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Measuring the Urban Expansion Process of Yogyakarta City in Indonesia

Urban expansion process and spatial and temporal characteristics of growing cities

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Abstract: Urbanization patterns in rapidly growing cities are complex. Such patterns reflect historic policy outcomes, economic characteristics and changing lifestyles. This research examined urban growth in Yogyakarta City in Indonesia to understand its urban expansion process. Several attributes of urbanization were measured to understand the city's urbanization pattern. Land-use data for 1997, 2002, and 2013 were derived from remote-sensing data; in addition, other supporting data of urbanization were measured with several spatial metrics. Analysis was performed for the whole city and for transections across the city to understand macro and local scale characteristics of the urbanization process. Urban land-use changes between 2002 and 2013 were studied to understand the land-use conversion process. Thereafter, the measurements were analyzed to understand temporal and spatial characteristics of urbanization in Yogyakarta City. It was observed that the urban expansion process in Yogyakarta has several distinct stages. Essentially, in the periphery of the city, urbanization has been fragmented. Over time, these fragmented urban patches develop into stable and less complex shapes.

1. INTRODUCTION

1.1 Urbanization Process

Cities are the engines of national development; they provide economics of scale and agglomeration, and allow many goods and services to be produced and traded more efficiently. Cities contribute to large shares of the national output of many Asian countries. By 2010, urban areas contributed 80% of the gross domestic product (GDP) of the Asia-Pacific region (UN-HABITAT, 2010). Migration into cities has increased the net productivity of economies by directing labor to locations where greater economic contributions are possible. Many rapidly expanding South East Asian countries have experienced an increasing rate of internal migration because of increased economic opportunities in urban areas (UN-HABITAT, 2010). In Southeast Asia, the proportion of urban population increased from 31.6% in 1990 to 42% in 2010 (ESCAP, 2013).

The outward urban expansion in Southeast Asian cities shows a distinct pattern compared to that of North American cities, where urban sprawl is considered as low-density suburbanization. Southeast Asian cities have maintained higher population densities while expanding (World Bank, 2015). In these cities, such urban expansion is not addressed adequately in planning practices. In addition, planning practices lack coordination for infrastructure provision to fragmented, expanding urban areas (Ooi, 2008).

Indonesia is a relatively urbanized country in the Southeast Asian region with 52% of the country's population living in urban areas (World Bank, 2014). Indonesia's urban population grew 3.5–3.7% annually between 2000 and 2010. The country's urban areas are fragmented spatially and across adjoining administrative districts. While population density is increasing, growth is uneven across the city. The objective of this research is to improve knowledge of this uneven urban expansion process.

1.2 Measuring urban expansion

Urban sprawl is defined as outgrowth of cities along their periphery. Although a clear definition is debatable, sprawl is accepted widely as unplanned and uneven growth driven by multiple processes that lead to inefficient use of resources (Bhatta, 2010). Often, sprawl is considered as undesirable by city authorities and policy measures are used in attempts to curb it. The "compact city" concept promotes high-density compact growth that is found in traditional Asian and European cities.

In the field of urban design, sprawl and scatter are conceded as unaesthetic. At the same time, these new developments are popular among people who like urban lifestyles in the periphery. These new growth areas provide affordable housing opportunities. Some of the short-term and long-term economic and environmental disadvantages of sprawl are infrastructure costs, conversion of valuable agricultural land, and deterioration of environmentally sensitive areas.

Decentralization of activities from the central core to the urban periphery is fundamental to sprawl. Therefore, sprawl is commonly linked with suburbanization of economic activities. In growing cities, this is connected with job creation in the form of industrial areas in the periphery. The other phenomenon that is unique to rapidly growing cities is the variability of infrastructure availability in sprawling areas and the spontaneous nature of growth.

There are numerous studies about sprawl in Northern American cities. These studies have examined sprawl from the perspectives of growth, social and aesthetic attributes (Calthorpe, 2001), decentralization (Galstera, 2001), accessibility (Hasse, 2004), density characteristics (Lang, 2003), fragmentation, loss of open space, and dynamics of sprawl. Some studies have proposed measuring the physical growth of sprawl quantitatively using multiple measurements (Torrens, 2008). In the Asian context, Murakami (2005) studied sprawl on a small scale. McGee (1995) explained expansion of Asian cities in the urban periphery as a new growth type and explained that it has a mixture of urban and rural features. There are several studies that attempt to understand this growth process as a demographic and social phenomenon in the Asian context.

Recent studies have attempted to compare the characteristics of sprawl in several regions of the world. Schneider and Curtis (2008) studied urban sprawl in 25 global cities to compare global characteristics and trends. They observed that only US cities and Montreal in Canada exhibit dispersed expansion with lower population densities. Huang et al. (2007) qualitatively examined urban form in metropolitan areas of Asia, the US, Europe, Australia, and Latin America. They observed a correlation between national wealth and urban form where wealthier cities demonstrate less compact and complex urban forms. In recent years, China has experienced large-scale urbanization in metropolitan areas and large regional cities. Several studies have measured urban expansion in these cities recently (Seto and Fragkias, 2005; Yu and Ng, 2007). Current research on measuring urban sprawl in the Asian region is concentrated mainly on Asian metropolitan regions and rapidly developing Indian and Chinese cities. The overwhelming proportion of urban growth will take place in developing countries in the next century (UN-HABITAT, 2010). In addition, most of this urban population will live in medium-sized cities (UN-HABITAT, 2010). Therefore, the question of the urban expansion process in such cities is especially relevant for policymaking.

The specific objectives of this study are to measure:

1. the urban expansion process in Yogyakarta City, Indonesia, and
2. the urban form of Yogyakarta City to understand how it varies across the city.

This study used spatial metrics, a class of metrics used originally in landscape ecology, to analyze the urban land use and expansion patterns in Yogyakarta City. Many metrics and statistical techniques are in use to measure sprawl. The metrics are numeric indicators that quantify spatial patterns of land-use patches. In the field of landscape ecology, such metrics are called landscape metrics and are used to describe, detect, and quantify characteristics of landscape patches to reveal properties of ecosystems in landscapes (McGarigal et al., 2002). These metrics are used widely in other fields, including urban studies, as quantitative indicators to describe the structures and patterns of landscape mosaics.

In recent studies, spatial metrics have been applied in the urban planning field to quantify urban growth, sprawl and fragmentation (Bereitschaft and Debbage, 2014; Lowry and Lowry, 2014; Ramachandra et al., 2015). Spatial metrics are a useful set of tools to quantify urban structure and patterns using data from thematic maps (Clarke and Couclelis, 2005). In recent years, the availability of historic remote-sensing images has enabled the combination of remote-sensing data with the application of spatial metrics as a potential method to study the spatial and temporal dynamics of urbanization.

Zipperer (2000) analyzed the applicability and uses of landscape metrics in urban studies. This study emphasized the validity of using ecological principles in land-use decisions. Recently, spatial metrics are being used to understand urban growth patterns and to validate urban growth models that represent complex social and environmental processes. Berling-Wolff and Wu (2004) used spatial metrics to assess the accuracy of urban growth simulation models. In addition, spatial metrics have been utilized widely recently to understand urban gradient and land fragmentation.

1.3 Study area

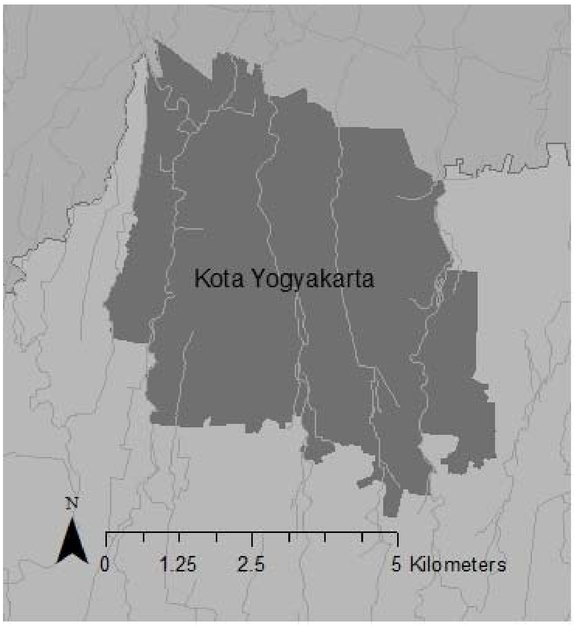

Figure 1. Yogyakarta City

During the last three decades, Indonesian urban areas have grown rapidly. Java Island, which has 59% of Indonesia's total population, recorded the highest consistent rate of urbanization among all Indonesian islands. For this study, Yogyakarta City was selected taking into account the city's rapid urbanization, dense population and medium size.

Yogyakarta City is the main urban center in the Yogyakarta Special Region of Daerah Istimewa Yogyakarta Province and is a hub of Javanese art and culture. In addition, the city is the second most important tourist destination in Indonesia. The average population density of Yogyakarta City in 2000 was 12,891/km^2. In addition, the conversion of agricultural land for construction is a major issue as the city has outgrown its urban boundaries and has spread to neighboring regions in recent decades. Specifically, the population of the large peri-urban areas that has spread to adjoining Sleman and Bantul is more than 1 million. Yogyakarta City and its peri-urban areas contain more than one third of the provincial population. Its high urban population growth and urbanization process has extended the city outwards and this trend is expected to continue. While the administrative area of Yogyakarta City is 33km^2, its large peri-urban area has expanded the functional urban area to 201km^2.

The urban growth process in Yogyakarta City is influenced by several significant aspects of transformation in administrative structure and infrastructural development. The outer ring road, which was completed in 1987, fostered outward expansion beyond the boundaries of the city. In 1999 and 2004, Indonesia changed its centralized administrative structure to a highly decentralized system. This process devolved significant power to local authorities with the intention of bringing services closer to the people. As a result, most government authority was transferred to the local authority, giving local authorities power equal to that of provincial governments in many areas. This created an environment for weaker central planning in matters related to regional planning.

While the outward expansion of Yogyakarta City has been prominent, the city has also expanded its densely-built areas along the periphery. Inevitably, this process has impacted on the environment and land use, which needs to be studied in a structured manner. The main objective of this research is to objectively and quantitatively analyze the expansion process of the densely built-up area.

2. METHOD AND DATA

2.1 Measuring urban expansion patterns

Sprawl is measured in relative and absolute scales by various researchers. Absolute measurements attempt to distinguish the growth process between compact cities and sprawling cities. Most of these studies have been undertaken for land-rich North American cities and some European cities. On the other hand, relative measures attempt to understand variations in growth patterns between different parts of a city or between different periods. The urban growth observed in rapidly growing cities occurs as a result of conversion of agricultural lands to developed land to accommodate growing populations. In Southeast Asian cities, urban population density has been observed to be increasing constantly in recent years (World Bank, 2015). Therefore, this study attempts to understand this growth process relative to time periods and among different parts of Yogyakarta City. This study does not attempt to define the threshold of sprawl and non-sprawl growth.

Angel et al. (2007) defined five attributes of growth by which urban expansion can be understood, such as urban extent, density, suburbanization, contiguity, and compactness. Torrens (2008) argued that sprawl must be measured in multiple scales.

In this study, the characteristics of urban expansion were examined by measuring the attributes of urbanization, both spatially and temporally. Measurements for spatial characteristics were carried out in two stages. First a land-use dataset derived from a series of satellite images was used to understand land-use conversion for the years 1997, 2002 and 2013. Later, changes in the urbanization pattern were measured for the whole city and for each period to understand the growth pattern. We measured five attributes of the growth pattern: urbanization, urban extent, scattered growth, suburbanization, and contiguity of the urban area. These attributes were measured using spatial metrics explained in *Table 1* and the extent of the built-up area.

PD measures the scattered growth of the urbanization pattern, which quantifies the number of urban patches per unit area (100ha). *COHESION* metrics and the proportion of urban footprint measure the suburbanization process. The contiguity metric (*CONTAG_MN*) measures the spatial connectedness of urban patches. Instead of population densities, this study used density of built-up area.

In the second stage of measuring spatial characteristics, the urbanization characteristic was measured using a transection across the city. The purpose of this method is to identify characteristics of urbanization using a section of the city. Each measurement was taken for five square tiles in a diagonal transection (*Figure 5*). The measurements were taken for all three periods. Five spatial metrics were employed to measure the characteristics of urbanization. The patch characteristics of tiles were measured using patch density (*PD*), number of patches in the landscape (*N*), and total landscape area (*A*). A landscape shape index (*LSI*) was measured to evaluate aggregation of urban patches. Perimeter-area fractal dimension (*PAFRAC*) measured the shape complexity of urban patches. Patch level *COHESION* metrics was employed to measure connectedness of corresponding patches.

Table 1. Spatial metrics and definitions

Number of patches (*NP*) NP = *N*
Patch density *(PD) N* = Total number of patches in the landscape, *A* = Total landscape area (m^2) $PD = \frac{n_i}{A}(10,000)(100)$ The number of patches in the landscape, divided by total landscape area m^2, multiplied by 10,000 and 100 (to convert to 100ha).
Perimeter-area fractal dimension (*PAFRAC*) at landscape level $PAFRAC = \frac{2}{\frac{\left[n_i \sum_{j=1}^{n}(lnp_{ij} \cdot lna_{ij})\right] - \left[\left(\sum_{j=1}^{n} lnp_{ij}\right)\left(\sum_{j=1}^{n} lna_{ij}\right)\right]}{\left(n_i \sum_{j=1}^{n} lnp_{ij}^2\right) - \left(n_i \sum_{j=1}^{n} lnp_{ij}\right)^2}}$ a_{ij} = area of (m^2)patch *ij*, p_{ij}= perimeter (*m*) of patch *ij*, N_i = number of patches in the landscape. Units: none. PAFRAC reflects shape complexity.
Landscape shape index (*LSI*) *E** = total length (*m*) edge in landscape, *A*= total landscape area. Units: None. *LSI* = 1 when the landscape consists of a single square patch. This provides a standardized measure of total edge or edge density that adjusts for the size of the landscape.
COHESION $COHESION = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}^*}{\sum_{j=1}^{n} P_{ij}^* \sqrt{a_{ij}^*}}\right] \cdot \left[1 - \frac{1}{\sqrt{Z}}\right]^{-1} \cdot (100)$ P^*_{ij} = perimeter of patch *ij* in terms of the number of cell surfaces, a^*_{ij} = area of patch *ij* in terms of the number of cells, *Z* = the total number of cells in the landscape. Units: none. *COHESION* measures the physical connectedness of the patches.
Contiguity index (*CONTIG)* $CONTIG = \frac{\left[\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}}\right] - 1}{v - 1}$ c_{ij} = contiguity value for pixel r in patch *ij, v* = sum of the values in a 3-by-3 cell template, a_{ij} = area of patch *ij* in terms of number of cells. *Contiguity index* assesses the spatial connectedness, or contiguity, of cells within a grid-cell patch to provide an index of patch boundary configuration. This research uses mean Contiguity Index Distribution *(CONTIG_MN)* in the landscape
Largest Patch Index (*LPI*) a_{ij} = area (m^2) of patch *ij*, *A* = total landscape area(m^2). Units = pecent. $LPI = \frac{max_{j=1}^{n} a_{ij}}{A}(100)$ *LPI* approches 0 when largest patch in the landscape is increasingly small. *LPI* quantifies the percentage of total landscape area comprised by largest patch.

The calculation of spatial metrics was performed using public domain software FRAGSTAT version 3.3 (McGarigal et al., 2002). This software became available in 1995, and has been developed continuously. FRAGSTAT provides a large range of metrics for patch-level, class-level, and landscape-level measurements.

2.2 Data

Data used for this study were prepared for three time periods. The study utilized three cloud-free Landsat Thematic Mapper (TM) datasets from 1997, 2002 and 2013 with 30m resolutions to extract urban areas and land-use data. All three images were selected from the months of June and July of each year so that seasonal variation effects would be minimized. Since the study area is a predominantly agricultural area and the main crop is paddy rice, it was important to select images from the same season. Images were acquired from USGS open Landsat image libraries. Land-use data with reasonable and consistent data scales were not found for the study area.

Data preparation for the study involved three stages, namely, pre-processing of data; classification of data for land-use classes; and extracting

$$LSI = \frac{.25\sum_{k=1}^{m} e_{ik}^{*}}{\sqrt{A}}$$

urban footprint and preparing overlay images to measure land-use changes. First, all the datasets were registered and geometrical corrections were carried out. An image for 2013 was selected as the reference dataset and all other datasets were co-registered with the 2013 image at pixel level. The image set for 2013 was selected as the reference owing to the availability of additional data from this period. Later, a dark object subtraction (DOS) method was used for atmospheric correction of the images. DOS is one of the simplest and widely used image-based absolute atmospheric correction approaches for classification. The DOS approach assumes the existence of dark objects (zero or small surface reflectance) throughout a Landsat TM scene and a horizontally homogeneous atmosphere. The minimum cell-value digital number value in the histogram of the entire scene was subtracted from all the pixels. Later, several composite images were created to visually compare the image datasets with land-use maps and Google Earth data.

Owing to the lack of reference data to verify the accuracy for the 1997 classification results, several experimental classifications were carried out for three image sets. First, all three datasets were classified using ISODATA unsupervised classification, which is a commonly used unsupervised image classification algorithm. The classification was useful enough to identify a few significant classes of land uses. Data were classified into 25 classes and identifiable classes were grouped into five class names. The first classifications separated water bodies, barren land, irrigated land, urban areas, and vegetated land. At this stage, dry paddy lands and deforested hillsides were not separated satisfactorily. Later, segmentation was used to identify recognizable classes in the unsupervised data and to develop a signature set for supervised classification. Thereafter, supervised classification was carried out using maximum likelihood classification. Classified data was filtered for unclassified pixels and for clear class separation using a segmentation classification method. The segmentation data were prepared using the same set of bands as the data (*Figures 2 and 3*).

The five land-use classes were:

(1) barren land; dry barren land, deforested hillsides, open grassland, golf courses.
(2) mixed built-up land; suburban land with significant vegetation cover, housing estates
(3) crop land; paddy rice land, irrigated crop land

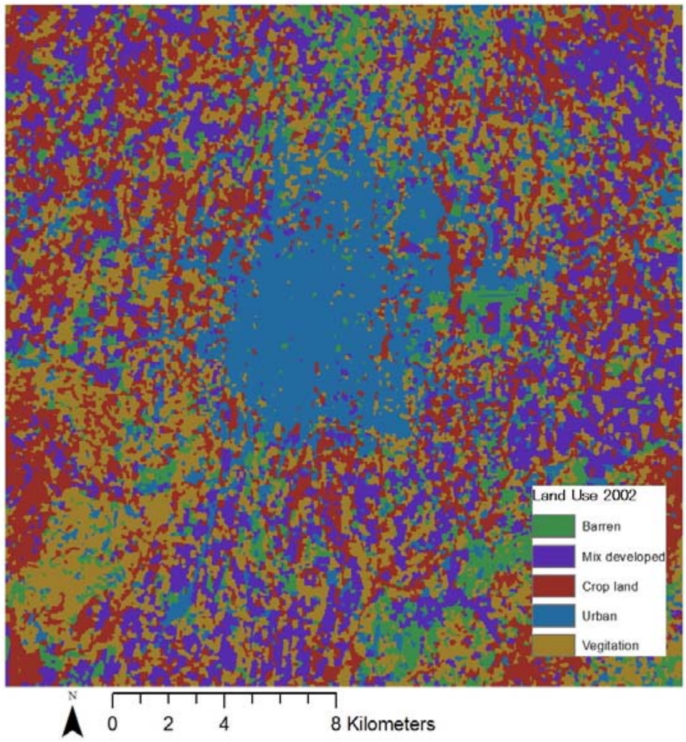

Figure 2. Land uses of 2002

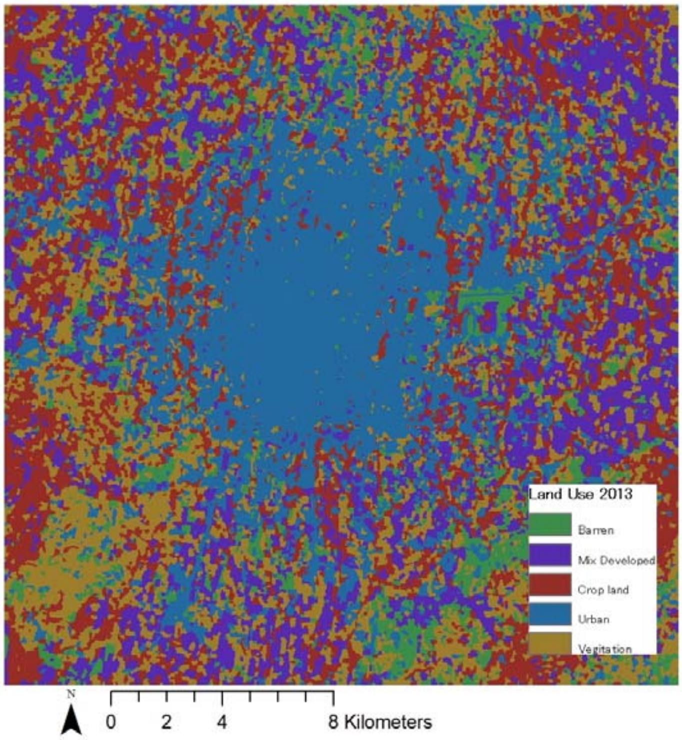

Figure 3. Land uses of 2013

(4) urban; built-up land, paved surfaces, streets
(5) vegetation; forest land, heavy vegetation.

On-screen digitization was utilized to rectify errors in classification. The classification of 1997 was verified against a scanned and projected GIS map of 1995. All datasets were transformed into 30m grid data on the proprietary geographic information system platform ArcGIS, and the built-up areas were extracted from the classified datasets for subsequent analysis.

3. MEASURING CHARACTERISTICS OF URBAN EXPANSION

3.1 Land-use change detection

The urban land-use changes *(Table 2)* detected from land-use classification indicate a high proportion of land-use conversion from vegetation land to urban activities. This phenomenon is due to the gap-filling growth pattern that converts existing green areas between 2002 urban patches. A large portion of vegetation land that was visible in the southeast hillsides and fragmented vegetation land in the northeast does not show extensive urbanization during 2002–2013 (*Figures 2 and 3*).

The crop land class consists of paddy rice land, both irrigated and barren, and other irrigated land visible in the classified image. Crop land is resistant to high-density urbanization during this period. In particular, crop land in the south of the city remained unchanged during this period. The eastern and northern crop land is observed to have been converted to high-density urban areas at a higher rate compared to the crop land of other regions (*Figures 2 and 3*).

The conversion of barren land to urban activities was also relatively high (*Table 2*). The barren land class consists of dry barren land, deforested hillsides, open grassland and golf courses (*Figures 2 and 3*). Some of the land classified as barren has urban land-use characteristics. In addition, vacant patches in or near the main urban center are classified in the barren land-use class.

3.2 Macro scale characteristics of urban expansion

Macro scale measurements show how urbanization has been progressing toward the countryside. The urbanized area in *Table 2* shows rapid expansion of urban land. The percentage of land urbanized during each period rapidly expanded the existing urban areas. The largest patch index (LPI) at the class level quantifies the percentage of the largest urban patch in the total landscape area *(Table 6 and Figure 4)*.

Widespread land-use changes prompted by rapid urbanization have led to fundamental changes in landscape pattern in the last decade. Other researchers have observed wide-scale peri-urbanization in the Yogyakarta region further away from the main urban centers (Richard, 2014). While peri-urbanization remains the dominant form of growth, expansion of existing urban centers is equally visible. The growth process observable in

Table 2. Urban land conversion estimated from other land uses to urban for the period 2002 to 2013. Key: 1. Barren, 2. Mixed developed, 3. Crop land, 4. Urban, 5. Vegetation.

Land use class		2013 land use area hectare					% change
		1	2	3	4	5	
2002 land use area hectares	1	5021.28	-	-	784.35	-	13.5
	2	-	11082.42	-	1198.44	-	9.7
	3	-	-	12578.85	1180.71	-	8.5
	4	-	-	-	10030.41	-	
	5	-	-	-	2313.36	12897.36	15.2

Table 3. Patch density for 1997, 2002 and 2013

Year	*PD*
1997	1.1158
2002	1.7264
2013	1.7296

Table 4. Proportion of suburbanization and COHESION

Year	Proportion of sub urban growth	*COHESION*
1997	42%	98.6729
2002	47%	98.7517
2013	34%	99.2085

Table 5. Contiguity

Year	*CONTIG_MN*
1997	0.7138
2002	0.7130
2013	0.6931

Table 6. Urbanized areas of 1997, 2002 , 2013 and *LPI*

Year	Total Area	% of land	LPI
1997	7832	12%	7.2433
2002	11409	18%	10.0833
2013	16932	27%	17.8341

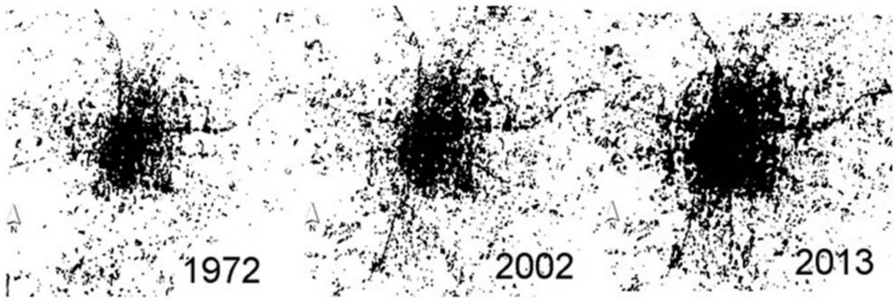

Figure 4. Urban area of 1997, 2002 and 2013

this data shows two growth patterns from 1997 to 2002 and from 2002 to 2013. No significant increase in patch density value was observed between 2002 and 2013 (*Table 3*).

The *COHESION* index (*Table 4*) measures the physical connectedness of the corresponding patch type. The *COHESION* value reaches zero if the focal class (in this case, urban patches) is increasingly scattered and less connected. From 1997 to 2013, the *COHESION* value (*Table 4*) increases, indicating an increase of connectedness of built-up patches. The proportion of the suburban area increased between 1997 and 2002. Later, between 2002 and 2013, the proportion of suburbanization decreased (*Table 4*). This indicates that in the last decade, there has been a significant expansion of the main urban area rather than new urban areas in the periphery. This observation is similar to the relative increase of the LPI value for identical periods (*Table 6*).

Visual observation of urbanization data for both periods shows that the most prominent expansion is observable in the west of the city (*Figures 2 and 3*). Most of the visible urban patches in the 2002 images were merged into larger urban patches in the 2013 images (*Figure 3*). Growth towards the east formed a strip of continuous urban stretch during 2002–2013 (*Figures 2 and 3*). Growth towards the west and north indicates a gap-filling trend. Larger patches are observable close to the main urban center (*Figure 3*).

Growth in the south corridor is not as prominent as other regions during 2002–2013 (*Figures 2 and 3*).

The contiguity index provides the connectedness of cells of a given land-cover class. Urban cells are less connected if the value of the contiguity index reaches zero. The value reaches one if urban cells are more connected. The contiguity index value decreased from 1997 to 2013 (*Table 5*). This indicates that there was an increase in the number of suburban built-up patches that are isolated and less connected. *PD*, the number of patches for a unit area, increased from 1997 to 2013 (*Table 3*). Increasing patch density and a decreasing contiguity index indicate a trend of isolated leapfrog growth of small urban patches in the landscape (*Tables 3 and 5*).

3.3 Local characteristics of urban expansion

The local characteristics of urbanization were measured by applying several spatial metrics to tiles in *Figure 4*. Five spatial metrics, *NP*, *PD*, *LSI*, *PAFRAC* and *COHESION*, were measured for all three datasets (*Table 1*). Tile 3 in Figures 4a–4e corresponds to the main urban area. Tiles 2 and 4 are outside the main urban area while tiles 1 and 5 are furthest from the main urban area.

The main finding of this analysis was the observation of characteristics of urbanization along an intersection through the main urban area (*Figures 5 and 6*). While the *NP* value of Tile 3 has the smallest value owing to it being fully urbanized, the highest numbers of urban patches were observed in Tiles 2 and 5 in all three datasets (*Figure 6a*).

The *NP* value varies from year to year. Tile 2 has the large increase in the number of urban patches between 1979 and 2002 (*Figure 6a*). Later, between 2002 and 2013, the number of urban patches decreased (*Figure 6a*) in tile 2. One possible explanation is that the original increase from 1997 to 2002 expanded and resulted in a small number of larger patches merging in 2013. Another possibility involves outward expansion of the main urban area. This observation is consistent with the behavior of the *COHESION* value observed for the total study area, as explained in Subsection 3.3 (*Table 4*). In addition, it is possible that both outward expansion and merging of

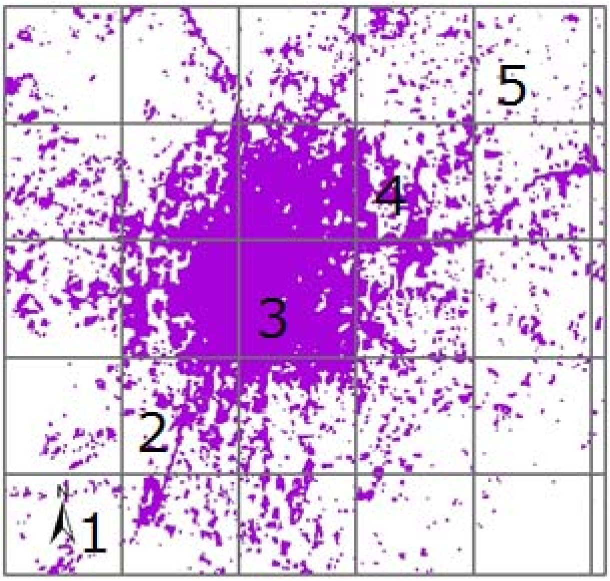

Figure 5. Tiles 1 – 5 of diagonal transection

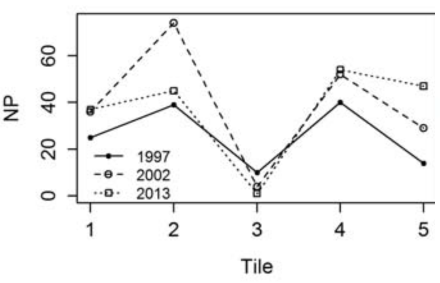

Figure 6a. NP

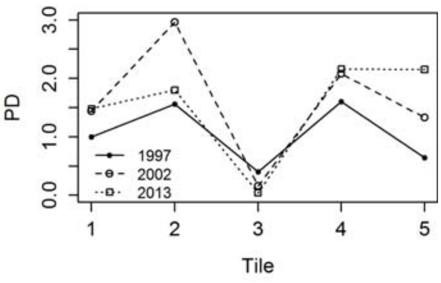

Figure 6b. PD

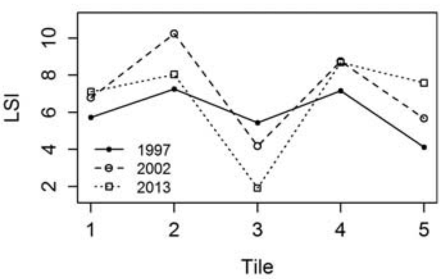

Figure 6c. LSI

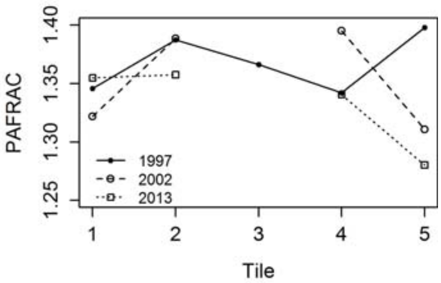

Figure 6d. PAFRAC

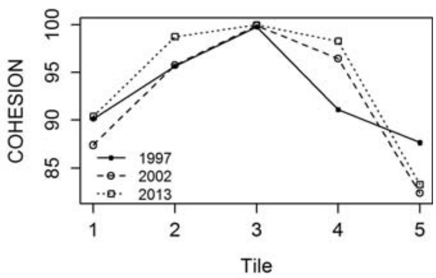

Figure 6e. COHESION

Figure 6. Spatial metrics measurements for Tiles 1-5 of diagonal transect

patches occurred at the same time to varying degrees.

The *NP* value changes in the core urban area for the same period (Tile 3). The value of *NP* decreased continuously from 1997 to 2013 (Tile 3). This may be because of infill growth in the main urban areas. The *NP* value is steadily increasing in Tile 5 (*Figure 6a*). The values of *PD* closely follow the corresponding value of *NP* (*Figure 6b*). The observation of land-use changes between 2002 and 2013 shows large-scale urbanization of the vegetation land class (Table 2). This observation can explain the urbanization of small vegetation land-use patches locked between urban patches.

The *LSI* provides a standardized measure of total edge or edge density adjusted for the size of the landscape (*Table 1*). The *LSI* reaches one when the landscape comprises a single square (or almost square) patch. The *LSI* increases without limit as the landscape shape becomes more irregular and/or as the length of edges within the landscape increases. The *LSI* has a close relationship with the *NP* and *PD* values. In Tile 3, the *LSI* value decreases with the value of the number of patches (*Figure 6c*). In Tiles 2 and 4, the LSI values again closely follow the *NP* and *PD* values. In 1997, there were large numbers of urban patches and they had complex shapes. Later, in 2002 and in 2013, the number of patches dropped and fewer urban patches with less complex shapes were observed in 2013.

PAFRAC reflects shape complexity across a range of spatial scales or patch sizes (*Table 1*). *PAFRAC* is undefined and reported as "N/A" if all patches are the same size or there are less than 10 patches. Therefore, the calculation of PAFRAC for 2013 was not possible for the main urban center. The urban area of 2002 shows the highest level of complexity. Local variation of shape complexity of urban patches can be identified by comparing the *NP* and *PAFRAC* values (*Figure 6d*). Urban data of 2002 shows high *NP* values in Tile 2 and those closest to the main urban center *(Figure 5a)*. In the northeastern part of the city there are fewer patches compared to the southwestern part (*Figures 2 and 3*). In addition, the northeastern urban patches (Tile 5) show more complex shapes than the urban patches of the southwest (Tiles 1 and 2) in 1997 and 2002. In 2013, urban patches lost the shape complexity of Tile 5 (*Figure 6c*). Distinct growth patterns can be observed for the northeastern and southwestern corners of the city.

The landscape *COHESION* index measures the physical connectedness of the corresponding patches. It approaches zero as the proportion of the landscape comprising the focal class decreases and the patch becomes increasingly subdivided and less physically connected. The *COHESION* values of Tiles 1 and 5 are low for all three years. Tiles 2 and 4 show increases in *COHESION* values (*Figure 6e*).

The *NP* and *PD* show increases from 1997 to 2013, indicating an increase of urban patches in Tiles 2 and 4. The *COHESION* index for both Tiles 2 and 4 shows increases during the same period. This observation can be explained as new urbanization in peripheral areas being an essentially fragmented process. In addition, with the progress of urbanization, these fragmented patches are interconnected, forming ever larger patches that tend to have complex shapes in certain areas. In particular, in the northeastern part of the city, urban patches have more complex shapes than those of the southeastern corner (Tile 1 and Tile 5).

4. CONCLUSION

The findings of this study show that the main urban area of Yogyakarta City is expanding faster than other parts of the urban region. The outward expansion of urban growth starts with small urban patches. Later, these patches expand and merge to form larger urban patches. These large patches may have various levels of complexity, depending on the region. This fact is visible in urban extent data from 1997 to 2013 and the *COHESION* value for the corresponding periods. Expansion of the main urban area was visible particularly for the period 2002–2013, when the proportion of urban growth was less than the previous period.

From these observations, several urban expansion patterns can be identified. The first comprises initially small urban patches in rural areas and along roads. The second involves expansion of the main urban area by encroaching into the surrounding area. The third is urban infill growth, which can be identified in the patterns of the *NP* and *PD* data between 1997 and 2013. The fourth observation is the complexity of urban patches in the outskirts of the city. Urban expansion within already developed areas are happening in the form of infill development in existing undeveloped green areas. Loss of green areas inside cities is one of the undesirable effects of densification. The LPI value shows that the core urban area is has been growing at an increasing rate in the recent decade. The city of Yogyakarta needs to develop methods that can preserve green open spaces within the city that are vital for vibrant and healthy city environments. While current research provides evidence of such growth, more detailed research is needed to understand the functions, extent and distribution of such open areas.

Yogyakarta City has experienced several stages of urbanization during the past decades. The completion of the city's outer ring road in 1987 prompted urbanization between the ring road and urban agglomeration. Decentralization of the Indonesian government's decision-making processes has accelerated the growth of peri-urban areas, which are expanding to adjoining administrative areas. Although the peri-urban areas are more attractive for living, Yogyakarta City's main urban agglomeration also has been growing steadily during the last decade. Observations from this study based on land-use data between 2002 and 2013 show that the main agglomeration is not occurring as low-density suburbs. There is more urban growth observed on agricultural and non-urban land, such as vegetation areas. This may be due to the availability of affordable land as well as weakness in land regulations to protect agricultural land. Thus, it is important to study the role of decentralization of administrative functions and decision making in order to understand the urbanization process in Yogyakarta City.

This research highlighted the regional and local trends in the urbanization process of Yogyakarta City. The methodology used in this research is useful to study temporal and spatial trends of urbanization to understand future priorities of land use planning. It is important to examine the current planning practice and economic trends of the city against findings of this study to recommend suitable measures for future planning.

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