Assessment of regulating ecosystem services in Surabaya City

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Abstract. Ecosystem services have been extensively studied in recent years. As a component of ecosystem services, regulating ecosystem services play an important role in promoting and maintaining liveable and resilient cities. There is a strong relationship between formulation of urban planning and regulating ecosystem services. A clear understanding is required to identify the indicators of regulating ecosystem services to be considered in spatial and development planning documents. Surabaya as the second largest city in Indonesia has very high dynamics of land use and environmental changes due to its rapid development. This aim of this study is to assess the regulating ecosystem services in Surabaya City. The specific objectives are to identify the indicators of regulating ecosystem services, to assess the regulating ecosystem services and to provide maps of the spatial distribution, and to calculate the composite index of regulating ecosystem services. Eight indicators of regulating ecosystem services were used in this study, namely climate regulation, water regulation, drought prevention and flood control (R2), prevention and protection from natural disasters, water purification, waste management and decomposition, air quality, natural pollination, and pest and disease control. The results show that the ecosystem service index in Surabaya City has medium score.

1. Introduction

The concept of ecosystem services has been extensively studied in recent years. It was launched by the Millennium Ecosystem Assessment (MA) in 2005 as a conceptual tool to examine how changes in ecosystem services influence human beings [1]. Since the launching of ecosystem services, interest in them has been increasing [2]. Ecosystem services are defined as the benefits that people obtain from ecosystems, including provisioning services, regulating services, cultural services, and supporting services [1]. The scope of ecosystem services is presented in Figure 1. In addition, Busch [3] stated that ecosystem services are related to spatial dimension of certain defined area where the services are provided.

Ecosystem services, particularly regulating ecosystem services play a significant role in promoting liveable and resilient cities [4], [5]. There is a strong linkage between urban planning and ecosystem services, because planning decision may effect urban regulating ecosystem services [6]. Previous studies show that urban plans have considered ecosystem services with a focus on enhancing the benefits of ecosystem services [7]–[9]. These benefits include flood control, air pollution reduction, and noise mitigation. Guo et al. [10] argued that human activities require increasing quantities of ecosystem services, particularly food supply, drinking water, clean air, and recreation. On the other hand, the environmental carrying capacity has resource limitations. Thus, it is important to understand how the ecosystem services are assessed and consider in the formulation of urban planning.
This study will focus on the regulating ecosystem services. Surabaya was chosen as a study area. In order to assess the regulating ecosystem services, it is required to determine the indicators of regulating ecosystem services. A study by Cortinovis and Geneletti [6] mentioned that methods and indicators to assess current condition of urban regulating ecosystem services are valuable, as discussed by recent studies [11]–[17]. Those studies were mostly conducted in developed countries, while studies related to ecosystem services, particularly regulating ecosystem services remain lacking.

The aim of this study is to assess the regulating ecosystem services in Surabaya City. The specific objectives are to identify the indicators of regulating ecosystem services, to assess the regulating ecosystem services and to provide maps of the spatial distribution, and to calculate the composite index of regulating ecosystem services.

The remainder of the article is organized in four sections. Section 2 describes the research approach, data collection method, and data analysis. Section 3 presents results and discussion on the identification of indicators of regulating ecosystem services, assessment of the regulating ecosystem services and mapping the spatial distribution, and calculation of the composite index of regulating ecosystem services. Finally, Section 4 draws some conclusions.

2. Research Method

2.1. Research Approach
This study was conducted using a spatial approach in Geographic Information System (GIS). The spatial approach was used to analyse the supporting capacity and the carrying capacity of environmental ecosystem services that includes air quality, climate regulation, prevention of disturbances, water management, waste treatment, soil protection, pollination, biological regulation, soil formation [18]. The maps produced information on the condition, distribution, and index of the carrying capacity of environmental ecosystem services.

2.2. Data collection technique
This study used both primary and secondary data. Questionnaire was used to collect the primary data related to the role of ecoregion and land cover for regulating ecosystem services. The primary survey applied in this study is a kind of rapid integrated survey, that is an integrated quick survey for the inventory of natural resources and the environment which is done by considering the needs of each data user. The secondary data was collected from two corresponding agencies, i.e. Environmental Agency of Surabaya City and Geospatial Information Agency.

2.3. Data analysis technique
Assessment of regulating ecosystem services in Surabaya City was carried out using two analysis techniques:

Ecosystem services:

- **PROVISIONING**
  (e.g., food, water, fiber, and fuel)
- **REGULATING**
  (e.g., climate regulation, water, and disease)
- **CULTURAL**
  (e.g., spiritual, aesthetic, recreation, and education)
- **SUPPORTING**
  (e.g., primary production and soil formation)
1) Analysis of land use and ecoregion maps
   Land use map was prepared using land cover maps from Light Detection and Ranging (LIDAR) Imagery. While ecoregion map was produced from morphological, geological, and slope maps. The next step was processing the land use and ecoregion maps using Geographic Information Systems (GIS). The maps are important for the step of evaluation of the role of ecoregion and land cover for regulating function of ecosystem services.

2) Evaluation of the role of ecoregion and land cover for regulating ecosystem services using the Expert Based Valuation Method
   The role of ecoregion and land cover for regulating function of ecosystem services was evaluated using Expert Judgment. Expert Judgment is a type of expert-based evaluation method. In this study, there were 31 experts involved, representing both government and academics. The expert judgment was carried out though the following steps:
   a. Scoring the environmental carrying capacity questionnaire based on ecosystem services
   b. Calculation of regulating ecosystem service rating/index
      The calculation of the rating/index of regulating ecosystem services was done to determine the spatial distribution and quality patterns of each ecosystem service in each ecoregion. The calculation of regulating ecosystem services index was done through land cover maps (Deputy of Environmental Management, Ministry of Environment, 2014). The steps are as follows:
      1. Arrangement of a pairwise comparison matrix
      2. Normalization of pairwise comparison matrices
      3. Calculation of the pairwise comparison matrix coefficients
      4. Calculation of the consistency ratio

3. Results and Discussion

3.1. Identifying the indicators of regulating ecosystem services
   To achieve the first objective, this study used previous related studies that discussed indicators of regulating ecosystem services. The indicators found from literature review were compiled and proposed for focus group discussion (FGD). The FGD involved technical staff from Planning and Development Agency and academics to decide the indicators used for the assessment of regulating ecosystem services. The indicators were agreed upon matching with the city characteristics. Finally, there are eight functions of regulating ecosystem services and 15 indicators used in this study.
   The eight functions of regulating ecosystem services consist of climate regulation (R1), water regulation, drought prevention and flood control (R2), prevention and protection from natural disasters (R3), water purification (R4), waste management and decomposition (R5), air quality (R6), natural pollination (R7), and pest and disease control (R8). The detail indicators for each function is shown in Table 1.

| Regulating ecosystem services | Ecosystem function                                      | Key references               |
|-------------------------------|--------------------------------------------------------|------------------------------|
| Climate regulation (R1)       | Global climate                                         | [1], [6], [17], [19], [20]  |
|                               | Regional/local climate                                 | [1], [17]–[20]              |
| Water regulation (R2)         | Water regulation and drought prevention                | [1], [17]                   |
|                               | Flood control                                          | [1], [2], [6], [16]–[18], [20] |
| Prevention and protection from natural disasters (R3) | Erosion                                               | [1], [2], [17]–[20]        |
|                               | Landslide                                              | [17]                        |
|                               | Storm                                                  | [18]                        |
|                               | Tsunami                                                | [1]                         |
| Water purification (R4)       | Water purification                                     | [1], [16], [18]–[20]       |
| Waste management and          | Water purification from waste                          | [1], [6], [17], [18], [20]  |

Table 1. List of the eight regulating ecosystem services considered in this study
Regulating ecosystem services | Ecosystem function | Key references
--- | --- | ---
Decomposition (R5) | Waste treatment | [1], [6], [17], [18]
Air quality (R6) | Air quality | [1], [6], [16]–[20]
Natural pollination (R7) | Pollination | [1], [2], [16], [18]–[20]
Pest and disease control (R8) | Pest and plant disease | [1], [18]–[20]
 | Livestock disease | [20]

3.2. Assessing the regulating ecosystem services and mapping the spatial distribution

3.2.1. Climate regulation (R1).

The services provided by this function cover both regional and global scales. Climate regulation ecosystem service is influenced by several biotic factors such as vegetation, location, and physical factors such as topography and landform. De Groot et al. [18] explained that local weather and climate ecosystem services are determined by complex interaction of regional and global circulation patterns with local topography, vegetation, as well as the configuration of, for example, lakes, rivers, and bays. Several components are related to climate regulation ecosystem services, such as temperature, humidity, rain, wind, greenhouse gas and carbon sequestration. Area with high vegetation densities and relatively high altitude such as mountains will have better climate regulation systems.

Table 2 shows that distribution of global and regional climate regulation ecosystem service in Surabaya is dominated by low and medium classifications (> 75%), meaning that more than 75% of the city has low to medium function of climate regulating ecosystem services, while less than 5% of the city area has function of climate regulating ecosystem services. Spatial distribution of global climate and regional climate regulation ecosystem services is presented in Figure 2.

Table 2. Area distribution of climate regulation ecosystem service

| Climate Regulation | Area of Climate Regulation Ecosystem Service (Ha) | Total |
| --- | --- | --- |
|   | Very Low | Low | Medium | High | Very High |
| R1.1 Global climate | 906.77 | 10582.20 | 9639.75 | 1782.17 | 682.32 | 23593.21 |
| R1.2 Regional climate | 2531.38 | 8964.05 | 8002.62 | 2926.56 | 1168.61 | 23593.21 |
| Total | 3438.15 | 19546.25 | 17642.36 | 4708.73 | 1850.93 | 47186.42 |
| Percentage (%) | 7.29 | 41.42 | 37.39 | 9.98 | 3.92 | 100.00 |

Figure 2. Spatial distribution of global climate (left) and regional climate regulation (right) ecosystem services

3.2.2. Water flow and flood control (R2).

Water flow and flood control regulating ecosystem services are related to ability of nature and infrastructure to accommodate, manage hydrological cycle. The hydrological cycle is important for human beings. It consists of the process of evaporation, condensation, precipitation and flowing. Table
3 shows the area distribution of water flow and drought prevention and flood control regulating ecosystem services. It also shows that majority of the area is dominated by low and medium classification of ecosystem service index. Figure 3 shows spatial distribution of water flow, drought prevention and flood control ecosystem service. In comparison to the other maps, the water flow and flood control regulation map shows that almost the whole area is coloured dark pink to red, meaning that almost the whole city area does not have function on water flow, drought prevention, and flood control ecosystem services.

Table 3. Area distribution of water flow, drought prevention, and flood control ecosystem service

| Water Flow and Flood Control | Area of Water Flow and Flood Regulation Ecosystem Service (Ha) | Total |
|-----------------------------|-------------------------------------------------------------|-------|
|                             | Very Low | Low | Medium | High | Very High |
| R2.1 Water regulation and drought prevention | 2532.38 | 10304.10 | 3926.95 | 6828.88 | 0 | 23593.21 |
| R2.2 Flood control | 3606.92 | 8540.92 | 5125.00 | 6320.37 | 0 | 23593.21 |
| Total | 6139.31 | 18845.91 | 9051.95 | 13149.25 | 0 | 47186.42 |
| Percentage (%) | 13.01 | 39.94 | 19.18 | 27.87 | 0.00 | 100.00 |

Figure 3. Spatial distribution of water flow and drought prevention (left) and flood control (right) regulation ecosystem service

3.2.3. Prevention and protection from natural disasters (R3).
The function of prevention and protection from natural disasters in this study is similar to disturbance prevention function in the study of de Groot [18]. Moreover, de Groot explained that this function is defined as the ability of ecosystems to ameliorate natural hazards, such as storms, floods, and droughts. The ability strongly relates to vegetative structure, because it plays a significant role in the prevention of landslides [16]. The types of natural disasters in this study are identified based on exposure and vulnerability to natural disasters for Surabaya, such as erosion, landslide, storm, and tsunami. Table 4 shows that 75% of the city area has medium classification in supporting function as prevention and protection from natural disasters regulating ecosystem services.

Table 4. Area distribution of prevention and protection from natural disasters regulation ecosystem service classification

| Prevention and Protection from Natural Disasters | Area of Prevention and Protection from Natural Disaster Regulation Ecosystem Service (Ha) | Total |
|-------------------------------------------------|-------------------------------------------------------------|-------|
|                                                | Very Low | Low | Medium | High | Very High |
| R3.1 Erosion | 0 | 2231.09 | 20025.41 | 1336.71 | 0 | 23593.21 |
| R3.2 Landslide | 0 | 7384.41 | 12479.24 | 3729.56 | 0 | 23593.21 |
| R3.3 Storm | 0 | 540.53 | 20663.74 | 1706.61 | 682.32 | 23593.21 |
Figure 4 shows that the city has more function as erosion protection and prevention function rather than landslide protection function. In Figure 5, it can be seen that almost the whole city area has function of protection and prevention from storm, which is represented by green colour. While the map of protection and prevention from tsunami disaster ecosystem service shows vary classifications.

### Table 4. Area distribution of regulation ecosystem service for water purification

| Water Purification (R4) | Area of Regulation Ecosystem Service for Water Purification (Ha) | Total |
|------------------------|---------------------------------------------------------------|-------|
|                        | Very Low | Low   | Medium | High    | Very High |
| R3.4 Tsunami           | 0        | 14378.90 | 71336.46 | 1364.64 | 0         | 23593.21 |
| Total                  | 0        | 14378.90 | 71336.46 | 1364.64 | 0         | 94372.84 |
| Percentage (%)         | 0.00     | 15.24   | 75.59   | 7.73    | 1.45      | 100.00   |

3.2.4. Water purification (R4).

Ecosystems have the ability to clean pollutants through chemical-physical-biological processes that take place naturally in water bodies. However, the ability of self-purification requires time and is influenced by the level of pollutants. Table 5 shows that almost 70% of the city area has low to medium function as water purification regulating ecosystem service. The spatial distribution of water purification ecosystem service is shown in Figure 6.

### Table 5. Area distribution of regulation ecosystem service for water purification

| Water Purification (R4) | Area of Regulation Ecosystem Service for Water Purification (Ha) | Total |
|------------------------|---------------------------------------------------------------|-------|
|                        | Very Low | Low   | Medium | High    | Very High |
| Total                  | 882.92   | 6312.51 | 9555.21 | 6842.57 | 0         | 23593.21 |
| Percentage (%)         | 3.74     | 26.76  | 40.50  | 29.00   | 0.00      | 100.00   |
3.2.5. Waste management and decomposition (R5).

Natural systems are able to recover certain amounts of organic and inorganic waste through dilution, assimilation, and chemical processes [18]. Similar to the statement, Millennium Ecosystem Assessment described that ecosystems have a function to filter out and decompose organic wastes introduced into inland waters, coastal and marine [1]. Table 6 shows that more than 80% of the city area has low to medium classifications of waste management and decomposition regulating ecosystem service. Figure 7 (left) provides information that the city area of Surabaya is dominated by medium classification for water purification from waste.

**Table 6. Area distribution of regulation ecosystem for waste management and decomposition**

| Waste Management and Decomposition | Area of Regulation Ecosystem Service for Waste Management and Decomposition (Ha) | Total |
|------------------------------------|---------------------------------------------------------------------------------|-------|
|                                    | Very Low | Low | Medium | High | Very High |
| R5.1 Water purification            | 344.34   | 6847.19 | 15084.72 | 1316.96 | 0 | 23593.21 |
| R5.2 Waste treatment               | 0        | 4981.25 | 12231.35 | 6380.62 | 0 | 23593.21 |
| Total                              | 344.34   | 11828.44 | 27316.07 | 7697.57 | 0 | 47186.42 |
| Percentage (%)                     | 0.73     | 25.07 | 57.89 | 16.31 | 0.00 | 100.00 |

**Figure 6.** Spatial distribution of water purification ecosystem service

**Figure 7.** Spatial distribution of water purification from waste (left) and waste treatment (right) ecosystem service
3.2.6. Air quality (R6).
Ecosystems have the ability to provide benefits in terms of good air quality regulation. Air quality is strongly influenced by the interaction between various pollutants emitted into the air with several meteorological factors, such as wind, temperature, rain, and sunlight as well as land use intensity on the earth. The higher the land use intensity, the more dynamic the air quality. In general, air quality regulating services in vegetated area and in high-topographic area are better than in non-vegetated area. The total percentage of low and medium classification of air quality regulating ecosystem service covers more than 70% of the city area and is presented in Table 7. Figure 8 provides information that the city area of Surabaya is dominated by gradation of yellow to red colours, meaning that the area has relatively medium to very low classifications of air quality function.

Table 7. Area distribution of regulation ecosystem service for air quality

| Air Quality | Very Low | Low  | Medium | High  | Very High | Total     |
|-------------|----------|------|--------|-------|-----------|-----------|
| Total       | 1405.64  | 10125.16 | 7163.89 | 3726.36 | 1172.17   | 23593.21  |
| Percentage (%) | 5.96 | 42.92 | 30.36 | 15.79 | 4.97 | 100.00 |

Figure 8. Spatial distribution of air quality ecosystem service

3.2.7. Natural pollination (R7).
Pollination is vital for reproduction of plants. This ecosystem function is provided by many wild pollinator-species [18]. This natural pollination is essential to maintain agricultural productivity, rather than artificial pollination that requires high cost. De Groot [18] also stated that the absence of pollination would affect to the extinction of many plant species and lower crops cultivation. Ecosystem plays a role in the distribution of pollinators [16]. Table 8 shows that distribution of regulation ecosystem service for natural pollination in Surabaya is dominated by low and middle classification of ecosystem service index. The proportion of low and medium classifications are somewhat similar. The spatial distribution of natural pollination regulating ecosystem service is presented in Figure 9. It can be seen that almost the whole city area of Surabaya has low to very low classifications for the function of natural pollination regulating ecosystem services.

Table 8. Area distribution of regulation ecosystem service for natural pollination

| Natural Pollination | Very Low | Low  | Medium | High  | Very High | Total     |
|---------------------|----------|------|--------|-------|-----------|-----------|
| Total               | 2531.38  | 8999.42 | 7163.89 | 3086.93 | 1811.59   | 23593.21  |
| Percentage (%)      | 10.73 | 38.14 | 30.36 | 13.08 | 7.68 | 100.00 |
3.2.8. Pest and disease control (R8).
Changes in ecosystem influence the occurrence of crop and livestock pests and diseases [1]. Ecosystem is able to control pests and diseases because genetic variations of plants and animals that enable them less prone to diseases [19]. De Groot [18] categorized pests and diseases control into biological control. More than 75% of the city area has medium classification function of pests and diseases control ecosystem service. Figure 10 shows that medium classification was spread almost in the whole city area of Surabaya.

**Table 9.** Area distribution of regulation ecosystem service for pest and disease control

| Pest and Disease Control | Area of Regulation Ecosystem Service for Pest and Disease Control Classes (Ha) | Total |
|-------------------------|--------------------------------------------------------------------------------|-------|
|                         | Very Low | Low | Medium | High | Very High |       |
| R8.1 Pest and plant disease | 0       | 2650.52 | 16303.01 | 4639.68 | 0       | 23593.21 |
| R8.2 Livestock disease  | 0       | 2532.38 | 19862.98 | 1197.85 | 0       | 23593.21 |
| Total                   | 0       | 5182.90 | 36165.99 | 5837.53 | 0       | 47186.42 |
| Percentage (%)          | 0.00    | 10.98 | 76.64  | 12.37 | 0.00    | 100.00 |

**Figure 10.** Spatial distribution of pest and plant disease control (left) and livestock disease control (right) ecosystem service
3.3. Calculating the composite index of regulating ecosystem services

To calculate the composite index of regulating ecosystem services, ecosystem service index (ESI) was used. Prior to calculating the ecosystem service index, it is required to ecosystem service coefficient from ecoregion and land use. The classification of ESI for regulating ecosystem services is grouped into five, namely very low, low, medium, high, and very high. First, the ESI for each indicator of regulating ecosystem services was calculated. Then, the average ESI was able to be calculated. Table 10 provides complete information on the results of regulating ecosystem service index of Surabaya City. It shows that the ESI for water flow and drought prevention and flood control has the lowest value, i.e. 0.40 and 0.39. This condition needs to be considered by the city government, so that the value will not decrease. The composite index of regulating ecosystem service is 0.457, meaning that the it falls into medium classification. The ecosystem service index provides information that the city has to maintain the environmental ecosystem services to be able to create liveable and resilient city.

Table 10. Regulating ecosystem service composite index of Surabaya City

| Types of Regulating Ecosystem Services | ESI  | ESI According to Ecosystem Services Group |
|----------------------------------------|------|-----------------------------------------|
| R1 Climate regulation                  |      |                                         |
| R1.1 Global climate                    | 0.441084 |                                       |
| R1.2 Regional climate                  | 0.438280 |                                       |
| R2 Water flow and flood control regulation |         |                                         |
| R2.1 Water flow and drought prevention | 0.400491 | 0.457                                  |
| R2.2 Flood control                     | 0.398209 |                                         |
| R3 Prevention and protection from natural disaster | |                                         |
| R3.1 Erosion                           | 0.479754 |                                         |
| R3.2 Landslide                         | 0.479878 |                                         |
| R3.3 Storm                             | 0.552069 |                                         |
| R3.4 Tsunami                           | 0.522023 |                                         |
| R4 Water purification                  | 0.426780 |                                         |
| R5 Waste management and decomposition  |      |                                         |
| R5.1 Water purification from waste    | 0.459827 |                                         |
| R5.2 Waste treatment                   | 0.484609 |                                         |
| R6 Air quality control                 | 0.444334 |                                         |
| R7 Natural pollination                 | 0.416368 |                                         |
| R8 Pest and disease control           |      |                                         |
| R8.1 Pest and plant disease           | 0.461938 |                                         |
| R8.2 Livestock disease                 | 0.457540 |                                         |

4. Conclusion

Analysis of the carrying capacity and ecosystem services are the most frequent approaches used in assessing environment. An advantage of these approaches is it can provide an overview of the quality, quantity and spatial environment condition of an area. The results of this study provide a useful information on the threshold of environmental quality standard for Surabaya City. Moreover, this study offers a valuable input for the preparation of spatial planning documents, environmental impact assessment, building permit, and environmental control.

The indicators of regulating ecosystem services are compiled from previous studies and determined through focus group discussion. There are eight indicators used in this study, namely climate regulation (R1), water regulation, drought prevention and flood control (R2), prevention and protection from natural disasters (R3), water purification (R4), waste management and decomposition (R5), air quality (R6), natural pollination (R7), and pest and disease control (R8). The assessment of regulating ecosystem services in Surabaya shows that almost all ecosystem functions have low and
medium classification of ecosystem services, meaning that the city has to maintain seriously the condition, so that the area with low and medium classification does not increase or change into lower classification. The calculation of regulating ecosystem service composite index represents the composite index of carrying capacity. The value shows 0.457, meaning that the composite index belongs to medium classification. Out of 15 indicators, the indicators of water flow regulation and drought prevention and flood control regulation have the lowest score. The results of this study have implication for the development direction in Surabaya. Environmental aspects have to be put forward in the formulation of spatial and development planning documents, so that ecosystem service index can be maintained or even better than current condition.

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