Environmental carrying capacity based on ecosystem services of Penajam Paser Utara Regency

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Abstract. Until 2017, the economy of Penajam Paser Utara Regency was still dominated by the primary sector of agriculture, plantations, and mining. The exploitation of this sector is oriented at economic growth resulting in environmental degradation and a decrease in ecosystem quality as indicated by the intensity of natural disasters. Notably, over the past eight years, there have been forty-six natural disasters. Therefore, the land use planning in Penajam Paser Utara Regency must be evaluated based on the carrying capacity of the environment. One possible approach is an ecosystem services assessment to ensure that future land use planning can match its ecosystem carrying capacity. The purpose of this research is a three-stage evaluation of land use planning in Penajam Paser Utara Regency based on the characteristics of its ecosystem services. First, environmental support analysis based on ecosystem services uses the Analytical Hierarchy Process assessment to obtain the weight of each variety. Then, the calculated current carrying capacity index is transformed into maps with five classifications namely very low, low, medium, high and very high. The study found twenty-two types of ecosystem services in Penajam Paser Utara Regency and the most dominant is the ecosystem service for energy provision with an area of 119.979 Ha.

1. Introduction

According to National Medium Term Development Plan (RPJMN/Rencana Pembangunan Jangka Menengah 2004-2009), natural resources are utilized for the benefit of the people's welfare, but their utilization must consider the preservation of environmental functions. Over time, aggressive, exploitative, and expansive patterns of production and consumption cause the carrying capacity and function of the environment to decrease, even leading to alarming conditions. Natural resource management needs to be done wisely to balance its supply while maintaining and improving diversity and its value [1]. Moreover, in referring to Presidential Regulation No. 7/2005 concerning the national midterm plan for 2004-2009 states that natural resources have the function of capital-based economic growth. Moreover, they serve as a life-supporting system that must be managed in a balanced manner through the application of sustainability principles in an effort to improve natural resource management and environmental preservation. Until 2017, the economic structure of Penajam Paser Utara Regency was still dominated by natural resource-based sectors, namely mining and quarrying, agriculture, and processing industries. This is evident from the magnitude of each sector. In 2017 the agricultural sector had a contribution to the GRDP of 20.75%, while the mining sector had a contribution of 30.56%. This is in line with the local spatial planning objectives as stipulated in...
Penajam Paser Utara Regency Regulation Number 3 of 2014 concerning the Regional Spatial Plan of Penajam Paser Utara Regency in 2011-2031. This regulation seeks to realize Penajam Paser Utara Regency as the center of agribusiness and the agro-industry based on the populist economy, as well as the sustainable development of the region's mining potential.

In order for the local government to achieve its spatial planning objectives, there have been changes in land use that are more in favor of economic development and pay less attention to environmental aspects. For instance, the regency saw a decrease in forest area from 2010 to 2016 amounting to 4,528 hectares, while the mining area increased from 526 ha in 2010 to 776 ha in 2016 [2]. Patterns of natural resource utilization that cause an uncontrolled economic growth coupled with land use changes lead to chaotic land use patterns that affect ecosystem survival [3]. This is evident from the relatively fixed land area; people tend to exploit existing land which causes environmental degradation [4]. The impact of intensive land exploitation with disregard to the sustainability of natural and environmental resource functions results in land degradation and triggers disasters such as erosion, sedimentation, flooding, and landslides [5]. From 2010 to 2018, 46 natural disasters occurred in Penajam Paser Utara Regency comprising 13 flood disasters, two drought events, three whirlwind disasters, 17 land and forest fires, and one landslide [6].

The environmental carrying capacity is the capacity or ability of the ecosystem to support the life of organisms in a healthy manner while maintaining productivity, adaptability, and the ability for self-renewal. Environmental carrying capacity is defined as the ability of the environment to support human life [7]. Whereas Government Regulation Number 46 of 2017 concerning Environmental Economic Instruments, defines Environmental Services as the benefits of ecosystems and the environment for humans and the sustainability of life which includes the provision of natural resources, natural and environmental arrangements, supporting natural processes and preserving cultural values. In this approach, the carrying capacity of ecosystem services is viewed in the context of "the benefits that people obtain from ecosystems". Examples include food and drug production, climate and disease regulation, the availability of productive land and clean water, protection against natural disasters, opportunities for recreation, maintenance of cultural heritage and spiritual benefits [8]. The essence of environmental carrying capacity is a balance between supply and demand. Supply is usually limited but faces unlimited demand. In this case, the causes of environmental pressure can be from population growth and increased regional economic activity [9]. Considering the above problems, it is necessary to conduct a study of environmental carrying capacity based on its ecosystem services.

2. Literature review
Ecosystems are complex entities consisting of a dynamic community of plants, animals, and microorganisms and their abiotic environments that interacting as a single functional unit [10]. Ecosystem services refer to the ability of ecosystem components to carry out natural processes of providing materials/goods and services needed to meet human needs [11]. Thus, ecosystem services are the benefits derived by humans from ecosystems both directly and indirectly [12]. In other words, ecosystem services are the benefits that humans can obtain from various natural resources and processes provided by an ecosystem. Based on the commonly used scientific definitions, Wahyudin [13] suggested that ecosystem services are various benefits obtainable to humans as a source of living and livelihoods, both directly and indirectly, and for the sustainability of the ecosystem. MEA classifies ecosystem services into four functions, namely:

- Providing services such as sources of food, water, genetic resources, fiber, fuel, and other materials.
- Regulating services that regulate air quality, climate, water flow, and flooding, and offer prevention and protection against natural disasters, water purification, waste treatment, and natural pollination, and pest control.
- Cultural services such as cultural identity and diversity, religious and spiritual values, knowledge (traditional and formal), aesthetic value inspiration, social relations, heritage values, recreation, etc.
- Supporting services such as primary production, land formation, oxygen production, soil resistance, pollination, habitat availability, and the nutrient cycle.

3. Methodology
This study comprises three stages: (i) composing multiple paired matrices for land cover variables and landforms; (ii) calculating the weight of ecosystem services and checking the consistency of the ratio; (iii) calculating the index value of ecosystem services.

3.1. Data source
The data collection for the compilation of ecosystem service capacity and capacity based on ecosystem services is carried out by using an expert-based valuation method. Specifically, a number of experts who are competent in their fields assess the role of each type of land cover and landform carried [14]. The expert-based valuation method is carried out using group communication of experts to discuss a problem. Generally, the experts have expertise in the field of problems being discussed and are very familiar with the study area. Assessment of the role of landforms and land cover for ecosystem services is done by giving a score. For the assessment of land cover using a questionnaire was distributed to selected stakeholders. This questionnaire contained tables that illustrate the comparison of the scale of the assessment of 20 ecosystem services comprising providing services, regulatory services, cultural services, and supporting services for each class of land cover and landforms.

The questionnaire was filled out based on theory and the knowledge, observations, and experiences of the respondents. Given the diversity of landforms and land cover in the observation area, the principle of generalization is carried out according to the depth of the observation scale. The process of transforming data from landforms and land cover into the value of ecosystem services is done by answering several questions about the importance and role of the types of landscapes and land cover for ecosystem services. The principle is a comparison of the level of importance or the role of the types of landscapes and land cover for the types of ecosystem services (the principle of relativity).

3.2. Data analysis
To obtain the environmental carrying capacity based on ecosystem services, the first step taken is to make a paired comparison matrix containing expert evaluations of the types of landforms and land cover. This pairing model evaluates the role of a variable for a particular interest by comparing it with other variables in pairs. The pairwise comparison matrix is an Analytic Hierarchy Process (AHP) method that is intended to produce weights from each classification of landforms and land cover for each stakeholder. This allows insight into each stakeholder’s assessment of the influence of each type of landform and land cover.

The second step is datanormalization to ensure data dependencies (i.e., avoid anomalies and inconsistencies in the data). After the data is normally distributed, it is possible to calculate the weight of ecosystem services and the consistency of the ratio. Calculation of weight values for ecosystem services for each land cover class and landform is through summing the values in each row. The total value obtained is the weight for each class of landforms or land cover for ecosystem services. Whereas to test hierarchical consistency (consistency ratio), Saaty [14] has proven that the consistency index of the n-order matrix can be obtained by the formula:

\[
CI = \frac{\lambda_{\text{max}} - n}{n-1}
\]  

\(CI\) = Consistency Index  
\(\lambda_{\text{max}}\) = The largest eigenvalue of the matrix with n
The greatest eigenvalue is obtained by summing up the results from multiplying the number of columns with the eigenvector. The inconsistency limit is measured by using a consistency ratio (CR), which is the comparison of the consistency index (CI) with the random generator value (RI). This value depends on the order of the matrix n. The consistency ratio can be formulated as $CR = \frac{CI}{RI}$.

The results obtained from the consistency test are in accordance with Saaty [14] that if the consistency ratio (CR) value is less than 10%, the inconsistency of opinion is still considered acceptable. If the value does not meet $CR < 0.100$, the assessment must be repeated.

The third stage is to calculate the index of ecosystem services based on index values of landform and land cover type. Based on this, the Ecosystem Services Index (IJE) is compiled by multiplying the formula contained in the environmental carrying capacity calculation guide (P3ES, 2016) as follows:

Simple IJE multiplication of landform base and IJE land cover base

$$IJE = iec \times ilc$$

(2)

Where:
- IJE = index of ecosystem services
- iec = index based on landform
- ilc = index based on land cover

Scaling IJE Value

The scaling process of the IJE value is done with the same equation as follows:

$$\sqrt{\frac{\sum IJE_{lc} \times IJE_{eco}}{\text{maks} (\sqrt{\sum IJE_{lc} \times IJE_{eco}})}}$$

(3)

Where:
- $IJE_{lc}$ : land cover index ecosystem service
- $IJE_{eco}$ : landform index ecosystem service
- Maks (maks) : Maximum value from the index synthesis results

The range of IJE values that have been normalized in the scaling process is between 0-1, whereas, the closer to the value of 1, the higher the Coefficient of Ecosystem Services (KJE) of an area is. Based on the distribution of KJE value data, IJE classification can be done based on geometric rules written in the formula as follows;

$$X_n = \frac{B}{A}$$

(4)

$$X = \frac{n B}{\sqrt{A}}$$

(5)

Where:
- B = Maximum Value
- A = Minimum Value
- n = Number of classes

Each ecosystem service has a different range of classes, resulting from varying minimum and maximum values. All coefficient values of ecosystem services are displayed in the ecosystem carrying capacity map of ecosystem services.

4. Results

Penajam Paser Utara Regency is located in East Kalimantan Province and has an area of 3,333.06 km². The regency is divided into four sub-districts, namely Babulu, Waru, Penajam, and Sepaku that have an area of 399.45 km², 553.88 km², 1,207.37 km², and 1,172.36 km², respectively. The Gross Regional Domestic Product (GRDP) of Penajam Paser Utara increases significantly each year with the mining and quarrying sector as the greatest contributor to the GRDP in 2017, amounting to 2,184,071.29 million.
Figure 1. Study location (Penajam Paser Utara Regency).

The carrying capacity of the environment is measured using the ecosystem services approach as carried out in the United Nation’s Millennium Ecosystem Assessment. The assumption is that greater ecosystem services translate to a higher carrying capacity of the environment. Ecosystem services are determined by the presence of endogenous factors and the dynamics of exogenous factors that are reflected by two components, namely the landform and land cover/land use as an estimator or proxy.

Penajam Paser Utara Regency has six common landforms, i.e., Fluvial Plains (Flat - Sloping), Fluvimarine Plains, Structural Plains, Fluvial Valleys, Fold Mountains and Folded Hills. The regency is dominated by 234,430.04 ha of Structural Plains (51.26%). The second most dominant landform is folded hills with a total area of 97,966.25 ha (21.42%). The third is fluvimarine plains (80,752.93 ha, 17.66%). The dominant land cover in Penajam Paser Utara is mixed plantations with a total area of 96,920.20 hectares (30.53% of the total area of the regency). The second most common land cover is primary dryland forest which covers 54,073.40 ha and makes up 17.06% of the total land cover in Penajam Paser Utara Regency.

4.1. Profile of ecosystem services provision
This paper discusses the provision of five ecosystem services, i.e., food, clean water, fiber, energy, and genetic resources. The five ecosystem services are elaborated according to their classification and area. The paper presents a table for the distribution of ecosystem services based on the analysis of the carrying capacity in Penajam Paser Utara Regency. The ecosystem services are classified into five categories, namely very low, low, medium, high and very high with the area in units of hectares.

| No | Code | Type of Ecosystem Services | Area Ha |
|----|------|----------------------------|---------|
| 1  | P1   | Food                       | Very Low| Low | Moderate | High | Very High |
|    |      |                            | 128,555 | 79,507 | 60,033 | 43,557 | 5,346     |
| 2  | P2   | Fresh Water                | 32,871  | 72,212 | 131,176 | 71,981 | 8,757     |
| 3  | P3   | Fiber                      | 32,001  | 95,743 | 143,637 | 42,906 | 2,711     |
| 4  | P4   | Energy                     | 39,014  | 53,588 | 26,060  | 78,356 | 119,979   |
| 5  | P5   | Genetic Resources          | 7,782   | 64,493 | 155,810 | 55,754 | 33,159    |

Based on the regency’s carrying capacity, Penajam Paser Utara does not have a good food supply since it is dominated by areas classified as very low and low. It does not have a good level of water supply either because the areas that dominate are classified as medium and low. Moreover, fiber
provision in Penajam Paser Utara Regency is poor since the area that dominates is classified as moderate and low. However, energy provision in Penajam Paser Utara Regency is very good since the area that dominates has high and very high classifications. Lastly, genetic resource provision in Penajam Paser Utara Regency is relatively good because most areas are classified as medium. Overall, the provision of ecosystem services in Penajam Paser Utara Regency is very low, meaning that the region has a very low carrying capacity.

4.2. Profile of regulating ecosystem services
Regulating ecosystem services consist of eight components, i.e., climateregulation, water flow and flood regulation, prevention and protection from disasters, water purification, waste management, air quality maintenance, natural pollination, and control of pests control and diseases. The eight ecosystem services will be discussed based on their classification and area. From the analysis of the carrying capacity based on ecosystem services in Penajam Paser Utara Regency, Table 2 was obtained that presents the distribution of regulatory ecosystem services that are classified into five categories, namely very low, low, medium, high and very high, with the area in hectares.

Table 2. Distribution of regulatory ecosystem services.

| Code | Types of Ecosystem Services | Area Ha |
|------|-----------------------------|---------|
|      | Very Low | Low | Medium | High | Very High |
| R1   | Climate Regulation | 7,782   | 66,085 | 133,479 | 73,125 | 36,526 |
| R2   | Water Flow and Flood Regulation | 34,297   | 153,556 | 103,235 | 20,638 | 5,271 |
| R3   | Prevention and Protection from Disasters | 31,451   | 66,306 | 156,588 | 60,420 | 2,232 |
| R4   | Water Purification | 5,149   | 49,437 | 34,497 | 157,675 | 70,240 |
| R5   | Waste Water Management | 23,333   | 52,707 | 118,871 | 104,146 | 17,941 |
| R6   | Air Quality | 7,910   | 14,334 | 68,530 | 130,269 | 95,955 |
| R7   | Pollination | 1,821   | 16,048 | 76,495 | 124,397 | 98,237 |
| R8   | Control of Pests and Diseases | 6,396   | 28,035 | 117,146 | 150,743 | 14,677 |

Penajam Paser Utara Regency has a relatively good level of climate regulation because the area that dominates is that with medium classification. Whereas the level of flood regulation is classified as not good because the area that dominates is low and medium classification. Disaster protection and prevention in Penajam Paser Utara Regency is classified as not good because the area that dominates is medium and low classification, whereas the level of water purification regulation shows a relatively good environmental carrying capacity because the areas that dominate have high and very high classification. Wastewater treatment is classified as less good because the area that dominates in Penajam Paser Utara Regency is high and medium classification, while the level of air quality regulation is relatively good because the area that dominates has a high and very high classification. The level of natural pollination also has a relatively good environmental carrying capacity because the high and very high classification dominated. Lastly, the pest and disease control in Penajam Paser Utara Regency has a relatively good carrying capacity because the area that dominates is classified high and medium. Overall, regulating ecosystem services in Penajam Paser Utara Regency are classified as very low.

4.3 Profile of cultural ecosystem services
Cultural ecosystem services consist of three components: residential and living, recreational and ecotourism, and aesthetic ecosystem services. The three ecosystem services will be elaborated according to their classification and area. From the analysis of the carrying capacity based on
ecosystem services in Penajam Paser Utara Regency, a table of the distribution of cultural ecosystem services was obtained containing five categories, i.e., very low, low, medium, high and very high with the area in hectares.

Table 3. Distribution of cultural ecosystem services.

| Code | Types of Ecosystem Services | Area Ha |
|------|-----------------------------|---------|
|      |                             | Very Low| Low | Medium | High | Very High|
| C1   | Residential and Living      | 56,887  | 142,014 | 105,172 | 8,301 | 4,625 |
| C2   | Recreational and Ecotourism | 5,035   | 40,239  | 92,426  | 122,484 | 56,813 |
| C3   | Aesthetics                  | 8,360   | 36,089  | 0       | 229,865 | 42,684 |

Penajam Paser Utara Regency has a low level of residential and living ecosystem services because the area with low and medium classification dominates. Whereas recreation and ecotourism ecosystem services in the regency is quite good because the area that dominates is classified as high and medium. The aesthetic ecosystem services are classified as good because the area that dominates is of high and very high classification. Overall, the classification of cultural ecosystem services in Penajam Paser Utara Regency is very low, meaning that the region has a very low carrying capacity for cultural ecosystem services.

4.4. Profile of supporting ecosystem services
Supporting ecosystem services consist of four components: soil formation and fertility maintenance; nutrient cycle; primary production; and biodiversity. The four ecosystem services will be elaborated according to their classification and area. From the analysis of the carrying capacity based on ecosystem services in Penajam Paser Utara Regency, a table of the distribution of supporting ecosystem services was obtained which was classified into five categories, namely very low, low, medium, high and very high with the area in hectares.

Table 4. Distribution of supporting ecosystem services.

| Code | Types of Ecosystem Services | Area Ha |
|------|-----------------------------|---------|
|      |                             | Very Low| Low | Medium | High | Very High|
| D1   | Soil Formation              | 6,348   | 28,094 | 91,969  | 147,865 | 42,721 |
| D2   | Nutrient Cycle              | 1,821   | 7,597  | 123,739 | 143,502 | 40,339 |
| D3   | Primary Production          | 5,192   | 29,698 | 91,509  | 172,622 | 17,978 |
| D4   | Biodiversity                | 7,643   | 9,324  | 107,849 | 174,635 | 17,547 |

Penajam Paser Utara Regency has a relatively good carrying capacity for soil formation because the dominating area is high and medium classification. Moreover, the regency has a relatively good level of the nutrient cycle as the high and medium classification area is dominant. The carrying capacity for supporting primary production is relatively good because the area that dominates is classified as high and medium. Likewise, biodiversity ecosystem services are quite good because the area that dominates is of high and medium classification. Overall, for supporting ecosystem services in Penajam Paser Utara Regency, the classification of ecosystem services is very low, meaning that the region has a very low carrying capacity for supporting ecosystem services.

5. Conclusion
Ecosystem services are determined by two important components, namely landform and land cover. The most dominant landform in Penajam Paser Utara Regency is the Structural Plains covering an area of 234,430 hectares and making up 51.26% of the total area of the regency. The land cover in Penajam Paser Utara Regency is dominated by mixed plantations with a total area of 96,920 hectares and covering 30.53% of the total land area of the regency. The food supply is the ecosystem services
provision with the most areas classified as very low (40.55%). Water flow and flood regulation is the regulatory ecosystem service that has the most areas classified as low in the regency (153,555 ha - 48.44%). Whereas aesthetics is the supporting ecosystem service which has the most areas classified as high, covering an area of 229,864 hectares or (72.51%). The ecosystem services with the most areas classified as high is energy provision with a total area of 119,979 hectares or 37.85% of the total ecosystem services of energy provision.

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