MAPPING THE STATUS OF ENVIRONMENTAL CARRYING CAPACITY FOR FOOD PROVISION BASED ON ECOSYSTEM SERVICES IN PALU

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Abstract—The increase in population and development activities impacts reducing resources or decreasing environmental quantity and quality. Palu city landscape is located in the ecotone area., which will influence environmental sensitivity and vulnerability due to population and development pressure. Ecotone area is relatively heterogeneous but vulnerable if facing environmental degradation. The impact of land use change affects the quality of the environment. Decreasing the quality and quantity of the environment can lead to disaster in that area. Therefore, it is necessary to consider aspects of an area's carrying capacity and capacity. This study aimed to obtain information on the distribution of environmental carrying capacity status based on the ecosystem services of food providers in the Palu city landscape. This study was conducted with the following stages; 1) Data Collection, 2) Potential Food Analysis of Palu City, 3) Spatial analysis of population density distribution, 4) Spatial analysis of the status of Palu City's Food Carrying Capacity. The spatial analysis process uses a grid system approach of variance scale. The results showed the distribution pattern and extent of the food carrying capacity status in the city of Palu, covering an area of 16,441.71 ha or 46.09% of the total area of the city of Palu, is an environmental area whose food carrying capacity status has been exceeded. The sub-districts whose area has more than 90% of their carrying capacity has been exceeded are West Palu, East Palu, Tatanga, and South Palu districts.

Keywords—carrying capacity, ecosystem services, food, provision

1. Introduction

The increase in human population directly affects the use of space and the quality of the environment [1]. The increase in population in the city of Palu directly affects the landscape of the city of Palu, which is in the ecotone area.

Ecotone is an area of natural conditions between ecosystems with different characteristics [2]. This area is relatively vulnerable if it is disturbed or damaged, which results in a decrease in environmental quality. The pressures for these changes include changes in land use from natural conditions or the impact of land use change. Changes in the function of land, which was initially in the form of agricultural land, dry fields or plantations and ponds to become non-agricultural land, occurred from 1990 to 2020 [3].

Population pressure on growing agricultural land can lead to conditions where the area can no longer meet its population's food needs[4]. In 2020 the food area will be reduced from 20% to 16% , Significant changes in paddy fields from 4,769 ha to 2,487 ha and fishing areas from 29 ha to 20 ha [5]. The land that is expanding in Palu City is a residential, industrial, and mining area. This condition needs attention from policymakers in development activities in the city of Palu to control the use of space so that the food area in the city of Palu can be maintained.

Policymakers need fast and accurate information regarding the location and status of the environment in taking strategic steps to maintain and maintain environmental balance. The consideration commonly used is an area's carrying

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capacity and capacity [1], [6]. Information about the status of environmental carrying capacity is increasingly being taken into account in making decisions to support the achievement of sustainable development goals.

The status of the environmental carrying capacity for food provisions is spatially needed in formulating development strategies and guiding policymakers. This status helps determine priority locations in the restoration of carrying capacity and critical ecosystems, particularly related to the carrying capacity for food supply in Palu. This study aims to obtain spatial information regarding the distribution of environmental carrying capacity status based on ecosystem services providing food in the landscape of Palu city.

2. Methods

This research was conducted with the following stages; i) data collection, ii) analysis of food potential in Palu city, iii) spatial analysis of food supporting capacity status in Palu. The spatial analysis process uses a variety scale grid system approach [7]. Input data in the spatial and non-spatial forms as follows.

Spatial Data	Non-Spatial Data
1. Ecosystem service performance map (food index value)	1. Data on the amount of Potential Food Energy (Kcal)
2. District administration map	2. Population data
3. Grid system resolution 5" x 5"	3. Weight for Road type
4. Land cover map	4. Weight for land cover type
5. Road network map	

The population distribution model depends on the type of land cover or land use and the road length. To model population density, the weights for land and road classes used in this study were adopted from the weight values according to Riqqi, 2008 and Nengsih, 2015.

The applied mathematical equation adopts the population density model [8], [9].

$$P_{ij} = \frac{W_{total}}{\sum_{i=1}^{j} W_{total}} \times P_j$$

Where Pij is the number of inhabitants of the ith grid in the district j (capita), Wtotal is population density weight based on land class and road type, Pj is population of district j (capita), and Σi=1Wtotal : the sum of the weighted population densities of all grids in district j.

The energy requirement for food is obtained by calculating the energy adequacy rate for each grid for one year. This calculation uses the following equation:

$$K_{Bi} = P_{ij}\ x\ AKE\ x\ 365$$

Where Pij is the number of inhabitants of the i-th grid in the j sub-district, and AKE (Energy Adequacy Rate per Capita, Kcal): 2,150 (Kcal/day)

At the stage of calculating food availability, the data used is the Population Distribution Map in a grid system, ecoregion data and ecosystem services index (IJE) values for food providers obtained from the document results of the study of the Carrying Capacity of the Ecosystem Services of Palu City in 2020. Then the availability food is distributed in a grid system using the equation adapted from Norvyani and Taradini (2016):

$$1IJEP_j = \frac{\sum W_j}{\sum IJEP_j}$$

Where 1IJEPj: availability for one IJEP per unit area, ΣWj: total availability for each unit area j, and ΣIJEPj: total IJEP for each unit area j.

After obtaining the availability value for one IJEP, the availability distribution is carried out in a grid system with the equation below [10].

$$W_{ij} = 1IJEP_j \times IJEP'_{ij}$$

Where Wij is availability on grid i area unit j (kcal), 1IJEPj is availability for one IJEP per unit area, and IJEP'ij is IJEP grid i in unit area j used.

The status of food carrying capacity is determined by calculating the difference between supply and demand and the population threshold. The approach to the difference between food availability and demand is obtained by reducing the availability and demand for food on the same grid. While the threshold approach, which is based on the population limit, is obtained by dividing the availability by the energy needs of food per capita per year. The mathematical equation used to calculate the difference in food energy is adapted from Norvyani and Taradini (2016), as follows:

$$K_{S_i} = K_{H_{ij}} - K_{B_i}$$

Where KSi: energy difference in grid i district j (kcal), KHij: food energy availability in grid i district j (kcal), and KBi: iAKE in grid i district j (kcal).

3. Results and Discussion

The status of the environmental carrying capacity for food supply in Palu City illustrates the comparison between food availability based on the food potential of various food commodities with the level of community need for these various food commodities. Moreover, based on environmental

service data, the index of ecosystem services for food providers, the status of environmental carrying capacity for food provision in Palu City is studied spatially using a variety scale grid system approach. Thus, the status of the environmental carrying capacity for food provision in Palu City can be mapped according to the status of the environmental carrying capacity in the entire coverage area of the Palu city administration.

The potential availability of food in Palu City is 60,243,490.62 Kcal/year from several types of food commodity production based on BPS data, where the production value per year is input data on food availability which is converted into Kcal units (Table 1)

Table 2. Data on the food potential of the city of Palu based on the production of several food commodities in energy units (Kcal/year)

3.1. Potential Food Availability

Food commodity	District								Total
	Palu Barat	Tatanga	Ulujadi	Palu Selatan	Palu Timur	Mantikulore	Palu Utara	Tawaeli	
Paddy	0	568.654	0	0	0	1.489.679	0	1.691.474	**3.749.807**
Paddy Field	0	0	0	0	0	0	0	0	**0**
Corn	0	768	2.334.720	40.96	0	492.8	220.8	3.360.000	**7.217.280**
Soya bean	0	0	0	0	0	0	0	0	**0**
Peanuts	0	0	25.2	0	0	324.45	141.75	73.5	**564.9**
Mung beans	0	0	0	0	0	0	0	0	**0**
Sweet potato	0	0	0	0	0	0	0	0	**0**
Cassava	0	73	474.5	0	0	0	1.606	328.5	**877.606**
Beef	66.24	309.12	250.125	226.665	26.565	786.255	517.673	943.058	**3.125.700**
Buffalo meat	0	0	0	0	0	0	0	0	**0**
Lamb	286.153	431.159	506.229	244.716	38.972	1.110.484	468.242	205.99	**3.291.945**
Sheep's meat	28.29	35.8	506.23	60.984	0	527.06	38.962	23.264	**1.220.590**
Local chicken meat	0	0	0	0	0	0	0	0	**0**
Laying chicken meat	29.309	354.585	0	56.064	0	1.092.823	16.013.840	0	**17.546.622**
Broiler meat	3.108.958	828.563	613.836	593.028	0	3.062.128	11.808.690	165.77	**20.180.974**
Duck	0	0	0	254	0	0	0	0	**254**
Broiler eggs	0	0	0	0	0	0	0	0	**0**
Local chicken eggs	13.302	0	0	0	0	0	0	0	**13.302**
Duck eggs	471	0	0	0	0	0	0	0	**471**
Fish	113.892	27.973	114.226	13.846	8.266	125.249	107.608	132.036	**643.097**
Mango	8.896	8.508	17.614	10.225	4.043	42.029	0	54.069	**145.384**
Jackfruit	6.886	17.755	199.492	2.915	5.229	80.631	24.981	44.343	**382.232**
Star fruit	133	0	0	36	163	6.36	2.34	342	**9.374**
Banana	42	922	8.633	0	1.264	181.485	16.306	24.684	**233.337**
Pawpaw	2.595	610	586	0	48	8.446	4.264	5.785	**22.333**
Grape	2.083	4.224	80	116	60	1.3	630	300	**8.793**
Shallot	0	52.48	23.76	1.292	0	22.919	70.52	615	**171.585**
Big chili	76	34.77	0	0	0	7.866	10.336	3.743	**56.791**
Chili	240	78.33	324.6	6.75	0	132.12	33.66	0	**575.7**
Spinach	0	1.46	0	0	0	0	0	0	**1.46**
Mustard	19	17.783	0	0	0	0	0	0	**17.802**
Tomatoes	51	131.082	0	0	0	38.724	2.892	2.088	**174.837**
Water spinach	118	4.983	0	1.804	0	0	3.402	1.008	**11.315**
Amount	**3.667.752**	**3.749.762**	**5.399.831**	**1.259.655**	**84.61**	**9.532.807**	**29.488.502**	**7.060.570**	**60.243.491**

The data in the table also shows that the food potential based on the content of the highest caloric value is found in Palu Utara, Mantikulore, Tawaeli, and Ulujadi districts, respectively. In contrast, other districts have food potential of less than 5 million Kcal per year.

3.2. Estimated Food Needs

The food needs are also calculated in units of energy or calories from food consumed by each individual in the population. For this reason, based on the population of the city of Palu in 2020, an estimate of the amount of food needed in the city of Palu can be made using the number of inhabitants in each district multiplied by the Standard Energy Adequacy Rate (AKE), which is 2,150/person/day which is then converted in units of time per year. The following is an overview of the food needs of Palu City, based on the population in 2022, presented in Table 3.

Table 3. Food needs in each district of Palu city, 2022

District	Population 2022	Food Needs per Year (Population ×AKE × 365)
Mantikulore	76.745.00	60.225.638.750
Palu Barat	46.435.00	36.439.866.250
Palu Selatan	72.059.00	56.548.300.250
Palu Timur	43.318.00	33.993.800.500
Palu Utara	24.458.00	19.193.415.500
Tatanga	52.580.00	41.262.155.000
Tawaeli	22.568.00	17.710.238.000
Ulujadi	34.220.00	26.854.145.000
Total	**372.383.00**	**292.227.559.250**

3.3. Status of Environmental Supporting Capacity for Food Providers

The supply and demand approach determines the exceeded or not exceeded status in the carrying capacity of food supply. If the value is negative, then the carrying capacity of the food supply environment in an area has been exceeded, and vice versa. It is declared has been within the limit.

The data show that food availability in Palu is 60,243,491 Kcal/year, and the total population in 2020 of 372,383.00. The data for food needs is 292,227,559,250 Kcal/year. The calculation showed that the carrying capacity of food in Palu exceeds -292,167,315,759.37 Kcal/year, which means that the environment's capacity for food provision in the city of Palu has been exceeded. The data is limited to showing the status of food carrying capacity based on the value of the difference in quantity resulting from the reduction of the food supply and the amount of food needed.

In order to provide information on the spatial distribution of the status of the carrying capacity of food provision in Palu city also necessary to input ecosystem service index data for food provision along with a map of ecosystem services for food provision. Both of these data are maps of food providers' indicative carrying capacity status, as shown in Figure 1. Then using a grid system approach of a variety scale, the distribution of ecosystem service index values into the grid system is based on the environmental services index of Palu food provision, with the assumption that the higher the index value in the area, the greater the value of the distribution of potential availability in the area.

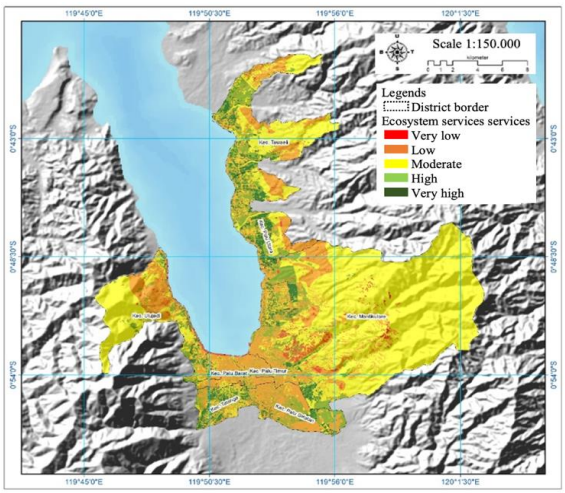

Figure 1. An indicative map of the carrying capacity of ecosystem service classes for the food supply of Palu (Source: Environmental carrying capacity study document based on ecosystem services in Palu, 2020).

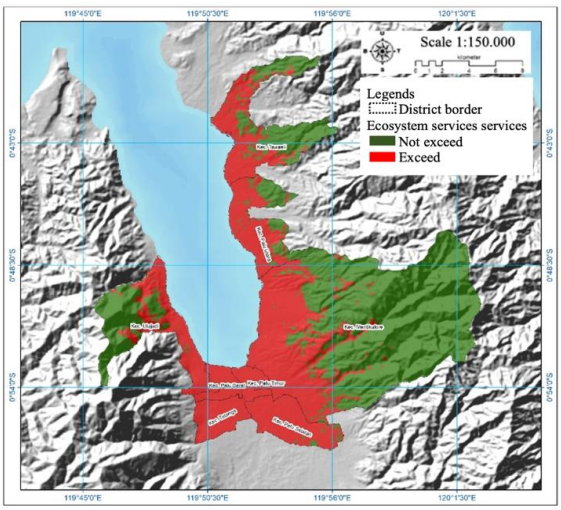

Figure 2. Map of distribution of food carying capacity status in Palu for 2022

Spatial information on the carrying capacity status for food provision can be generated, which represnting the need for food for the population in a district (Figure 2). Information on the area coverage of the status of food carrying capacity in each district is presented in Table 4.

Table 4. Status of food carrying capacity in each district in 2022.

District	Status of food carrying capacity				Total (ha)
	Not exceed		exceed		
	Area (ha)	%	Area (ha)	%	
Mantikulore	13,864.63	70.30%	5,856.21	29.70%	19,720.85
Palu Barat	0.00	0.00%	615.84	100.00%	615.85
Palu Selatan	110.67	5.37%	1,948.48	94.63%	2,059.16
Palu Timur	0.04	0.01%	624.76	99.99%	624.80
Palu Utara	928.86	32.69%	1,912.14	67.31%	2,841.00
Tatanga	0.33	0.03%	1,271.69	99.97%	1,272.02
Tawaeli	2,239.19	51.17%	2,136.51	48.83%	4,375.71
Ulujadi	2,085.12	50.11%	2,076.06	49.89%	4,161.18
Total	19,228.86	53.91%	16,441.71	46.09%	35,670.56

Table 4 shows that there are 16,441.71 ha or 46.09% of the total area of Palu with food carrying capacity status that has been exceeded. The districts whose area has exceeded 90% status are the Palu Barat, Palu Timur, Tatanga, and Palu Selatan Districts. Those districts have the most rapid development in their region. Palu Barat and Palu Timur, which have an area of less than 700 ha, limited space for development activities and exceeded carrying capacity in the food supply. Therefore it needs special attention and handling to maintain the food supply chain in these areas.

CONCLUSION

About 16,441.71 ha (46.09%) of the total area of Palu has a food-carrying capacity status that has been exceeded. Covering the areas of Palu Barat sub-district, East Palu sub-district, Tatanga sub-district, and South Palu sub-district.

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