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Food Carrying Capacity in Gerbangkertosusila Metropolitan Area Using Ecosystem Service-Based Carrying Capacity

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***Abstract*—The issue of food security in Indonesia will persist due to the availability of agricultural area and problems surrounding it. Agricultural land conversion, urbanization-led urban expansion, endogenous and exogenous growth of the region with its population also helps intensify the issue of food security. Gerbangkertosusila metropolitan area is the largest urban agglomeration in East Java Province. Compared to other area in East Java, it has a relatively rapid increase in growth. This causes the quality and quantity of the environment to decrease. Efforts to support the sustainability of an area to meet the needs of humans and other living things require the carrying capacity and capacity of the environment. Therefore, it is necessary to analyze the status of food carrying capacity based on the environmental service. This research uses the modified environmental service-based carrying capacity with spatially calculated dynamic, as opposed to the administrative-based calculation that the common measurement has. The spatial dynamics in a region are captured with the grid-system, with other variables also follows the same grid. The result shows that mostly over 89% of the regions' (represented in grids) food carrying capacity has already been overshot, and that all of the population threshold has also been overshot with exception in Lamongan Regency. It shows that Gerbangkertosusila metropolitan area is currently in a critical situation where it couldn't support the food security by itself and that it needs to rely on other region forming a larger regional system to maintain its sustainability.**

Keywords*—carrying capacity, environmental service, food security, spatial planning

I. INTRODUCTION

THE issue of food security in Indonesia will persist due to the availability of agricultural area and problems surrounding it. Agricultural land conversion, urbanization-led urban expansion, endogenous and exogenous growth of the region with its population also helps intensify the issue of food security [1]. This problem needs an urgent response, especially in Java Island and its metropolitan area since the development of Java Island's metropolitan area tend to keep on increasing along the surrounding peri-urban and rural areas [2-4]. Food security by itself is the condition where demands for food is fulfilled for every individual in a region, as reflected in the availability and surplus of food production (both in quality and quantity) [5]. Therefore, the availability of agricultural land is one of the things that should be considered to ensure future food security [6].

Agricultural area retains an array of comprehensive economic, social, and environmental function [1]. However, in many developing countries (such as Indonesia), agricultural areas often have a significantly lower land rent compared to those of the built-up areas [7]. Therefore, it could trigger land-use change towards non-agricultural area and further worsen the condition. Coupled with the ever-increasing population trends, the fixed and static land availability could also cause a high conversion of agricultural area. The situation around spatial planning policy as well as the zoning policy didn't help much to prevent agricultural loss [3,4]. Issues in landuse change also often targets agricultural area as the converted land-use, which results in the average of around 30% decrease in agricultural area due to urban expansion [8,9]. Other issues also shown a shifting economic activity from agriculture to other sector's, with the decrease of agricultural sector distribution at around 23% in the last decade [10]. Therefore, this issue needs to be approached using a proper comprehensive planning.

Food has a strong correlation with the condition of the area it associated with, one of which is used as the physical basis for the food production/agricultural area. Food crops are plants that can be cultivated on land, rice fields, fields or yards that can produce main food ingredients, such as paddy which produces rice, crops which produce corn, and beans and tubers [11]. An analysis of the carrying capacity of agriculture is very important given the increasing population which drives the demand for food crops to increase as well. The regional carrying capacity for agricultural area is the ability of a region to meet the food needs of the local population to live in prosperity. Carrying capacity analysis related to agricultural activities needs to be done especially regarding the need for food. This is useful to prepare a scenario for food needs in the corresponding region. This analytical approach is critical as a component in sustainable development.

This research aims to identify the state of food carrying capacity in Gerbangkertosusila (GKS) Metropolitan Area Using Environmental Service-Based Carrying Capacity. The entirety of GKS Metropolitan Area is analyzed due to a persisting trend of urban expansion, urbanization, and sub-urbanization as well as agricultural land conversion itself. Using environmental service concept at its core [12] the comparison of total manageable (consumable) resource with total population needs for consumption. This comparison shows that environmental service-based carrying capacity is directly proportional to the amounts of available resources and inversely proportional to the amount of consumption. That is, population growth without an increase in the number of resources causes carrying capacity to get closer to its threshold. The steps taken to map environmental service-based carrying capacity based on food ecosystem services consist of three parts, including distribution of population in a grid system, calculation, and distribution of differences in food energy availability, determination of environmental service-based carrying capacity status based on thresholds, and visualization of the distribution of environmental service-based carrying capacity status in the form of a map. These results were analyzed in a quantitative descriptive manner to describe the distribution of environmental service-based carrying capacity (including distribution and area) through numbers and graphics to better explain the current situation.

II. METHODS

A. Measuring of Food Carrying Capacity Status Using

Table 1.
Input Difference Between Water and Food Carrying Capacity

No	Water Carrying Capacity	Food Carrying Capacity
1	Grid Index Map (5”x5”)	Grid Index Map (5”x5”)
2	Ecosystem Service Value	Ecosystem Service Value
3	Administrative Boundaries	Administrative Boundaries
4	Land-use	Land-use
5	Transportation Network	Transportation Network
6	River Network	Paddy Yield
7	Surface Water Availability	Paddy Yield Index
8	Population	Regional Rice Consumption
9		Population

Environmental Service-Based Carrying Capacity

The main concept of measuring food carrying capacity in this research is carried out based on Ministry of Forestry and Environment’s [13] guideline to determine carrying capacity, with the main difference of methodology in terms of data used and the calculation of supply and demand of food/water (Table 1), and the other modification to relate with food carrying capacity and to better represent in spatial context (represented in a grid) as opposed to the original regional administrative-based measurement. A grid system is a two-dimensional structure that divides an area into contiguous sets of unique and distinct cells. Each cell identifier (identifier) is used for spatial indexing [14]. The concept of a variety scale (multiscale) is used for describes a phenomenon with a pattern that does not change or changes monotonically on a scale by utilizing information that refers to a range of scales simultaneously [15]. The food that is considered in this research is rice, as it is the staple food in Indonesia and that the policy regarding agricultural area is mainly focusing on rice supply-demand.

B. Grid-Based Rice Demand Calculation

To calculate the need for rice per capita per grid, an administrative map is needed in the form of a grid and an assessment of the distribution weight per grid is required. To determine the distribution weight per grid, it is necessary to identify the land-use weight and transportation network. The following is the weight of each type of land-use and transportation network used (Table 2):

$$W_{TR} = \frac{Road_i Length}{TotalRoad\ Length}\ X\ TR_i weight$$

$$W_{LU} = \frac{LU_i Area}{Grid_i Area}\ X\ LU_i weight$$

$$W_{Grid} = W_{LU} + W_{TR}$$

$$Pop_{grid} = \frac{W_{grid}}{\sum grid_{adm}}\ X\ Pop_{adm}$$

Where :

i : Landuse class type

W_{TR} : Weight of transportation network

W_{LU} : Weight of landuse

W_{GRID} : Weight of each identified grid

Table 4.
Number of Population and Grids

No	Adm Region	W_{grid}	Total Grid	Avg. Population per Grid
1	Bangkalan	1,071,712	1,669	642
2	Gresik	1,320,570	1,568	842
3	Lamongan	1,356,027	2,272	597
4	Mojokerto	1,125,522	1,320	853
5	Sidoarjo	2,091,930	934	2,240
6	Mojokerto City	133,272	23	5,751
7	Surabaya City	2,880,284	421	6,841
	Total	**9,979,317**	**8,207**	**1,216**

Pop_{grid} : Number of populations in each grid

Then to determine the need for rice per grid, the population calculation results per grid are multiplied by the standard per capita rice requirement per year, in which in this research we use the assumption of 91.3 kg/capita/year of average rice consumption.

C. Grid-Based Rice Availability

Spatially mapping the environmental service-based carrying capacity shows the complexity through the unscalable administrative-based data to represent each of the carrying capacity components, while the availability of spatial data or spatially oriented data in Indonesia still have a massive gap to cover [16]. To apply spatial dynamic aspects in this research, we use a grid system to better represents the dynamic of carrying capacity within a region without having to upscale or descale the data which will create a bias. The availability of rice per grid is done by converting the area of existing agricultural area into the amount of rice production per Kg per year.

After identifying rice production in kg per year, the next step is to distribute the total rice to the previously prepared grids by comparing the value of the environmental services index for each grid to the total environmental services index (ESI) for the Gerbangkertosusila region (GKS). The ESI calculation is done by weighting the ESI based on the proportion of the area of each object to the area of one grid using the following formula:

$$Prod_{rice} = Total\ area_{harvest} \times Productivity \times Coefficient$$

$$ESI_{polygon} = \frac{polygon\ area\ (feature\ part)}{grid\ area} X\ ESI$$

$$ESI_{grid} = \sum ESI_{polygon}$$

The result of ESI_{grid} in GKS Metropolitan area are calculated per the energy produced for every 1 ESI to get the value of rice availability per grid using the following formula:

$$RA_{grid} = \frac{ESI_{grid}}{\sum ESI_{grid}} X\ RA_{tot}$$

Where :
ESI : Environmental Service Index value
$ESI_{polygon}$: ESI per polygon (feature part)
ESI_{grid} : ESI per grid
RA : Rice availability value
RA_{grid} : Rice availability per grid
RA_{tot} : Total rice availability

D. Food Carrying Capacity Status

Food carrying capacity (FCC) status is obtained by subtracting the energy availability per grid and energy demand per grid. Aside of the carrying capacity status, all the obtained data can be calculated to produce the population threshold (the number of maximum supported population) on each grid and region with the following formula:

$$PT_{grid} = \frac{FCC}{91.3} + Pop_{grid}$$

Where :
PT_{grid} : Population treshold per grid
91.3 : Rice consumption standard per capita per year

Table 3.
Average Distribution of W_{grid} Value in East Java

No	Administrative Region	W_{grid}
1	Bangkalan	352.26
2	Gresik	264.83
3	Lamongan	5.86
4	Mojokerto	84.84
5	Sidoarjo	473.39
6	Mojokerto City	231.82
7	Surabaya City	169.47

III. RESULT AND DISCUSSION

A. Rice Demands in Gerbangkertosusila Metropolitan Area

Rice as the main staple food in Indonesia carries a strategic function besides other commodities such as soybeans, maize, beef, shallots, and sugar [17]. The share of household expenditure on rice is the largest across all household income quintiles [18]. Hence the reason why agricultural policy often revolves around the production, consumption, and distribution of rice. Rice demands is directly proportional with population growth in a region. Hence the calculation of rice demands must also consider the number of populations in a region. From the grid-based calculation, we could identify the population in each grid with consideration of activity centrality in each administrative region as shown in Table 3. Sidoarjo and Bangkalan Regency shows the biggest W_{grid}

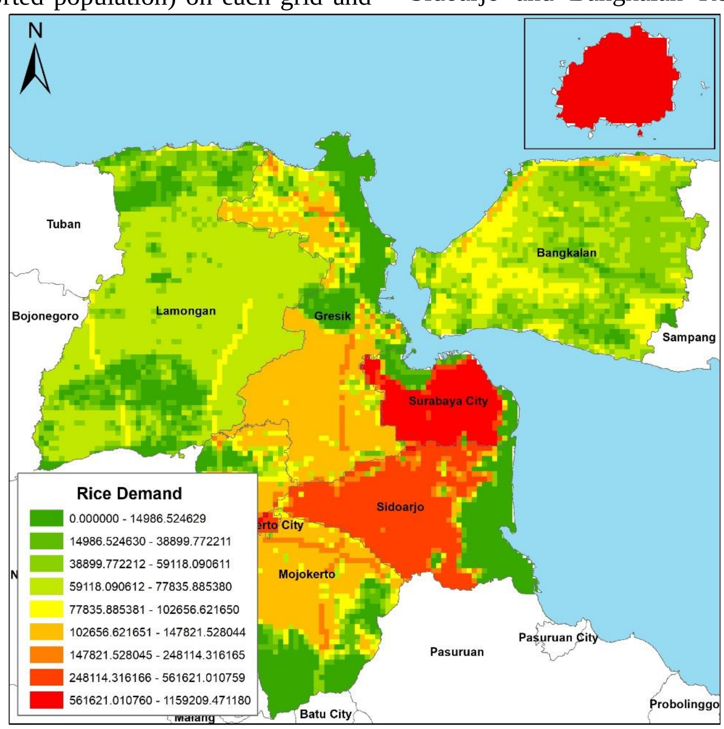

Figure 1. Rice Demands Map in GKS Metropolitan Area

Table 5.
Rice Demand in GKS Metropolitan Area

No	Administrative Region	Rice Demand (kg/year)
1	Bangkalan	97,847,305.60
2	Gresik	120,568,041.00
3	Lamongan	102,760,158.60
4	Mojokerto	190,993,209.00
5	Sidoarjo	190,993,209.00
6	Mojokerto City	12,167,733.60
7	Surabaya City	262,969,929.20
	Total	**911,111,642.10**

value due to the combination of agricultural and urban activities in them, as well as the reason why the capital of East Java (Surabaya City) has a lower W_{grid} value due to the minimum agricultural activities in it.

Based on the population in the Table 4 above, the weight distribution of the population for each grid and the number of grids, the population per grid calculation is obtained in the GKS metropolitan area with a range of 0.000 to 12,696.71 inhabitants per grid. Rice demands are then calculated by multiplying the population in each grid by the rice needs per capita (91.3/kg/capita/year) with the result as shown in Table 5 and Figure 1.

Surabaya City, as hypothesized, has the biggest rice demands by a significant margin with 262,969,929.20 kg/year and Mojokerto City with the smallest at 12,167,733.60 kg/year. The difference in rice demands is largely affected by population number, and the weight in each grid that represent the centrality of activity in each grid. A major example shown by Surabaya as the capital of East Java with the highest intensity of activity will needs a significantly larger demands for rice. Rice demands in the context of environmental service-based carrying capacity could also be interpreted as the energy demands/footprint in the region.

B. Rice Availability in Gerbangkertosusila Metropolitan Area

Rice availabilities are used as the main indicator in the capacity of a region to maintain its food security and carrying capacity. Before adjusted into a grid, total rice production is calculated with the following formula:

Table 6.
Rice Availability in GKS Metropolitan Area

No	Administrative Region	Rice Availability (kg/year)
1	Bangkalan	33,426,765.60
2	Gresik	49,186,489.93
3	Lamongan	262,353,274.48
4	Mojokerto	39,669,285.51
5	Sidoarjo	13,263,262.81
6	Mojokerto City	1,468.79
7	Surabaya City	167,800.32
	Total	**398,068,347.43**

$$Rice_{prod} = Harvest\ area\ X\ Productivity\ X\ Yield\ Coef.$$

After that, the rice production is distributed into their respective grids based on the Environmental Service Index (ESI) to further comprehend itself into the capacity of a region to supply the need for food, or in terms of environmental service-based carrying capacity is the ability of a region to take on the footprint or supply the energy demand of its population. Table 6 shows the rice availability in GKS metropolitan area and Figure 2 the grid distribution of the availability, where Lamongan shows to have the highest availability with 262,353,274.48 kg/year and Mojokerto City is the lowest with 1,468.79 kg/year. The significant difference in results between districts/cities in the Gerbangkertosusila (GKS) region is basically influenced by factual rice field area and productivity in each district/city which in the previous

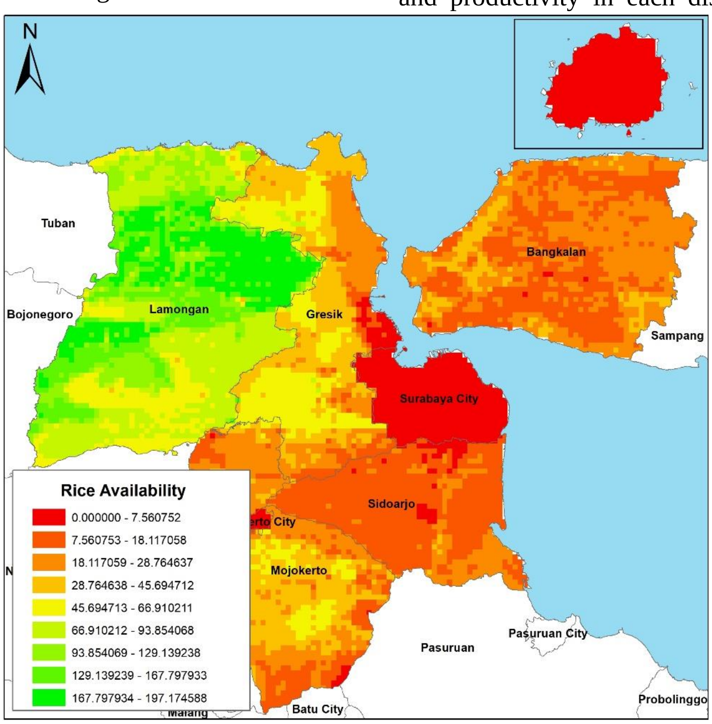

Figure 2. Rice Availability Map in GKS Metropolitan Area

analysis already had high inequality. This is inseparable from the ESI of food providers which depends on the type of ecosystem found in each administrative area such as agriculture and plantations, livestock food products, marine products and including food from forests.

C. Food Carrying Capacity Status in Gerbangkertosusila Metropolitan Area

Food carrying capacity can be obtained by subtracting rice availability with rice demand so that it will show a surplus or deficit status. Carrying capacity has become an essential basis for measuring the degree of coordinated development in a region [19]. Carrying capacity could also mean the number of maximum populations that can be accommodated in a region. It is essentially needed in the current age where population flow is very dynamic by taking account into daily activity and mobility. A surplus or deficit status of carrying capacity could indicate the development sustainability in a region with a more thorough evaluation. In a metropolitan context, surplus condition could mean that the metropolitan area itself can function completely as an entire system without having to rely much on the surrounding rural areas. The condition of food carrying capacity in GKS metropolitan area as shown in Table 7 and 8 indicates that only Lamongan Regency still maintain its surplus status. It means that Lamongan Regency acts as the main food supplier in the entire GKS metropolitan area. But after a more thorough evaluation using spatial grid system, it is shown that 7357 (89.64%) of total grid counts as deficit as shown in Figure 3. This result also coincides with the national data on national rice supplier area, where Lamongan coupled with Bojonegoro, Tuban, Ngawi, and Jember acts as the anchor in the East Java's food security. Lamongan's role are deemed to be crucial in the GKS regional system to support the sustainability of the region.

Table 7.
Food Carrying Capacity Status in GKS Metropolitan Area

No	Administrative Region	Δ Rice Supply	Status	Overshot Grid Capacity	Deficit Precentage
1	Bangkalan	-64,420,540.00	Deficit	1,653	99%
2	Gresik	-71,381,551.07	Deficit	1,354	86%
3	Lamongan	138,548,009.38	Surplus	2,158	95%
4	Mojokerto	-63,090,873.09	Deficit	1,068	81%
5	Sidoarjo	-177,729,946.19	Deficit	734	78%
6	Mojokerto City	-12,166,264.88	Deficit	23	100%
7	Surabaya City	-262,802,128.88	Deficit	367	87%

Table 8.
Population Threshold in GKS Metropolitan Area

No	Administrative Region	Δ Rice Supply	Status	Overshot Grid Capacity	Deficit Precentage
1	Bangkalan	-64,420,540.00	Deficit	1,653	99%
2	Gresik	-71,381,551.07	Deficit	1,354	86%
3	Lamongan	138,548,009.38	Surplus	2,158	95%
4	Mojokerto	-63,090,873.09	Deficit	1,068	81%
5	Sidoarjo	-177,729,946.19	Deficit	734	78%
6	Mojokerto City	-12,166,264.88	Deficit	23	100%
7	Surabaya City	-262,802,128.88	Deficit	367	87%

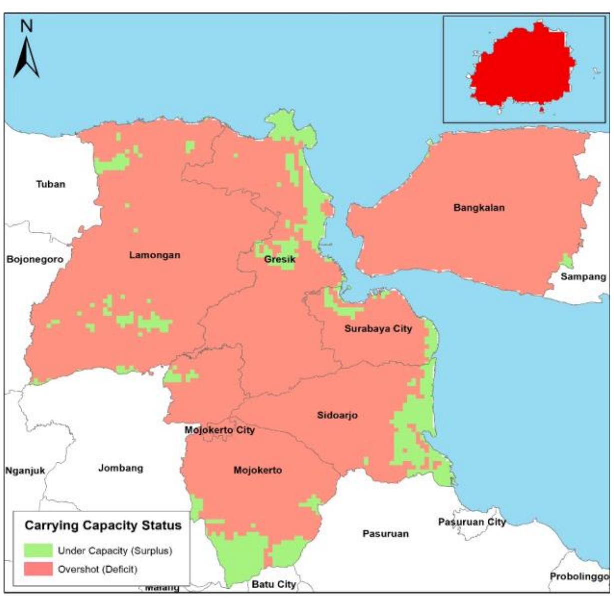

Figure 3. Food Carrying Capacity Map in GKS Metropolitan Area

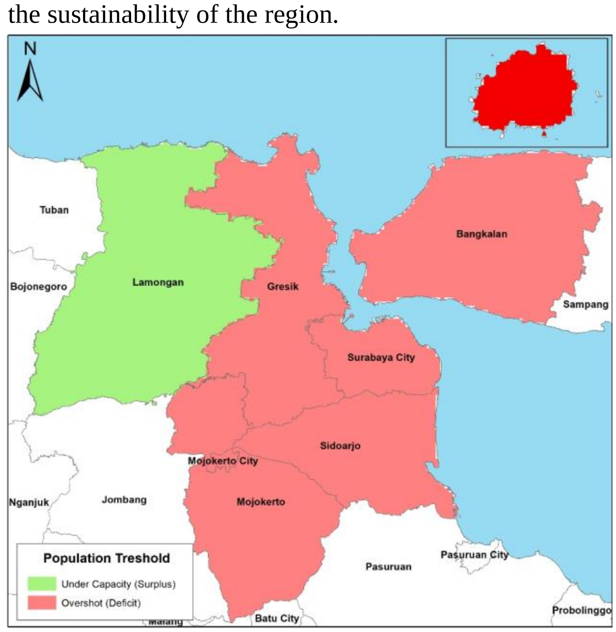

Figure 4. Population Threshold in GKS Metropolitan Area

IV. CONCLUSION

This paper explores carrying capacity in the context of food production-consumption scale. Gerbangkertosusila (GKS) metropolitan area in this context works as an entire regional system where resources (human, natural, economic) keep on flowing in-and-out of each administrative region, making the classic carrying capacity measurement by administrative region to be inaccurate. Therefore, this research uses a grid system to capture the dynamic inside an administrative region to better explain intensity of activities and its' carrying capacity. The result shows that over 89% of the regions' (represented in grids) food carrying capacity and population threshold has already been overshot, with exception being in Lamongan Regency. Some grids that still holds it carrying capacity are usually the strategic agricultural area in each administrative region. The current trends and situation reflect that Indonesian planning policy are leaning way towards economic growth and sidelining agricultural protection policy. It also shows that GKS metropolitan area is currently in a critical condition where it couldn't sustain itself in terms of food needs/demand. While in economic perspective, it is understandable that GKS metropolitan area has to fulfil its role as the main economic pole of East Java, further consideration towards the environmental sustainability and food security must also be taken into account in the planning process, and that East Java in a higher regional hierarchy must also built an adequate regional system to support the sustainability of GKS metropolitan area.

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