Spatial interaction between urban and peri-urban regions of Surabaya metropolitan area and its impact to the carbon footprint of transportation sector

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Abstract. Surabaya Metropolitan Area is the dominant urban agglomeration in East Java Province as the center of regional economic development. The population growth and economic activities have significantly affects to the periphery area, one of which is Sidoarjo Regency where is directly border to the southern part of Surabaya City. Sidoarjo Regency as a supporting area has a main function in the provision of residential and industrial areas which causes the expansion of urban areas of Surabaya. The relationship between urban and peri-urban areas has the potential to increase the flow of people, goods and vehicles from Surabaya to Sidoarjo and vice versa. It causes congestion and air pollution problems from vehicles in the corridor of the area with a high level of interaction. The purpose of this study is to estimate the level of spatial interaction between urban and peri-urban areas as well as the environmental impacts, mainly carbon emissions and ecological footprint. The analysis was carried out using the gravity method to measure spatial interactions, while carbon emissions analysis uses quantitative method with data on emission factors and the number of vehicles between Surabaya City and Sidoarjo Regencies, as well as their effects on ecological footprint. The results show that the peri-urban area surrounding border of Surabaya City has the highest level of spatial interaction. The strong interaction between urban areas and peri-urban areas has an impact on increasing carbon emissions between these two regions and also their ecological footprint.

Keywords: Spatial interaction, Peri-urban region, Carbon footprint, Transportation sector

1. Introduction

Indonesia as one of the countries that are growing rapidly both in the economic, social and demographic sectors has the central points of strategic growth with the main characteristics of the development is metropolitan area as a centre of economic activity. The development of economic activity centres in the metropolitan area is supported by the strategic location of the area, both geographically and accessibility which is closely related to the transportation of goods and people. The metropolitan area in Indonesia consists of one growth point (city) which is supported by several regencies or surrounding cities as a supporting area for physical, economic and social activities. The development of this region resulted in changes from rural areas to urban areas. This phenomenon is called urban sprawl where changes in the physical appearance of the area become less rural and show more urban characteristics [1]. This area is called a peri-urban area which has the main land use characteristics as an agriculture area which is slowly
transforming into a built-up area, rapid population growth with high population density, and a change in the mindset of rural people into urban communities [2]. The central city of growth and the peri-urban area has a close relationship with the fulfillment of consumption needs, where the peri-urban area provides natural resources that the city cannot provide. In the economic field, this relationship can be seen in the supply and demand process.

Surabaya and the surrounding urban areas are referred to as a Gerbangkertasusila metropolitan area which causes urban sprawl in the city of Surabaya to other regions, one of which is Sidoarjo District [3]. Based on BPS Sidoarjo Regency in 2016, Waru and Taman districts which are directly adjacent to the City of Surabaya experienced the highest population growth compared to other districts in Sidoarjo with 11.38% and 10.79% respectively. Whereas, in other areas located close to Parks and Waru districts namely Sukodono, Gedangan, and Candi also experienced an increase in population density roughly 7,000 people / km2. Another peri-urban characteristic that appears to occur in Sidoarjo Regency is the change in land use from agricultural land to residential and industrial land, around 5.3 thousand of which have been diverted in land use. The calculation is based on remote sensing analysis from 2002 and 2017. Land use changes into built-in areas, namely settlements and industries will directly increase the number of vehicles and the movement of vehicles from the peri-urban area to urban areas, especially in districts that are directly adjacent to urban areas because in that area lies a residential area that cannot be provided by urban areas. CO2 emissions derived from burning fossil fuel vehicles contribute 50% of the effects of greenhouse gases [4]. CO2 gas is an important gas and if in normal circumstances it is not dangerous and useful in the process of photosynthesis of plants, excessive amounts can pollute the air and cause greenhouse gas effects [5]. The increase in population and the number of motor vehicles as a source of CO2 emission increases its concentration in the air [6,7].

Therefore, a study is needed related to the relationship between urban areas and peri-urban as well as their effect on the increasing number of vehicles and carbon emissions to implement the sustainable development in the metropolitan area. The objectives of this research were, 1) seeing the pattern of urban sprawl in Sidoarjo regency with normalized prevention of built-up index (NDBI) method by using Landsat satellite image year 2002 and year 2018 with the help of GIS, 2) studying the characteristics of regional calculating by gravity model, and the last 3) calculating carbon emission on Sidoarjo regency.

2. Data and methods

2.1 Study site

Sidoarjo Regency is located on East Java which is directly adjacent to the City of Surabaya. This area is included in the development area of Gerbangkertasusila metropolitan with the main land use of agriculture with a large area of 36.2% of the total land area and 17.5% built land consisting of residential land, commercial area, industrial area, and other land use.
The population of Sidoarjo Regency reached to 2,223,002 peoples in 2017 according data recorded by Central Bureau of Statistics of Sidoarjo Regency. It is indicated that the most densely population district is Waru with 242,004 inhabitants. Meanwhile, the smallest number of population is in Jabon district which up to 61,015 peoples.

The table above shows that the largest population is located in the Districts of Waru, Taman, and Sidoarjo with roughly 230 thousand people on each district. Population fluctuations are one of the attributes of urban sprawl where there is a movement of residents from the city of Surabaya who moved to Sidoarjo regency due to the limited land of settlements in the city of Surabaya.

2.2 NDBI
Normalized Difference Built-up Index (NDBI) analysis required landsat imagery to delimitate built-up. Images that were used in this analysis selected from the available imagery the earliest and the latest using satellite captures with clear skies to get more precise result. The images that were selected to
reflect urban growth trends in Sidoarjo regency were from 2002 and 2017 imagery from landsat imagery. Based on the calculation of standardized differentiation of Band 5 and Band 4 will result binary image. In which, woodland and farmland pixels have value close to 0 (zero), negative value for waterbodies, and positive values for built-up areas.

2.3 Gravity model
This analysis method is used to calculate the magnitude of inter-regional spatial interaction. Gravity model measures the strength of interaction between 2 different poles (in this case 2 different regions namely Surabaya and Sidoarjo). Calculations was done buy multiplying the number of populations between Surabaya population and districts in Sidoarjo and then divided by the square of distance between those two regions times to constata number (1).

The general formulation above is adopted by Vaz & Nijkamp resulted a new formulation. Mass from the initial formulation is likened to be change of population in a city with the acceleration of built-up changes [8]. With that assumptions, Fp is population changes in the area, and a is changes of built-up area.

\[
F = k \frac{m_1 m_2}{r_{12}^2}
\]

\(F\) = interaction forces with Surabaya
\(F_p\) = changes of population
\(a\) = changes of built-up area
\(m_1\) = mass of urban sprawl area_1
\(m_2\) = mass of urban sprawl Surabaya
\(r_{12}\) = distance of area_1 and Surabaya
\(k\) = constanta

2.4 Carbon emission calculation
Emissions released from transportation mode use activities are calculated through fuel consumption per type of transportation mode. This amount of consumption is derived from the average population consumption of BBM from the 2017 Income Bureau of East Java Province data [9].

To find out the number of emissions released from these two activities, the energy consumption is calculated with the emission factor. The amount of CO2 emissions generated from an activity can be written in the formula below.

\[
ECO_2 = A \times FE
\]

\(ECO_2\) = CO2 Emission
\(A\) = Energy Consumption
\(FE\) = Emission Factor

Based on Suhandi in Srikandi (2009), the emission factor of a vehicle with fossil fuel is 2.5 Kg CO2 /liter [10]. This type of vehicle is only distinguished from the type of fuel, including small vehicles (motorcycles, cars, jeeps, sedans, etc.) namely gasoline and large vehicles (buses, trucks, heavy vehicles, etc.) with diesel fuel. Both types should have different uses of the type of fuel used, namely gasoline for small vehicles and diesel for large vehicles. Fossil fuel consumption per year can be seen on table 2. from SUSENAS 2014 and Ismayanti [11].
Table 1. Fossil Fuel Consumption per-Vehicle

| Fossil Fuel Type  | Number of Uses (Litre/year/unit) |
|------------------|----------------------------------|
| Gasoline         | 140.28                           |
| Diesel Fuel      | 3,819.1                          |

3. Result and discussion

3.1 NDBI

![Figure 3. NDBI result of Sidoarjo Regency year 2002 and 2017](Source: [12])

Based on the calculation of the raster data from Landsat imagery, it can be seen that there is an increase in the density of the built-up area as shown in Figure 4. This raster shows also the magnitude of the NDBI index that will be used as an input gravity model.

![Figure 4. Built-up area transformation number of Sidoarjo in 2002 and 2017](Source: [12])
3.2 Gravity model
This analysis method is used to calculate the magnitude of inter-regional spatial interaction and calculate the strength of interaction between the two regions. The results of the gravity model calculation are shown in Table 2.

**Table 2. Results of interaction analysis of Sidoarjo’s Districts to Surabaya City**

| No | District   | a    | Fp   | $m_1 = \frac{Fp}{a}$ | $r_{12}$ | $F = k^{m_1 \cdot m_2 \cdot *}$ |
|----|------------|------|------|----------------------|----------|------------------------------|
| 1  | Jabon      | 8096 | 13332| 1,64673913           | 31,152   | 0,01372                      |
| 2  | Tarik      | 1269 | 17294| 13,62805359          | 29,744   | 0,12456                      |
| 3  | Krembung   | 11155| 20761| 1,861138503          | 28,198   | 0,01893                      |
| 4  | Balongbendo| 788  | 21446| 27,21573604          | 26,652   | 0,30983                      |
| 5  | Porong     | 985  | 18854| 19,14111675          | 28,193   | 0,19474                      |
| 6  | Prambon    | 4361 | 22400| 5,136436597          | 25,907   | 0,06189                      |
| 7  | Tanggulangin| 5058 | 42839| 8,469553183          | 25,875   | 0,10301                      |
| 8  | Tulangan   | 15098| 35020| 2,319512518          | 23,778   | 0,03318                      |
| 9  | Wonoayu    | 11993| 25366| 2,115067122          | 19,868   | 0,04333                      |
| 10 | Candi      | 15857| 69055| 4,354859053          | 23,219   | 0,06532                      |
| 11 | Buduran    | 3033 | 38875| 12,81734257          | 18,254   | 0,31106                      |
| 12 | Krian      | 4871 | 46351| 9,515705194          | 19,643   | 0,19942                      |
| 13 | Sedati     | 3997 | 40745| 10,19389542          | 16,682   | 0,29623                      |
| 14 | Sidoarjo   | 14338| 78431| 5,470149254          | 21,267   | 0,09780                      |
| 15 | Sukodono   | 10124| 60998| 6,025088898          | 14,619   | 0,22799                      |
| 16 | Gedangan   | 723  | 26749| 36,99723375          | 12,983   | 1,77500                      |
| 17 | Taman      | 4989 | 56754| 11,37582682          | 11,454   | 0,70123                      |
| 18 | Waru       | 1962 | 31578| 16,09480122          | 10,120   | 1,27082                      |

$m_2 = 8.086478867$

The results of these calculations can be seen that each districts have different interactions values. Then the interaction value is classified into 5 classes from highest to lowest.

**Table 3. Range and classification of each districts in Sidoarjo Regency**

| Classification | Range          | Districts                                      |
|---------------|----------------|-----------------------------------------------|
| Class 1       | 1,77500 – 1,42275| District Gedangan                             |
| Class 2       | 1,42274 – 1,07048| District Waru                                 |
| Class 3       | 1,07047 – 0,71821| -                                             |
| Class 4       | 0,71820 – 0,36595| District Taman                                |
| Class 5       | 0,36594 – 0,01368| District Sukodono, Jabon, Tarik, Krembung, Balongbendo, Porong, Prambon, Tanggulangin, Tulangan, Wonoayu, Candi, Buduran, Krian, Sedati, dan Sidoarjo |

Based on Table 3 it can be known that the biggest interaction in Sidoarjo Regency towards Surabaya City is Gedangan District, the second strongest namely Waru District which has a direct border and has access levels of national and provincial roads. Whereas the weakest is located far from the border of...
Surabaya City namely Sukodono, Jabon, Tarik, Krembung, Balongbendo, Porong, Prambon, Tanggulangin, Tulangan, Wonoayu, Candi, Buduran, Krian, Sedati, and Sidoarjo. Based on these results it can also be seen that the closer and more densely populated and the built area of Surabaya City has a strong urban character than districts that are farther from Surabaya. the existence of urban sprawl occurring in Sidoarjo Regency shifts from Waru District and Taman to District Gedangan where there is a rapid development of residential areas.

3.3 Carbon emission calculation
Calculation of carbon emissions is based on the number of vehicles, type of vehicle fuel and emission factors as described in the equation 4. The number of vehicles will be shown in table 4, the total of Carbon Emissions is presented in Gha (Globalhectares).

| Total of Small Vehicle | Conversion of uses (lt/year/unit) | Total of Large Vehicle | Conversion of uses (lt/year/unit) | Total | Emission Factor | Total x Emission Factor (Gha) |
|------------------------|----------------------------------|------------------------|----------------------------------|-------|-----------------|-------------------------------|
| 1.446,358              | 140.28                           | 46,054                 | 3,819.1                          | 378,779,931.6 | 2.5             | 946,949,829.10               |

Table 5. Total vehicle emission on 3 strongest interaction Districts in Sidoarjo

| District Name | Total Carbon Emission (Gha) |
|---------------|-------------------------------|
| Sidoarjo      | 9,586,463                     |
| Buduran       | 4,431,832                     |
| Candi         | 6,898,798                     |
| Porong        | 3,756,742                     |
| Krembung      | 3,143,717                     |
| Tulangan      | 4,358,947                     |
| Tanggulangin  | 4,563,374                     |
| Jabon         | 2,599,104                     |
| Krian         | 5,747,422                     |
| Balongbendo   | 3,356,834                     |
| Wonoayu       | 3,707,371                     |
| Tarik         | 3,021,845                     |
| Prambon       | 3,549,419                     |
| Taman*        | 9,944,796                     |
| Waru*         | 10,308,837                    |
| Gedangan*     | 5,681,651                     |
| Sedati        | 4,609,678                     |
| Sukodono      | 5428,152                      |

*Main Urban Sprawl Districts

Based on the calculation of carbon emission in Sidoarjo Regency which is shown in table 6, the total carbon emissions in all Sidoarjo regency is 946,949,829.10 which accounts for nearly 20% of the total number of vehicles in the Metropolitan Gerbangkertasusila area and occupies the second position of the largest number of vehicles after Surabaya City. Based on the data above, it can also be seen that 3 districts with the highest level of interaction with the City of Surabaya contribute to large carbon
emissions. Waru and Taman Districts which are directly related to Surabaya City contribute the largest carbon emissions, followed by District Gedangan which has the largest spatial interaction value of Surabaya City with a value of 48,296,953.70 Gha.

4. Conclusion
From the three analyzes that have been carried out in this study (including NDBI analysis, Gravity Model and Carbon Emission Calculation), it can be concluded that the peri-urban area in the southern part of Surabaya City has converted the agricultural land use area to a built-up area of up to 43.95% due to the expansion of urban areas. The increase in spatial interaction in the urban area with the peri-urban area in Sidoarjo occurs due to the movement of people and goods through the transportation sector, which is viewed from the Gravity model and sees the impact on increasing the carbon footprint in the area with the highest spatial interaction. Districts of Gedangan, Waru, and Taman contributed 48,296,953.70 Gha of carbon emissions, 103,088,367.19 Gha, and 99,447,959.65 Gha respectively.

5. References
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