



Carrying capacity and food self-sufficiency of paddy field resources: NDVI analysis in Batang Regency, Central Java Province, Indonesia

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ABSTRACT

Food self-sufficiency policy in Indonesia relies on the sustainability of productive land that meets the requirements for carrying capacity of agricultural land. But the fact is that in various regions, the existence of agricultural land resources is increasingly being degraded in terms of quantity and quality. This study aims to evaluate paddy field with NDVI analysis with extensive GIS calculations and integrated with the food self-sufficiency formulas. Monitoring of paddy field area using remote sensing and mapping techniques has been well recognized and efficient. The research was conducted in Batang Regency, Central Java Province, Indonesia, that annually produces 104,211 ton rice on average. The results showed that the production of lowland rice is sufficient to meet the daily rice needs of 897.19 gr per capita. The regency also showed a surplus of rice production of more than 342 gr per capita above the daily needs, fulfilling the criteria of food self-sufficiency. Food self-sufficiency classification is associated with the carrying capacity analysis found ca. 4.179 ($\alpha > 1$), revealing that rice production can fulfil the needs of the population of Batang Regency.

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INTRODUCTION

The growth of population has resulted in increased development activities in various fields to meet the needs of the community (Li et al., 2017). It is associated with the construction of settlement facilities, infrastructure networks, commercial facilities, or social facilities. The increase in development activities will undoubtedly be accompanied by the rise in land requirements to accommodate these development activities (Trihatmoko, 2020). It means that the higher activities in the development lead to less land availability.

Since the imposition of regional autonomy in 2001, local governments in Indonesia have had broader authority in determining the right development policies and programs for improving the welfare of the people and the progress of their respective regions. The management of natural, human, and other resources requires development priorities by paying attention to regional importance (Mawardi, 2007). The balancing of the potential local excellence with emphasis on the carrying capacity of the environment will be able to create efficiency and effectiveness in regions. The condition related to the use and management of

development resources can improve community welfare and regional development.

The concept of land carrying capacity is widely applied to animal studies, especially to measure the amount of environmental capacity to support animal life expressed per unit in certain area. Later, the carrying capacity of the environment is also applied to the human population. Another carrying capacity analysis is also based on plant biomass (rice) produced by rice fields in a certain area and time. Thus, the carrying capacity is the ability of the environment to be able to support human life ([Li et al., 2017](#)).

The development of regional potentials such as the agricultural sector refer to the Law No. 41/2009 concerning Protection of Sustainable Food Agricultural Land (PLP2B). The PLP2B program protects the agricultural sector in each region so that both quantity and quality of corresponding resources are maintained. One of the implementations of this program is the one based on productive land in Indonesia that meets the requirements for the carrying capacity of agricultural land. However, the fact is that agricultural land in many regions in Indonesia is decreasing both in quantity and quality ([Asmuti & Tjandra, 2020](#)).

Most of the population in Batang Regency work as farmers who highly depend on the availability of the land to meet their needs. In addition, Batang Regency is also known as a fertile agricultural area for its various food crops or annual crops. Also, it potentially features the low geomorphological dynamic on its lowland areas especially most of the coastal areas ([Trihatmoko, 2020](#)). The low geomorphological dynamic indicates that this area is suitable for massive development in particular for food crop production. On the other hand, Batang Regency also displays very dynamic economic development in its coastal areas, along the Java Sea coast ([Marfai et al., 2019](#)). The economic development is also seen at the fact that this regency has been targeted for the development of an industrial area which is very attractive for investment ([KFMAP, 2021](#)). In this regard, it is necessary to research the environmental carrying capacity of Batang Regency based on land availability and needs for agricultural sector, specifically to protect rice field availability and the PLP2B program.

This research was aimed to reveal the carrying capacity using geographic information system (GIS) by Normalized Difference Vegetation Index (NDVI) analysis from the series of Sentinel-2 satellite images.

The Sentinel-2 satellite images were chosen as the free and newest medium-high spatial resolution (10 m). In certain periods, the satellite has a regular frequency of return geostationary visits (10 days and combined constellation revisit in 5 days) for three to four harvests of paddy in a year. The research is also related to how paddy field resources in Batang Regency, Central Java Province, Indonesia, indicate the carrying capacity of food self-sufficiency, especially for rice production. The combination of GIS-NDVI processes and land carrying capacity for food self-sufficiency analysis are also expected to fill the gap of the previous researches that were mostly conducted separately or being positioned as the preliminary statement for one to another ([Sukmono & Ardiansyah, 2017](#); [Zhou et al., 2020](#)).

RESEARCH METHOD

This research was conducted in Batang Regency, Central Java, Indonesia. Research area selection was conducted in all its 15 districts. The object of research focused on all types of paddy fields, i.e., technical irrigation paddy fields, simple irrigation, and rainfed paddy fields.

The primary data were from the latest cross-check field data of changes in land use the and agricultural commodity productivity. The secondary data included statistical and satellite image data. Geographic information system data were taken from the website of the Geospatial Information Agency (BIG), as well as satellite imagery data from the United States Geological Survey (USGS).

The Sentinel-2 satellite imagery relies on multispectral high-resolution optical observations over the global terrestrial surface, including land change monitoring, emergency response and security services activities. The use of Sentinel 2A Satellite imagery emphasized the design of a reliable multispectral land observation system by featuring a Multi-Spectral Instrument (MSI) with 13 spectral bands ranging from visible and near-infrared to shortwave infrared. Spatial resolution varied from 10 m to 60 m, depending on the spectral band, with a field of view of 290 km. The combination of high spatial resolution, wide field of view, and broad-spectrum coverage showed an advantage over other multispectral images.

Normalized Difference Vegetation Index

Vegetation index is analyzed based on digital brightness values as a result of the near-infrared (NIR)

and red band reflectance and absorption from vegetation (Campbell, 2002; Zhou et al., 2020). This is part of the analysis and manipulation processes in GIS scope (Aronoff, 1989) that is conducted for experiments measuring biomass or vegetative level. NDVI measures flourishing green vegetation and also investigates changes in the ecological environment (Li et al., 2017). The combination of the different formulation of normalization and the use of the highest absorption and reflection of the chlorophyll makes it durable under various conditions (Syamsia et al., 2018). The index value ranged from -1 to 1. The general range for green vegetation is 0.2-0.8 (Rouse et al., 1974), with the following equation.

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (1)$$

NDVI was calculated by adjusting the bright visualization from NIR effect. The function was being normalized by the difference/sum ratio of red band.

Land Availability

Land availability was determined based on the total of local actual production data of each commodity in a particular area, added up with the products of all commodities. For agricultural commodities, land availability analysis was carried out by calculating land availability. The formula for land availability used the equation below (Ministry of Environment, 2009).

$$SL = \frac{\sum(Pi \times Hi)}{Hb} \times \frac{1}{Ptvb} \quad (2)$$

in which SL is land availability (ha), and Pi is the actual production of each type of commodity (the unit depends on the type of product), including agriculture, plantation, forestry, and animal husbandry. Hi is the unit price for each type of commodity (Rp per unit) at the producer level. Hb represents the unit price of rice (Rp per kg) at the producer level. Pt is Rice productivity (kg per ha).

The Needs of Land

Population pressure on the carrying capacity of land was determined by the value of the ratio between the population and the percentage of farmers with a minimum area of land to live properly. The land requirement formula used in research is shown in the following equation (Ministry of Environment, 2009).

$$DL = N \times KHL_L \quad (3)$$

DL is the needs of land in total equal to rice (ha). N represents population and KHL is the needs of land to live properly.

Carrying Capacity of the Land

Food self-sufficiency is an attempt to meet their own food needs by cultivating food crops such as cereal (rice and the like), secondary plants, cassava, and others. Another researcher suggested that land capability implies land carrying capacity (Notohadiprawiro, 1987). Previous research said that the land carrying capacity degradation is influenced by an increasing population and a low percentage of farmers (Trihatmoko, 2020).

The carrying capacity of the land was obtained from a comparison between the availability of land (SL) and land requirements (DL) (Ministry of Environment, 2009):

$$Cc = \frac{SL}{DL} \quad (4)$$

If $s_L > D_L$, a surplus of land carrying capacity. If $s_L < D_L$, a deficit of land carrying capacity. To get the precise carrying capacity of the land (α) the calculation was continued as follows.

$$\alpha = \frac{X}{K} \quad (5)$$

X is the available area on site location, calculated using the following formula.

$$X = \frac{\text{Total Area of Harvest}}{\text{Population}} \quad (6)$$

Meanwhile, K stated in the formula as follows:.

$$K = \frac{\text{minimum rice consumption (kg)}}{\text{Average rice production per ha}} \quad (7)$$

The surplus of land carrying capacity was emphasized on the rice production analysis by using formula:

$$\text{Rice production in Total} = \frac{\text{Total area of paddy field (ha)} * IP * \text{productivity (tons per ha)}}{\quad} \quad (8)$$

The total rice production was assumed as the conversion value of milled unhusked rice (GKG) then the value of rice obtained is as follows.

$$\text{Rice} = \text{Index GKG} * \text{total harvest} \quad (9)$$

The level of productivity of paddy fields in meeting the needs of the population of rice in Batang was calculated based on the following formula.

$$\text{Supply} = \frac{\text{Rice production in 1 year}}{\text{Population in one regency}} \quad (10)$$

RESULT AND DISCUSSION

Spatial Pattern and Land Use

Batang Regency is a hilly area both in the north along the shore line of Java Sea and in the southern region bordering Banjarnegara Regency. The south part of the region was dominated by tea plantations, which were located in an upland area with a cool climate. Most of the southern part of Batang Regency area (30.2%) was plantation area (Table 1). The forest area in the north was mostly cultivated for teak forest or tree plantations. The industrial area development in Batang Regency was predominantly spread along the north coast road as the densest traffic path in Indonesia (Hartatik, 2016), i.e. Kandeman, Tulis, Subah, and Banyuputih Districts. This condition is the main consideration for industrial development that requires adequate accessibility.

Table 1. Land Use Distribution in Batang Regency, 2016

| Land use type | Area Size | |
|----------------------|-----------|-------|
| | ha | % |
| Forest | 13,309.4 | 15.5 |
| Industry and Tourism | 141.9 | 0.2 |
| Water body | 1,275.6 | 1.5 |
| Grassfield | 615.1 | 0.7 |
| Dry field | 3,134.4 | 3.6 |
| Mix garden | 6,158.5 | 7.2 |
| Settlement | 11,209.4 | 13.0 |
| Garden | 25,980.7 | 30.2 |
| Paddy Field | 24,081.4 | 28.0 |
| Total | 85,906.4 | 100.0 |

Source: Spatial Plan (RTRW) data analysis of Batang Regency.

Batang Regency has favorable and reliable natural resource potential for food crop agriculture (paddy) on condition that proper resource management support is met. In the region, the area of irrigated paddy fields amounted to 28% of the regency area (Table 1) and was spread over all districts (Table 2).

Most of the paddy fields were located in the northern and southern areas of Batang Regency (Figure 1). The central area was dominated by teak forest area. It was also used for residential and industrial areas. The districts with the small size area of paddy fields were Warung Asem, Limpung, Pecalungan, and Tulis districts. Those areas were mostly hilly and some of them showed an indication of growing rapidly in industrial sector.

Table 2. Paddy Field Area by District in Batang Regency, 2019

| District | Area size | |
|-------------|-----------|------|
| | % | ha |
| Bandar | 2,436.3 | 10.2 |
| Banyuputih | 1,228.1 | 5.1 |
| Batang | 1,830.2 | 7.6 |
| Bawang | 1,782.0 | 7.4 |
| Blado | 1,420.8 | 5.9 |
| Gringsing | 2,143.2 | 8.9 |
| Kandeman | 1,565.3 | 6.5 |
| Limpung | 1,324.5 | 5.5 |
| Pecalungan | 866.9 | 3.6 |
| Reban | 1,685.7 | 7.0 |
| Subah | 1,998.8 | 8.3 |
| Tersono | 1,878.3 | 7.8 |
| Tulis | 987.3 | 4.1 |
| Warung Asem | 1,252.2 | 5.2 |
| Wonotunggal | 1,661.6 | 6.9 |

Source: BPS (2021)

Maintaining the existing spatial pattern in Batang Regency is a necessity for all stakeholders, including the community, the private sector, universities, and the government in order to support PLP2B policy. At the same time, the agricultural sector is also the leading sector of the region in terms of gross regional domestic product (GRDP) (BPS, 2021). In addition, the agricultural sector of Central Java has an important role in contributing to the economy, ranking the third in regional GDP with an economic share of 14.30% GRDP, while the highest share was the manufacturing industry at 34.52% (Central Java Province GDP 2016-2020). Therefore, the province of Central Java is expected to become one of the supporters of national food resources, especially rice. This is influenced, among others, by the availability of fertile paddy fields and the application of increasingly modern technology and equipment (Putri, 2016). This technology will support more effective and efficient farming. This progress is expected to increase farmers' yields in terms of quality and quantity.

Carrying Capacity of the Land

Batang Regency has abundant natural resource potential in agriculture, especially the availability of paddy fields. The area of paddy fields reached 24,081.4 ha or equivalent to 28.0% of the total area of Batang Regency. This did not include rainfed rice fields which reached 3,134.4 ha or equivalent to 3.6% of the total land area. This condition indicates that Batang Regency has a very significant carrying capacity of agricultural land as stated in the Central Statistics Agency (BPS, 2018) (Table 3).

Table 3. Land Carrying Capacity Status of Batang Regency in 2017

| District | Land Availability | Land Required | Carrying Capacity of the Land ¹ |
|-------------|-------------------|---------------|--|
| Wonotunggal | 3,523.65 | 218.25 | 32.66 |
| Bandar | 3,299.83 | 409.60 | 16.54 |
| Blado | 1,570.51 | 539.15 | 6.48 |
| Reban | 1,241.75 | 624.59 | 4.58 |
| Bawang | 1,828.26 | 540.98 | 7.82 |
| Tersono | 4,855.25 | 167.85 | 60.74 |
| Gringsing | 5,132.30 | 247.64 | 41.90 |
| Limpung | 3,411.77 | 210.02 | 33.43 |
| Banyuputih | 1,567.76 | 565.71 | 5.97 |
| Subah | 3,278.63 | 319.41 | 23.11 |
| Pecalungan | 2,203.62 | 367.13 | 13.50 |
| Tulis | 3,801.68 | 197.82 | 50.18 |
| Kandeman | 3,173.66 | 306.32 | 20.95 |
| Batang | 1,340.23 | 808.28 | 13.32 |
| Warungasem | 4,665.30 | 325.50 | 28.83 |

¹All district showed surplus status (BPS, 2018)

Table 3 shows that 15 districts indicated high carrying capacity of land. The highest carrying capacity was at Warungasem District which is located

at the lowland in the coastal area. The lowest carrying capacity was found at Reban District which is located at the highland area (southern part). Furthermore, Table 3 indicates that the government should ensure strict control over the development of built-up area as the side effect of the rapid economic development that is commonly concentrated in north coast of Java Island (Marfai, 2011; Hartatik, 2016; Trihatmoko, 2020).

The NDVI analysis identified the rice fields from the amount of chlorophyll that reached its maximum point in its growth phase. NDVI analysis was able to estimate that the area of rice field reached 6,967.5 ha. The mature rice plants were visually recorded from the spectral reflection which was very bright compared to other plants. NDVI can identify high brightness sensitivity even though it is lower than the brightness of water bodies (Figures 2, 3, and 4). In panchromatic satellite image analysis, the amount of cloud cover will cover or reduce the accuracy of image classification.

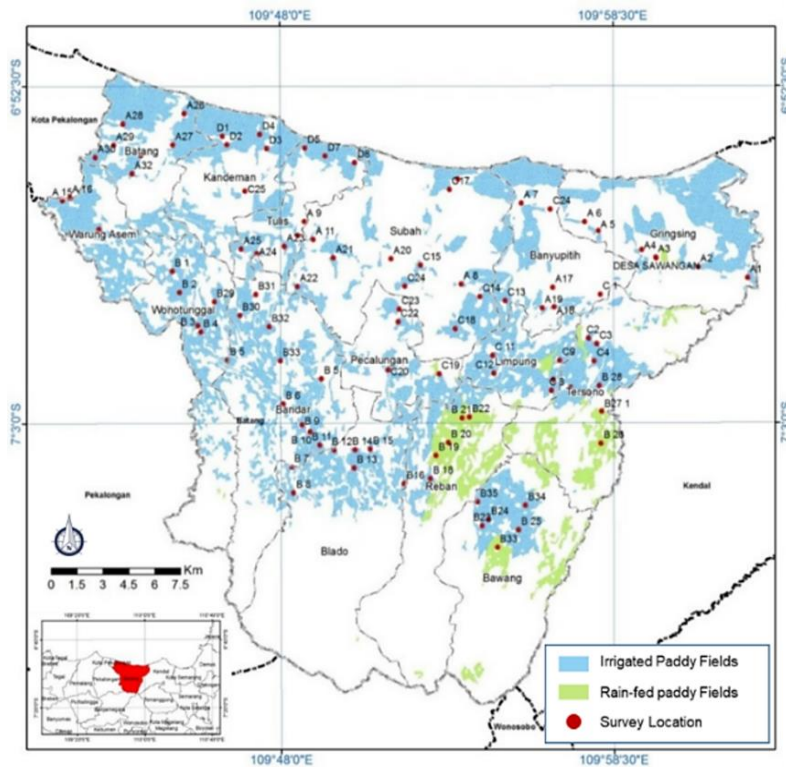


Figure 1. Paddy field area by district in Batang Regency

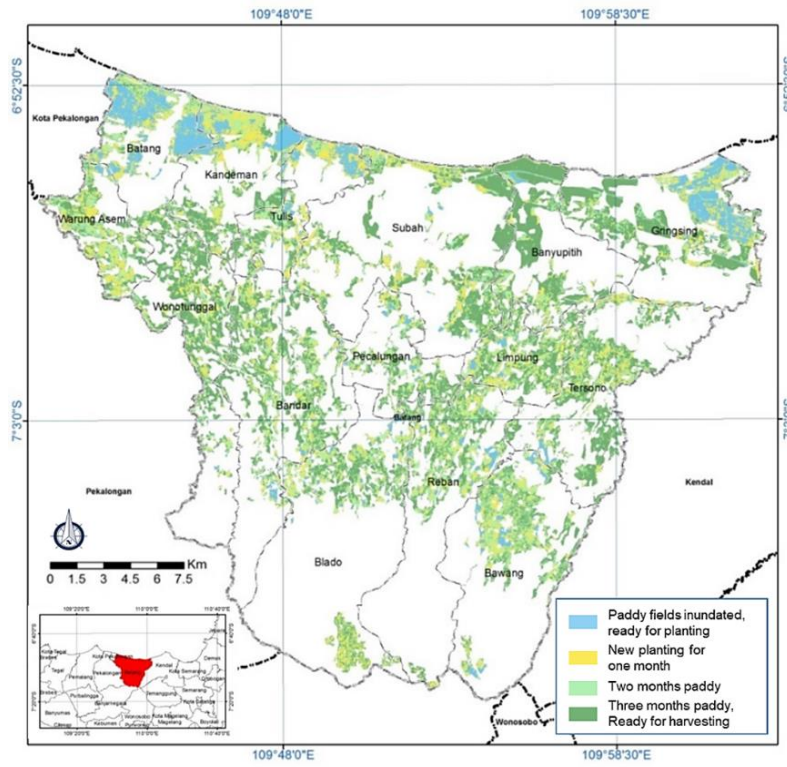


Figure 2. The paddy field area identification in February 2017

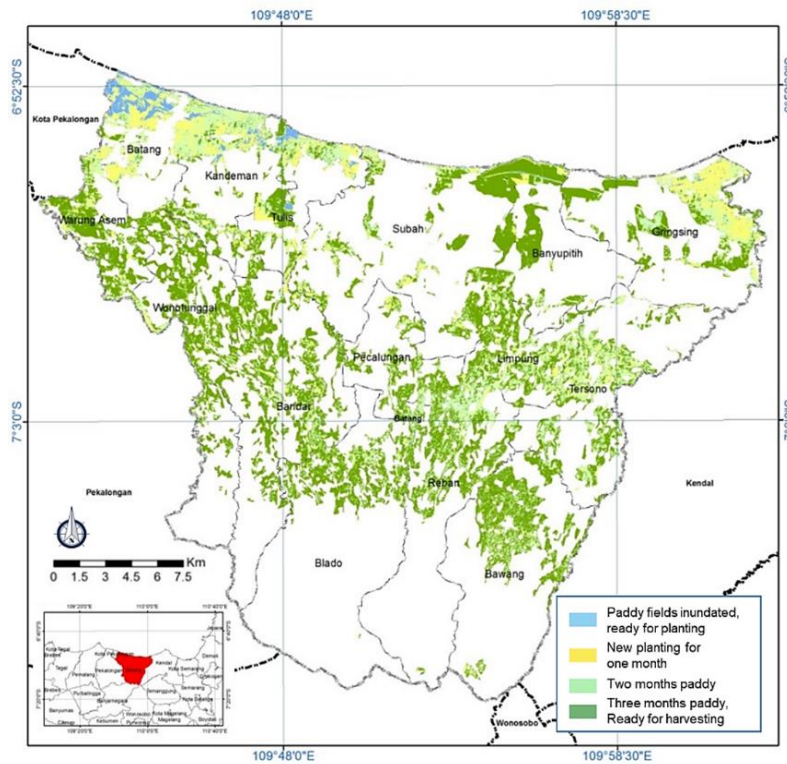


Figure 3. The paddy field area identification in August 2017

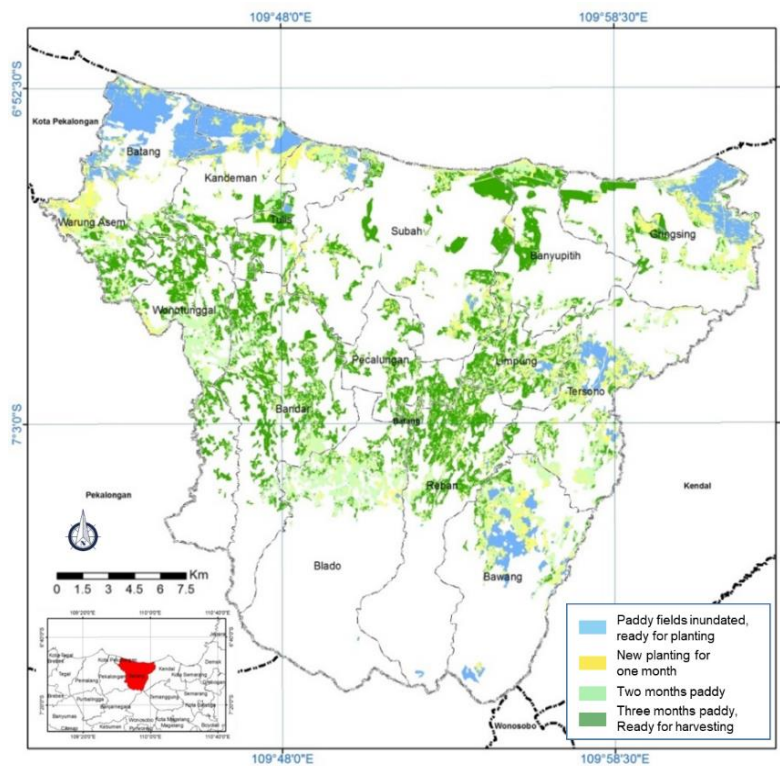


Figure 4. The paddy field area identification in October 2017

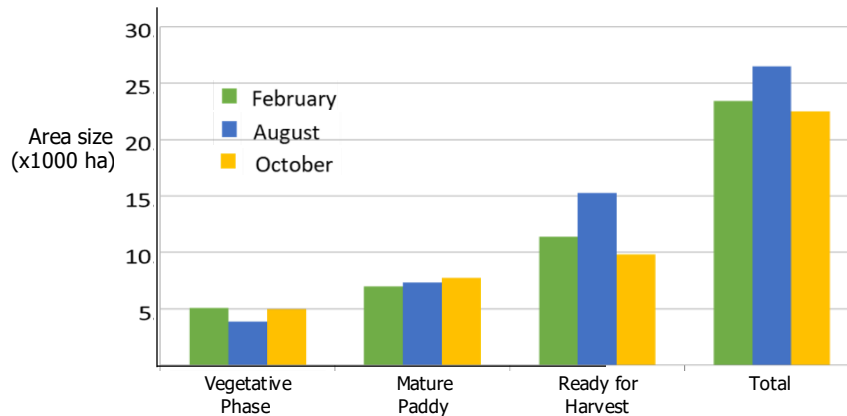


Figure 5. The paddy field area calculation from Sentinel 2A in 2017

Overall, observations of the Sentinel 2A Satellite imagery (Figure 5) indicated that Batang Regency had a very suitable planting area. This means that paddy fields can be cultivated throughout the year, both in the rainy and dry seasons. This can be justified by observing the imagery of rice planted land that did not show extreme differences between the northern and southern parts of Batang Regency (Figure 6),

represented by survey locations A2 and B8, respectively, as shown in Figure 2. Meanwhile, areas with simple to technical irrigation showed relatively productive farming management. NDVI analysis has indeed proven to be able to provide an accurate assessment of the observation of paddy fields, and it allows for the development of other environmental analyzes (Zhou et al., 2020). The NDVI analysis also

fills research gaps related to the abundance of rice fields in Batang Regency as requested by the local government in the process of this research being conducted.

The evaluation of daily rice consumption was found to be 342 gr per capita or equivalent to 124.89 kg per capita annually. Meanwhile, the average productivity of rice was 6.5 tons per ha, so that the K value was 0.0192. With the values of X and K, the carrying capacity of the land (α) was 4.179 (Table 4). Average rice production per ha was converted from paddy to rice (62.74%). The value α is used as an indicator of the ability of paddy fields to the population in one region (Ma, 2017). Value of α is used as an indicator of the capacity of paddy fields relative to the population number in an area. The α value more than 1.0 means that the area has a functional carrying capacity so that it indicates food self-sufficiency. On the other hand, α value less than 1.0 indicates that the area does not have the carrying capacity so that food self-sufficiency is not met. When α value equals to 1.0, the region has an optimal carrying capacity, and the availability of food can support the community needs in or outside the region.

Supply and Demand Balance

The sequence analysis results demonstrated that the production of the rice was double the rice demand (Table 4). It means one-time harvesting equalled to two years of consumption for population in Batang Regency.

Table 4. Production, Consumption and Carrying Capacity of Paddy Field in Batang Regency

| Variable | Unit | Value |
|--|---------------|---------|
| Production | ton per year | 245,516 |
| Demand | ton per year | 104,211 |
| Surplus | ton per year | 141,305 |
| Number of populations | people | 749,720 |
| Consumption per capita | Kg per year | 124.890 |
| Area of harvest needed per capita (X) | ha per capita | 0.803 |
| Consumption/production ratio | - | 0.019 |
| Carrying capacity of the land ($\alpha=X/K$) | - | 4.179 |

The area of paddy fields with irrigation systems was 24,081.4 ha (28% of the total area in Batang Regency), which was very likely to produce significantly more rice production. In addition, the planting intensity (planting index) in several locations also employed three planting seasons in a year. The

results of the study showed that the average planting index reached five harvests in 2 years or the equivalent of 2.5 times a year, with an average productivity of 6.5 tons per ha. Thus, the total rice production in all Batang Regency was calculated as ca. 391,323 tons per year or 245,516 tons per year in milled grain (62.74% conversion). The production was higher than the demand for one year (104,211 tons per year), which shows an indication of a production surplus. Furthermore, the calculation of food needs (Wilis et al., 2020) found an annual production of 327.476 kg per capita or equivalent to 897.19 gr per capita.

The total demand for rice in Batang Regency was 104,211 tons per year. The amount of production has been met to achieve food self-sufficiency. This result placed Batang Regency as a mainstay agricultural area for rice production, and was then asked to contribute to meeting the rice needs of other districts or regions, because Central Java province was not self-sufficient in food during the 2014-2018 period (Pratiwi et al., 2020). Considering this strategic position, the government needs to consider the allocation of more industrial estates in Batang Regency or instead find alternative allocations to outside the region (KFMAP, 2021). Planning for rice production needs estimate without considering the main potential of land resources can lead to degradation (Wilis et al., 2020).

Research Implication

By considering the carrying capacity of paddy fields and its variables such as land availability and land requirements for rice production, this study contributes to policy formulation as a guideline for evaluation and control in the management of the PLP2B program, especially to support agricultural development. As discussed, this research is also related to regional development, as well as development planning especially for Batang Regency. Also, the results of this study can be used as evaluation material for the government in importing rice policy which is still being carried out nowadays (Widarjono, 2018). The implementation of the PLP2B program to maintain agricultural land in Batang Regency needs more attention. The proposed allocation of industrial estates must be reconsidered because Batang Regency has the potential to become a "rice barn" in Central Java and even at the national level (KFMAP, 2021).

Along with the industrial estate development plan, the government needs to consider the speed of change that will occur due to the growth of new economic centers (Putri, 2016), which will ultimately affect the agricultural sector. Ante et al. (2016) stated that the rapid development brings consequences for the widespread use of agricultural land along with the socio-economic changes of the urban to rural transition. This is due to the development of modernization in which urban residents perceive that the non-agricultural sector is better than the agricultural sector, thereby encouraging the conversion of agricultural land into non-productive land. This tendency becomes a serious threat if it occurs continuously.

The potential of rice farming by considering the carrying capacity of land, land availability, and population should provide incentives for farmers' livelihoods or at least increase the farming activity pride. The farmers of Batang Regency can carry out rice farming activities and have an interest in supplying outside the region or export, where the value of a reaches 4.179. This means that the achievement of a surplus occurs up to more than four times the threshold. This can be a source of pride for farmers because it yields high number of production.

This research led to multidisciplinary studies approach which involves the fields of GIS, regional planning, and environmental science as part of the geographical analysis. It means that the research directly affects the geography study development as well as the management of natural and environmental resources. Furthermore, this research can enrich and gain the focus on research roadmaps for research activities with multidisciplinary approaches in land resource conservation associated with efforts to develop food self-sufficiency.

CONCLUSION AND SUGGESTION

Overall, all districts in Batang Regency have sufficient availability of paddy fields. By 2017, Batang Regency indicated surplus of productive rice fields, with an area of 24,081.4 ha of irrigated rice fields (equivalent to 28% of the district's area). Such large number has not been added to the rainfed rice fields which amount to 3,134.4 ha (3.6% of the district area).

Based on the observations of Sentinel 2A satellite imagery, Batang Regency has a suitable cultivated

land throughout the year during the rainy and the dry season. This can be identified by paddy field planted area that does not show significant imagery difference at some occasions. The most significant differences are found at the rainfed rice fields in the district areas located along the coast, while the upland consists of areas with simple to technical irrigation.

The total demand for rice in Batang Regency reaches 104,211 ton per year. Meanwhile, the results of the calculation of the daily rice needs of the population in Batang Regency reaches 897.19 gr per capita. According to the criteria, Batang Regency is classified as having a surplus because the daily supply is 342 gr per capita, exceeding the daily needs.

Batang Regency can be categorized as having food self-sufficiency. Its value of the carrying capacity is 4.179, which means the rice production in the region is able to meet the needs for population, even generating a substantial surplus.

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