Analysis of carrying capacity of agricultural land in supporting sustainable food self-sufficiency in Tegal Regency

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Abstract. Population growth and industrial development led to the conversion of agricultural land, and then disturb the food self-sufficiency. The objective of this research is to analyze the status of food self-sufficiency in Tegal Regency, estimated from Carrying Capacity (CC), using secondary data from BPS Statistics Indonesia. The formula of CC developed from a combined concept of the theory of Odum, Cristeiler, E Howard and Issard. The results showed that there were three Subdistricts in Tegal Regency, namely Balapulang, Pagerbarang and Warureja Subdistricts that were capable of self-sufficiency in food and were able to provide a decent life for their residents. The agricultural land carrying capacity in Tegal Regency was 1.62, which means that Tegal Regency is capable of self-sufficiency in food but has not been able to provide a decent life for its population. The carrying capacity of agricultural land is projected to decline to 1.34 in 2037. However, in 2037 Tegal Regency will remain self-sufficient in rice with the condition that it can maintain a trend of the population growth rate of 0.33%, rice consumption of 114.6 kg/capita/year, planting index (IP) 168% or 1.68 and rice crop productivity of 5.82 tons/ha per year.

Keywords: agricultural land, carrying capacity, sustainable food self-sufficiency

1. Introduction

Indonesia is a developing country with a large portion of the population making a living in the agricultural and maritime fields. The great dependence on the agricultural sector makes the dependence of the lives of Indonesian people on agricultural land increasingly high. According to Hafidah [1], the welfare of agricultural and rural communities is very dependent on agricultural land in fulfilling their daily needs. Dependency is higher as the population increases. BPS data [2] shows that the population in Indonesia is increasingly increasing, in 2017 the population in Indonesia is recorded at 262 million.

The increasing population which is increasingly high accompanied by development activities certainly requires land or space as a place to live as well as the place where development activities take place, this can lead to the conversion of agricultural land into industrial estates or settlements. According to Bappenas [3], the conversion of land into residential areas often occurs on productive agricultural land. The conversion of agricultural land will certainly have an impact on the decline in agricultural production.

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Sakti et al. [4] said that one of the government's efforts to reduce the conversion rate of paddy fields was by issuing a law. Law Number 26 of 2007 concerning Spatial Planning which contains the allocation of space for food crop agricultural land [5], Law Number 41 of 2009 concerning Protection of Sustainable Food Agriculture Land (PLP2B) [6]. The policy of sustainable food agriculture land protection in The Tegal Regency uses the regulation of the Regional Regulation of Tegal Regency Number 10 of 2012 concerning Tegal Regency Regional Spatial Planning for 2012-2032 [7]. It was stated in the regional regulation in article 31 paragraph (5) that the area of Sustainable Food Agriculture (LP2B) was set at an area of approximately 41,296 hectares which included areas of wet agricultural land and dry agricultural land.

The objectives in this study are: (1) Analyzing the carrying capacity of agricultural land and identifying the status of food self-sufficiency in Tegal Regency. (2) Projecting the carrying capacity of agricultural land and the need for extensive paddy fields for food self-sufficiency in Tegal Regency in 2037.

2. Methodology
This research was conducted in Tegal Regency. The selection of research locations was chosen based on population density and reduced agricultural land due to land conversion in Tegal Regency. The research starts from April to July 2019. The research conducted is quantitative descriptive research. The type of data used in this study is secondary data. Secondary data is used to analyze the carrying capacity of agricultural land and the status of food self-sufficiency. Secondary data needed in this study include data on population, harvest area and rice production data in Tegal Regency.

2.1. Analysis of Agricultural Land Carrying Capacity
This study uses data analysis that determines the level of carrying capacity of agricultural crops used a formula from the combined concept of Odum’s, Christeller’s theory, Ebenezer Howard and Issard [8], namely:

\[ \Phi = \frac{X}{K} \]

Where:
\( \Phi \) = Level of carrying capacity of agricultural land
\( X \) = Per capita food crop harvest area, with the following formula:
\[ X = \frac{\text{Harvest Area}}{\text{Population Amount}} \]
\( K \) = Area of land for food self-sufficiency, with the following formula:
\[ K = \frac{\text{Minimum Physical Requirement}}{\text{Food Crop Production}} \]
Or:
\[ \Phi = \frac{\text{Harvest Area} \times \text{production per hectare per year}}{\text{Total Population} \times KFM} \]

2.2. Analysis of Food Self-Sufficiency Status
Based on the analysis of the carrying capacity of the agricultural land, the classification specified is:

Class I \( \sigma > 2.47 \): Areas that are capable of self-sufficiency in food and can provide a decent life for the population.
Class II \( 1 \leq \sigma \leq 2.47 \): Areas that are capable of self-sufficiency in food but have not been able to provide a decent life for the population.
Class III \( \sigma < 1 \): Regions that have not been able to be self-sufficient in food.
2.3. Analysis of Projected Land Carrying Capacity and Extensive Needs of Rice Fields for Food Self-Sufficiency in Tegal Regency

2.3.1. Population Projection Value (Pn). Data used to project population growth is time-series data for 5 years, from 2013-2017 based on BPS data from Tegal Regency. Assuming population growth projections are used geometric methods with the formula:

\[ P_n = P_0 \left(1 + \frac{r}{100}\right)^n \]  

Where \( P_n \) = nth year data to be projected, \( P_0 \) = initial year data, \( r \) = population growth rate (%) previous period and \( n \) = number of initial year range to \( n \)

2.3.2. Food Needs (Kp)

\[ K_p = \left(\text{Rice consumption per capita} \times P_n\right) / 0.6402 \]  

Where: Rice consumption per capita based on BPS data is 114.6 kg/capita/year, and 0.6402 is the conversion rate of GKG to rice-based on BPS data.

2.3.3. Area Harvest Needs (Klp)

\[ K_{lp} = \left(\text{Food Requirement}\right) / \left(\text{Productivity} \times 0.8338\right) \]  

Where: The average rice productivity in 2013-2017 was 5.82 tons/hectare and 0.8338 was the conversion value from GKP to GKG based on BPS data.

2.3.4. Rice Field Raw Needs (Klb)

\[ K_{lb} = \left(\text{Harvest Area Requirement}\right) / \left(\text{Planting Index (IP)}\right) \]  

Where: Planting Index of Tegal Regency was 1.68 based on BPS data

3. Results and Discussion

3.1. Analysis of Agricultural Land Carrying Capacity

The carrying capacity analysis is carried out by calculating the rice crop/capita harvest area and land area for food self-sufficiency. The harvested area of rice/capita is obtained by dividing the harvested area of rice by the population while determining the land area for self-sufficiency in food is obtained by dividing the minimum physical consumption number with the productivity of paddy fields for rice. In this case, the minimum physical consumption rate refers to BPS, which is equal to 114.6 kg/capita/year.

From the table above, it can be analyzed the crop harvest area per capita obtained by dividing the harvested area by population and analysis of land area for food self-sufficiency obtained by dividing the minimum physical consumption (KFM) with rice productivity, so that can be analyzed the carrying capacity of agricultural land and status of food self-sufficiency in Tegal Regency and obtained the following results (table 1).

| Class | Carrying Capacity of Agricultural Land | Total | Location |
|-------|--------------------------------------|-------|----------|
| I     | \( \sigma > 2.47 \)                  | 3     | Balapulang, Pagerbarang, Warureja |
| II    | \( 1 \leq \sigma \leq 2.47 \)        | 10    | Margasari, Bumijawa, Bojong, Lebaksiu, Jatinegara, Kedungbanteng, Dukuhwaru, Tarub, Kramat, Suradadi |
| III   | \( \sigma < 1 \)                      | 5     | Pangkah, Slawi, Adiwerna, Dukuhtruri, Talang |

Source: Processed Data (2019)
Based on the results of the analysis of the carrying capacity of agricultural land shows that there are Three Subdistricts in Tegal Regency in 2017, namely Balapulang Subdistrict, Pagerbarang and Warureja which are capable of self-sufficiency in food and able to provide a decent life for the population. Meanwhile, five Subdistricts have less than 1 carrying capacity (σ <1) which means that they have not been able to be self-sufficient in food, namely Pangkah, Slawi, Adiwerana, Dukuhturi, and Talang Districts. On average, the carrying capacity of agriculture in the Tegal Regency is 1.62, which means that the Tegal Regency is capable of self-sufficiency in food but has not been able to provide a decent life for its residents.

3.2. Analysis of Projected Land Carrying Capacity and Extensive Needs of Rice Fields for Food Self-Sufficiency in Tegal Regency

After analyzing the carrying capacity of agricultural land and knowing the status of food self-sufficiency in the Tegal Regency, then analyzing the projected land requirements for self-sufficiency in food, projections of rice availability and consumption over the next 20 years, from 2017 to 2037.

The data used to project population, land needs and rice consumption are data on the average increase in the population growth rate of Tegal Regency from 2013-2017 and the assumed data is the level of rice consumption of 114.6 kg/capita/year, planting index (IP) 168% or 1.68 and rice crop productivity of 5.82 kg/ha based on BPS data from Tegal Regency. In the projection of rice availability, rice production data was used in 2013-2017 and the conversion rate of harvested dry grain (GKP) into milled dry rice was 83.38% and the conversion rate of GKG into rice was 64.02% [9].

Within five years in the period of 2013 to 2017, Tegal Regency experienced an increase in population from previously 1,414,989 people in 2013, increasing to 1,433,515 in 2017. This means that there has been an increase in the population of 18,526 people or (1.31%). The average population growth from 2013-2017 is 0.33%, so the population in Tegal Regency in 2037 is projected to increase to 1,522,022 people. Besides that, in line with the increasing number of population, the level of rice consumption is assumed to be constant at 114.6 kg/capita/year, the amount of rice consumption in Tegal Regency has increased from 162,158 tons in 2013 to 164,281 tons in 2017 or an increase of 2,123 tons or equivalent to 1.31%. In 2037 rice consumption is projected to increase along with the increase in population, which is 174,424 tons of rice/year.

The need for the harvested area in Tegal Regency in the period of 2013 to 2017 is quite fluctuating but overall increased from 52,740 hectares in 2013 to 54,183 hectares in 2017. This means that there has been an increase of 1,443 hectares or 2.74%. Projected in 2037 along with an increase in population and rice consumption, the need for the harvested area will be 56,144 hectares. In detail population growth, rice consumption and the need for harvested rice fields in Tegal Regency in 2013-2017 and projections for 2018-2037 are presented in table 2.

Table 2. Population growth, rice consumption, and rice field harvest requirements in 2013-2017 and projections for 2018-2037

| Year | Population | Consumption/capita | Rice Consumption | Needs Harvested Area |
|------|------------|-------------------|-----------------|---------------------|
|      | Total      | Growth (%)        | (kg/year)       | (tons)              | (ha)                |
| 2013 | 1,414,989  | -                 | 114.6           | 162,158             | 52,740              |
| 2014 | 1,420,132  | 0.36              | 114.6           | 162,747             | 55,133              |
| 2015 | 1,424,891  | 0.34              | 114.6           | 163,293             | 50,149              |
| 2016 | 1,429,386  | 0.32              | 114.6           | 163,808             | 50,975              |
| 2017 | 1,433,515  | 0.29              | 114.6           | 164,281             | 54,183              |
| **Average** | **0.33** | | | | |
| 2018*) | 1,437,816 | -                 | 114.6           | 164,774             | 53,038              |
| 2027*) | 1,477,106 | -                 | 114.6           | 169,276             | 54,487              |
| 2037*) | 1,522,022 | -                 | 114.6           | 174,424             | 56,144              |
Description: *) Projections

Based on BPS data from Tegal Regency, rice production data in 2013 amounted to 354,537 tons of milled dry grain (GKG), equivalent to 226,975 tons of rice. The harvested area of rice is 61,576 ha and rice productivity is 5.76 tons/ha. Whereas in 2017 it amounted to 373,255 tons of milled dry grain (GKG), equivalent to 238,958 tons of rice. Harvested area of rice was 65,660 ha and rice productivity was 5.64 tons/ha. The average rice production growth is 1.28% per year, so rice production in 2037 is projected to reach 481,371 tons of milled dry grain (GKG), equivalent to 308,173 tons of rice. The availability of rice in 2013-2017 and the projections for 2018-2037 are presented in table 3.

### Table 3. Availability of rice in 2013-2014 and the projections for 2018-2037

| Year | Productions | GKG to Rice Conversion Value (%) | Availability of Rice (tons) |
|------|-------------|---------------------------------|----------------------------|
|      | Tons        | Growth (%)                      |                            |
| 2013 | 354,537     | -                               | 64.02                      | 226,975                   |
| 2014 | 334,928     | -5.53                           | 64.02                      | 214,421                   |
| 2015 | 382,161     | 14.10                           | 64.02                      | 244,659                   |
| 2016 | 394,022     | 3.10                            | 64.02                      | 252,253                   |
| 2017 | 373,255     | -5.27                           | 64.02                      | 238,958                   |
|      | Average     | 1.28                            |                            |                           |
| 2018*) | 378,033 | 64.02                            | 242,017                   |
| 2027*) | 423,880 | 64.02                            | 271,368                   |
| 2037*) | 481,371 | 64.02                            | 308,173                   |

Description: *) Projections

Based on the level of rice consumption and the level of rice availability in tables 2 and table 3. The rice balance from 2013 to 2017 experienced a surplus of rice even though the availability of rice from 2013 to 2017 was always volatile. The rice balance in 2013 was 64,817 tons, up 9,860 tons to 74,677 tons in 2017. Based on the projected rice consumption and the availability of rice in 2037, it is projected that Tegal Regency is still a surplus with a balance of 113,749 tons of rice. The 2013-2017 rice balance and 2018-2037 projections are presented in table 4.

### Table 4. Rice balance sheets for 2013-2017 as well as 2018-2037 projections

| Year | Rice consumption (tons) | Availability of Rice (tons) | Balance Sheet (tons) | Information |
|------|-------------------------|-----------------------------|----------------------|-------------|
| 2013 | 162,158                 | 226,975                     | 64,817               | Surplus     |
| 2014 | 162,747                 | 214,421                     | 51,674               | Surplus     |
| 2015 | 163,293                 | 244,659                     | 81,366               | Surplus     |
| 2016 | 163,808                 | 252,253                     | 88,445               | Surplus     |
| 2017 | 164,281                 | 238,958                     | 74,677               | Surplus     |
| 2018*) | 164,774 | 242,017                     | 77,243               | Surplus     |
| 2027*) | 169,276 | 271,368                     | 102,092              | Surplus     |
| 2037*) | 174,424 | 308,173                     | 133,749              | Surplus     |

Description: *) Projections

Based on rice harvest area and land area for food self-sufficiency, Tegal Regency in 2013 had a carrying capacity of 1.56 and in 2017 had a carrying capacity of 1.61. This means that from 2013 to 2017 Tegal Regency has been able to self-sufficiency in food but has not been able to provide a decent life for its residents. The average harvested area of rice from 2013 to 2017 was 63.197. Based on these averages, it can be projected in 2037 the carrying capacity in Tegal Regency is 1.34. This means that
Tegal Regency will remain self-sufficient in rice provided that it can maintain a population growth trend of 0.33%, rice consumption of 114.6 kg/capita/year, and rice productivity of 5.82 tons/ha. Carrying capacity for 2013-2017 and projections for 2018-2037 are presented in Table 5.

| Year  | Total population (people) | Harvest Area (Ha) | Minimum Physical Consumption Number (Kg/cap) | Rice Productivity (ton/ha) | Carrying Capacity |
|-------|---------------------------|-------------------|---------------------------------------------|---------------------------|------------------|
| 2013  | 1,414,989                 | 61,576            | 114.6                                       | 5.76                      | 1.56             |
| 2014  | 1,420,132                 | 60,620            | 114.6                                       | 5.53                      | 1.49             |
| 2015  | 1,424,891                 | 62,628            | 114.6                                       | 6.10                      | 1.68             |
| 2016  | 1,429,386                 | 65,499            | 114.6                                       | 6.02                      | 1.72             |
| 2017  | 1,433,515                 | 65,660            | 114.6                                       | 5.68                      | 1.62             |
| Average | 1,437,816               | 63,197            | 114.6                                       | 5.82                      | 1.61             |
| 2018*) | 1,477,106               | 63,197            | 114.6                                       | 5.82                      | 1.42             |
| 2027*) | 1,522,022               | 63,197            | 114.6                                       | 5.82                      | 1.38             |
| 2037*) | 1,522,022               | 63,197            | 114.6                                       | 5.82                      | 1.34             |

Description: *) Projection

Based on the results of the analysis, Tegal Regency from 2013 to 2017 has achieved rice self-sufficiency, and it is projected that until 2037 Tegal Regency will remain self-sufficient in rice provided that it can maintain a population growth trend of 0.33%, rice consumption of 114.6 kg/capita/year, planting index (IP) 168% or 1.68 and paddy productivity of 5.82 kg/ha per year. Thus, in terms of food sufficiency in this case rice, Tegal Regency has been able to meet the food needs of its own population without having to depend on the supply of rice from other regions. Even the excess rice production in Tegal Regency can be used as a reserve for the next period or used to support other areas around it.

Based on the 2013-2017 time-series data obtained from BPS, the scenario used in this study is to project the carrying capacity of agricultural land until 2037. The data used is assuming that population growth increases every year based on the average rate of population growth in 2013-2017 that is equal to 0.33%. Meanwhile, rice productivity is fixed based on 2013-2017 average data of 5.82 tons/hectare, the rice consumption level is assumed to remain at 114.6 kg/capita annually and for planting index (IP) it remains based on BPS data in 2017 by 168% or 1.68. Population growth rate, per capita rice consumption rate, planting index (IP) and rice productivity and assumptions (scenarios) used for the 2018-2037 projection are presented in table 6.

| Year  | Population Amount (people) | Growth (%) | Consumption on/capita (kg/year) | Planting index (IP) (%) | Rice Productivity (ton/ha) |
|-------|----------------------------|------------|---------------------------------|-------------------------|---------------------------|
| 2013  | 1,414,989                  | -          | 114.6                           | -                       | 5.76                      |
| 2014  | 1,420,132                  | 0.36       | 114.6                           | -                       | 5.53                      |
| 2015  | 1,424,891                  | 0.34       | 114.6                           | -                       | 6.10                      |
| 2016  | 1,429,386                  | 0.32       | 114.6                           | -                       | 6.02                      |
| 2017  | 1,433,515                  | 0.29       | 114.6                           | 168                     | 5.68                      |
| Average | 1,437,816                | 0.33       | 114.6                           |                          | 5.82                      |
| 2018*) | 1,477,106                 | 0.33       | 114.6                           | 168                     | 5.82                      |
| 2027*) | 1,522,022                 | 0.33       | 114.6                           | 168                     | 5.82                      |
| 2037*) | 1,522,022                 | 0.33       | 114.6                           | 168                     | 5.82                      |

Description: *) Projection
Based on the analysis of the projected carrying capacity of agricultural land using the scenarios in table 7, it is produced that in 2037 Tegal Regency is still self-sufficient in rice. For this reason, strategies are needed to maintain rice self-sufficiency to be sustainable by maintaining trends in population growth rate, per capita rice consumption level, planting index (IP) and crop productivity.

4. Conclusion
The results showed that there were three sub-districts in Tegal Regency in 2017, namely Balapulang Subdistrict, Pagerbarang and Warureja which were capable of self-sufficiency in food and were able to provide a decent life for the population. Meanwhile, five Subdistricts have less than 1 carrying capacity (σ<1), which means that they have not been able to self-sufficiency in food, namely Pangkah District, Slawi, Adiwerna, Dukuhturi, and Talang.

In general, the average carrying capacity of agriculture in the Tegal Regency is 1.62, meaning that Tegal Regency is capable of self-sufficiency in food but has not been able to provide a decent life for its residents. The carrying capacity of agricultural land increased from 1.56 in 2013 to 1.62 in 2017. The average rice productivity from 2013-2017 was 5.82 tons/ha. Based on these averages, it is projected that Tegal Regency in 2037 will have a support capacity of 1.34, which means that Tegal Regency is still capable of food self-sufficiency but has not been able to provide a decent life for its residents with the condition that it can maintain the trend of average population growth, rice productivity and rice consumption level.

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