Ecological sustainability level of Surabaya City based on ecological footprint approach

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Abstract. Surabaya is the second largest metropolitan city in Indonesia and is a growth point in East Java. Rapid economic growth and population growth due to urbanization have a negative impact on the sustainability and environmental sustainability resulting in the emergence of environmental issues such as decreasing land productivity and environmental pollution. In an effort to realize sustainable development, development must pay attention to the carrying capacity of its environment. Therefore, in this study a study was conducted using an ecological footprint approach by identifying the components of consumption and emissions resulting from human activities (ecological footprint). Furthermore, identification of the constructed productivity of each type of land such as agricultural land, forestry land, fishery land and constructed land is recorded as a component of natural resources availability (biocapacity). The difference arising from the calculation of consumption and availability of resources will indicate the level of ecological sustainability in Surabaya. The surprising results obtained from this study indicate that Surahaya's sustainability level is already at a deficit level with a biocapacity value of 35,665 Gha and an ecological foot of 139,242 Gha. Such a far-reaching difference in value, where the ecological footprint value is almost four times that of biocapacity, should be the basis of early warning to stakeholders that development with sustainable regional concept is urgent to be initiated concretely.

Keywords: Biocapacity, Ecological Footprint, Carrying Capacity

1. Introduction

Land as a limited natural resource must be utilized optimally and environmentally friendly. The existence of land use that is not optimal can cause environmental damage. The soil has limited carrying capacity, in terms of quantity and continuity. Environmental degradation due to land use that overrides environmental regulations leads to environmental pollution, increased social problems and decreased productivity, so that the current resources will be exhausted and unable to accommodate the needs of future generations [1]. In minimizing the impact of environmental degradation, urban development must be organized with the three main economic, social and environmental pillars as mandated by Law no. 26 of 2007 on spatial planning. In the development of urban areas, environmental aspects tend to be ruled out so as to threaten the needs and consumption of city dwellers. Ideal development needs to be done with the principle of sustainability by maintaining environmental balance so that natural resources to maintain human survival can also be maintained.
One of the concepts of environmental carrying capacity in supporting sustainable development is to use an ecological approach. This concept focuses on measures of the balance of population consumption on nature in the provision of resources and emission reducers for future environmental sustainability [2][3]. The carrying capacity of the region is seen through the comparison of consumption and biocapacity called the ecological deficit in the Global Hectare unit (GHA) [4]. Thus the size of the equilibrium and the activity of the area can be determined through the calculation of ecological deficits. Ecological footprint calculations indicate the ecological status of both the overall and the status of each type of land use in the calculation area. Ecological status is affected by per capita biocapacity and ecological footprint per capita. Thus the population is important. If certain regions are unable to support the life of certain populations with signs of decreased food availability and increased population mortality and declining carrying capacity, this condition is called an excess population that does not reflect environmental sustainability [5].

Surabaya is the capital city and metropolitan city in East Java Province. As one of the second largest cities in Indonesia after the city of Jakarta, the city has a population of 2,848,538 in 2016 with an area of 350.54 km² making Surabaya city as one of the densest cities in Indonesia. With the Juanda airport and two ports namely Tanjung Perak make Surabaya as one of the city with a strategic position of business and trade center. The increase in population in Surabaya is due to the high level of urbanization to this region and the high demand of public consumption, both primary and tertiary materials. Development and activities that occur a city must be able to accommodate by the environment so that human needs who live in the city can be met. Starting from the land as a residence and place of activity and the need for basic consumption and fuel, all these needs must be able to accommodate by the environment. Therefore, it needs a study of environmental carrying capacity through calculation of ecological sustainability of Surabaya city with ecological footprint approach.

2. Data and Methods

2.1. Collecting Data
Data collection in this study using secondary data that is data obtained from the institutional survey and processed data interpretation Landsat Image 2017. Related to the requirement of the calculation of biocapacity, the data related to the population using the data sourced from BPS in 2016. The data of agricultural productivity is collected from the Department of Agriculture sourced from the document of Food Crop Productivity Report of East Java Province in 2016. Data related to forest land productivity conducted several approaches using the data of timber production assumed that each unit of forest land (Ha) has the same stand productivity. The conversion is obtained from the Forest Service Information of East Java Province.

| Table 1. Productivity Conversion of Timber Standing Stock |
|-----------------------------------------------------------|
| Conversion | 1 m³ = 3 Timber Standing Stock |
| Productivity Every Timber Standing Stock | 1.400 | Timber Standing Stock/Ha |
| 466,67 | m³/Ha |

Source: [13]

For data of land area of each type of land use obtained from processed data of Landsat Image 2017 with supervised and unsupervised merging method so that later obtained cluster classification result. While the data used for the calculation of ecological foot used data consumption of agricultural products such as Rice, Corn and Soybean based on data obtained from the Department of Agriculture and Food Security East Java Province in 2016.

The data of land fishery consumption is obtained through assumption of comparative value of fishery consumption divided by land and sea waters combined with the consumption of land fishery divided fishery land. From the calculation, got the average value of consumption of fishery land then multiplied by the population of Surabaya. For the consumption of constructed land, its value is equal
to its biocapacity where the ability to accommodate the built land is equal to the consensus obtained by the calculation of landsat imagery [6].

For forestry consumption data an approach is assumed that the forestry consumption in absorbing carbon from vehicles and electric emissions and divided by wooden sinks is 93.53 [7]. Emission Factor can be seen in Table 3. The consumption rate of wood is assumed to be 0 because there is no wood production in the city of Surabaya, so the need for wood consumption is provided by other areas.

| Table 2. Emission Factors of Electricity and Vehicles |
|-----------------------------------------------------|
| Emission Factor of Electricity | Emission Factor of Vehicles |
|--------------------------------|----------------------------|
| 0.72                           | 2.5                        |

Source: [14]

2.2. Analytic Methods

Based on the method developed by Global Footprint Network (GFN) (2016) in Guidebook to the National Footprint Accounts 2016 Edition, biocapacity (BB) for all land categories is calculated using the following equation:

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

(1)

Where:

- **BC**: Biocapacity
- **A**: Land area of each land category
- **YF**: Yield factor
- **EQF**: Equivalence factor

While consumption is calculated from net consumption is actual consumption which is influenced by trading activity (export-import) in the following equation:

\[ EF = (P/YN) \cdot YF \cdot EQF \]  

(2)

Since, **YF = YN / YW**, then the EF formula can be simplified as follows:

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

(3)

Where:

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

In the calculation of ecological footprint (EF) and biocapacity calculation (BC), 2 (two) conversion factors are used:

- **Equivalent Factor**
  Equivalent factor is a factor that converts a particular local unit into a universal unit, the global hectare (Gha). Equivalent factors have been determined by the Global Footprint Network for 5 (five) categories of land, namely agricultural land (2.56), forest land (1.28), fishery land (0.35) and constructed land (2.56). This factor is measured from the level of sustainability of land type and population dependence on the land category.

- **Yield Factors**
  Based on the method developed by GFN which also refers to Borucke et al [8], Yield factor is ratio between the productivity of a land category in certain area with the average of productivity of same land category in the world and in the same year. The following equation:
YFL : yield factor for L land category
YNL : Land productivity (yield) of L land category in the calculation area
YWL : World yield productivity for product i.

Ecological deficits occur when the Ecological Footprint of an area exceeds its Biocapacity (globalfootprintnetwork.org, November 2015). That is, the consumption of the population is greater than the capacity or ability to provide the resources of a particular region. In summary, deficit conditions occur when Ecological Footprint of Land > Biocapacity of Land. On the other hand, an area will experience a surplus condition if the consumption needs of the population or the ecological foot of the land is no greater than the biocapacity of the land. Or it can be described as Land Biocapacity > Ecological Footprint of Land. The ecological deficit can be calculated using the following equation:

$$ED = \text{total BC} - \text{total EF} \quad (5)$$

ED : Ecological deficit
BC total : Biocapacity total
EF total : Ecological footprint total

3. Result and Discussion

3.1. Biocapacity

In the calculation biocapacity of Surabaya City required harvesting factors and equalizing factors. the agriculture factor is the ratio between land productivity in a region and the world’s productivity of the same type of land at the same time [8]. To obtain the value of agriculture factors, then calculated in advance the land use productivity of Surabaya with the same land productivity in the larger scope of Indonesia. This is done to compare the extent and productivity of land in research areas globally on the same commodity. Here is an agriculture for each type of land use in the city of Surabaya.

| Table 3. Harvest Factors of Each Type of Land Use |
|--------------------------------------------------|
| Region | Agriculture | Forestry | Land Fishery |
|        | Yw = 25.93  | Yw = 0.82 | Yw = 62.21   |
|        | YK  | YF  | YK  | YF  | YK  | YF  |
| Surabaya City | 9.47 | 0.37 | 0  | 0  | 9.53 | 0.15 |

Harvest factors can be an indication that the productivity of land in a region is better or smaller than the productivity of the world's land in the same year. From the calculation table above harvest factors note that the land productivity of Surabaya is small compared to the productivity of land Indonesia. In addition, the forestry value is 0 because in Surabaya there is no forestry land, in this case protected forest and production forest.

The equalizing factor is the factor that converts the unit of land, either hectare or other units, into global hectare units (gha). From various types of land use in Surabaya City, determined the equalizing factor in accordance with the characteristics of each land as follows.

| Table 4. Equivalence Factors for Each Type of Land Use |
|------------------------------------------------------|
| Type of Landuse | Equivalence Factors |
| Agriculture    | 2.56 |

YFL = YNL / YWL \quad (4)
| Type of Landuse     | Equivalence Factors |
|--------------------|---------------------|
| Foresty            | 1.28                |
| Land Fishery       | 0.35                |
| Built Area         | 2.56                |

*Source: Global Footprint Network, 2016*

Figure 1. Landsat Imagery of Surabaya

The picture above is a map of land use in the Surabaya area in 2017 covering agricultural land, forestry, land fisheries, and built up land. This data of land use is used to attain biocapacity in the Surabaya area. In this method of calculation, in accordance with the Global Footprint Network (2016), the biocapacity and ecological footprint of the constructed land is always directly proportional. This is because both illustrate the loss of bioproductivity due to the encroachment of infrastructure. Therefore, in this study it is assumed that ecological biocapacity and ecological footprints of land are built together to reduce bioproduction due to infrastructure development, so that the number of ecological footprints and biocapacity of the built land will be equal or equivalent.

After obtained the factors of harvesting and the factor of equalization, then done the calculation of biocapacity. Result from its biocapacity, in the year 2016 data biocapacity of Surabaya City amounted to 25,664.92 Gha, for the biocapacity value of each category of land can be viewed in the following table.

Table 5. Total Biocapacity of Each Land Use in Surabaya City

| Region          | Biocapacity of Land Use (Gha) | Total Biocapacity (Gha) |
|-----------------|-------------------------------|-------------------------|
| Agriculture     | 5,449.53                      | 20.018,44               |
| Forestry        | 0                             | 196,95                  |
| Land Fishery    | 196,95                        | 20.018,44               |
| Built Up Area   | 25,664,92                     |                         |

Based on the above table it is known that the greatest biocapacity value of Surabaya City is land constructed up, this is because Surabaya City as Capital City in East Java Province with high population. High population presence affects the availability of upgraded land. As for the other land category that is the biocapacity of agriculture only 5,449.53 Gha and land fishery 196.95 Gha. For forestry land biocapacity value 0 because in the city of Surabaya there is no protection forest and production forest. The results of this biocapacity calculation will be used to determine the ecological sustainability of Surabaya City by comparing the value of ecological footprint.
3.2. Ecological Footprint

Ecological Footprint calculation is based on the calculation of natural resource consumption which is the amount of community need for natural resources in fulfilling their life needs. Larger cities with more populations increase consumption and ecological footprint. The ecological site consists of land cover types such as agricultural land, forestry land, fishery land and built up land.

The average consumption of agricultural products such as rice, corn and soybeans in 2016 were rice averaged 78.96 kg / capita / year, corn consumption of 5.28 kg / capita / year and 23.76 kg / capita / year. So the total consumption average of 108 kg / capita / year or equal to 0.108 ton / capita / year. Ecological footprint of agricultural land derived from the total consumption of rice, corn and soybeans as the main ingredient of the people of East Java. Furthermore, the value of consumption is changed to Gha through an ecological footprint formula.

| City      | EQF Agriculture Product = 2.56 |
|-----------|--------------------------------|
| City      | Consumption (ton) | YKL | YFL | EF (Gha) |
| Surabaya  | 307.642           | 9.47| 0.37| 30.771 |

For forestry products are used as emissions absorber. Ecological footprint of forest land is obtained by calculating carbon sink demand and wood consumption requirement. The need for carbon sinks is obtained through the carbon footprint of the vehicle and the use of electricity that is converted in Gha units by dividing land cover and multiplying by forest land factor. The Surabaya city does not have forest land so it does not have forest products.

| Types of Fuel | Amount of usage (litre/year/unit) |
|---------------|----------------------------------|
| Gasoline      | 140.28                           |
| Diesel Fuel   | 3.819.1                           |

**Source:** [15]

Based on the table of vehicle number and conversion of fuel consumption can be seen total vehicle consumption in Surabaya is shown by table 8. In addition to transportation activities, daily activities using electrical energy are also included in emissions-producing consumption. Total electricity used in Surabaya is 8,358,783,540 KwH produced in 3 generators in South, West and East of Surabaya. The total ecological footprint of Surabaya’s forestry land is 88,132.15 Gha.

| Small Vehicles | Conv | Large Vehicles | Conv | Total Consumption (litre/year/unit) | Emission Factor | Total Emission |
|----------------|------|----------------|------|-------------------------------------|----------------|----------------|
| 2.576.321      | 140.28| 13.8374        | 3.819.1| 889.870.453.3                      | 2.5            | 2.224.676.133,20 |

**Table 9. Total Emission**

| Electricity Consumption | Emission Factor | Value | Total Vehicles Emission |
|-------------------------|-----------------|-------|--------------------------|
| 8.358.783.540           | 0.72            | 6.018.324.149 | 2.224.676.133,20          | 8243000,282    |
Table 10. Ecological Footprint of Forestry Land (Analysis, 2017)

| Carbon Emission (degradation potency of trees: 93.53) EQF= 1,28 | EQF= 1,28 | Total EF/TE (Gha) |
|---------------------------------------------------------------|-----------|------------------|
| Vehicles Emission                                             | Electricity Emission | EF/TE (Gha) | Consumption (Ton) | YKL | YFL | EF/TE (Gha) |
| 6.018.324.149                                                 | 2.224.676.133,20 | 88132,15 | - | - | 0 | - | 88.132,15 |

Consumption of fishery products based on Marine and Fishery Data of East Java in 2016 is 11.76 kg / capita / year which is a combination of consumption of land and sea fisheries. While in this study, consumption of fishery products is limited to consumption of aquaculture products with an average consumption of 0.0034 tons / capita / year and multiplied by the population of Surabaya City to obtain total consumption. In addition to transportation activities, daily activities using electrical energy are also included in emissions-producing consumption.

Table 11. Ecological Footprint of Land Fisheries Product

| Total Popoulation | EQF Land Fishery= 0.35 |
|-------------------|------------------------|
| Consumption (ton) | YKL | YFL | EF/TE (Gha) |
| 2.848.538         | 11.898,59 | 9,53 | 0,15 | 65,55 |

In the calculation of the ecological foot of the developed land used ecological footprint formula with the value of EQF 2.56. Total Ecological Footprint of Surabaya amounted to 20,273.76 Gha. The number of areas built increased with the rapid development of Surabaya as the largest city in East Java Province.

Table 12. Ecological Footprint of Constructed Land

| EQF Constructed Land = 2.56 |
|-----------------------------|
| Consumption (Ha) | YFL | EF/TE (Gha) |
| 21.403,89 | 0,37 | 20.273,76 |

Table 13. Total Ecological Footprint of Surabaya City

| City      | Ecological Footprint of Land Use (Gha) | Total EF (Gha) |
|-----------|----------------------------------------|----------------|
| Agriculture | Forestry | Land Fishery | Constructed Land |
| Surabaya  | 30.771 | 88.132 | 65.55 | 20.273,76 | 139.242 |

Surabaya City has the highest ecological footprint value in the GKS metropolitan area. This is because the city of Surabaya is the main node of the development of GKS metropolitan area and eastern Java province, thus causing population growth and the necessities of life. This happens because of the high population due to urbanization, in addition to the high use of motor vehicles exacerbate the ecological footprint conditions in the city of Surabaya. Of the total ecological footprint value, the highest value is in the constructed land and the lowest is the ecological foot of the land fishery land.
3.3. Ecological Deficit Level (Sustainability)
The level of ecological sustainability is derived from the calculation of biocapacity and ecological footprint of the city of Surabaya by comparing whether the environmental condition in Surabaya is in deficit (beyond the carrying capacity of the land) or still surplus (consumption is still less than its carrying capacity).

Table 14. Total Biocapacity and Ecological Footprint of Surabaya (Analysis, 2017)

|                      | Agriculture | Forestry | Land Fishery | Built up Area | Total     |
|----------------------|-------------|----------|--------------|---------------|-----------|
| Biocapacity          | 5.449.53    | 0        | 196.95       | 20.018.44     | 25.664.92 |
| Ecological Footprint | 30.771      | 88.132   | 65.55        | 20.273.76     | 139.242   |
| Conditions           | Deficit     | Deficit  | Surplus      | Deficit       | Deficit   |

Based on the ecological footprint table above, it can be seen that in Surabaya as a whole there is a deficit due to the existing biocapacity condition cannot accommodate high consumption level requirement. For each category of land also experienced deficit except land fishery where in land fishery land still can fulfill requirement of population consumption because consumption of fishery result is provided by sea fishery product. While in this study is limited to the consumption of the results of terrestrial fisheries. The high value of the ecological footprint is based on the contribution of the forestry sector, namely the absorption of emissions from motor vehicles and the emissions of carbon and electricity as well as land.

4. Conclusion
Through the research of Determination of Ecological Sustainability Level of the Region, it is known the condition of biocapacity or availability of land, ecological footprint or land consumption, and ecological sustainability level in Surabaya City. From the calculation results can be concluded that the city of Surabaya experienced a deficit condition where the existing resources cannot meet the needs of existing population consumption. This is indicated by a biocapacity value of 25,664.92 Gha and an ecological footprint value of 139,242 Gha. Of the two values can then be calculated gap value of ecological balance of 113,557.08 GHa. The deficit conditions affect agriculture, forestry, and land sectors. For the land fishery sector, the condition is surplus. The large ecological deficit values indicate that Surabaya City is over populated and needs to be taken curative or preventive measures to overcome the negative impacts that arise. In this case, the concept of sustainable regional-based...
development can be one solution because Surabaya as the center of East Java growth cannot meet its own needs.

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Acknowledgements

This research was supported by LPPM Institut Teknologi Sepuluh Nopember for the PUPUT research grant 2017. We are thankful to our colleagues who provided expertise that greatly assisted the research.