KnE Engineering

GEODETA 2019
The 1st International Conference on Geodesy, Geomatics, and Land Administration 2019
Volume 2019

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Conference Paper

Land Use Change Detection and Urban Sprawl Monitoring in Metropolitan Area of Jakarta (Jabodetabek) from 2001 to 2015

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Abstract

Being 13^{th}largest city in the world makes Jakarta as a fascinating city in South East Asia. Its surrounding regions are included in a particular metropolitan area called ``Jabodetabek''. Population growth in this metropolitan area about 10 million only in 15 years from 2000 to 2015. Consequently, loss of vegetation and agricultural land, less water resources, increasing demand for housing and transportation infrastructure as the effect of this ever-growing population take place. This phenomenon can be detected using Landsat satellites images. The settlement or urban area in Jabodetabek shows a huge increase in percentage from 2001 to 2015, so much that the urban area is the dominant land cover and reaches up to 61 percent of Jabodetabek in year 2015. Moreover settlement density in Jabodetabek (ring zones 25 to 45 km from central city) shows an increase of more than 20% urban areas in year 2015. Furthermore, the result of compactness reveals that this urban expansion in Jabodetabek was spread out from 2001 to 2008 and became more compacted by 2015.

Keywords: Land Use, Urban Sprawl, Monitoring, Landsat

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Received: 3 August 2019
Accepted: 25 November 2019
Published: 26 December 2019

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the GEODETA 2019 Conference Committee.

1. Introduction

Development of human civilization in the 21^{st} century causes many changes on land surface. Regional land use pattern is a result of socioeconomic, natural and anthropogenic factors. Urban growth is one of the main factors that causes land use change in many areas around the world, particularly in developing countries e.g. Indonesia [1].

Information of land use change can be obtained by identifying differences from land use through remote observations at different times. Understanding this information is very crucial for the monitoring of urban expansion and change detection studies which can help to improve the planning processes of land use for basic human needs and prosperity. Nowadays, due to the development of existing survey technologies, natural features and human activity products e.g. settlements on earth, geospatial data from a region can be obtained using satellite observations [2].

The basic concept of remote sensing method to detect land use change is by identifying any process between two or more dates of satellite data. The advantages of utilizing remotely sensed data to study the change in land use are its low cost, short time and easily available information concerning the spatial variability of the land surface. Furthermore, an appropriate platform for data analysis and update can be provided in association with GIS [3].

Landsat data are the most common kind of satellite images which are used to detect land use changes during the last 3 decades. Moreover, global satellite images from Landsat are free of charge for scientific usages and have the potential to characterize land surface [1]. Every satellite from Landsat mission has different characteristics and due to its lengthened operational period, only Landsat 7 and 8 are still returning useful data. However, Landsat 7 has a scan line corrector (SLC) failure since 2003 that makes 22% data loss of Landsat 7 image. In comparison to Landsat 7 sensor (ETM+), Landsat 8 has several new built in features such as two new sensors (OLI and TIRS), two new spectral bands (coastal aero- sol and cirrus bands), one thermal band which is split in two bands. All these features help the satellite in having a better quality of satellite images [3].

From Landsat 7 and 8, six satellite scenes were collected in order to perform an interdisciplinary project. The main purposes of this project are to detect changes of land use and investigate the patterns of urban expansion by integration of remote sensing methods, GIS techniques and urban planning concepts.

2. Study Area and Status of Problem

The capital city of Indonesia, Jakarta and four other urban areas including Bogor, Depok, Tangerang and Bekasi comprise the metropolitan region of Jabodetabek on the north-western coast of the world`s most populated island called Java. Jabodetabek comprises an area of about 6800 km^2 and its administrative centre is ``Special Capital Region of Jakarta`` (Daerah Khusus Ibukota Jakarta, DKI Jakarta) with a total area of 667 km^2, which is about 10% of Jabodetabek [4]. Nowadays, Jabodetabek is the largest metropolitan area in Southeast Asia and is increasing in size and population constantly, which has exposed a challenge to the authorities of Jakarta.

Respectively, Jabodetabek is experiencing accelerated population growth in the last decades and is one of the fastest growing agglomerations in the world. Jabodetabek`s unexpectedly high growth was greater than the 6.6 million added in both the Shanghai and Manila regions over the same period and above the 5.8 million increase in the

Beijing region. According to the statistical data of 2015, about 30 million people populate Jabodetabek, which is three times the total population in the capital city Jakarta. Besides Jakarta, the individual municipality in Jabodetabek with both the largest amount of total urban land and highest growth in urban land is Tangerang, which is located in the Banten province. The jurisdiction with the highest population, as well as the one with the highest population growth was Bogor in West Java [4]. Moreover, a comparison of census data in 2010 and 2000 indicates that 84 percent of the metropolitan area population growth occurred in the suburbs over the past decade. Table 1 summarizes the historical development of population in the past decades in each part of Jabodetabek.

Table 1: Population distribution in Jabodetabek in millions (1980-2010) [5].

	1980 1990	2000 2010
Jakarta	6.50 8.26	8.39 9.60
Tangerang	1.53 2.77	4.15 5.93
Depok	n.a. n.a	1.14 1.75
Bekasi	1.14 2.10	3.28 5.01
Bogor	2.74 4.01	3.67 5.73
Jabodetabek	11.91 17.14	20.63 28.02

This continuing trend of suburbanization in Jabodetabek is a mixture of two phenomena. On one hand, many socially weak Jakarta natives move from the fast modernizing centre of Jakarta to the fringe areas in order to find more affordable accommodations. In addition to this population, many migrants come from various parts of Indonesia to peripheral areas of Jakarta looking for employment.

On the other hand, many middle and upper class families leave central Jakarta to suburbs for better amenities. Construction of three major highways stretching from Jakarta to the peripheries (the Jagorawi toll road, the Jakarta-Cikampek toll road, and the Jakarta-Merak toll road) attracted more poeple to move out of the city centre.

In accordance with the implementation of highways, private industrial parks came to existence on the margins of the cities. The average size of the industrial parks are 500 hectares, while some have a total area of up to 1800 ha. Major industrial centres are located in Cikupa-Balaraja of Tangerang Regency and Cikarang of Bekasi Regency. The industrial centre of Cikarang with a total industrial land area of nearly 6,000 hectares is the largest planned industrial centre in Southeast Asia [4].

Increasing suburbanization, rapid industrialization, unorganized immigration and unrestrained urban sprawl are among the main causes of land use and land cover transformation especially in developing countries. Hence this work attempts to detect the land use change in metropolitan area of Jakarta and monitor the characteristic of

urbanization in the context of Jabodetabek from 2001 to 2015. For this purpose, remote sensing techniques based on Landsat satellite images were used.

3. Methodology

The present study consists of four main steps: data acquisition and preparation; image processing; land use classification; land use change analysis as well as urban sprawl monitoring and discussion about the outcomes. The goal of this work was to determine the land use changes and urbanization from 2001 to 2015 and three dates were chosen in the way that it would be as closely as possible for having the same vegetation seasons: September 2001, July 2008 and August 2015. Dry season lasts from June to September in the metropolitan area and three chosen dates are in this period, so that the satellite images would affected as least as possible by cloud cover (lower than 10%) [6].

The used data in this study is based on Landsat 7 ETM+ and Landsat 8, which was downloaded from USGS Global Visualization Viewer (GloVis) as ``Level-1 Product'' in GeoTiff format. USGS GloVis provides an archive of data for the study area from 1987 to 2017. In order to achieve accurate and trustworthy results in land use change detection, several steps of correction are implemented for Landsat images. Values that are used for computing the correction are obtained from metadata in each image acquisition and constants which are given in satellite image handbook [7]. During earth observation, reflected solar energy are captured by sensors of Landsat and transformed it to radiance. Landsat 7 sensors rescale this radiance into 8 bits digital number (DN), while the radiance values are rescaled into 16 bits DN by Landsat 8. For processing satellite images, DN will be converted again into radiance. Relatively clear Landsat images can be taken by converting spectral radiance into planetary reflectance or albedo with a normalization for solar irradiance. Atmospheric correction in satellite images are done in order to remove effects from clouds and aerosols in the atmosphere. The result of this process is a surface reflectance image that can be extracted to derive accurate spectral value from features on the Earth's surface. One of most common atmospheric correction is Dark Object Subtraction (DOS)1 Correction [8].

After SLC-Off mode in 2003, many digital image improvement techniques have been offered in order to fill the gap (gap-fill) in Landsat 7 images. One of the common method is triangulation method. In this method, gap in ETM+ images are restored by using Delaunay triangulation method which corrected the bad pixels with triangles calculated from the surrounding good values. So that only one image is needed to implement this

process [8]. Research area for this project is covered by two rows of satellite images. Therefore, mosaicking process was essential to combine two georeferenced images from the same date into one image. This process was executed by removing the black background of images and merging these two images into one image.

4. Land Use Classification

For posterior analysis of land use change in metropolitan area, the prepared and calibrated satellite images must be classified according to land use types. Aside from classical visual image interpretations, digital image analysis and computer-assisted classification are mainly used. The main two image classifications are so-called unsupervised and supervised classification. In this work, the supervised classification method was used to reach more reliable results for each date. Maximum Likelihood Classification is one of the options which better suits the purposes of this study. Two principles support the idea of Maximum Likelihood: firstly, the cells in each class sample in the multidimensional space are normally distributed and secondly, Bayesian rule for making the decisions [9]. Five land use classes were utilized to create the classification scheme that are representing urban areas or settlements, green areas including agricultural lands and non-forested vegetation, forests, barren lands, and water bodies. In addition to the land uses, clouds were also classified in a separated one. Table 2 provides a summary of land use classes and their details.

Table 2: Class descriptions used for supervised classification.

Class	Description
Urban area	Includes all residential, commercial, and industrial areas with transportation
Non-forested vegetation	Including agricultural and pasture grasslands, recreational grasses, scrub or shrub like vegetation
Forest	All forest vegetation types
Barren	Bare earth or soil
Water	All water bodies including freshwater lakes, rivers and streams

The next step was to create the training by using the training sample area. For creating the samples for each class, different band combinations and indices such as Tasselled Cap Transformation, NDVI and so forth are very helpful to identify the differences between pixels. Providing reliable training samples is a very time consuming and critical part of supervised classification. It is noteworthy to be stated that the nature of the training samples may affect the ability of the classifier for generalization, which

affects consequently the classification accuracy. In the case of this study, the number of included pixels in each training sample set to be at least 100 times the band numbers. In some references, it is recommended that for each class to have at least 30 pixels and according to other references between 10 and 100 times the number of bands. Better result also can be obtained by create several smaller training samples rather than providing fewer big samples, which may comprise of mixed and copious pixels. Moreover, the training areas should be homogenous but they should be able to depict the variability within a thematic class [10].

5. Land Use Change Analysis

In order to deal with the SLC-off problem with the satellite image of 2008, the supervised classification was performed several times to achieve an acceptable result. The official land use maps were available for 2001 and 2015 to make a comparison. The results for these two dates were satisfying with value of confusion matrix above 90 %.

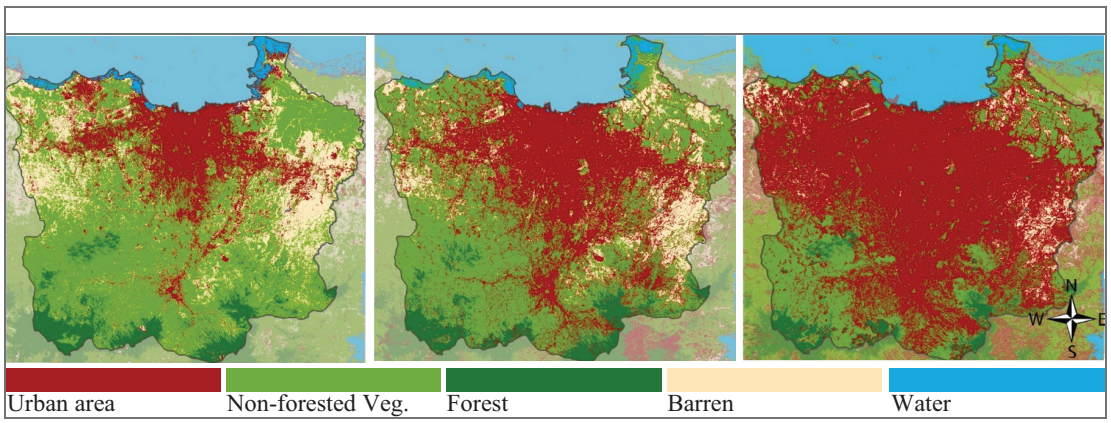
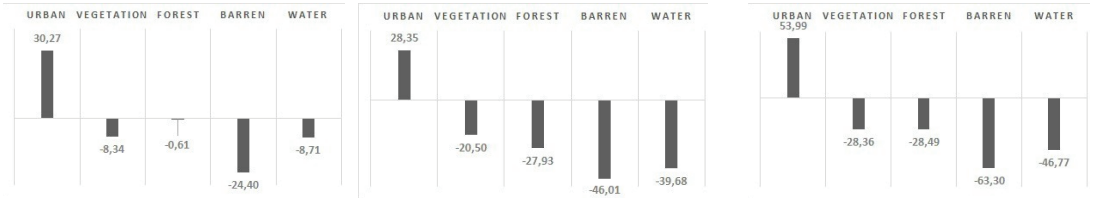


Figure 1: Land use in Jabodetabek.

Figure 1 is the result of supervised classification for three predefined dates. The first thing that attracts the attention is the conspicuous expansion of urban areas in Jabodetabek. Consequently, changes in vegetation and barren lands are obvious if we compare the images of 2015 and 2008 to 2001. In the next section, the land use changes will be addressed more explicitly.

After classification of three satellite images, it is now possible to analyse the land use structure and changes in Jabodetabek. Vegetation with 54% of the metropolitan total area in 2001 is the most frequent land cover in Jabodetabek, it decreases to 46 and 30% in the next years. The settlement or urban area in Jabodetabek shows in contrast a huge increase in percentage from 2001 to 2015, so much that the urban area is now the dominant land cover and reaches up to 61 percent of Jabodetabek in year 2015.

Similar to many other developing areas of the world, transformation of barren land to built-up areas is a common phenomenon in Jakarta metropolitan area. Just 4% of Jabodetabek was barren in 2015, which shows a loss of 14% in comparison to 2001. Forest areas are mostly distributed in the south part of Jabodetabek and located in Bogor and Depok. From 2001 to 2008, the proportion of forest areas remains quite unchanged but it reduces to 4% in 2015 with the development of settlements in Bogor.



(a) (b) (c)

Figure 2: Percentage of land use changes from each date to the subsequent data in Jabodetabek; (a) from 2001 to 2008, (b) from 2008 to 2015, (c) from 2001 to 2015.

All land uses show a similar negative trend except for urban and settlement areas. Apart from the vicinity of Jabodetabek and specifically Jakarta to Java Sea and having a wide coastal area in the north, there are many narrow rivers and canals that are unable to be distinguished in image classification due to the resolution limitation of Landsat data. The increasing construction on the coastal area has also changed the appearance of seashore and consequently resulted in negative percentages in 2008 and 2015. Although in some cases, the season or month of the year and average precipitation can affect the quality of vegetation, the decrease of vegetation from 2001 to 2015 is approved by many references in Jabodetabek [4]. The most negative evolution in land use change belongs to barren land. Up to 64% of barren lands were transformed in the period between 2008 and 2015. This also approved the minimal amount of barren lands considering the total area of Jabodetabek in 2015.

6. Urban Development Analysis

After independence and at the time of President Sukarno in the 1960s and 1970s, the expansion and development of Jakarta and its suburbs were made possible by construction of major highways such as the Jagorawi highway. In the next years up to 1988, the built-up area in Bogor, Tangerang, and Bekasi had reached more than three times as much as built-up area in Jakarta. In the following decade (1990s), the outskirts of Jakarta experienced a vast urban sprawl as the policy of the National Land Agency of

Indonesia (*Badan Pertanahan Nasional*/BPN) permitted to build 80,000 ha of housing in the suburban area. This trend has continued until today, so that Jabodetabek is the largest metropolitan area in West Asia and has reached a population of about 30 million [4].

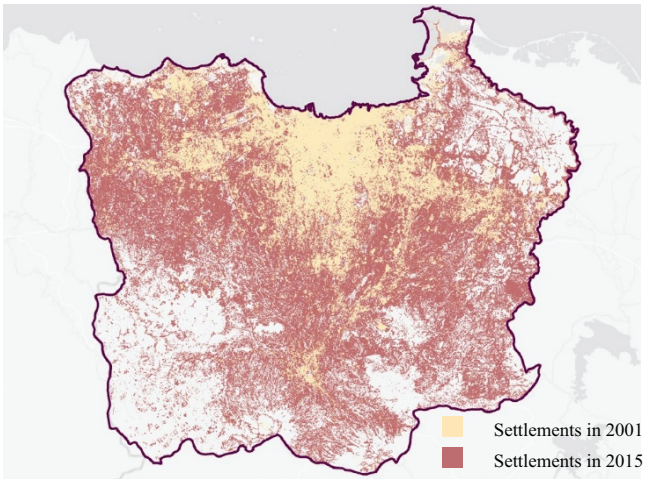


Figure 3: Comparison of urban areas in Jabodetabek between 2001 and 2015.

Figure 3 indicates the obvious development of settlements and urban areas in Jabodetabek by overlapping the urban areas in 2015 and 2001. Moreover, fig. 4 shows the direction of urban sprawl from 2001 to 2008 and then from 2008 to 2015 more precisely. It is obvious that in the first period is the concentration of urbanization on the west and east of Jakarta (mainly towards Tangerang and Bekasi) but in the following period between 2008 and 2015, the expansion of Jabodetabek takes place mostly in the southern part of the metropolitan area (towards Depok and Bogor). This change of direction in urbanization was mainly due to the displacement of farmers and their agricultural lands from the designated areas to industrial and housing sectors in master plans. These developments also changed the appearance and role of the southern cities in Jabodetabek. An example for this phenomenon is Depok, which had actually functioned as water reservoir for the metropolitan area but today is a dense urbanized area. The spatial planning concepts were strengthened in Indonesia after a revision of law in 2007. The result of this revision was the National Spatial Plan (*RTRWN*) in 2008, which gave Jabodetabek the function of national centre of activities in the national urban system. At the same time, the first plans also created for environmental protection which resulted to Jabodetabek-Punjur (Puncak Cianjur) as a ``national strategic area'' [4].

The concepts of decentralization and de-concentration of services and activities exposed a great pressure on the outskirts of cities. In response to this rising problem, the concept of compact city was introduced to appeal with urban sprawl [11]. The term

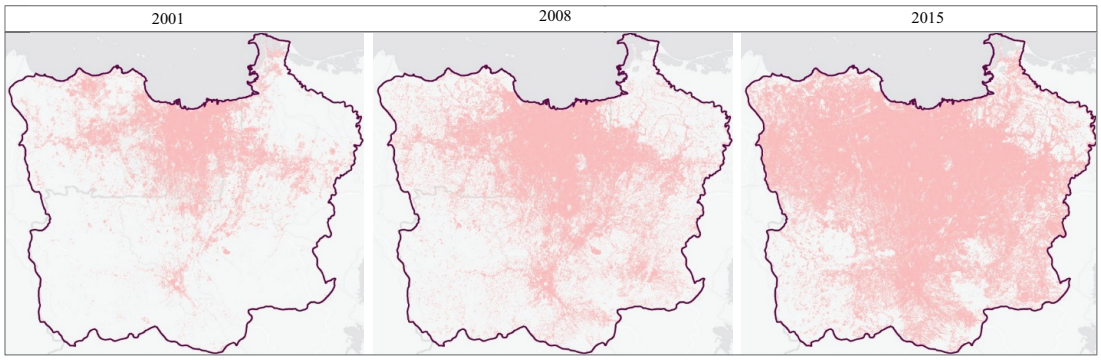


Figure 4: Urban areas in Jabodetabek.

``compact city'' was first used in 1973 by mathematicians whose utopian vision was largely driven by a desire to see more efficient use of resources. Later, it was adopted by urban planners alongside the principles of sustainable urban planning in the late 1990s. Compact city or city of short distances rests upon two policies: more densified urban development rather than dispersed activities on one hand and on the other hand more mixed uses horizontally or vertically in the city [12]. Therefore, urban activities should be located closer together to ensure better access to services and facilities via public transport, walking, and cycling, and more efficient utility and infrastructure provision.

In order to determine whether Jabodetabek`s development is congruous with the ideas of compact city or not, two geostatistical methods are used: analysis of urban area by means of density gradient and analysis of compactness by using the idea of equivalent circle. Compactness is based on the assumption that, in the case of a circle, the ratio of circumference to area is the smallest and the circle has the most suitable and compacted geometric form. In order to perform a density gradient analysis, the extent of Jabodetabek is used as the analysis frame. The next step was to define the centre of city development which is usually the historical origin of a city. In this case, the municipality of Jakarta was chosen as the centre of analysis. Now, it will be buffered every 5 km around this centre up to the farthest point of the urban area. It amounts to 60 km from the centre of Jakarta to the farthest urban areas in Depok in the south. For covering this area, 12 rings are produced, in each of which, the proportion of urban or settlement area or in other words the density of urban land use will be calculated. The result of this step shows not only the main cores of urban development for each date but also makes it possible to compare the urban sprawl between the satellite images, which can reveal the expected the characteristic and direction of urbanization in the future.

Figure 5 indicates the density gradient of urban areas in 12 rings for 2001, 2008 and 2015. An obvious jump can be seen between 25 and 45 km from the centre of Jakarta from 2008 to 2015. For the same ring zones (25 to 45), a comparison between 2001 and 2015 shows an increase of more than 20% urban areas. In ring 60, settlement density reaches to ca. 10% for in 2015, while it was less than 1% in year 2001, which confirms the wide urban sprawl of Jabodetabek especially in the south.

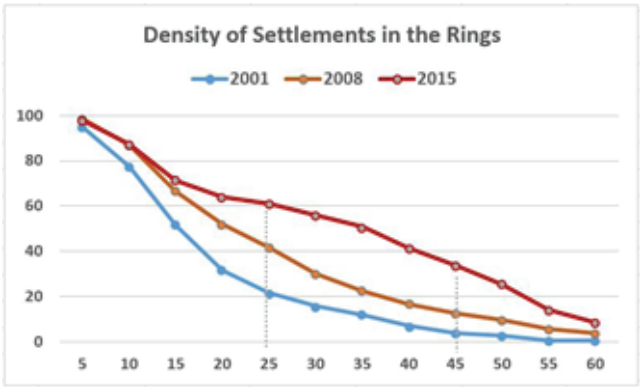


Figure 5: Density gradient of settlements for 3 dates.

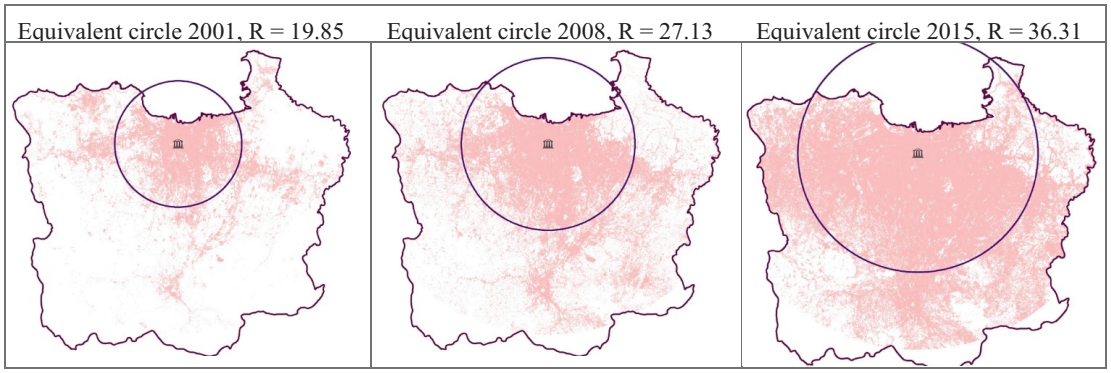


Figure 6: Equivalent circle equal to urban area in Jabodetabek.

For the analysis of compactness in Jabodetabek, it is necessary to calculate first of all the radius of the circle that corresponds to the area of settlements for each date. Compactness will be closer to value 1, if the urban area is totally dense and compacted. Figure 6 indicates the equivalent circle for the urban area in 3 dates. The radius of equivalent circle is 19,85 km for 2001, while it is 36,31 km for 2015, which means that the urban area (as a factor of r^2) has an almost fourfold increase within 14 years in Jabodetabek. The result of compactness reveals that the development of settlements was spread out in Jabodetabek from 2001 to 2008 and the urban area of Jabodetabek became more compacted by 2015 as shown in Table 3.

Table 3: Key figures about the urban structure of Jabodetabek.

	2001	2008	2015
Perimeter of settlements (km)	22397	39722	35810
Area of equivalent circle (km^2)	1237.4	2311.6	4141.3
Radius of equivalent circle (km)	19.85	27.13	36.31
Perimeter of equivalent circle (km)	124.72	170.46	228.14
Compactness	179.57	233.02	159.76

7. Conclusion

Jabodetabek or Metropolitan Area of Jakarta is now home to more than 30 million people. The historical development of this area shows that Jakarta and its peripheries has always attracted people from Java Island and even the whole of Indonesia. Therefore, the rate of migration has climbed dramatically in the last 3 decades. As an example, during 10 years (1995-2005) the average number of people who migrated to the peripheral areas of Jakarta was 1.6 million people per year.

This population growth has an enormous effect on the land use and appearance of earth, which this study has approved by using Landsat images. Through the classification of land cover in Jabodetabek, it became clear that the urban and settlement area is now covering the most part of administrative area of Jabodetabek. The settlement or urban area in Jabodetabek shows a huge increase in percentage and reaches up to 61 percent of Jabodetabek in year 2015. Moreover there is just a little vegetation and green area left in the southern part of Jabodetabek, which is a strong evidence that rapid urbanization in Jakarta must be reduced. Due to lack of enough open spaces, Jakarta is now experiencing a rapid ``vertical village development``, which means more population, higher density and more load on the infrastructure and natural resilience of the city the result of compactness reveals that this urban expansion in Jabodetabek was spread out from 2001 to 2008 and became more compacted by 2015. Although Landsat images are very helpful in classifying earth surface and this study met its goals, but it seems impossible to make conductive statements about 3D development and consequently land use change by using remote sensing based on satellite images.

Acknowledgment

This work was supported in part by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia and by the HafenCity University, Hamburg.

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