Monitoring the transformation of Yogyakarta's urban form using remote sensing and Geographic Information System

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Abstract. Urban form transformation can be seen as the results of urbanization spatially, where the land changed into an urbanized one. Monitoring its changes, however, require many human and financial resources. Accordingly, this research aims to identify urban form transformation using GIS/remote sensing and its spatial implications to the peri-urban area. In order to analyze the land cover changes, this research uses multispectral images from 1990-2016 for built-up extraction using New Built Up Index (NBUI) analysis and population data 1996-2015 combined with primary data from the respondents and key informants. Based on the analysis, it is seen that the compacted Yogyakarta Urban Area scattered predominantly to the Northern part of its periphery with the increase of urban area from 21.19% in 1990 to 50.91% in 2017. While this urbanization is an on-going process, the population of urban core showed a de-concentration phenomenon in 2015, spreading to its periphery causing some negative implications to the peri-urban area.

1.   Introduction

Urban form affects habitat, ecosystem, endangered species, and water quality as reported on Our Built and Natural Environment by the U.S. Environmental Protection Agency in 2001, through land use changes and ecosystem segregation, thus, its transformation may also impact the functionality of people's living environment. To some extent, urban form transformation can be seen as the results of urbanization spatially, where the land changed into an urbanized one. The rapid one causes land transformation from agricultural, rural, and natural landscapes into urban areas [1]. Furthermore, it may lead to regional (urban – peri-urban – rural) problems due to its dynamic land use changes.

As one of the indicators on improving urban economic, urbanization is a global phenomenon especially in developing countries and it may lead to urban sprawl resulted in the decrease of vegetation area and deteriorating environmental quality. Just like an organism, the urban area may grow as its inhabitant grows with its certain structure. However, it could affect not only the urban itself, but also the peri-urban area, a transitional area between urban and rural, mixed areas beyond urban influence but with rural morphology in which many conflicts may arise, such as land use, economic, and social activities so that affecting environmental quality. Thus, one of the challenges is how to identify problems as implications of urban form transformation.

Urban expansion due to rapid urbanization also influences peri-urban area such as development problems from the insufficient infrastructure to provide its growing inhabitant to the air quality due to the increase in road traffic. This rapid urbanization also occurred in Yogyakarta, Indonesia, in which its urbanization level increased from 57.6% in 2000 to 66.4% in 2010, already passed the national level at 53% in 2010 [2].

Yogyakarta is a capital city of Yogyakarta Special Region inhabited by 412.331 people in 2016 known as the center of education and its classical Javanese art and culture. With the area of only 46 km^2, it is a compact city where its infrastructure and facilities fulfilled its citizen's needs and made this city as the most livable city in Indonesia [3]. The urban structure affecting the urban form is planned to fulfill the needs of its citizen.

However, the rapid growth of population of Yogyakarta urban area may influence the environmental quality both within or surrounding its periphery and at the same time results in problems such as land use conflict between agriculture activities and vertical housing, urban activities oriented in rural environment, to the social conflicts that objected to the urban development surrounding their residential areas.

In order to comprehend the urbanization processes spatially, monitoring on its spatial aspects need to be assessed so that data required for further spatial analysis can be conducted. Population data to explain the urbanization processes is important, however, it cannot describe the location aspects such as where is the direction of the urbanization processes. Monitoring of its changes also require many resources due to the vast area and occurred rapidly, thus, it needs to be identified and analyzed. Further, the implication of this urban form changes to other areas especially the peri-urban area also important to be assessed. The local community or the stakeholders may get the implication of this transformation. Shortly, based on the problems stated previously, this research has the main objective: "To identify urban form transformation of Yogyakarta Urban Area using GIS/remote sensing and assess the implications of urban form transformation to the peri-urban area.

Figure 1. Problems in peri-urban area due to urbanization (land use conflicts, social conflicts, urban-oriented land usage).

The urban form can be defined as the spatial organization of permanent elements within a metropolitan region including the spatial pattern of land uses and their densities and, as the spatial pattern of human activities in general, it can be categorized into density, diversity, and urban spatial structure pattern [4]. It can be differentiated into three archetypal forms (based on population and employment density):
1. The concentric city (urban economic theory). Central Business District is the main focal: the location with maximum employment density, the maximum number of trip ends, and the maximum rent.
2. The radial city. While the central business district is the main focus but sectors of intense land use stretch out along major lines of transport from CBD, leaving areas of sparse development between them.
3. The multinucleated city. This form is a more complex, hierarchical system of transport infrastructure where not all routes are oriented toward the CBD – the higher overall level of connectivity in the city.

The Urban form can also be viewed from various geographical scales and classified into such levels as metropolitan area, city, and neighborhood [5]. In metropolitan scale, urban form can be differentiated into several dimensions i.e. metropolitan size, density, unequal distribution, centrality, continuity, and other measures such as spatial autocorrelation.

Monitoring urban form transformation could be a burdensome work in planning and managing the urban area since it involves vast areas and needs a long-time period of observation. However, the advancement of technology in earth observation can be utilized accordingly. Multi-temporal satellite images can be useful in studying urban growth and planning [6], such as the Landsat images provided by the USGS.

There are many methods to analyze remote sensing data started from NDVI (Normalized Difference Vegetation Index), NDBI (Normalized Difference Built-up Index), to NBUI (New Built-up Index). The NDVI firstly developed by Tucker in 1977 to detect healthiness of vegetation by utilization of Near Infra Red/NIR Band and Red Band of satellite images. While the NDBI was proposed to detect the impermeable surface by utilization of Near Infrared/NIR and Shortwave Infrared/SWIR Band [7]. The least, NBUI, purposely to detect impervious surface material, green vegetation, bare soil, and water body (urban land use) [8]. Table 1 shows the three examples of methods used in satellite image analysis comparison.

Table 1. Comparison of satellite images analysis methods

Indicator on Landsat images analysis	Developed by	Usage
NDVI (Normalized Difference Vegetation Index)	Tucker, 1977	Vegetation healthiness detection
NDBI (Normalized Difference Built-up Index)	Zha, et.al., 2003	Urban impermeable surface detection
NBUI (New Built-Up Index)	Sinha, et.al., 2016	Impervious surface material, green vegetation, bare soil, and water body (urban land use) detection

This research adopted the NBUI analysis to monitor Yogyakarta urban form transformation from 1990 to 2017 utilizing Landsat 5 TM and Landsat 8 OLI/TIRS Level1. The NBUI use almost all wavelengths of Landsat images to represent major urban land use. The equation [8] is as follows:

$$NBUI = \frac{SWIR - NIR}{10*\sqrt{SWIR + TIR}} - \left(\frac{(NIR - R) * (1 + l)}{NIR - R + 1} + \frac{G - SWIR}{G + SWIR} \right) \quad (1)$$

where,
SWIR = Shortwave Infrared Band; R = Red Band;
NIR = Near Infrared Band; G = Green Band;
TIR = Thermal Infrared Band; l = 0-1 (l = 0 high, l=1 low density vegetation).

2. Research Site
This research focuses on Yogyakarta Urban Area, Special Region of Yogyakarta, Indonesia centered at Latitude 7°48'14.54"S and Longitude 110°21'51.78"E. According to Special Region of Yogyakarta Regional Spatial Plan 2009-2029/RTRW DIY 2009-2029, the Yogyakarta Urban Area consists of three municipalities, the Yogyakarta City as the city center, the Sleman and Bantul Regency as the peri-urban area, with the total of 71 villages while the relative position on its regional perspective can be seen in figure 2.
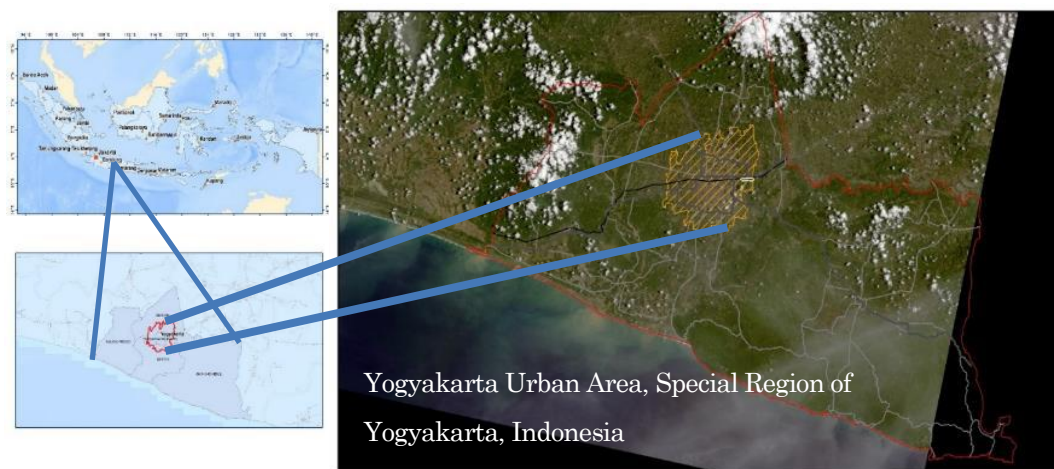
Figure 2. The research sites.

3.   The Method

Based on the literature review on the previous section, urban form transformation is influenced by the growth of urban core and its interaction with surrounding city or villages represented by the road network. The urban growth leads to the expansion of its spatial interface into the peri-urban area and may overlap the existing village nearby. This peri-urbanization, not only result in some implications to the community inhabit this area, but also influence the overall environmental quality. Thus, the increase of the population will develop urban/built up density and the peri-urban will get negative implications due to unplanned/uncontrolled urban form transformation. Monitoring urban form transformation needs to be conducted so that the urban expansion can be anticipated in the future and possible impacts may be lessened. Diagrammatically, the conceptual framework of urban form transformation can be seen in figure 3.
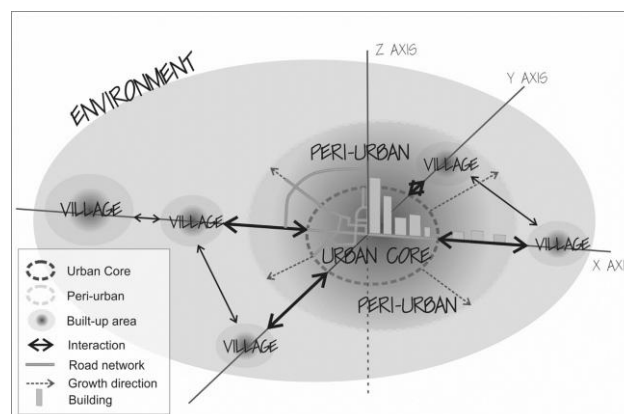

Figure 3. Urban form transformation conceptual framework.

In order to identify urban form transformation of Yogyakarta Urban Area and assess its implications to the peri-urban area, this research uses an integrated analysis system consists of several quantitative analyses. This research used multi-temporal Landsat 5 TM and Landsat 8 OLI/TIRS from 1990-2017 as the input for urban extraction using NBUI analysis to identify the urban density changes coupled with population data to describe the population density changes from 1996-2015 and the urban area size changes. Finally, the results of this research disseminated to the society through the utilization of 5D world map system [9].
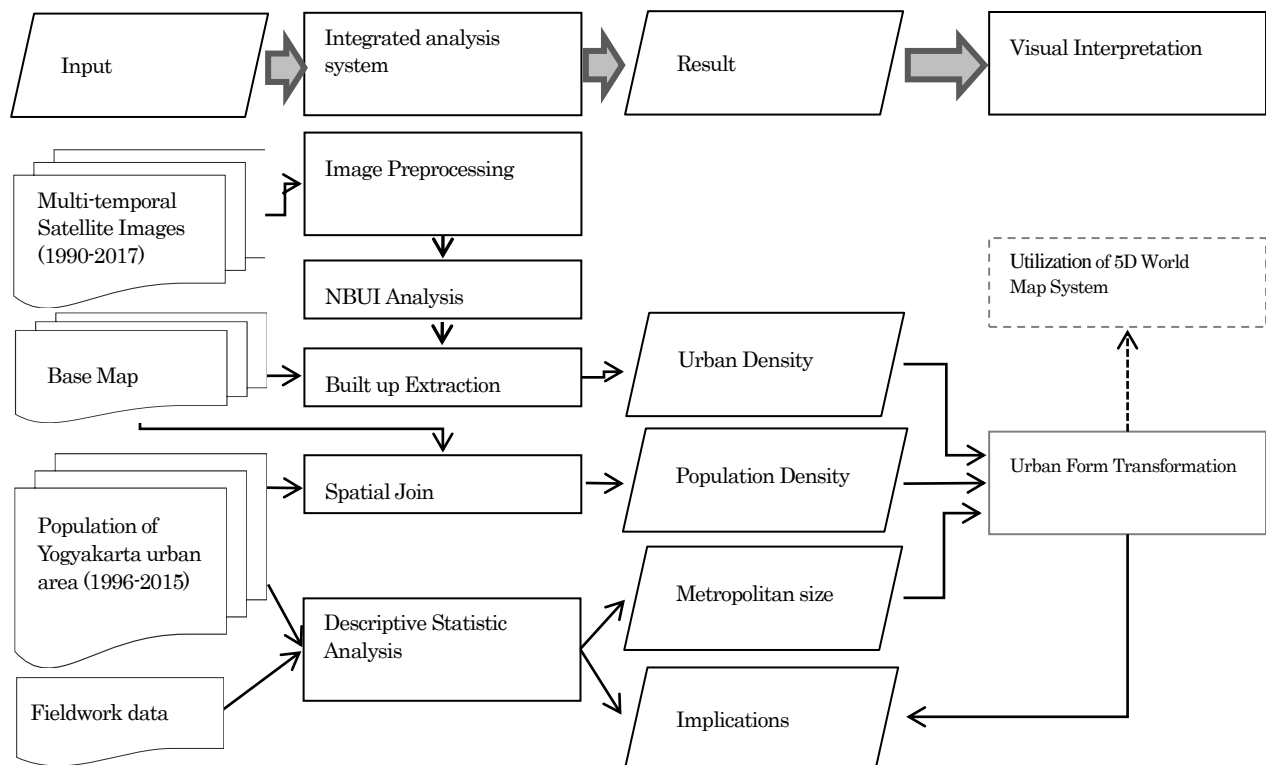
Figure 4. Research method.

Table 2. The research data.

Nr.	Data	Data Coverage	Period	Samples	Data Source
1	Satellite Images (Landsat TM 5 & Landsat 8 OLI/TIRS C1 Level1)	Yogyakarta urban area (Path 120, row 65)	1990, 1995, 2000, 2007, 2011, 2017	-	USGS - https://earthexplorer.usgs.gov/
2	Population	Yogyakarta urban area	1996-2015	-	Central Agency on Statistics, Indonesia
3	Base Map	Yogyakarta urban area	Till present	-	Yogyakarta Special Region, Local Government Office
4	Urban built up-development	Yogyakarta urban area	2016/2017	-	Field study/ Observation
5	Local community perceptions	Peri-urban area (Sleman Regency)	2017	120	Questionnaire (Proportionate sampling)
6	Land cover ground truth	Yogyakarta urban area	2017	113	Field study

Satellite images data (Landsat TM5 & Landsat 8 OLI/TIRS C1 Level 1, path 120, row 65) of the year 1990, 1995, 2000, 2007, 2011, and 2017 in this research were obtained for the built-up area and transformation detection and processed using Arc GIS 10.2. All of the data was pre-processed so that all images similar and able to be considered taken at the same environmental conditions, and by the same sensors and its digital numbers (DNs) was changed into radiance and/or surface reflectance for a quantitative analysis of multiple images on different acquisition time [8]. The radiometric calibration of Landsat 5 in this research followed the equations suggested by Chander and Markham [10], while the conversion of Landsat 8 into the TOA Radiance/Reflectance used the equation provided by the USGS. The acquired data also was geo-referenced to the WGS 1984 UTM Zone 49 S projection system so that it harmonizes with other map sources available especially the governmental data. More detailed data used in this research can be seen in table 2.

4.   Results and Discussions

Urban development form in developing countries can be divided into the controlled residential-commercial area; unplanned peri-urban area; and satellite town [11]. It includes a number of physical and non-physical aspects including size, shape, scale, density, land uses, building types, urban block layout, and distribution of green space [12]. The growth of an urban influenced its form in the long term, and it may transform from one form to another.

The term of urban sprawl is also used, including contiguous suburban growth, linear patterns of strip development, and leapfrog or scattered development and sprawling forms can be reckoned to lie along a continuum from relatively compact to completely discrete developments [13]. A typology based on continuous dimensions can be used to describe urban forms: settlement density (high and low) and physical configuration (ranging from contiguous and compact to scattered and dis-contiguous).

Conventionally, in understanding the relationship between urban areas and their hinterlands, or people's activities in such area has been explained based on a simple urban-rural dichotomy by some social scientists studying on urbanization, assuming the peri-urban area as a short-term transitional area that had little interest or importance [14]. The peri-urban area is the term used to describe the transitional areas, mixed areas beyond urban influence but with rural morphology. It can be defined as areas around or outside the city center that are ecologically and socio-economically integrated into their core city [15]. It also describes the interface between urban, rural, and natural areas with relatively rapid growth, dynamic and mixed physical and socio-economic attributes [16].

Urban growth may expand into its periphery and transform its physical and non-physical condition into a more urbanized one. Its transformation which took place outside the urban cores refers to peri-urbanization processes [17]. It generally refers to the process of urban growth in contiguous transitional areas between city and countryside. The changes in peri-urban area are mostly caused by intensified pressure towards urban development [18]. The urban growth also explains the urbanization process due to its economic activities. Urbanization economies can be explained as factors stimulating many activities to be located in big cities where population concentrated and efficient urban infrastructure provided, thus strategic spatial plan on decentralization of urban core is needed [21]. The urbanization process also occurs in Yogyakarta due to its student and tourism city predicate as the strong pull factors [22]. However, the concept on urbanization based on population activities often neglecting the spatial aspects on the analysis. Low population in-migration many times interpreted also as low urbanization, conversely the land use change occurred rapidly especially in the peri-urban area and transforming the urban form. By utilizing built-up maps, the spatial aspects of urbanization can be analyzed.

As described earlier, by using remote sensing analysis, built up area maps can be extracted from Landsat 7/8 satellite images. However, compared to the real land coverage, the results may produce some errors compared and lower the accuracy. Thus, in order to assess the accuracy of maps generated, the ground truthing processes were conducted by comparing the image analysis result with actual land cover in the field with the total sample of 113 locations. It is found out that the accuracy for built-up is 87.5 % while in overall, the accuracy is 83.19 %.

Tabel 3. Accuracy assessment on NBUI analysis map,

NBUI map:	Ground truth:		Total
	Built-up	Non-built-up	
Built-up	49	12	61
Non Built-up	7	45	52
Total	56	57	113
Accuracy (%)	87.5	78.95	83.19

In 1990, the first period of monitoring, Yogyakarta showed a relatively compact city with the built-up area occupied 23.19% of the area while the non-built-up area 76.81% of the observed area. The core, the Yogyakarta city, showed a densely urbanized area while the peri-urban area dominated by non-built up area. In 1995, the urbanized area started to increase significantly, compared to previous year of observation, especially in the peri-urban area. The built-up area recorded at 33.51% more scattered in the peri-urban area while the non-built up area 66.49%. The built-up area in 2000 reached 37.72% and the non-built-up area 62.28%. There is an increase compared to previous year and its form almost the same, compacted in the city center and scattered in the peri-urban area. There is no increase recorded in the built-up area in 2007 compared to previous period. The built-up area almost remains the same at 37.21% and the non-built-up area at 62.79%. So, does the urban form, compacted in the core and scattered in the peri-urban area. Even though there is no increase in 2007, however, there is a significant increase in 2011 where the built-up area recorded at 47.65 % and the non-built-up area 52.3 %. While it is more scattered in the peri-urban area, the urban area denser in the Northern part of the urban. Figure 5 shows the detail on the increase of urbanized area. The increasing trend of the urbanized area continues in 2017, where the built-up area occupying 62.19% of the area, while the Non-built-up area continues to decrease to 37.81 % of the area. The peri-urban area now is dominated by a more urbanized land usage such as settlement, shops, hotels, restaurants, and education institutions especially in the Northern part of the urban area.

A well-planned city will have a good structure and land use pattern arrangement, of which the urban form is generated so that it will efficiently support its citizen. In the long term, the development of infrastructure will also improve the city condition and increase the pull factor of people to migrate by the creation of new opportunities. This urbanization phenomenon, however, explained by many researchers with the focus only on population, few of them focus on describing the urbanization spatially. This will explain the location factor, where the urbanization took place and which direction its trend of growth. Monitoring the urban form transformation is the first step to understand, not only describing the urbanization spatially, but also define its growth trend and pattern.

Based on its spatial pattern, the Yogyakarta Urban area in 1990 is more compacted in the core or the city of Yogyakarta. The urban density is higher in the center but is lower in the periphery. However, in 1995 the peri-urban started to be more urbanized where the built-up area started to increase significantly, from 22.88 % in 1990 to 33.40 % in 1995. One factor that influences the increase is the development of Yogyakarta Ring Road (the Northern and Western part) in 1994-1996. The development of new road improves people's accessibility and lead to both direct effects in the form of reduced journey time, reduced costs, and improve reliability and indirect effects, changes that are stimulated by the direct effects: changes in investment, transport service supply and demand, competition, etc [19].

The increasing trend continues in 2000 but remains steady in 2007. Nonetheless, there is a significant increase of built-up area in 2011, from 37.21 % in 2007 to 47.65 % in 2011, and in 2017 the peri-urban become more urbanized, the built-up area becomes 62.19 % in this year. Figure 5 and figure 6 illustrate the pattern and the changes of urban form in Yogyakarta Urban Area.

The images extracted from the previous analysis show the form of Yogyakarta urban area transformed from a relatively compact city in the early year of observation to be more scattered in the periphery in the last year of observation, even though the center is still compacted. The Yogyakarta city remains as an urban center while its size enlarges to the periphery.
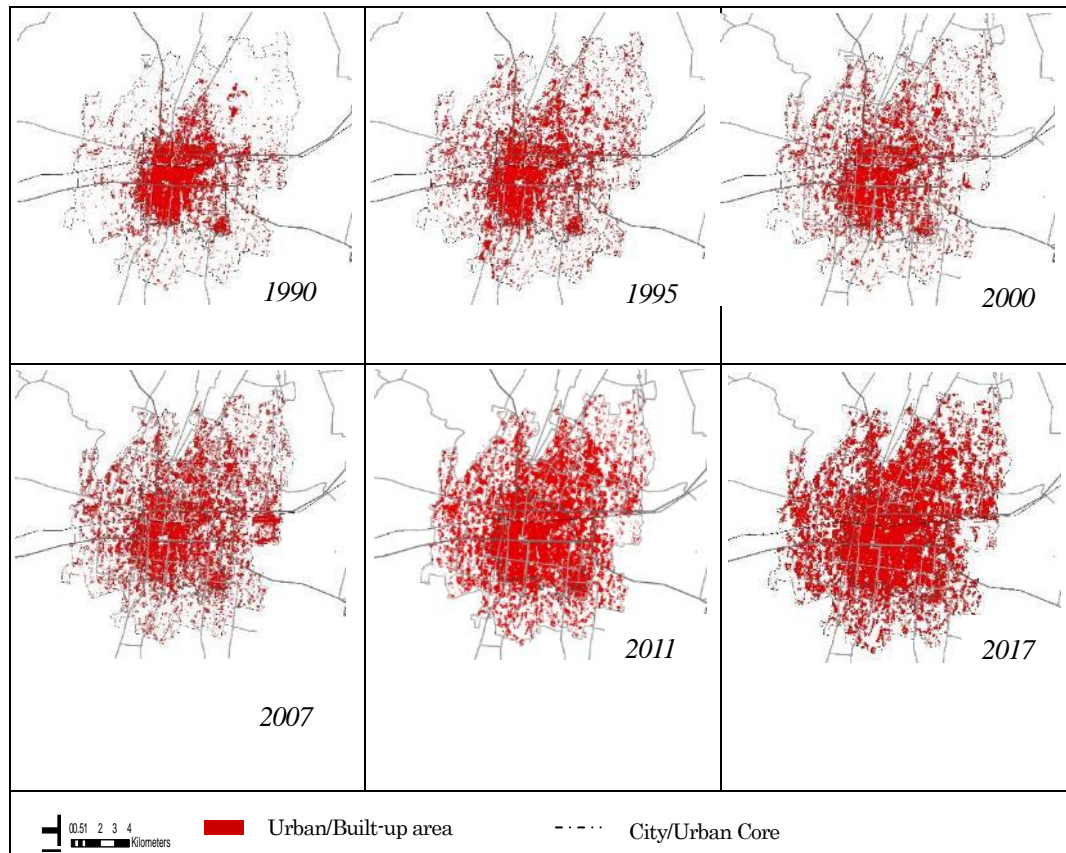
Figure 5. Yogyakarta urban form transformation 1990-2017.
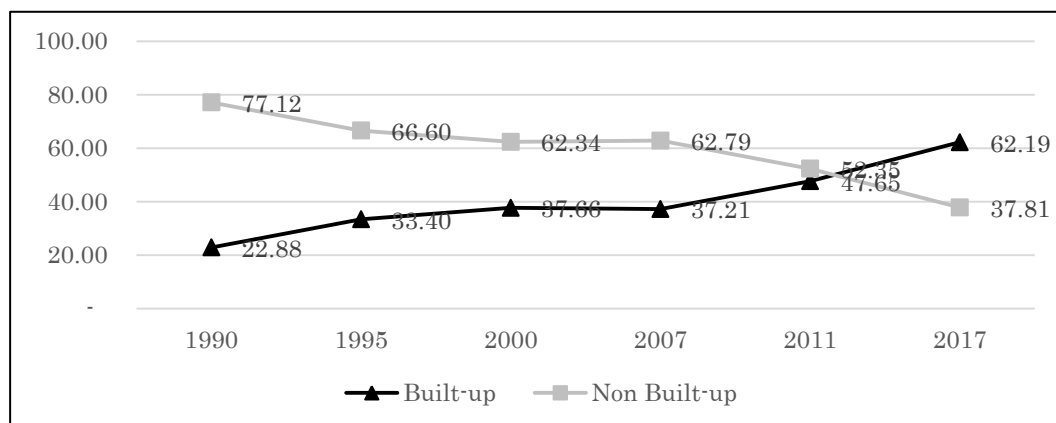

Figure 6. Yogyakarta Urban Area changes 1990-2017

Using population data as other indicator in monitoring urban form transformation, Yogyakarta Urban Area was concentrated in its core and classified into five categories: very low, low, medium, high, to very high. The area with higher population density located in the urban center varies from medium to very high density. In contrast, the peri-urban area is dominated by very low and low-density population. Using 1996 data as based on observation and to normalize following year data, population growth trend can be monitored spatially. It started to sprawl to the Northern and to the Eastern Part of the area in 2000 and continue in 2005. The expansion of population in 2010 undertook to the Eastern and some Western part of the area. However, the density trend in 2015 started to expand to the Southern part of the area.

By observing figure 7, it can be seen that the density at some part of the area both in the urban and peri-urban area increased during 1996-2005. Nonetheless, while the peri-urban density continued to grow until 2015, the density at some part (eastern) of urban core started to decrease. The density de-concentrate in the urban core and may indicated as the occurrence of counter-urbanization, migration from the city center to the peri-urban.
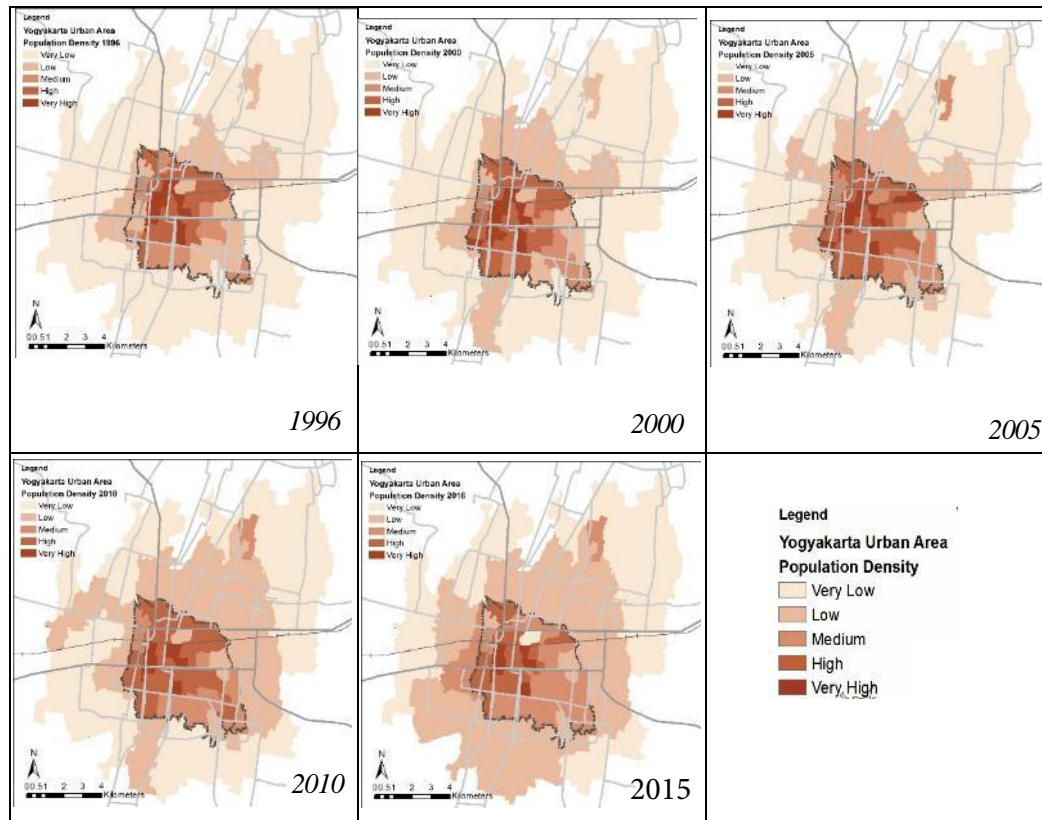

Figure 7. Population density changes 1996-2015.

As described earlier, urban form transformation results in several effects to the peri-urban area such as the loss of the non-built-up area. This area is characterized by the coexistent of agricultural and urbanized activities and functioning as supporting the inner city. Not only securing the food supply but also maintain other important environment function such as air quality and groundwater catchment area.

Some field observation and interview to key informants for a triangulation process were conducted to explain the implication of urban form transformation to the society. Triangulation is a measurement technique to put an object in space by depending on two known points in order to assess on an unknown fixed point in that space and use this concept in the validation process of social research results [20]. The in-depth interview steps are initiated with stakeholders mapping process so that it can be used as further guidance and analysis.

The peri-urbanization, as the consequences of the urban growth, realized by some community members and worrisome their daily lives. New urbanized development surrounding their neighborhood, to some extent, is a good thing resembling grow and overall economic condition improvement. They hope getting benefit from the multiplier effects of the new development, whether directly and/or indirectly benefitted. To the shop owners, the development means bigger opportunities for new potential consumers. Producers also could increase their production capacity to fulfill new demands. However, there are some people who have anxiety towards the effects this new urbanized development.

There are some negative perceptions given by the respondents towards the transformation of the urban form. The transformation, which is represented by peri-urbanization, has been blamed as one of the factors on

the increase of average daily temperature. The peri-urbanization felt by some of the respondents, to some extent, contribute to the global warming by lessening the number of trees while increasing the number of vehicle and the needs of electricity and energy. Respondents believe that the presence of trees surrounding their residential area will contribute to better air quality and lower the average temperature.

Since the peri-urban area used to be dominated by agricultural activities, many roads are built without pedestrian facilities such as the sidewalk. Many respondents felt discomfort if they have to walk at roadside since their safety is threatened, despite the good traffic conditions. Their surrounding environment recently is more urbanized, but the infrastructure provided was focused on agriculture activities.

Another issue as the effects of peri-urbanization is the people's anxiety of the availability of groundwater. Almost all respondents use well as a source of clean water since they are not living in an area covered by local clean water provider agency network. The urbanized development nearby their residential, such as apartments or hotels will require plenty of clean water for their activities. Thus, since their area is not covered by the clean water network, respondents have doubtfulness towards developers in fulfilling the groundwater extraction regulation. Another reason that the development would impact the water catchment ability of the peri-urban area, since more ubiquitous impermeable surfaces.

5. Conclusions

Based on data results, analysis, and discussion in previous sections, it can be concluded that:

1. The Yogyakarta Urban Area form experienced a transformation from a relatively compact in its core in 1990 into a more sprawled and scattered urban area in 2017, followed by the increase of built-up area from 22.8% to 62.19% respectively.
2. While its form remains compact in core since 1990, Yogyakarta Urban Area scattered to its peri-urban dominated by the development of the built-up area to the Northern part of the urban area, with the speed of 1.46% per year.
3. The Yogyakarta Urban Area showed a symptom of population de-concentration at its core in 2015, while the peri-urban area population density increased gradually. It is also followed by the new development of a more urbanized land used in the peri-urban area.
4. Yogyakarta urban area as a metropolitan area required new infrastructure, i.e. new road, however, it drives the built up to increase rapidly in the peri-urban area.
5. The Yogyakarta peri-urban communities faced some negative implications due to urban form transformation.

6. References

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