Landsat Imagery and Census Data for Urban Population Density and Urban Density Modeling in Palembang, Indonesia

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Abstract

This research is to understand the condition of population Density concentration in the city of Palembang. According to the 2018 United nations booklet (Nations, 2018), the city of Palembang is dimmed to be one of the fastest growing city in Indonesia. Palembang has an annual growth rate between 2.4% to 6% and according to the research the exponential growth will have an impact to its urban fabric conditions. The problem in urban growth for researcher is the limitation of datasets available from the government, and mostly the datasets are not tailored for urban designers need. The statistical datasets available are often linked to the administrative area called “kecamatan” without knowing the true population density in that particular area. This paper is using Landsat images and population density data, acquired respectively from Earth Explorer USGS and Balai Pusat Statistik to verify the morphological changes that has happened in Palembang between the year 2001, 2007, and 2016. The result output shows the LUDI / Land use dynamic Index and also verifying the density of each “kecamatan” as and administrative area in Palembang. The research output may contribute in the development of spatial research in urban design in Palembang and could also help future research for urban development and population density verification in the city of Palembang.

Keyword: population density, Landsat images, urban, kecamatan.

Introduction

The urban population has been essential data for planning in urban design. However, the data in developing countries are often not available and has adequate geographical scales or even not updated routinely. Also, if the census data are available, usually the data are not scaled down in an exact size, and often it is created in larger zones. Population density and the distribution of the population is essential to represent the economic activity in an urban environment (Wang, 2006) and also it is a necessary tool for the urban designer to assess the development of an urban area. The problem in acquiring the dataset in developing countries is that the census data is a large administrative zone with large scale areas; however, such data could not be used to evaluate density in smaller urban areas.

The case study used for this paper is the City of Palembang, as the oldest city in Indonesia with a total population of 1,623,099 people in area size of 369.22 km2. The overall density of the city is 4,400/km2 for the 2017 population census data. The population in 1986 is 878,732, and the population has grown doubled since then, this has an impact on the growth of the urban area of the city. Although it is a developing country, the census data is collected continuously annually to measure the increase in the city. The problem is that the census data is being published only in a spreadsheet format of the 16 administrative zones without any information of map to show the census unit of the city. Therefore, it is essential to develop a reasonable way to create a model for estimating the population into a geographical map that could acquire detailed density in the urban area Palembang.

Remote sensing has been widely adopted for population estimation and correlates population and classified urban areas with the allometric growth model by using mean reflectance values of the multispectral bands for population estimation. With the availability of high resolution Landsat images with Landsat Thematic Mapper (TM) with research of (Langford, 1991; Yuan et al., 1997) and also the Landsat Enhanced Thematic Mapper (ETM+) with analysis of (Li & Weng, 2005; Lu et al., 2006; Wu & Murray, 2003) it is possible to use the method by classifying the Multi-Spectral band to precisely define the dense urban areas of the city.

Urban population density is somehow related to the intensity of the modification on the Earth's surface; this is known in geographical terms as Land use and Land Cover or LULC. Even though LULC is not directly linked with the information of biophysical attributes nor the information about housing and population models. A VIS (Vegetable, Impervious Surface, Soil) model was created in 1995 (Ridd, 1995) to characterize the urban environment by the geographical composition of Vegetation, Impervious surface, and Soil. With the Impervious surface as materials that prevent water from infiltrating the soil, the presence of the Impervious materials can be considered as a piece of information about housing density.

This paper seeks to construct a population regression model for Palembang, Indonesia using remote sensing, explicitly using the Landsat ETM+ data extracted from USGS datasets. The model will have the potential for future use in estimating the population patterns with the limitation of developing country census data.

Study Area

The study area is Palembang, the capital of South Sumatera Indonesia, and it is the oldest existing city in Indonesia dated back to the 6th century. According to the Balai Pusat Statistik (BPS) an Indonesian government office branch that collect the population data, the city of Palembang had a population in 2017 of 1,600,000 within the area of 338.49 km2.

The administrative area of the city was divided into 16 administrative counties. With the limited knowledge of technology, the BPS works in collecting the statistical data in the form of the spreadsheet without regarding the density of land use and land cover of the administrative area. Each of the administrative counties in Palembang has a wide range of sizes with the smallest county is 6.22 km2, and the largest county is 68.78 km2 with density respectfully of 11,457/km2 and 930/km2. BPS only released the population data without any spatial data and GIS format or other socio-demographic information. To reconstruct the GIS database for this study, I downloaded from http://tanahair.indonesia.go.id/portal-web/login, an Indonesian GIS database for an administrative zone, providing a digitize shapefile of polygon unit for the ArcGIS platform.

Figure 1. The map shows the density of each administrative area in Palembang according to the census data. Map by author in 2019

This map is showing the 16 administrative areas in the city of Palembang, and the collected data is added to the table of attributes in ArcMap to create a visual population density of each administrative area. The population density is the ratio between person per km2 by dividing the number of census data divided by the size of the area, and the map of Palembang shows that there are areas that have a high density of 22780 people/km2 and the lowest area show a density of 2000 person/km2

The city boundaries of Palembang have changed over time, the earliest source of city boundary was created around the 1820s, and today the city has since used the latest city boundary, with the total administrative size of 338.49 km2. With the rapid city growth, the city has expanded merging with the neighboring administrative area, and the sum size of the city has double the size of its administrative area. This has raised a question if the administrative area of Palembang has used the maximum growth of its administrative boundary? From the study area, the urban growth could be studied to analyze the growth of the urban built area in Palembang.

Figure 2. The map shows the main feature and historical morphological phases of Palembang. Map by author in 2018

In Figure 3 we could see the census data collected from BPS that show the number of people and the size of the administrative zone in km2. The census spreadsheet data is than added to the attribute of the shape file in ArcMap to show the density of each administrative zone compared to the area size shown in Figure 1.

Figure 3. Census datasheet provided by the BPS in Palembang 2018

Methods

The method used in this paper is by choosing the Landsat image that is related to the time of the Census data of 2018. Landsat satellite has been continually monitoring the Earth surface since 1972; this continuation of data is beneficial on validating the long-term evaluation of the model. The satellite image data is obtained from U.S. Geological Survey (USGS) Earth Explorer resources https://earthexplorer.usgs.gov/ and the specific image chosen for the particular site with the lowest percentage of cloud cover (5%) and high-resolution tif images. In this research, I used four methods to determine the impervious surface of the study area to identify the urban land use in Palembang.

The first method used in the images was using a rational linear regression method to distinguish the impervious surface estimation method using Linear spectral mixture analysis (LSMA (Wu & Murray, 2003) and regression analysis using linear regression method of greenness component from ETM+ images (Bauer et al., 2007). Using this method to distinguish the VIS (Vegetable, Impervious material and Soil) model would allow predicting the population density that is related to the fractions of vegetation, residential houses or impervious surface material and the soil captured by the remote sensing data. The image data of Landsat ETM+ image is processed using the LSMA method to obtain the V-I-S fraction images. The regression is the value of tasseled cap transformation in the value of each band on the remote sensing data. This research has been conducted by Joseph to verify the density value in Port-au-Prince, Haiti (Joseph et al., 2012).

Impervious Surface measurement

The second method on verifying the impervious surfaces is using the vegetation indices from Landsat imagery with calculating the value of Normalized Vegetation Index / NDVI, and the Soil adjusted vegetation index / SAVI that are converted to IS fractions by also estimating the fractional of vegetation cover.

The Normalized Difference Vegetation Index (NDVI) is a measure of greenness that indicates the relative abundance of vegetation. The product pixel based NDVI values were calculated based on the reflectance information of the red band and the near infrared band.

The soil adjusted Vegetation Index (SAVI) is developed to adjust the influence of variations in soil background color on the near-infrared and red band relationship in areas with partial vegetation cover. L is the adjustment factor, which varies from 0 to 1 with the different vegetation density and leaf area index (LAI). The SAVI is structured similar to the NDVI but with the addition of a “soil brightness correction factor,” where NIR is the reflectance value of the near infrared band, RED is reflectance of the red band, and L is the soil brightness correction factor. The value of L varies by the amount of cover of green vegetation: in very high vegetation regions, L=0; and in areas with no green vegetation, L=1. Generally, an L=0.5 works well in most situations and is the default value used. When L=0, then SAVI = NDVI.

The sub-pixel fractional vegetation cover (FR) is a calculation using the measurement of NDVI, where vegetation is considered as one of the end members. FR is calculated using the relationship between NDVI and values of the dense vegetation index (NDVIs) and bare soil (NDVIo) equation. NDVIo/NDVIs is not constant and a spatiotemporal value that must be applied when calculating FR for different cities. The values are determined by the topography and color of non-vegetated surface in the satellite sensor.

To quantify the value of Impervious Surface is be subtracting 1 with the value of the fractional cover of the NDVI, assuming that urban areas are comprised of the combination of the vegetation cover and IS and calculating the impervious surface fractions.

The third method on verifying the impervious surface / built urban area is by estimating the continuous imperviousness index using linear combination of image bands or ratios. The dependent variable is the multivariate regression model to estimate continuous imperviousness index from the ETM+ image. The independent variables were derived from the six ETM+ bands with the array of blue, green, red, NIR, SWIR1 and SWIR2 with the three image ratios of NDVI, brightness, and greenness.

Index

Band 2

(Blue)

Band 3

(Green)

Band 4

(Red)

Band 5

(NIR)

Band 6

(SWIR 1)

Band 7

(SWIR 2)

Brightness

0.3029

0.2786

0.4733

0.5599

0.508

0.1872

Greenness

−0.2941

−0.243

−0.5424

0.7276

0.0713

−0.1608

Wetness

0.1511

0.1973

0.3283

0.3407

−0.7117

−0.4559

Tasseled cap indices give the measure of Greenness, Brightness and Wetness of each pixel and utilize a linear combination of 6 Landsat bands (From 2nd band to 7th band). Tasseled cap indices are calculated by the following equation

$$\text{Tas\_cap } i = (coeff_2 * band2) + (coeff_3 * band3) + (coeff_4 * band4) + (coeff_5 * band5) + (coeff_6 * band6) + (coeff_7 * band7)$$

Where Tas_cap i is the calculated tasseled cap index for brightness, greenness, or wetness from the coefficient given. Then a statistical model can be built using a step wise multivariate regression (Yang, 2006).

Where IS is the imperviousness index and B and G is the brightness and greenness derived from the tasseled cap transformation of the ETM+ image. The adjusted R square value of this model is 0.91 and the standard error of the estimation is 8.5%. the imperviousness index map is represented in continuous with diverging sequential color scheme.

Population Density and Analysis of Urban Expansion

The fourth method is population density; in this research is the dependent variable in the regression model. The population density is the measurement of the number of persons per km2. There have been several transformations of population density to maximize the model's fitness. The transformation of datasets is to show the built urban area density with the use of dependent population datasets for a particular value of the dependent variable to view the standard deviation to the density value. The density will show the percentage of the value estimating the density of the study area and the models will be modified to visually show the difference in the density between the census data model with the built area density model. The estimation of this model is taking account of the independent variable of the location, also affect the relative condition of the study area and giving weight as neighbor part of the study area.

This research will also analyze the value of urban expansion with the dynamic change of the urban built of the spatial structure in the city. The value of change in the spatiotemporal data, with the dynamics of land use that represents the change in the quantity of land use in a unit time. The dynamics of land use with the extent of the urban expansion can be compared quantitatively according to the following formula:

Ua and Ub is the value of urban built areas at time a and b respectively, and T denotes the length of time from time a and time b and T is the unit value in year. LUDI is the

Land Use Dynamic Index and show the annual rate of change in the area for the land use class.

Result and Research Findings

Figure 4. The result map of Palembang using Tesseled indices with 4 different land use and land cover 2018

The initial identification for this research is to compare the Land use and Land Cover / LULC in Palembang into four categories of water, vegetation, urban, and soul defined by the administrative city boundaries. To identify each area, this result uses the tasseled indices value of each land-use provided in previous research of (Joseph et al., 2012). Each index is calculated using the raster calculator and each band from the ETM+ Landsat 7 images, and creating new tif with various low and high value that shows the corrected images for Vegetation, Soil and Urban built area/house. Based on the identification on the 2018 Landsat Image we could see the proportion of area in Palembang with the value of the urban area of 26.43% and the total value of vegetation, soil, and water of 73.57% from 338.49 km2 of the administrative area in Palembang.

Figure 5. The built urban areas in Palembang on 2018 shown in the green dot colors

The second identification of this research is to verify the growth distribution of the 16 administrative areas in Palembang. The 16 administrative areas in Palembang are respectively Plaju with 15.17 km2, Seberang Ulu Satu with 10.69km2, Seberang Ulu dua with 17.44km2, Kertapati with 42.56km2, Kalidoni with 27.92km2, Ilir Timur dua with 25.58km2, Ilir Barat dua with 6.22 km2, Bukit Kecil with 9.92km2, Ilir Timur Satu with 6.5km2, Kemuning with 9km2, Sematang Borang with 36.92km2, Sako with 18.04 km2, Sukarami with 51.46km2, Alang Alang Lebar with 34.58km2, Ilir Barat Satu with 19.77km and Gandus with 68.78km2. The size of Administrative was divided by the growth of Palembang City, where small administrative area were the older established areas, while the new administrative areas are more extensive. From the research output, we could see the use of every administrative area compared to the built and the unbuilt areas, and there is the administrative area that is densely built while there are others that show uneven growth by the comparison of built urban areas with the population census data. The most densely built administrative area is Ilir Barat Dua, with the contrast between population census and built urban area of 71,267 people with 1.49km2 showing the urban density of 47,673 people/km2. The lowest density in the administrative area is Sukarami, with a population of 155,590 people with the built urban area of 15.48km2 showing the urban density of 10,048 people/km2. This result is very different compared to the population density model provided by the census data by measuring the population with the administrative area. This method of comparing the census population with administrative data is only showing information of a general density but the flaw of this data that it does not show any information about the actual urban density of built urban areas.

Figure 6. The result map of each of the 16 administrative areas in Palembang 2019

Figure 7. The population comparison between the 16 administrative areas population density vs urban built area density of Palembang

With the identification result from the 16 administrative areas in Palembang, we could see the difference between the population census provided by the BPS with the urban built density of Palembang. From this understanding, the future urban planners could help identify the government on which area that has slower growth than the other and needed an even distribution of urban growth to help sustain the development index in Palembang.

The table is showing the value of population density from the census data by dividing the population value with the administrative area size, compared to the urban built density by dividing the population value with the built area size. The result shows that there is a difference in the actual density of each area

Figure 8. comparison between population density and built area density in Palembang

Figure 9. Urban density map transformation in the city of Palembang from 2001 to 2016

Figure 9 shows the three classifications of urban growth in Palembang of Land-use cover maps from 2001,2007 and 2016 and detected the difference in built or changes from the non-built area with the built area. In 2001, the Palembang urban built area had 66.75km2, which increased to 99.02km2 in 2007 and 116.25km2 in 2016. This shows that the Urban built area has an annual increased of growth of approximately 2.83% in the past 15 years (2001-2016), with the rate of 3.3km2 every year.

LUDI = 116.25 - 66.75 x 1/15 x 100%

116.25

= (49.5 / 116.25) x 1/15 x 100%

= 0.425 / 15 x 100%

= 2.83 %

Figure 10. intensity of ULC / Urban Land cover in Palembang

Discussion

The urban growth in other Major Cities in South Asia and developing countries is caused by birth and migration. Among other countries in South Asia such as Sri Lanka (1.1%), Bangladesh (3.4%), Nepal (3.2%), Pakistan (3.3%), and India (2.4%) (Subasinghe et al., 2016). Palembang has shown significant urban growth of 2.83% and can be considered as a rapidly growing metropolitan area. The population growth and urban-built area have been driven by urban migration to metropolitan areas, and it has been shown that the population growth in Palembang is also significantly high.

Urban growth and sprawl are moving simultaneously from the edge of the city and becoming a dominant form (Glaeser & Kahn, 2004). There have been changes in the Urban built area in Palembang where the mixture of housing is more derived to the outer part of the city, while commercial functions stayed at the center. The result of Urban expansion and the government plan of creating a satellite city in Palembang of Jakabaring Sport City has impacted the shape of the city. The green area has decreased rapidly in the city center, and the availability of mass transport such as the LRT / Light Rapid Transit in Palembang has created growth around the city centers. The growth of the city center should be balanced with the announced program from the government to develop a healthy and balanced growth in other administrative areas in Palembang.

The condition of growth in Palembang is known as ribbon development, due to the existing of the main road. Bhatta refers to Harvey about the concept of ribbon development as one of the major causes of urban sprawl (Bhatta, 2010). The ribbon development is the result of urban area fragmentation along the roads and the development of housing and commercial buildings as well as main transportation plan that causes a direct effect on the land-use planning creating a significant urban sprawl. From this urban growth density map, we could analyze that Palembang could result in a similar problem created by accessibility feature, a needed balanced growth would be the solution for the future of Palembang.

Conclusion

Remote Sensing is a powerful tool to analyze the urban changes phenomena by collecting the Landsat data, and it is possible to see the various changes in Land-use and Land-cover variety and changes in a specific area. Satellite imagery has become a more consistent and reliable tool, with the growth of multiple techniques to verify the land cover, the method and tools will be more precise given the comparative measurement for result accuracy.

Urban growth in Palembang has shown that there is a high number of urban density area from the year 2001-2007 and created the dispersion of urban pattern in the city. This urban growth has continued to evolve but creating a similar pattern that is attached to the center of the city. This growth of ribbon development is in a disruptive pattern with the addition of the mass transport development in Palembang that is connected to the main road of the city. This will lead to a potential of urban sprawl and also environmental degradation in the future.

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