shift toward agricultural intensification, where productivity improvements partially offset the decline in land availability (Ibrahim et al., 2023). However, this condition is likely driven by land conversion and increasing population pressure, which reduces agricultural land per capita over time (Harini, 2025b). This finding aligns with previous studies; however, unlike prior research that emphasizes productivity as the main determinant, this study highlights the dominant role of spatial inequality in shaping carrying capacity (Bununu et al., 2023). As a result, reliance on productivity gains alone may not be sufficient to sustain long-term food production, indicating potential risks to food security (Ikhwanto, 2019). These findings highlight the importance of balancing land availability and productivity, which subsequently influences agricultural land carrying capacity as discussed in the next section.

Table 3. Results of Agricultural Land Carrying Capacity Calculation in Grobogan Regency, 2019

District	Population	Harvested Area (ha)	Rice Productivity (kg/ha)	DDL (σ)
Kedungjati	39,820	1,065	5,293.90	1.14
Karangayung	91,026	5,219	5,950.95	2.75
Penawangan	59,169	9,029	6,086.06	7.49
Toroh	108,198	7,368	6,189.06	3.40
Geyer	60,016	6,460	5,605.57	4.87
Pulokulon	101,921	9,671	5,892.26	4.51
Kradenan	76,515	8,130	5,587.58	4.79
Gabus	67,850	8,130	5,582.41	5.39
Ngaringan	67,603	9,681	5,689.70	6.57
Wirosari	87,343	10,014	5,955.76	5.51
Tawangharjo	55,571	5,390	5,781.26	4.52
Grobogan	76,858	4,909	5,962.72	3.07
Purwodadi	138,310	7,851	6,143.55	2.81
Brati	47,063	4,020	6,007.46	4.14
Klambu	35,017	4,351	6,087.34	6.10
Godong	79,797	12,795	6,195.47	8.01
Gubug	77,741	7,932	6,086.61	5.01
Tegowanu	55,002	7,845	5,889.87	6.77
Tanggungharjo	39,937	2,382	5,378.67	2.59
Grobogan Regency	1,364,757	132,155	5,916.13	4.62

Source: Statistics Indonesia (BPS) and the Department of Agriculture of Grobogan Regency, 2020 (processed)

Agricultural Land Carrying Capacity

The assessment of agricultural land carrying capacity (DDL) was conducted at the sub-district level using a minimum physical consumption (KMF) value of 124 kg/capita/year, as stipulated in the Regulation of the Minister of Agriculture of the Republic of Indonesia Number

16/Permentan/HK.140/4/2015. The results of agricultural land carrying capacity in 2014 are presented in Table 2. In 2014, the aggregate carrying capacity of Grobogan Regency was recorded at σ = 3.45, indicating that the region was classified as Class I (surplus), meaning it was capable of achieving food self-sufficiency while providing a decent standard of living. Spatially, significant disparities were observed across sub-districts. Godong exhibited the highest carrying capacity (σ = 6.97), reflecting strong agricultural productivity and sufficient land availability, whereas Kedungjati was the only sub-district categorized as Class III (σ = 0.89), indicating insufficient capacity for food self-sufficiency. The results for 2019 are presented in Table 3.

By 2019, the aggregate DDL increased to σ = 4.62, reflecting an overall improvement in agricultural capacity. This increase was driven by higher productivity and expansion of harvested area, indicating improved efficiency in land utilization. All sub-districts reached at least Class II, suggesting a more balanced distribution of agricultural capacity compared to 2014. The results for 2024 are presented in Table 4.

Table 4. Results of Agricultural Land Carrying Capacity Calculation in Grobogan Regency, 2024

District	Population	Harvested Area (ha)	Rice Productivity (kg/ha)	DDL (σ)
Kedungjati	45,199	1,022	6,150.68	1.12
Karangayung	104,145	4,585	6,381.24	2.27
Penawangan	66,655	7,111	6,395.16	5.50
Toroh	121,679	6,988	6,169.15	2.86
Geyer	68,328	5,910	5,935.03	4.14
Pulokulon	113,072	8,522	6,104.55	3.71
Kradenan	85,459	7,299	6,171.67	4.25
Gabus	76,438	8,635	5,994.09	5.46
Ngaringan	72,076	7,677	6,133.78	5.27
Wirosari	96,216	7,590	6,128.59	3.90
Tawangharjo	60,537	7,243	6,017.26	5.81
Grobogan	80,386	6,819	6,132.13	4.19
Purwodadi	143,152	6,989	6,276.58	2.47
Brati	52,618	4,333	6,009.46	3.99
Klambu	40,295	4,280	6,110.05	5.23
Godong	90,807	8,210	6,478.44	4.72
Gubug	86,974	6,612	6,158.50	3.78
Tegowanu	59,036	6,491	6,252.04	5.54
Tanggungharjo	43,302	2,752	6,166.06	3.16
Grobogan Regency	1,506,374	119,068	6,174.51	3.94

Source: Statistics Indonesia (BPS) and the Department of Agriculture of Grobogan Regency, 2020 (processed)

However, in 2024, the aggregate carrying capacity declined to σ = 3.94, although it remained within Class I. This decline occurred despite higher rice productivity because the increase in population and the reduction in harvested area was proportionally greater than the productivity gains achieved during the same period. The harvested area decreased from 132,155 ha in 2019 to 119,068 ha in 2024, while the population increased from 1,364,757 to 1,506,374 persons, resulting in lower agricultural land availability per capita. In addition, spatial disparities among sub-districts contributed to uneven agricultural capacity, particularly in densely populated areas such as Purwodadi and Karangayung, where land pressure became more apparent. At the sub-district level, Karangayung, Kedungjati, and Purwodadi were classified as Class II, indicating increasing constraints in agricultural capacity.

Table 5. Classification of Agricultural Land Carrying Capacity in Grobogan Regency, 2014–2024

Year	Class	DDL Criteria	Number of Districts	Districts
2014	Class I	σ > 2.47	14	Penawangan, Pulokulon, Kradenan, Gabus, Ngaringan, Wirosari, Tawangharjo, Grobogan, Purwodadi, Brati, Klambu, Godong, Gubug, Tegowanu
	Class II	1 ≤ σ ≤ 2.47	4	Karangayung, Toroh, Geyer, Tanggungharjo
	Class III	σ < 1	1	Kedungjati
2019	Class I	σ > 2.47	18	Penawangan, Pulokulon, Kradenan, Gabus, Ngaringan, Wirosari, Tawangharjo, Grobogan, Purwodadi, Brati, Klambu, Godong, Gubug, Tegowanu, Karangayung, Toroh, Geyer, Tanggungharjo
	Class II	1 ≤ σ ≤ 2.47	1	Kedungjati
	Class III	σ < 1	0	–
2024	Class I	σ > 2.47	16	Penawangan, Pulokulon, Kradenan, Gabus, Ngaringan, Wirosari, Tawangharjo, Grobogan, Tanggungharjo, Brati, Klambu, Godong, Gubug, Tegowanu, Geyer, Toroh
	Class II	1 ≤ σ ≤ 2.47	3	Karangayung, Kedungjati, Purwodadi
	Class III	σ < 1	0	–

Source: Processed data

The classification results in Table 5 further confirm these dynamics. The number of Class I sub-districts increased from 14 in 2014 to 18 in 2019, but declined to 16 in 2024. Sub-districts such as Karangayung, Kedungjati, and Purwodadi shifted to Class II, indicating emerging constraints in land capacity. This trend highlights that improvements in productivity alone are no longer sufficient to offset the effects of population growth and land conversion.

From a broader perspective, these conditions pose significant risks to long-term food security. Declining land availability per capita reduces production resilience and increases dependence on productivity gains, making the system more vulnerable to external shocks such as climate variability (Das & Mondal, 2021). In addition, sub-districts experiencing declining carrying capacity may face socio-economic challenges, including reduced farm income and increasing regional inequality (Sudrajat et al., 2021).

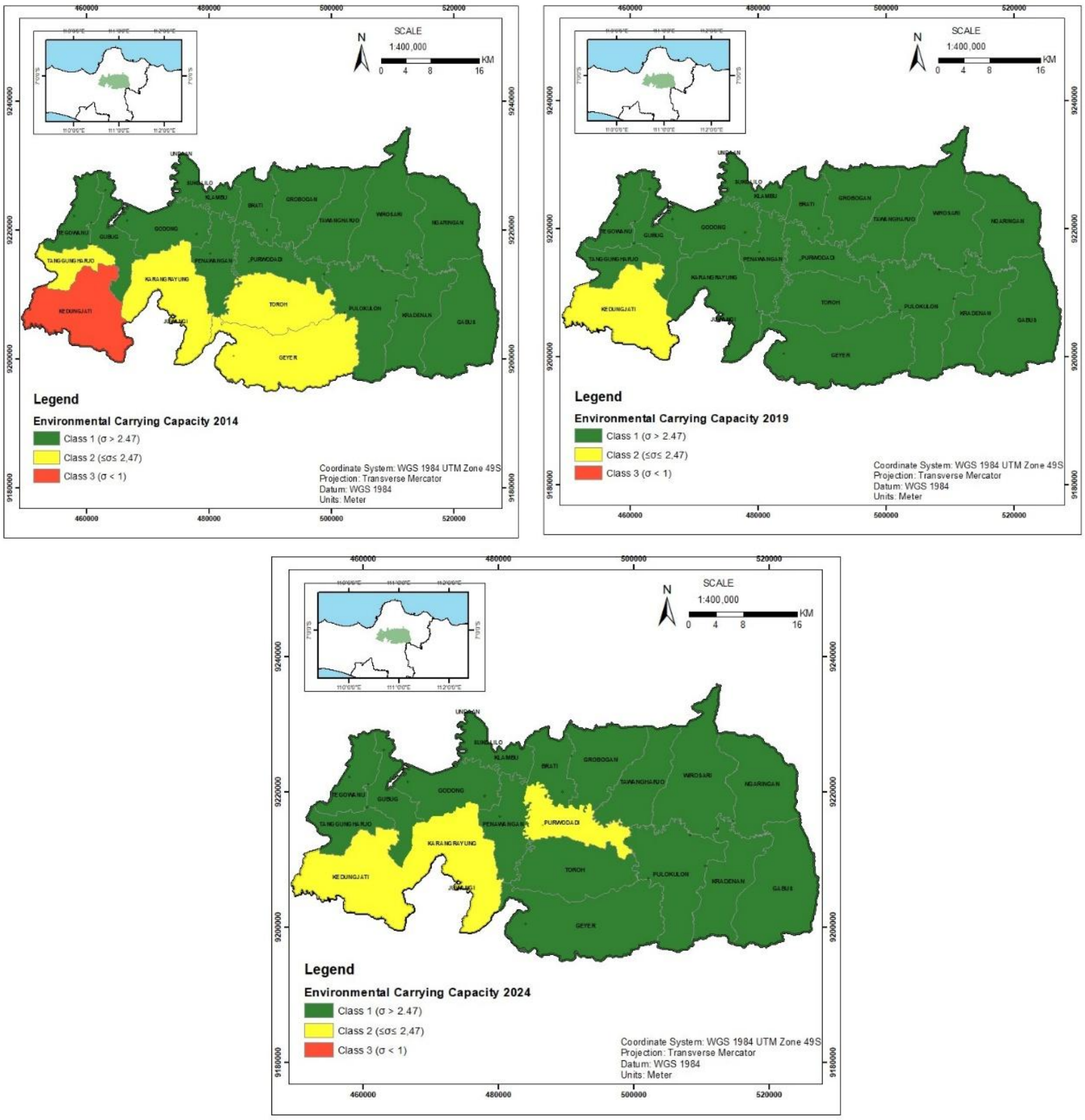


Figure 3. Map of Agricultural Land Carrying Capacity of Grobogan Regency in 2014, 2019, and 2024

Therefore, agricultural sustainability in Grobogan Regency requires not only improving productivity, but also strengthening land management and spatial planning policies. Policy interventions should focus on controlling land conversion, optimizing land use allocation, and ensuring a more equitable distribution of agricultural resources across sub-districts.

Figure 3 illustrates the spatial distribution of agricultural land carrying capacity across sub-districts in 2014, 2019, and 2024. The map highlights both improvements and emerging pressure areas, particularly in regions with higher population concentration. This confirms that agricultural land pressure is spatially uneven and concentrated in specific sub-districts, emphasizing the importance of spatial-based policy interventions.

Projection of Agricultural Land Requirements

The KPB value used in the calculation of agricultural land requirements (KLPR) is 114.6 kg/capita/year, derived from the conversion of national rice consumption (124 kg/capita/year × 0.925 correction factor). The projection of agricultural land requirements in Grobogan Regency based on population growth is presented in Tables 6 and 7.

Table 6. Projection of Agricultural Land Requirements in Grobogan Regency, 2029

District	Population 2029	KPB (kg)	P (kg/ha)	Pr × 0.632	KLPR (ha)
Kedungjati	48,147	114.6	6,150.68	3,887.23	1,419.42
Karangayung	111,925	114.6	6,381.24	4,032.95	3,180.45
Penawangan	70,799	114.6	6,395.16	4,041.74	2,007.43
Toroh	129,588	114.6	6,169.15	3,898.90	3,808.96
Geyer	72,823	114.6	5,935.03	3,750.94	2,224.90
Pulokulon	119,561	114.6	6,104.55	3,858.08	3,551.44
Kradenan	90,655	114.6	6,171.67	3,900.49	2,663.51
Gabus	81,112	114.6	5,994.09	3,788.27	2,453.73
Ngaringan	74,915	114.6	6,133.78	3,876.55	2,214.66
Wirosari	101,568	114.6	6,128.59	3,873.27	3,005.14
Tawangharjo	63,582	114.6	6,017.26	3,802.91	1,916.02
Grobogan	82,818	114.6	6,132.13	3,875.51	2,448.96
Purwodadi	147,031	114.6	6,276.58	3,966.80	4,247.70
Brati	55,977	114.6	6,009.46	3,797.98	1,689.06
Klambu	43,373	114.6	6,110.05	3,861.55	1,287.19
Godong	97,272	114.6	6,478.44	4,094.37	2,722.62
Gubug	92,391	114.6	6,158.50	3,892.17	2,720.34
Tegowanu	61,808	114.6	6,252.04	3,951.29	1,792.62
Tanggungharjo	45,280	114.6	6,166.06	3,896.95	1,331.58
Grobogan Regency	1,590,174	114.6	6,174.51	3,902.29	46,699.19

Source: Processed data

In 2029, the total agricultural land requirement is projected to reach 46,699.19 ha. Purwodadi Sub-district records the highest land demand (4,247.70 ha), while Klambu shows the lowest (1,287.19 ha), reflecting differences in population distribution and demographic pressure across sub-districts. These variations indicate that areas with larger populations tend to require more extensive agricultural land to meet food needs. Compared to the harvested area in 2024 (119,068 ha), the projected requirement remains relatively lower, suggesting that the region still has sufficient capacity to meet future food demand under current conditions. However, this aggregate surplus does not necessarily indicate equal land availability across all sub-districts. Several areas with high population concentration, such as Purwodadi and Karangayung, experience greater demographic pressure and lower land availability per capita compared to other sub-districts. As a result, land pressure emerges not at the regional level, but through localized land scarcity and spatial inequality in agricultural resource distribution. This condition indicates that future food security challenges are closely related to spatial imbalances in land availability rather than the total regional land area alone.

Table 7. Projection of Agricultural Land Requirements in Grobogan Regency, 2034

District	Population 2034	KPB (kg)	P (kg/ha)	Pr × 0.632	KLPR (ha)
Kedungjati	51,287	114.6	6,150.68	3,887.23	1,511.99
Karangayung	120,286	114.6	6,381.24	4,032.95	3,418.04
Penawangan	75,200	114.6	6,395.16	4,041.74	2,132.23
Toroh	138,011	114.6	6,169.15	3,898.90	4,056.53
Geyer	77,613	114.6	5,935.03	3,750.94	2,371.25
Pulokulon	126,423	114.6	6,104.55	3,858.08	3,755.26
Kradenan	96,166	114.6	6,171.67	3,900.49	2,825.45
Gabus	86,071	114.6	5,994.09	3,788.27	2,603.76
Ngaringan	77,865	114.6	6,133.78	3,876.55	2,301.89
Wirosari	107,218	114.6	6,128.59	3,873.27	3,172.30
Tawangharjo	66,780	114.6	6,017.26	3,802.91	2,012.39
Grobogan	85,324	114.6	6,132.13	3,875.51	2,523.05
Purwodadi	151,015	114.6	6,276.58	3,966.80	4,362.81
Brati	59,551	114.6	6,009.46	3,797.98	1,796.89
Klambu	46,686	114.6	6,110.05	3,861.55	1,385.51
Godong	104,198	114.6	6,478.44	4,094.37	2,916.46
Gubug	98,146	114.6	6,158.50	3,892.17	2,889.77
Tegowanu	64,709	114.6	6,252.04	3,951.29	1,876.78
Tanggungharjo	47,349	114.6	6,166.06	3,896.95	1,392.42
Grobogan Regency	1,678,635	114.6	6,174.51	3,902.29	49,297.08

Source: Processed data

By 2034, the agricultural land requirement is projected to increase to 49,297.08 ha, indicating a consistent upward trend in line with population growth. However, this apparent surplus may be misleading when viewed from a spatial perspective. The increasing land demand is primarily driven by population growth, which intensifies pressure on agricultural land, particularly in high-density sub-districts. This condition may lead to localized imbalances where land availability becomes insufficient despite regional adequacy. As a result, the growing gap between land demand and land distribution poses potential risks to long-term food security. In addition, declining land availability per capita may reduce farm sizes and limit farmers' income, thereby increasing socio-economic vulnerability in rural communities. These findings highlight the importance of integrating spatial planning and land-use control policies to ensure balanced agricultural development. This finding is consistent with previous studies indicating that increasing population pressure and land conversion significantly reduce land carrying capacity and threaten long-term agricultural sustainability (Akmal & Mohammadi, 2025).

Land Use Change

The analysis of land use change in Grobogan Regency over the period 2014–2024 using a GIS-based spatial overlay is presented in Tables 10 and 11.

Table 10. Percentage Changes in Land Use in Grobogan Regency, 2014–2019

Land Use Type	2014 (%)	2019 (%)	Change (%)
Forest	15.96	13.60	-2.36%
Non-Forest Vegetation	33.22	35.21	+1.99%
Agricultural Land	12.97	13.12	+0.15%
Built-up Land	37.85	38.07	+0.22%

Source: GIS analysis results (processed)

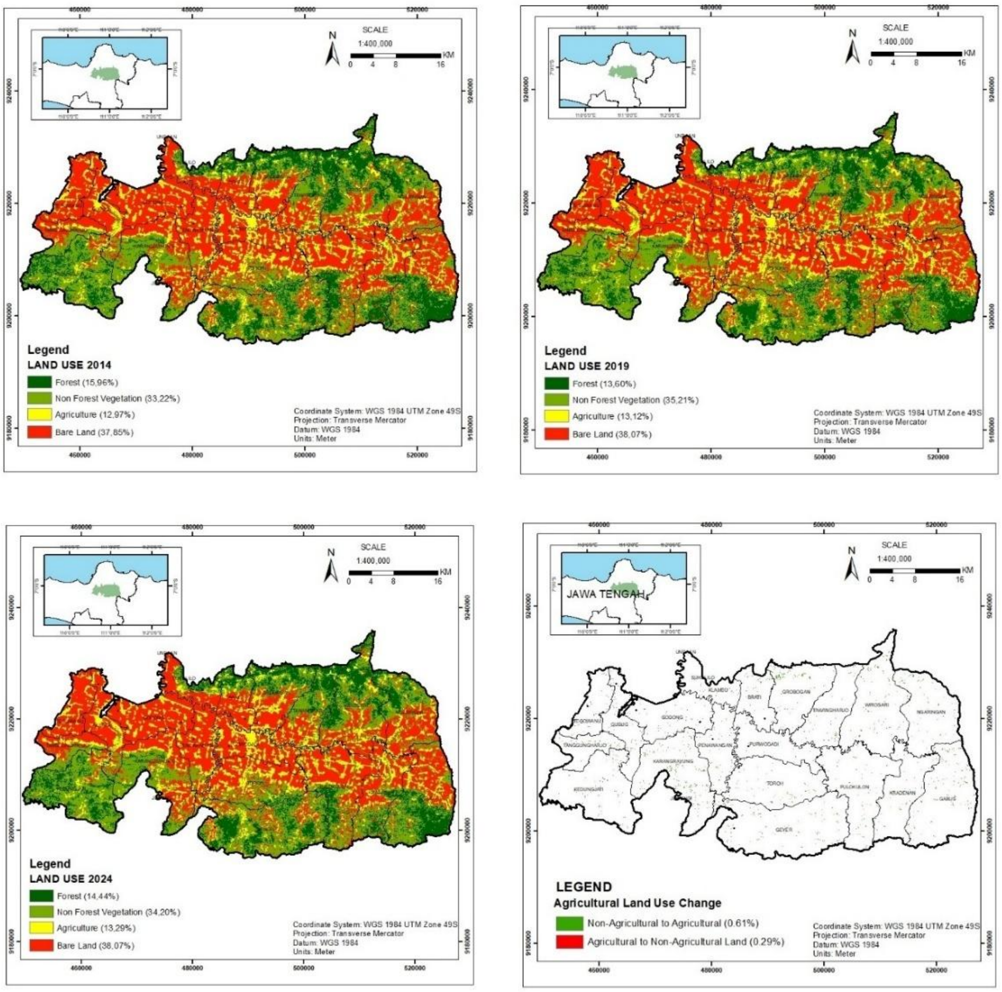
During the 2014–2019 period, forest areas experienced the most significant decline (-2.36%), followed by increases in non-forest vegetation (+1.99%), agricultural land (+0.15%), and built-up areas (+0.22%). This pattern indicates a conversion of forest land into other land uses, particularly agriculture and non-forest vegetation, which is likely driven by the need to expand productive land in response to population growth and economic demand.

Table 11. Percentage Changes in Land Use in Grobogan Regency, 2019–2024

Land Use Type	2014 (%)	2019 (%)	Change (%)
Forest	13.60	14.44	+0.84%
Non-Forest Vegetation	35.21	34.20	-1.01%
Agricultural Land	13.12	13.29	+0.17%
Built-up Land	38.07	38.07	0%

Source: GIS analysis results (processed)

During the 2019–2024 period, forest areas showed a recovery (+0.84%), while non-forest vegetation declined (-1.01%) and agricultural land increased slightly (+0.17%). Built-up areas remained relatively stable, indicating a slowdown in urban expansion. Overall, the net conversion from non-agricultural land to agricultural land (0.61%) exceeded the reverse conversion (0.29%), suggesting ongoing agricultural extensification. These conversion values were derived from spatial overlay analysis, which identifies the direction of land-use transition between agricultural and non-agricultural categories rather than merely comparing the aggregate percentage of each land-use class. However, the increase in agricultural land area identified through GIS analysis does not necessarily indicate an increase in harvested area. Agricultural land area refers to land classified spatially as agricultural use, whereas harvested area reflects the actual intensity of cultivation within a given year. Therefore, harvested area may decline despite the expansion of agricultural land due to reduced cropping intensity, productivity constraints, climate variability, or changes in farming practices. This finding indicates that the expansion of agricultural land alone is insufficient to ensure higher



agricultural production capacity and sustainable food supply.

Figure 4. Land Use and Agricultural Land Use Change Map of Grobogan Regency, 2014–2024

However, these dynamics reflect a complex interaction between environmental and socio-economic factors. The expansion of agricultural land may support short-term food production, but it also indicates increasing pressure on land resources and potential environmental trade-offs, particularly related to forest sustainability. At the same time, the gradual increase in built-up areas, although limited, signals a long-term trend of land competition between agricultural and non-agricultural uses. This condition may reduce the availability of productive land per capita and pose risks to long-term food security, especially in areas experiencing population concentration. Therefore, land use dynamics in Grobogan Regency highlight the need for integrated spatial planning and land management policies to balance agricultural expansion, environmental conservation, and socio-economic development.

As shown in Figure 4, land-use patterns in Grobogan Regency changed spatially during the 2014–2024 period. The figure illustrates that agricultural and non-agricultural land transitions were not evenly distributed across the region, but occurred in specific areas. This spatial pattern supports the results of the overlay analysis by showing that land-use change is not only reflected in aggregate percentage changes, but also in the location and direction of land conversion.

Policy Implications for Sustainable Agricultural Development

The findings indicate that, although the overall agricultural land carrying capacity in Grobogan Regency remains positive, several warning signals have emerged. These include a decline in the number of Class I sub-districts from 18 in 2019 to 16 in 2024, an increase in projected land requirements reaching 49,297 ha by 2034, and a reduction in harvested area from 132,155 ha in 2019 to 119,068 ha in 2024. While the aggregate gap between land availability and demand remains sufficient, spatial analysis reveals localized pressure, particularly in high-density sub-districts such as Purwodadi, Karangayung, and Kedungjati, which experienced lower carrying capacity and declining land availability per capita. These areas require priority policy intervention through stricter land conversion control, protection of Sustainable Agricultural Land Areas (KP2B), and more efficient land-use allocation to maintain agricultural production sustainability.

These conditions indicate the need for spatially targeted agricultural policies rather than uniform regional interventions. First, the protection of Sustainable Agricultural Land Areas (KP2B) should be strengthened, particularly in sub-districts with declining carrying capacity and increasing demographic pressure. Second, agricultural intensification through appropriate technology, irrigation improvement, and productivity-oriented farming practices should be prioritized to compensate for the decline in harvested area. Third, GIS-based land monitoring should be integrated into regional planning to support early detection of land conversion and spatial inequality in agricultural land resources. Previous studies have also emphasized that agricultural sustainability is closely linked to rural livelihoods and economic resilience, particularly in regions experiencing rapid demographic growth (Bachtiar et al., 2023). Therefore, these policy directions are essential not only to maintain agricultural production sustainability, but also to protect farmers' livelihoods and strengthen long-term regional food security.

CONCLUSION

This study shows that the agricultural land carrying capacity of Grobogan Regency remained positive at the aggregate level during the 2014–2024 period, with σ values of 3.45 in 2014, 4.62 in 2019, and 3.94 in 2024. However, the decline in the number of Class I sub-districts and the shift of several areas into Class II indicate increasing localized pressure on agricultural land resources. The findings also show that projected agricultural land requirements will continue to increase, reaching 49,297.08 ha by 2034, driven by population growth. Although land availability remains relatively sufficient at the regency level, spatial pressures in Purwodadi, Karangayung, and Kedungjati indicate that regional adequacy does not necessarily reflect local agricultural sustainability.

The main contribution of this study lies in integrating agricultural land carrying capacity, land requirement projection, and GIS-based land-use analysis within a multi-temporal and spatially explicit framework at the sub-district level. This integrated approach provides a stronger basis for identifying spatial inequality in agricultural land resources and for formulating targeted land-use and agricultural planning policies. The findings imply that sustainable agricultural development in Grobogan Regency should prioritize the protection of productive agricultural land, stricter control of land conversion, productivity improvement, and GIS-based spatial monitoring to support long-term food security and rural economic resilience. This study is limited by its reliance on secondary data and projection assumptions that do not fully account for migration, climate variability, changes in productivity, land ownership patterns, and household-level socio-economic conditions. Future research should incorporate these variables to provide a more comprehensive assessment of agricultural resilience and sustainable food security.

Author Contribution

Muhammad Fauzan (Author 1) contributed to the conceptualization of the study, methodology development, data collection, data analysis, interpretation of the findings, and drafting of the manuscript. Mochammad Arief Budihardjo (Author 2) contributed to the refinement of the research topic, critical review and revision of the manuscript, and supervision of the research process. Budi Prasetyo Samadikun (Author 3) contributed to manuscript review, language editing, and critical revision of the manuscript. All authors have read and approved the final version of the manuscript.

REFERENCES

Afni, N. (2016). Daya dukung lingkungan Kecamatan Pattalassang Kabupaten Takalar [Environmental carrying capacity of Pattalassang District, Takalar Regency]. *Plano Madani, 5*(1), 74–85. https://doi.org/10.24252/jpm.v5i1.984

Akmal, F. A., & Mohammadi, Y. (2025). The nexus of agricultural land use change and food security: A comprehensive systematic review. *Land Use Policy, 158*, 107717. https://doi.org/10.1016/j.landusepol.2025.107717

Bachtiar, B. A., Haq, F. S., Janah, M., Amalia, N. R., Novaldi, J., & Budiasih, B. (2023). Penyerapan tenaga kerja sektor pertanian tanaman pangan pada Generasi Z [Labor absorption in the food crop agricultural sector among Generation Z]. *Seminar Nasional Official Statistics, 2023*(1), 491–502. https://doi.org/10.34123/semnasoffstat.v2023i1.1706

Bununu, Y., Bello, A., & Ahmed, A. (2023). Land cover, land use, climate change and food security. *Sustainable Earth Reviews, 6*. https://doi.org/10.1186/s42055-023-00065-4

Cahyanto, A. (2021). Analisis daya dukung lahan dan proyeksi kebutuhan lahan pertanian di Kabupaten Klaten [Analysis of land carrying capacity and projection of agricultural land requirements in Klaten Regency]. *Jurnal Samudra Geografi, 4*(1), 16–29. https://doi.org/10.33059/jsg.v4i1.2505

Das, S., & Mondal, P. (2021). Socio-economic factors affecting agricultural production and income in Bangladesh. *Journal of Agricultural Socio-Economics (JASE), 2*(2), 56–63. https://doi.org/10.33474/jase.v2i2.10856

Faoziyah, U., Rosyaridho, M. F., & Panggabean, R. (2024). Unearthing agricultural land use dynamics in Indonesia: Between food security and policy interventions. *Land, 13*(12), 2030. https://doi.org/10.3390/land13122030

Gamaputra, Y., & Nuswantara, B. (2023). Analisis komoditas unggulan pertanian tanaman pangan berdasarkan nilai produksi di Kabupaten Grobogan [Analysis of leading food crop agricultural commodities based on production value in Grobogan Regency]. *Journal Agrotech, 13*(2), 144–149. https://doi.org/10.31970/agrotech.v13i2.133

Harini, R., Ariani, R. D., Kuncoro, A. B., Buana, A. S., & Puspitaningrum, I. N. (2025a). Impact of land conversion on agricultural carrying capacity and sustainable food agricultural land in Sleman Regency. *Jurnal Geografi, 17*(1), 15–31. https://doi.org/10.24114/jg.v17i1.57795

Harini, R., Rijanta, R., Pangaribowo, E. H., Putri, R. F., & Sukri, I. (2025b). Modeling the effects of land use change on agricultural carrying capacity and food security. *Global Journal of Environmental Science and Management, 11*(2), 533–554. https://doi.org/10.22034/gjesm.2025.02.10

Hidayat, I., Efani, A., & K, M. P. (2025). From land capability to food security: Mapping agricultural spatial directives in West Nusa Tenggara using GIS-based analysis. *Journal of Agri-Sociopreneur and Rural Development, 36*(December), 246–263. https://doi.org/10.21776/ub.habitat.2025.036.3.20

Ibrahim, J. T., Amir, N. O., & Suprapti, P. S. D. (2023). Minat anak petani terhadap pekerjaan di sektor pertanian [Farmers' children's interest in working in the agricultural sector]. *Paradigma Agribisnis, 6*(1), 10–19. https://doi.org/10.33603/jpa.v6i1.8762

Ikhwanto, A. (2019). Alih fungsi lahan pertanian menjadi lahan nonpertanian [Conversion of agricultural land into non-agricultural land]. *Jurnal Hukum dan Kenotariatan, 3*(1), 60–73. https://doi.org/10.33474/hukeno.v3i1.1919

Jakapratama, I. D., Arrasyid, R., Zidan, M., Alfiah, N. S., & Alifia Rahma, S. D. (2021). Analisis daya dukung dan kebutuhan lahan pertanian di Kabupaten Purwakarta tahun 2028 [Analysis of carrying capacity and agricultural land requirements in Purwakarta Regency in 2028]. *Jurnal Kajian Ilmu dan Pendidikan Geografi, 4*(1), 16–29. https://doi.org/10.33059/jsg.v4i1.2505

Jayadi, I. M. Y., Christiawan, P. I., & Sarmita, I. M. (2017). Dampak pertumbuhan penduduk terhadap daya dukung lahan pertanian di Desa Sambangan [The impact of population growth on agricultural land carrying capacity in Sambangan Village]. *Jurnal Pendidikan Geografi Undiksha, 5*(2). https://doi.org/10.23887/jjpg.v5i2.20658

Kementerian Pertanian Republik Indonesia. (2015). *Peraturan Menteri Pertanian Republik Indonesia Nomor 16/Permentan/HK.140/4/2015 tentang Pedoman Penguatan Lembaga Distribusi Pangan Masyarakat Tahun 2015* [Regulation of the Minister of Agriculture of the Republic of Indonesia Number 16/Permentan/HK.140/4/2015 concerning guidelines for strengthening community food distribution institutions in 2015]. https://disperta.pesisirselatankab.go.id/transparasi/file/Permentan_No_Tahun_2015_Ttg_Pedoman_Penguatan_Lembaga_Distribusi_Pangan_Masyarakat.Pdf

Martanto, R., Ngabekti, S., Juhadi, Hamid, N., Mahat, H., Natsir, N., & Aroyandini, E. N. (2023). Determination of sustainable food land directions in Bantul Regency, Indonesia based on food security level and land use conversion. *International Journal of Sustainable Development and Planning, 18*(1), 161–169. https://doi.org/10.18280/ijsdp.180117

Moniaga, V. R. B. (2011). Analisis daya dukung lahan pertanian [Analysis of agricultural land carrying capacity]. *AGRI-SOSIOEKONOMI, 7*(2), 61–68. https://doi.org/10.35791/agrsosek.7.2.2011.92

Mubarokah, N., Rachman, L. M., & Tarigan, S. D. (2020). Analysis of carrying capacity of crop agricultural land in Cibaliung Watershed, Banten Province. *Jurnal Ilmu Pertanian Indonesia, 25*(1), 73–80. https://doi.org/10.18343/jipi.25.1.73

Mulya, S. P., Hudalah, D., Prilandita, N., & Sakti, A. D. (2024). Spatio-temporal changes in agricultural land and rural–urban transitions in Greater Jakarta, Indonesia. *Regional Environmental Change, 24*, 145. https://doi.org/10.1007/s10113-024-02306-4

Nugroho, F., & Afandi, A. (2024). Analisis faktor-faktor yang mempengaruhi indeks harga pangan di Indonesia tahun 2000–2023 [Analysis of factors affecting the food price index in Indonesia, 2000–2023]. *Jurnal Kebijakan Ekonomi dan Keuangan, 3*(1), 1–9. https://doi.org/10.20885/jkek.vol3.iss1.art1

Peltonen-Sainio, P., Jauhiainen, L., Laurila, H., Sorvali, J., Honkavaara, E., Wittke, S., Karjalainen, M., & Puttonen, E. (2019). Land use optimization tool for sustainable intensification of high-latitude agricultural systems. *Land Use Policy, 88*, 104104. https://doi.org/10.1016/j.landusepol.2019.104104

Rochaida, E. (2016). Dampak pertumbuhan penduduk terhadap pertumbuhan ekonomi dan keluarga sejahtera di Provinsi Kalimantan Timur [The impact of population growth on economic growth and prosperous families in East Kalimantan Province]. *Forum Ekonomi: Jurnal Ekonomi, Manajemen dan Akuntansi, 18*(1), 14–24. https://doi.org/10.29264/jfor.v18i1.42

Ruwanto, S., & Banowati, E. (2021). Analisis perubahan penggunaan lahan sawah menjadi lahan terbangun di Kecamatan Gubug Kabupaten Grobogan tahun 2000–2018 [Analysis of paddy-field land-use conversion into built-up land in Gubug District, Grobogan Regency, 2000–2018]. *Geo Image, 10*(1), 60–67. https://journal.unnes.ac.id/sju/geoimage/article/view/47324/19133

Sarastika, T., & Anggrasari, H. (2024). Analisis daya dukung lahan pertanian sebagai upaya mendukung ketersediaan pangan di Kawasan Sleman Tengah [Analysis of agricultural land carrying capacity as an effort to support food availability in Central Sleman Area]. *Jurnal Tanah dan Sumberdaya Lahan, 11*(2), 413–421. https://doi.org/10.21776/ub.jtsl.2024.011.2.12

Setyowati, D. L., & Hardati, P. (2025). Community-based springs management of the Sukolilo Karst landscape area to fulfill clean water needs. *Geografi, 13*(2), 33–61. https://doi.org/10.37134/geografi.vol13.2.2.2025

Statistics Indonesia of Grobogan Regency. (2015). *Grobogan Regency in figures 2015*. Statistics Indonesia of Grobogan Regency. https://grobogankab.bps.go.id/id/publication/2015/10/30/f16dde2a035f6bb577b060bf/statistik-daerah-kabupaten-grobogan-2015.html

Statistics Indonesia of Grobogan Regency. (2020). *Grobogan Regency in figures 2020: Data provision for development planning*. Statistics Indonesia of Grobogan Regency. https://grobogankab.bps.go.id/id/publication/2020/04/27/e44d829b03d429bd01828642/kabupaten-grobogan-dalam-angka-2020.html

Statistics Indonesia of Grobogan Regency. (2025). *Grobogan Regency in figures 2025*. Statistics Indonesia of Grobogan Regency. https://grobogankab.bps.go.id/id/publication/2025/02/28/8c2e6a8a777dff15f92e26e9/kabupaten-grobogan-dalam-angka-2025.html

Sudrajat, J., Suyatno, A., & Oktoriana, S. (2021). Land-use changes and food insecurity around oil palm plantations: Evidence at the village level. *Forest and Society, 5*(2), 352–364. https://doi.org/10.24259/fs.v5i2.11376

Suhardjo, D., & Tukiran. (1990). *Studi literatur konsep yang sudah ada mengenai daya tampung wilayah* [Literature study of existing concepts on regional carrying capacity]. Kantor Menteri Negara Kependudukan dan Lingkungan Hidup.

Wang, J. (2025). The impact of urban expansion on food production: A bibliometric study of development, hotspots, and future prospects. *Frontiers in Sustainable Food Systems, 10*, 1550373. https://doi.org/10.3389/fsufs.2025.1550373

Wang, X. (2022). Managing land carrying capacity: Key to achieving sustainable production systems for food security. *Land, 11*(4), 484. https://doi.org/10.3390/land11040484