Carrying capacity and environmental capacity analysis based on ecosystem services in Surabaya

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Abstract. Surabaya City is experiencing rapid development. This rapid development of the city can affect the decline in environmental quality. Carrying capacity and environmental capacity are conceptual units that have a close relationship with ecosystem services. The higher the ecosystem services of a region, the higher the ability of the environment to support human life. This study aims to determine the carrying capacity and environmental capacity of the environment in Surabaya based on the value of its ecosystem services. This study is done by calculating the Ecosystem Services Index (ESI) and the Important Ecosystem Services Index (IESI) in Surabaya from 39 types of ecosystem services. The results show that the type of ecosystem services for dwelling (social space) and ecosystem services for cultivation (business/economic space) have the highest ESI values with 0.693335 and 0.632751 values respectively. Moreover, the type of water regulating, and drought prevention ecosystem services and flood control ecosystem services have the lowest ESI values with 0.400491 and 0.398209 values, respectively. Based on the IESI, Surabaya is in class III or moderate level with 29894.967 Ha extent or 84.15% of the city’s total area.

1. Introduction

Urban areas are areas that have very rapid growth compared to other area outside it. This is because urban areas are the center of community activity. The dynamics of urban development occur over time. The growth of urban areas is followed by a decline in the quality of the urban environment. This is the phenomenon that often occurs in many cities.

Surabaya as a growth center in East Java Province has been experiencing very rapid development. This development was followed by population growth which demands the fulfillment of basic needs in the form of water, food and land. In addition, improvements in various sectors including infrastructure, housing, industry and other development sectors, are unavoidable phenomena in Surabaya.

The high rate of development in urban areas of Surabaya can impact the management and protection of living environments in the city of Surabaya. In 2016, the Surabaya City Government stated that until now there were still many environmental problems ranging from the availability of clean water, garbage, to air pollution. The availability of clean water in Surabaya is supplied from Jagir River and Kalimas River with quality number 3, which means that existing clean water is not proper for drinking and can only be used for bathing and washing. Other problems include the problem of household waste production reaching 8-9 thousand tons per cubic meter, while the available landfills (TPA) can only
accommodate 1.4 thousand tons per cubic meter [1]. On the other hand, Surabaya is also still faced with other environmental problems such as congestion, density, and flooding.

Carrying capacity or environmental capacity implies the ability of a place to support the life of living things optimally in a long period of time. This can be realized through planning, utilization, control, maintenance, supervision, and law enforcement [2]. In the actual implementation of development, environmental factors must be considered in order to maintain the sustainability and balance of the ecosystem. If we relate the challenge to the sustainable use of resources, the context here is the effort to use resources for human welfare in such a way so that the rate (level) of use does not exceed the carrying capacity of the provided resources. In other words, the sustainability of resources utilization is very much determined by the carrying capacity of the resources [3] [4]. Land carrying capacity is an important thing that must be considered in regional spatial planning, in order to be able to support land use activities in a sustainable manner [8].

The approach and concept of ecosystem services have long been a concern of environmental scientists, but formally found the strength since the launch of the Millennium Ecosystem Assessment (MEA) [5], an international program created to assist policy makers in obtaining scientific information about the relationship between ecosystem changes and human welfare. MEA gave birth to a more comprehensive concept and operational definition of environmental services (ecosystem services). The MEA concept provides a good explanation of the relationship between ecosystem services and development. At present, an analysis of the carrying capacity of an ecosystem-based ecosystem service is considered appropriate because it can provide a quantitative and spatial insight of the environment condition. Based on this, it is important to carry out environmental carrying capacity analysis based on ecosystem services in Surabaya.

2. Methods
The research method in compiling the carrying capacity and environmental capacity based on ecosystem services is carried out through literature review, data collection, and analysis. Data collection including LIDAR photo data to produce Surabaya land cover map. Geological maps, geological maps, geomorphological maps and altitude maps are collected to produce ecoregion map of Surabaya.

The analysis is based on processing ecoregion maps and land cover maps through the Geographic Information System (GIS). The two types of maps will be assessed by experts (expert judgment) with a questionnaire instrument to determine the role of ecoregion and land cover for ecosystem services. The involved respondents are officials from the Surabaya government. The government are represented by the Department of Environment and the Surabaya City Planning Agency, while respondents from academics were represented by environmental, urban planning, geology and environmental biology experts. Furthermore, the results of the experts’ evaluation will be arranged into a pairwise comparison matrix. Through the calculation of pairwise comparison matrix, the coefficient of pairwise comparison matrix is obtained. This is supported by the calculation of the consistency ratio of expert judgment.

After expert judgment is considered consistent through a consistency ratio, the matrix coefficient values based on ecoregion and land cover are overlaid in GIS. The results are synthesized through multiplication of coefficient values based on ecoregion and land cover. The following is the formula for calculating Ecosystem Service Coefficient (ESC):

\[
ESC = ESC_{EC} \times ESC_{LC}
\]

where:
- \( ESC \) = Ecosystem Service Coefficient
- \( ESC_{EC} \) = Ecosystem Service Coefficient based on ecoregion
- \( ESC_{LC} \) = Ecosystem Service Coefficient based on land cover

After calculating ESC, the next step is calculating the ESI. This can be done by using the following formula:
\[ \text{ESI}_{i,x} = \frac{(\text{ESC}_{i,a} \times PE_a) + (\text{ESC}_{i,b} \times PE_b) + (\text{ESC}_{i,c} \times PE_c) + \ldots + (\text{ESC}_{i,n} \times PE_{i,n})}{AE_{tot}} \]

where:
- \( \text{ESI}_{i,x} \) = ESI value for \( i \) (for example food) in region \( x \)
- \( \text{ESC}_{i,a} \) = ESC value for \( i \) (for example food) in polygon \( a \)
- \( PE_a \) = Polygon extent \( a \) with ESC \( a \)
- \( AE_{tot} \) = Total of polygon extent

To identify the level of importance from an area or ecosystem in Surabaya, IESI needs to be calculated. The formula is as follows.

\[ I\text{ESI}_{i,x} = \sum \text{ESC}_{i,x} \]

where:
- \( I\text{ESI} \) = Important ecosystem services index in ecoregion \( x \) city
- \( \sum \text{ESC}_{i,x} \) = ESC for \( i \) (for example food) in polygon \( x \)

The higher the index value of an important ecosystem, the more it becomes a priority in protecting and maintaining the function of ecosystem services. To find out the priority level, classification is made into five (5) levels using the following formula.

\[ X = \sqrt{\frac{B}{A}} \]

Where:
- \( B \) = Maximum value
- \( A \) = Minimum value
- \( n \) = Class number

The description of the analysis processes in this research could be explained by the following diagram.

Figure 1. Research Analysis Framework

Source: Analysis, 2019

3. Results
Ecosystem services are categorized into four, which comprise provisioning services, regulating services, cultural services, and supporting services [5]. Based on these four categories, the Ministry of Environment and Forestry classifies ecosystem services into 20 sub-classifications [6] [7]:

a. Provider Services: (1) food, (2) clean water, (3) fiber, (4) fuel, wood, and fossil (5), genetic resources.
b. Regulatory Services: (6) climate regulation, (7) regulation of water flow and flood management, (8) prevention and protection from natural disasters, (9) water purification, (10) waste treatment and decomposition, (11) maintenance of air quality, (12) natural pollination arrangements, (13) pest and disease control;

c. Cultural Services: (14) residence and living space (sense of place), (15) recreation and ecotourism, (16) aesthetics.

d. Supporting Services: (17) formation of soil and fertility maintenance, (18) nutrient cycle, (19) primary production, (20) biodiversity (germplasm protection).

The value of the Surabaya ecosystem services index (ESI) in more detail can be explained through the following table.

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| CODE | ENVIRONMENTAL SERVICES FUNCTION | CLASSIFICATION | ESI |
|------|---------------------------------|----------------|-----|
| P    | Provisioning Services           | P1 Food        | 0.506719 |
|      |                                 | P1.1 Food, Vegetable and Fruit Cultivation Plants | 0.508736 |
|      |                                 | P1.2 Livestock and Animal Consumption | 0.560515 |
|      |                                 | P1.3 Food from fish | 0.481613 |
|      |                                 | P1.4 Food from the Forest (Wild Plants and Animals) | 0.476011 |
|      | **Clean water**                  | **R1 Climate Settings** | **0.439682** |
|      | **Water Flow & Flood Management Arrangements** | **0.39935** |
|      |                                 | R1.1 Global Climate | 0.441084 |
|      |                                 | R1.2 Regional Climate | 0.43828 |
|      |                                 | R2.1 Water Management and Drought Prevention | 0.400491 |
|      |                                 | R2.2 Flood Control | 0.398209 |
|      |                                 | R3.1 Erosion | 0.479754 |
|      |                                 | R3.2 Landslide | 0.479878 |
|      |                                 | R3.3 Storm | 0.552069 |
|      |                                 | R3.4 Tsunami | 0.522023 |
|      |                                 | R4 Water Purification | **0.42678** |
|      |                                 | R5 Waste Treatment and Decomposition | **0.472218** |
|      |                                 | R5.1 Water Purification | 0.459827 |
|      |                                 | R5.2 Waste Treatment | 0.484609 |

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Table 1 explains that the index value of ecosystem services (ESI) ranges from 0 (small) - 1 (large). The greater the index value of ecosystem services (close to value 1), the higher the carrying capacity of the ecosystem. Based on this, it can be seen that the type of ecosystem services of living and living space (sense of place) in the cultural function has the highest ESI value of 0.663043 with dwelling (social space) value 0.693335 and cultivation (business/economic space) value 0.632751. This shows that Surabaya has a large carrying capacity for residential services (social space) and cultivation services (business/economic space).

On the other hand, the type of ecosystem services that have the lowest ESI value is the regulation of water flow and flood regulation with 0.39935. Moreover, the function of water management and drought prevention has 0.400491 value and the function of flood control is 0.398209. That is, these two functions have low environmental carrying capacity in the city of Surabaya. Furthermore, to know the level of importance of each area (polygon) to environmental services (ecosystem) in Surabaya, it is necessary to calculate Important Ecosystem Services Index (IESI) and classify it into their importance. From here we can obtain information on the distribution of areas that have value of environmental services (ecosystem). With this step, it will be easier to prioritize environmental protection in Surabaya. The results of the calculation of the IESI value in Surabaya can be explained as follows.

| CODE | ENVIRONMENTAL SERVICES FUNCTION | CLASSIFICATION | ESI  |
|------|--------------------------------|----------------|------|
| R6   | Maintenance of Air Quality     |                | 0.444334 |
| R7   | Natural Pollination Settings (Pollination) |          | 0.416368 |
| R8   | Control of Pests and Diseases  |                | 0.459739 |
| R8.1 | Pests and Plant Diseases       |                | 0.461938 |
| R8.2 | Animal Diseases                |                | 0.45754  |
| C    | Cultural Services              |                | 0.663043 |
| C1.1 | Residential (Social Space)     |                | 0.693335 |
| C1.2 | Cultivation (Business/Economic Space) |            | 0.632751 |
| C2   | Recreation and Ecotourism      |                | 0.509045 |
| C3   | Aesthetics (Nature)            |                | 0.466781 |
| C4   | Education and Knowledge        |                | 0.503915 |
| C5   | Cultural Ties, Culture and Lifestyle |                  | 0.588508 |
| C6   | Spiritual and Ancestral Inheritance |                  | 0.593865 |
| S    | Supporting Services            |                | 0.418552 |
| S1   | Soil Layer Formation and Fertility Maintenance |       | 0.429351 |
| S2   | Nutrition Cycle (Nutrient)     |                | 0.483159 |
| S3   | Primary Production              |                | 0.434084 |
| S4   | Biodiversity (Germplasm Protection) |              | 0.462112 |
| S5   | Habitat of Breeding Flora and Fauna |                | 0.478402 |
| S5.1 | Flora Breeding Habitat         |                | 0.445822 |

Source: Analysis, 2019
Figure 2. Priority Distribution of Environmental Protection Map Based on Important Ecosystem Services Index of Surabaya

Source: Analysis, 2019

Table 2. Priority Levels Classification of Environmental Protection Based on Important Ecosystem Services Index of Surabaya

| Classification | Formulation | Interval | Important Ecosystem Values | Extent (Ha) | Percent (%) |
|----------------|-------------|----------|----------------------------|-------------|-------------|
| Class I        | A - Ax      | 0 - 0.30043 | Very low                   | 0           | 0           |
| Class II       | Ax - Ax²    | 0.30043 - 0.40576 | Low                      | 3159.34647 | 8.8930691  |
| Class III      | Ax² - Ax³   | 0.40576 - 0.548115 | Moderate                | 29894.0967 | 84.1472344 |
| Class IV       | Ax³ - Ax⁴   | 0.548115 - 0.740348 | High                    | 2472.49768 | 6.95969654 |
| Class V        | Ax⁴ - Ax⁵   | 0.740348 - 1       | Very high               | 0           | 0           |

Source: Analysis, 2019

From the map and table, it can be explained that generally the environmental carrying capacity of Surabaya based on ecosystem services is in priority 3 or moderate, with 29894.0967 Ha or 84.15% of the total area of Surabaya. If this important ecosystem services index map is overlaid with land cover maps, the result shows area with buildings, reeds, dams, lakes/lakes, irrigation channels, shrubs, ponds, embankments and reservoirs land cover.

The environmental carrying capacity of Surabaya based on ecosystem services in class II or low level is 3159.34647 Ha or 8.89% of the total area of Surabaya. Types of land cover included in this category include buildings, roads, ponds, swamps, land and sea sand, surface pavement, vacant land and rivers. Lastly, the carrying capacity in class IV or high level is 2472.49768 Ha or 6.96% of the total area of Surabaya. This class is dominated by land cover in the form of plantations, rice fields, city parks, fields, mixed crops, grasslands, other vegetation and non-cultivation vegetation, industrial park forests,
mangrove/mangrove forests, and swamp forests. From the results of this analysis, the existence of land cover in class IV or high level needs to be maintained in Surabaya.

4. Conclusion
Surabaya is dominated by an ecosystem service index in moderate level; this means that the carrying capacity of the environment in Surabaya based on its ecosystem service function is at a level to be monitored. This is because of the high development of the city that cause changes in land use and could lead to a decline in environmental service functions in Surabaya. Based on the types of ecosystem services, services for dwelling (social space) and for cultivation (business/economic space) have the highest ESI values, with values of 0.693335 and 0.632751 respectively. While the water management ecosystem services and drought prevention and flood control ecosystem services have the lowest ESI values with values of 0.400491 and 0.398209.

The index value of important ecosystem services in Surabaya shows that quantitatively and spatially, Surabaya area falls in priority 3 or moderate, which is 29894.0967 Ha or 84.15% of the total area of Surabaya. The area in priority 4 or low is 3159.34647 Ha or 8.89% of the total area of Surabaya, and area in class 2 or high is 2472.49768 Ha or 6.96% of the total area of Surabaya. From these results, what needs to be understood by the Surabaya Government include (1) All types of land cover that fall into class 2 or high priority need to be maintained, (2) evaluate development policies, especially on area that has a better/higher value of environmental services.

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