Ecological sustainability of Gerbangkertosusila Region based on ecological footprint approach for the land use controlling

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Abstract. Gerbangkertosusila region is a prime mover of regional economic activity within East Java Province and even the national level. The impetus for economic growth has an impact on the carrying capacity of the environment. Thus, to achieve sustainable development goals, it is necessary to conduct a study of environmental carrying capacity which is related to the maximum capacity/entropy that can be utilized by the human being. An ecological footprint approach is an approach of the environmental carrying capacity to identify the components of natural resource consumption, waste, and availability of natural resources in each type of land use. Carbon footprint which is the biggest part of the ecological footprint has a relation with CO2 emission production, which influences climate change mitigation. The purpose of this study was to formulate land use control policies based on the ecological footprint approach. The analysis method consists of three phases. First, the calculation of biological capacity was based on the availability level of natural resources. Second, the calculation of an ecological footprint was based on the consumption level of natural resources. The final phase was sustainability calculation to get the result to accommodate the population consumption within the region. The finding showed that Mojokerto City, Surabaya City, and Sidoarjo Regency were regions which a deficit in terms of ecological sustainability. The rest regions within the Gerbangkertosusila region were considered regions that are experiencing a surplus. It has a surplus of 87,424,615 gha or equal to 9.13 gha/capita.

1. Introduction

The concept of environmental capacity is defined as the ability of the environment to absorb substances, energy [1]. The Carrying capacity is relating to the maximum load (entropy) of the environment that can be utilized by humans. The Carrying capacity concept is related to the critical question about the productive land is needed to support human needs [2]. The Ecological footprint is an environmental carrying capacity that relates to the components of natural resource consumption and waste and the availability of the natural resource in each type of land. This can be known from the biocapacity value and the ecological footprints of each region according to the sustainability level of a land-use type [3]. The measurement of sustainability can be determined by comparing the consumption of human activities with environmental capability or biocapacity to provide for their consumption needs [4]. This is an ecological footprint advantage to measure environmental carrying capacity. The high consumption of natural resources such as productive land can influence the natural resources depletion and environmental degradation that impacts biodiversity, ecosystem quality, and CO2 emission. The security of ecosystem service provision is an important issue to mitigate climate change in the long-term [5].
The Gerbangkertosusila region is the fast-growing region in the East Java Province. These consequences should be particularly anticipated in urban regions of the Gerbangkertasusila region which consists of Surabaya, Sidoarjo, Gresik, Bangkalan, Mojokerto, and Lamongan regions in which the population growth rates far exceeding growth rates in other rural regions in East Java. Gerbangkertasusila region also has a role as a center of national-scale activities to provide its challenges in realizing sustainable development in the context of urban ecology. The core of sustainability is how the region is managing the natural capital [6].

With the rapid development of the Gerbangkertasusila metropolitan area, the region will be highly vulnerable to ecological sustainability. Important facts that have occurred nowadays in metropolitan cities in some regions of the world know that the current human ecological footprint of natural resources has surpassed global biocapacity by 50% [7] and cities have consumed nearly 75% of global resources that lead to increasing numbers of greenhouse gas emissions [8]. Carbon footprint which is the biggest part of the ecological footprint has a relation with CO₂ emission production, which influences climate change mitigation. The climate change mitigation needs to be done through the land use regulation so that the increase in carbon emissions and ecological footprint can be controlled in this area. The purpose of this study is to formulate land use control policies based on the ecological footprint approach. It is necessary to study the level of environmental carrying capacity in the Gerbangkertasusila region to achieve a sustainable development goal.

2. Methods
The ecological footprint indicator used a consumer-based approach that measures the aggregate demand on the ecological assets for the resource-consumption and waste absorption due to human activities [9]. The data was collected uses secondary data from the statistical publication. The land use data was measured based on the interpretation of the Landsat imagery 2016. The research variables consist of:

| No. | Research Step                  | Variable                                                                 |
|-----|--------------------------------|--------------------------------------------------------------------------|
| 1   | Biocapacity                    | 1. Population                                                            |
|     |                                | 2. The productivity of land use                                         |
|     |                                | 3. Land use                                                              |
| 2   | Ecological Footprint           | 1. Population                                                            |
|     |                                | 2. The productivity of land use                                         |
|     |                                | 3. Land use                                                              |
| 3   | Ecological Sustainability Level| Biocapacity compare to Ecological Footprint (Result Classified as Surplus, Deficit or Balance) |

Ecological sustainability level calculation was based on the Global Footprint Network guidelines [10]. This study case used four categories consist of forest land, inland fishing ground, cropland, and built-up land. Cropland productivity would be compared with the level of consumption of agricultural products, as well as inland fishing ground. Meanwhile, forest land would be compared with the consumption of forest products and carbon emissions.

The estimation used the method that the Biocapacity (BC) for all land use categories used the following equation (1):

\[
BC = A \times YF \times EQF
\]

| BC | A | YF | EQF |
|----|---|----|-----|
| Biocapacity | : Land region of each land use category | : Yield Factor | : Equivalence Factor |
The consumption from the net consumption was actual consumption in the following equation (2):

\[ EF = \left( \frac{P}{N} \right) \times YF \times EQF \]  

(2)

Where, \( YF = \frac{YN}{YW} \), then the Ecological Footprint (EF) formula could be simplified as follows equation (3):

\[ EF = P \times YW \times EQF \]  

(3)

**EF**: Ecological Footprint  
**P**: Number of products harvested or waste generated (consumption in the region)  
**YN**: Productivity of the land use category in the calculation region  
**YW**: Productivity of the world land use category

The calculation of Ecological Footprint (EF) and Biocapacity (BC) calculation use 2 (two) conversion factors follow:

1. **Equivalent Factor (EQF)**  
   The Equivalent Factors (EQF) were determined for four categories of land use, namely cropland (2.56), forest land (1.28), inland fishing ground (0.35), and infrastructure (2.56) that converts a particular local unit into the global hectare (gha). This factor was measured from the land use type and population.

2. **Yield Factors (YF)**  
   The Yield Factor (YF) is a ratio between the productivity of a land category \( (YN,i) \) with the average productivity of the land category in the world \( (YW,i) \) and the same year \[11\]. The following equation (4):

\[ YF_L = \frac{YN_{i}}{YW_{i}} \]  

(4)

**YF_L**: Yield factor for L land use category  
**YN_{i}**: Land productivity (yield) of L land category in the calculation region  
**YW_{i}**: The World yield productivity for a product i.

There are 3 conditions of Ecological Sustainability Level (ESL), firstly, ecological deficits are a condition when the Ecological Footprint (EF) of Land higher than the Biocapacity (BC) of Land or the level of consumption is greater than the capacity or ability to provide the resources of a particular region \[12\]. Secondly, a region is a surplus condition if the population’s consumption level is lesser than the Biocapacity (BC) or Land Biocapacity (BC) higher than Ecological Footprint (EF) of Land. Ecological balance occurs when the Ecological Footprint (EF) and Biocapacity (BC) has the same value. The Ecological Sustainability Level (ESL) can be identified using the following equation (5):

\[ ESL = \text{total } BC \text{ - total } EF \]  

(5)

The land use category is obtained from the results of the Landsat satellite image processing. Image data is processed by band composite and image classification to get the map of land use in the Gerbangkertasusila region (see Figure 1).
3. Results and discussion

3.1. Estimation of biocapacity (BC)

The harvest factors describe that the land productivity of regency/city was greater than the productivity of the world's land especially on the forest land in the Lamongan regency, and the inland fishing ground in Mojokerto regency and Lamongan regency. The yield factors could be an indication that the productivity of land in a region was better or smaller than the world's land productivity in the same year.

Table 2. Land Productivity (yield) by land use category

| City/Regency        | Cropland | Forest Land | Inland fishing ground |
|---------------------|----------|-------------|-----------------------|
|                     | Yw = 25.93 | Yw = 0.82   | Yw = 62.21            |
|                     | YK       | YF          | YK       | YF          | YK       | YF          |
| Gresik Regency      | 13.98    | 0.54        | 466.67   | 569.11      | 1.27     | 0.02        |
| Bangkalan Regency   | 10.15    | 0.39        | 466.52   | 568.93      | 1.99     | 0.03        |
| Mojokerto Regency   | 12.55    | 0.48        | 466.19   | 568.53      | 138.77   | 2.23        |
| Mojokerto City      | 6.66     | 0.26        | 0        | 0           | 24.38    | 0.39        |
| Surabaya City       | 14.10    | 0.54        | 0        | 0           | 16.04    | 0.26        |
| Sidoarjo Regency    | 9.47     | 0.37        | 0        | 0           | 9.53     | 0.15        |
| Lamongan Regency    | 14.20    | 0.55        | 447.03   | 545.16      | 132.13   | 2.12        |

1) Yw : Productivity of the world land use category  
2) YK : Productivity of land in a region  
3) YF : Yield Factor

The equalizing factors are needed to calculate the biocapacity with classifications such as cropland, forestry land, inland fishing ground, and constructed land. The factors were identified according to the characteristics of each land as follows.
Table 3. Equivalence factors by type of land-use

| Type of Land | Description | Equivalence Factor |
|--------------|-------------|--------------------|
| Cropland     | Land for the cultivation of food crops. Land for the demand for timber and carbon absorb consists of a. Production forest; production forest consisting of the community forest and forest managed by Perhutani (state forest). b. Protected forest; the forest whose utilization is specified as a protected function | 2.56 |
| Forestry Land| Land for the demand for timber and carbon absorb consists of protected forest; the forest whose utilization is specified as a protected function | 1.28 |
| Inland fishing ground | Land for fishing and aquaculture | 0.35 |
| Constructed Land | Land for the buildings, without considering its function. | 2.56 |

The total biocapacity in the Gerbangkertosusila region was 88,197,814.22 gha with the highest biocapacity value as forest resources. The distribution of forest area was only concentrated on the highland areas such as in Lamongan, Bangkalan, and Mojokerto Regencies. The forest area of Mojokerto in the national forest park Raden Soerjo is a tropical rain forest with high biodiversity and high-quality water springs.

Table 4. Biocapacity on land types by city/regency

| City/Regency       | Cropland       | Forest Land     | Inland fishing ground | Built-up Land | Total Biocapacity (gha) |
|--------------------|----------------|-----------------|-----------------------|---------------|-------------------------|
| Gresik Regency     | 52,204.05      | 7,254,045.96    | 115.86                | 55,409.87     | 7,361,775.74            |
| Bangkalan Regency  | 54,179.48      | 31,148,049.24   | 9.82                  | 32,844.48     | 31,235,083.01           |
| Mojokerto Regency  | 55,180.62      | 17,476,696.82   | 529.02                | 36,189.37     | 17,568,595.83           |
| Mojokerto City     | 386.70         | 0               | 23.35                 | 685.43        | 1,095.48                |
| Surabaya City      | 25,775.01      | 0               | 563.59                | 56,237.45     | 82,576.05               |
| Sidoarjo Regency   | 5,449.53       | 0               | 196.95                | 20,018.44     | 25,664.92               |
| Lamongan Regency   | 122,298.62     | 31,740,998.81   | 1,550.05              | 58,175.71     | 31,923,023.19           |
| **Total Region**   | **315,474.01** | **87,619,790.83** | **2,988.63**          | **259,560.75** | **88,197,814.22**       |

The Lamongan regency contributed to the highest biocapacity in the Gerbangkertosusila region of 31,923,023.19 gha. This was due to the high level of land availability in forest land, inland fishing ground, cropland, and built-up land. Lamongan Regency had the greatest vast amount of cropland as compared to the other region. While Mojokerto City, Sidoarjo Regency, and Surabaya City contributed low biocapacity. These three areas had low biocapacity because of the low score on the forest land.

3.2. Estimation of the ecological footprint (EF)

The consumption of cropland is calculated based on how much population consumption for basic food crops. The consumption rate of forest land is calculated by the rate of forest product consumption as timber. Forest land is an area that also carries a responsibility to absorb carbon emissions from electricity usage and vehicles. Thus, the total carbon emission has resulted from both resources also used to add the total number of consumption rates of forest land. Furthermore, the consumption of land fisheries derived from how many fish is consumed by the population from ponds, reservoirs/dams in the area. The consumption of built-up land is identified by the total area which is converted from unbuilt-up to the built-up area. The ecological footprint level is inversely proportional to the magnitude of
productivity. That means, if the land productivity is higher, the ecological footprint is lower. This happens because the land is sufficient to supply the consumption of land products.

Table 5. Ecological footprint by land-use types in the Gerbangkertosusila region

| City/Regency       | Ecological Footprint (gha)       | Total Ecological Footprint (gha) |
|--------------------|---------------------------------|---------------------------------|
|                    | Gresik Regency                  | 13,420                          | 88,680                          |
|                    | Bangkalan Regency               | 10,133                          | 45,807                          |
|                    | Mojokerto Regency               | 11,426                          | 81,182                          |
|                    | Mojokerto City                  | 1,357                           | 5,424                           |
|                    | Surabaya City                   | 30,771                          | 139,242                         |
|                    | Sidoarjo Regency                | 22,419                          | 111,962                         |
|                    | Lamongan Regency                | 12,723                          | 300,903                         |

The ecological footprint in the Gerbangkertosusila region was in the amount of 773,199 gha with the highest land consumption score from the built-up land. It means that the conversion of cropland was also massive, with the assumption that the increase of built-up land area was resulted from converting cropland into the built-up area. The urban activities in Surabaya City had widely spread and influence its periphery areas such as Sidoarjo, Mojokerto, and Gresik. The hinterland of Surabaya was dominated by housing when previously several parcels of cropland still can be found. The Lamongan regency contributes 39% of the ecological footprint in the Gerbangkertosusila region. This was due to high levels of land consumption as well as the high level of carbon emissions resulted from industrial activities, thus causing an increase in the ecological footprint in this region.

3.3. Ecological sustainability level (ESL)
It aimed to compare the carrying capacity of regency/city that is still surplus to support the activities by the land use. It is considered a surplus condition if the value of biocapacity is higher than the ecological footprint. The ecological deficit leads to the urbanized areas, such as Mojokerto City, Surabaya City, and Sidoarjo Regency. Land-use change from cropland to the built-up area is overwhelming and becomes an important issue in the peri-urban area of Surabaya such as the Sidoarjo regency. Furthermore, Surabaya City and Mojokerto City do not have sufficient cropland because of the expansive built-up area for urban development, and only have limited space for the green open space area. So far, the food supply for Surabaya City and Mojokerto City is supported by regions like the Lamongan Regency and Mojokerto regency that has a surplus of the food stock.

Table 6. Ecological sustainability level by biocapacity and ecological footprint

| Regency/City      | Biocapacity | Ecological Footprint | Value  | Ecological Condition |
|-------------------|-------------|----------------------|--------|----------------------|
| Gresik Regency    | 7,361,776   | 88,680               | 8,302% | Surplus Level 1      |
| Bangkalan Regency | 31,235,083  | 45,807               | 68,188%| Surplus Level 1      |
| Mojokerto Regency | 17,568,596  | 81,182               | 21,642%| Surplus Level 1      |
| Mojokerto City    | 1,095       | 5,424                | 20%    | Deficit Level 1      |
| Surabaya City     | 82,576      | 139,242              | 59%    | Deficit Level 2      |
| Sidoarjo Regency  | 25,665      | 111,962              | 23%    | Deficit Level 1      |
| Lamongan Regency  | 31,923,023  | 300,903              | 10,609%| Surplus Level 1      |

The ecological deficit is caused by the consumption of people that exceed the availability of natural resources. The regency/city that has the limited biocapacity should be supported by the other regencies.
which are still surplus on ecological capacity. The biocapacity has supported the contribution of the forestry sector in the absorption of carbon emissions from the transportation, electricity, and domestic sectors. The Lamongan regency had the highest biocapacity because of this regency as one of the primary rice suppliers in the East Java province. Meanwhile, the deficit ecological capacity of the Surabaya was influenced by the lowest cropland and the highest population concentration. The ecological deficit can be controlled by the arrangement of land-use that restricted the land conversion in Surabaya, Mojokerto, and Sidoarjo areas.

![Biocapacity Total Ecological Footprint Total](chart.png)

**Figure 2.** Ecological sustainability level in Gerbangkertosusila region

The increasing value of the ecological footprint due to the rise of consumption has occurred in metropolitan areas in all parts of the world. Many factors can affect the increase of ecological footprints, which arise from the population's boom, the form of the city that triggers the movement of motorized vehicles, socio-economic conditions, and patterns of consumptive urban lifestyle [13]. In urban areas, the highest consumption level in the food category, built-up land in the form of settlements and infrastructure, and transportation far exceed the needs of rural areas which exceeds the availability of natural resources available in urban areas.

The government also needs to take into account the changes in the land use functions and the population growth also decreases in the agricultural and forestry production, conservation areas, and decreasing environmental quality. However, the ecological footprint has not been able to estimate the process of land degradation due to the land conversion [14], so that there is a need to control the land-use conversion in the Gerbangkertosusila region. The future technology and management systems will be extremely sensitive for the allocation of ecological footprint and biocapacity across time, as well as space [15].

Furthermore, carbon emissions as one of the biggest ecological footprint contributors in the Gerbangkertasusila metropolitan area, mainly produced in urban areas, one of them is Surabaya City, which was the prime mover of the metropolitan area, it leads to traffic congestion and increases excess carbon dioxide emission into the water. One way to reduce the level of carbon dioxide in the air is by providing adequate green open space. Existing, the amount of green open space in Surabaya is 20% of the total land area of Surabaya city [16]. However, in reality, this number is still not able to perfectly neutralize carbon emissions in the air. Therefore, the existence of an adequate quantity of green open space needs to be harmonized with the increase in the quality of the green open space, both by minimizing the type of soil pavement which is difficult to absorb water and the types of plants that can absorb carbon and water optimally.
The demand for wood to support the development of the Gerbangkertosusila region is quite large. However, the timber extraction from forest areas needs to be controlled, especially in protected forest areas from illegal logging activities. Protection of forest parks is done in addition to functioning as a carbon sink as well in the context of protection of water springs and biodiversity. There is an effect of changes in the use of forests in national forest parks on the carrying capacity of the environment based on indicators of rainfall and water source discharges for 20 years in the Soerjo forest park [17]. Therefore, some of the national forest parks in the Mojokerto regency need to get regular supervision and control to keep the forest sustainable. The Soerjo forest park has an important role in protecting the ecosystem service and also in absorb CO₂ emission in this region as an effort to mitigate climate change.

There should be arranged through the cooperation among regions to increase the biocapacity and also to control the ecological overshoot and footprint. One mechanism that is useful to maintain ecological sustainability through the regulation related to the land use policy. The incentive/disincentive schemes are approaches that can be carried out in environmental management and regional development [18]. The regions that can increase their biocapacity should get the incentives, and vice versa, the regions...
that are unable to control their ecological footprint get the disincentives. There should be more attention to the environment, ecosystem, and ecological footprint issues in the city and regional planning and decision-making to suppress excessive use of ecosystem [19]. The mechanism of land-use control must be arranged based on the ecological footprint by the provincial government concerning environmental degradation and carbon emission in these areas.

4. Conclusion
The Gerbangkertosusila region had an ecological balance surplus amount of 87,424,615 gha or 9.13 gha/capita which was considered good as the unity of the region. However, the condition of each regency/city was different depends on the biocapacity and ecological footprint. There were areas with an ecological surplus consist of the Mojokerto Regency, Gresik Regency, Lamongan Regency, and Bangkalan Regency. The other areas with an ecological deficit were consist of Mojokerto City, Sidoarjo Regency, and Surabaya City, also very dependent on the ecological surplus from another regency. The growth of urbanized areas is pushed to increase the ecological footprint and tends to decrease their biocapacity. Therefore, the government's policy such as incentive/disincentive regulations and urban parks establishment is urgently needed to manage the biocapacity and control the ecological footprint for ecological sustainability in the long run. Land-use control through the spatial plan can be guided by the land utilization and smart growth region. The advanced technologies are needed to generate in the agricultural field to improve both the quality and quantity of its product also advanced carbon filtration to suppress its emission to the open air.

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