Land Cover Change Impacts on Land Surface Temperature in Jakarta and Its Satellite Cities

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Abstract. Indonesia’s capital city, Jakarta, is surrounded by several satellite cities and has grown spatially into a larger region called Jabodetabek. The development in Jabodetabek has resulted in changes in the landscape. The increase of impervious surface and decrease of green space has led to the formation of an urban heat island (UHI). UHI could be detected through land surface temperature (LST) monitoring. Therefore, the objectives of this study were to analyze the land cover changes in Jakarta and its satellite cities and to analyze the impact of these changes on LST using GIS-based analysis. We analyzed Jakarta and its three satellite cities, Depok, Tangerang, and Bekasi, through a satellite image time-series analysis in 1989/1990 and 2015/2018. It is found that, among the four cities we analyzed, Tangerang has the highest built-up area expansion proportion, followed by Bekasi with a slight difference, then Depok and Jakarta. As for the LST, the city that has the most significant difference between mean LST in the initial and recent year is Bekasi with 12.66°C, then followed by Tangerang (11.05°C), Jakarta (8.34°C), and Depok (6.43°C). These orders’ inconsistency might be caused by higher proportion of built-up area combined with higher loss of vegetated area. This shows that the land cover change played a big role in the temperature increase.

Keywords: built-up expansion, land surface temperature, remote sensing, satellite city

1. Introduction
Cities in developing countries have been growing rapidly within the past few decades. Asian countries are the most rapidly growing regions and among them, Indonesia has the highest urbanization rate of 4.1% per year. With this level of urbanization, 68% of the Indonesia population is expected to live in cities by 2025 [1]. Indonesia’s capital city, Jakarta, is a megacity that has more than 10 million people. In 2016, the population of Jakarta was 10,277,628 people, which increased as much as 0.98% from the previous year [2]. Urbanization in Jakarta started to accelerate in the early 1980s when Jakarta began shifting its economic growth into a new mode of export-oriented industrialization [3].

Jakarta has grown spatially into a larger region called Jabodetabek (Jakarta Metropolitan area). The name ‘Jabodetabek’ is an abbreviation formed from the first syllables of Jakarta and its surrounding cities and regencies: Jakarta, Bogor, Depok, Tangerang, and Bekasi. These cities become the buffer of Jakarta to support people’s needs of a residence, tourism, etc. The built-up area has been expanding widely, not only inside, but also beyond the capital city. As a result, rapid development also occurs in its surrounding/satellite cities. It is expected that the development in these areas in recent years might be even faster than in Jakarta that is almost fully occupied.

The urban development in the satellite cities of Jakarta mostly aims to meet the increasing needs of the residential area and its residents’ services, including housings and shopping malls. These projects consumed a large area of land, specifically agricultural land [4]. This results in
unpredicted replacements of existing agricultural land and green space into buildings, roads, and other infrastructure. This type of unpredicted development makes it important to investigate the urbanization process because there may be some opportunities we could utilize and some challenges we could tackle to improve the city development planning. Therefore, this study aimed to analyze the built-up area expansion pattern of Jakarta and its satellite cities.

Some similar studies have investigated the built-up area expansion in the Jakarta Metropolitan Area [5], [6]. These studies focused on individual cities or the Jakarta Metropolitan Area as a whole; however, no available study has compared the built-up area expansion patterns among Jakarta and its satellite cities. Additionally, no existing study has done a city-by-city analysis. Working with big spatial data all at once is challenging and could result in slightly lower accuracy due to the large heterogeneity in the study area. Nevertheless, by investigating the large area, as has been done for some smaller areas, this study aimed to fill gaps and provide an updated and more accurate overall result.

The increase of urban area and the decrease of green space in Jabodetabek intensify the effect of urban heat island (UHI) in the city. UHI occurs when an urban region has a higher temperature compared to its surrounding area [7]. This study focuses on surface UHI, where the identification method is measured indirectly by remote sensing. Therefore, the land surface temperature (LST) of the study area was monitored to detect the existence of UHI.

Analyzing the land-use/land-cover change is the most important part of understanding the built-up area expansion and the impact it may cause to LST. Therefore, the objectives of this study were (1) to analyze the land cover changes in Jakarta and its satellite cities and (2) to analyze the impact of these changes on LST using GIS-based analysis.

2. Material and Methods

2.1. Study area and materials

The study area (Figure 1) includes Jakarta and its directly connected satellite cities: Depok, Tangerang, and Bekasi. The wet season in the study area lasts from October to May, while the dry season lasts from June to September.

![Figure 1. Map of the analyzed area. (a) The location in Indonesia, (b) Jakarta and its satellite cities, (c) Landsat satellite image of the study area in false color.](image-url)
We used Landsat-5 Thematic Mapper (TM) and Landsat-8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) imagery with 30-m spatial resolution downloaded from the Earth Explorer United States Geological Survey (USGS) website. We analyzed two sets of different timeframe satellite imagery for each city (Table 1). Patching was needed when the main image was cloudy. All the maps were first re-projected into UTM Zone 48S, WGS84 datum.

| City      | Image Acquisition Date | Sensor | Bands |
|-----------|-------------------------|--------|-------|
|           | Main Imagery            |        |       |
|           | Year | Date | Patch     | Year | Date |        |       |
| Jakarta   | 1990 | 9 Jul | 1990 | 6 Jun | Landsat-5 | 1-5 & 7 |
|           | 2015 | 31 Aug | 2014 | 13 Sep | Landsat-8 | 2-7   |
| Depok     | 1989 | 6 Jul | No cloud |       | Landsat-5 | 1-5 & 7 |
|           | 2018 | 1 Apr | No cloud |       | Landsat-8 | 2-7   |
| Tangerang | 1989 | 6 Jul | 1989 | 12 Jun | Landsat-5 | 1-5 & 7 |
|           | 2015 | 31 Aug | 2014 | 13 Sep | Landsat-8 | 2-7   |
| Bekasi    | 1989 | 6 Jul | No cloud |       | Landsat-5 | 1-5 & 7 |
|           | 2015 | 31 Aug | No cloud |       | Landsat-8 | 2-7   |

2.2. Cloud patching
As the cloud is often a problem when working with satellite images of a tropical area, the cloud coverage was masked using the Fmask function developed by Zhu & Woodcock [8]. If the Fmask algorithm could not detect the cloud, the cloud masking process was performed manually by drawing a shapefile over it. The area covered by the cloud mask was removed and then patched by another set of Landsat images from the closest time possible.

2.3. Land cover classification
We classified the land cover of the study area into five categories: water, grass, trees, built-up, and bare land. The water category includes rivers, canals, lakes, ponds, and flooded paddy fields in the early stage of planting. The grass category includes natural grasslands, golf courses, grass fields, and low plant crops in agricultural areas. The tree category includes natural woodlands, urban forests, and urban trees; the built-up category includes residential, commercial, and industrial areas and transportation infrastructures; and bare land includes open soil and unplanted farmland. The images were classified by a supervised classification in QGIS using the Semi-Automatic Classification Plug-in and maximum likelihood algorithm.

2.4. Accuracy assessment
We created a layer of random points in Arc GIS. The number of the random points for each class ranged from 50 to 70 points, it exceeded the recommended minimum of \( n \) \( (n + 1) \) where \( n \) is the number of classes [9]. Every point was assigned to a class value (1: water, 2: grass, 3: trees, 4: built-up, 5: bare soil). This layer was then exported into a KML format to be displayed on Google Earth and compared to the higher resolution map displayed in Google Earth’s historical imagery. The ground truth data obtained from the comparison was then inputted to create an error matrix in Arc GIS and Ms. Excel.

2.5. Land cover change detection analysis
The land cover change was detected by a post-classification comparison that involved an independently produced classification result. The raster value of the maps was reclassified and then multiplied using the raster calculator function in Arc GIS. The advantages of this method are: it reduces atmospheric, sensor, and environmental impact, it produces complete matrices of change, and it also minimizes the impact of using multi-sensor images [10].
2.6. LST retrieval

The LST values were estimated from the conversion of digital number (DN) values of thermal infrared bands. The bands used were band 6 and band 10 for images acquired by Landsat-5 and Landsat-8, respectively. The retrieval of LST involved the following steps [11].

1) Converting the DN values to spectral radiance. The conversion followed Eq. (1) in the case of Landsat-5 TM and Eq. 2 in the case of Landsat-8 OLI/TIRS.

\[
L_\lambda = L_{\text{min}} + \left( \frac{L_{\text{max}} - L_{\text{min}}}{255} \right) \times DN
\]

\[
L_\lambda = M_L \times DN + A_L
\]

where

\( L_\lambda \) = Spectral radiance (Watts / (m\(^2\) * srad * µm))

\( L_{\text{min}} \) = Band minimum radiance value

\( L_{\text{max}} \) = Band maximum radiance value

\( M_L \) = Radiance multiplicative scaling factor for the band

\( A_L \) = Radiance additive scaling factor for the band

2) Converting the spectral radiance to surface temperature using Eq. (3).

\[
T = \frac{K_2}{\ln \left( \frac{K_1}{L_\lambda} + 1 \right)}
\]

where

\( T \) = Surface temperature

\( K_1 \) = Thermal conversion constant for the band

\( K_2 \) = Thermal conversion constant for the band

3. Results & Discussions

3.1. Accuracy assessment of land cover maps

A minimum of 250 random points was placed dispersely throughout the map with each land cover type covered by at least 50 points. The overall classification accuracy is shown in Table 2. These accuracy levels are considered reliable enough because they exceed the target overall accuracy of 85% with no class less than 70% accurate [12]. When there was any data that did not reach this level, reclassification was mandatory.

| City    | Reference Year | Overall Classification Accuracy | Overall Kappa Statistics |
|---------|----------------|-------------------------------|-------------------------|
| Jakarta | 1990           | 91.48%                        | 0.89                    |
|         | 2015           | 93.60%                        | 0.92                    |
| Depok   | 1989           | 85.97%                        | 0.82                    |
|         | 2018           | 93.81%                        | 0.92                    |
| Tangerang | 1989        | 93.05%                        | 0.91                    |
|         | 2015           | 89.60%                        | 0.87                    |
| Bekasi  | 1989           | 92.38%                        | 0.90                    |
|         | 2015           | 89.15%                        | 0.86                    |

3.2. Land cover change

The summary of combined land cover maps from the initial year (1989/1990) and the recent year (2015/2018) is shown in Figure 2. Jakarta is more developed in the initial year compared to the other cities, but in the recent year, the built-up area has expanded and occupied most parts of the cities. The detail of each class’ total area is shown in Table 3. A graphic is created to compare the land cover class proportion between the initial and recent years (Figure 3).
The difference between the built-up area in the recent year and the initial year shows the built-up area expansion. The built-up area expansion was 19,042.56 ha in Jakarta, 8,003.34 ha in Depok, 16,092.81 ha in Tangerang, and 9,910.17 ha in Bekasi. In terms of total area, Jakarta had the highest built-up area expansion, followed by Tangerang, Bekasi, and Depok; however, in terms of proportion, Jakarta had the lowest expansion. The highest belongs to Tangerang, followed by Bekasi with a slight difference, then Depok. This result occurred because Jakarta is much larger and was initially more developed than in other cities.

Table 4 is derived from the matrices of change that were produced by land cover change detection analysis. It shows the total area and proportion of each land cover type that is converted to the built-up area. The expansion of the built-up area seemed to happen mostly by
replacing the vegetated area. The proportion of grass and tree area loss is almost the same in each city, except in Tangerang which grass area loss is near twice the tree area loss. This is due to the larger proportion of grass/low plant class in the initial year in Tangerang.

Table 4. Land cover types in the initial year that are converted to the built-up area in the recent year (100% = the total area of each city)

| Land cover | Jakarta (2015) | Depok (2018) | Tangerang (2015) | Bekasi (2015) |
|------------|---------------|-------------|-----------------|---------------|
|            | Hectares      | %           | Hectares        | %             | Hectares      | %             | Hectares      | %             |
| Water      | 836.19        | 1.28        | 452.88          | 2.25          | 73.80         | 0.21          | 63.90         | 0.30          |
| Grass      | 8,950.32      | 13.71       | 4,394.79        | 21.86         | 8,703.99      | 25.00         | 4,253.76      | 19.84         |
| Trees      | 8,595.90      | 13.17       | 4,069.26        | 20.24         | 4,736.52      | 13.61         | 4,366.08      | 20.36         |
| Built-up (still) | 31,548.06 | 48.34 | 3,349.08 | 16.66 | 5,975.19 | 17.16 | 4,998.51 | 23.31 |
| Bare land  | 2,909.70      | 4.46        | 458.55          | 2.28          | 3,868.56      | 11.11         | 1,894.23      | 8.83          |
| Total      | 52,840.17     | 80.96       | 12,724.56       | 63.29         | 23,358.06     | 67.09         | 15,576.48     | 72.64         |

3.3. Built-up area expansion

The built-up area expands towards the outer part of Jakarta (Figure 4). There are some unchanged vegetated areas that are located in the middle of Jakarta, such as golf courses, city parks, and city landmarks. Agricultural land in the western and eastern part of Jakarta is converted to built-up, along with the forest area in the southern part of Jakarta.

The initial built-up area in Depok was relatively small. In 1989, there were only a few concentrated high-density residential areas in the middle and the northern part of the city that is directly bordering with Jakarta. The initial built-up area included a train station and a government office. Tangerang is located on the west of Jakarta, so the eastern part of Tangerang is expected to be more developed. The initial built-up area in 1989 is mostly located near Jakarta and in the northern part of the city that consisted of Soekarno-Hatta International Airport and some compact residential areas. The expansion in Tangerang is mostly for residential area and shopping mall area.

In Bekasi, the initial built-up area was only distributed in the center and northern parts of the city. The center of the initial built-up area is the location of Bekasi’s mayor office and railway stations (Kranji station and Bekasi station). Besides the railway, this area is connected to Jakarta through a major traffic road. Road network is one of the major factors that affect built-up area expansion in a city [13]. This is suspected to be one of the main factors why built-up area expansion occurred quickly in that area.

Figure 4. Built-up area expansion from the initial year to recent year
3.4. Impacts of land cover change on land surface temperature

LST distribution maps of the study area are shown in Figure 5. The LST pattern is highly related with the land cover distribution. In 1989/1990, the high LST area is mostly distributed in the center part of Jakarta where the built-up area is concentrated. The outer part of Jakarta had lower temperatures as that area was covered by more vegetation compared to the center part. Compared to Jakarta, other cities had a lower temperature. The high LST area continued to increase following the land conversion to the built-up area. When the area is converted to built-up, the temperature increased which results in high LST distribution in 2015/2018.

Figure 6 illustrated the mean LST fluctuation by different land cover types and Table 5 shows the mean LST in numbers. In general, the temperature of the built-up area was the highest among the land cover types, followed by bare land, trees, then grass with a slight difference, and finally water. In the initial year, Jakarta had the highest mean LST, followed by Bekasi, Tangerang, and Depok; however, in the recent year, Bekasi had the highest mean LST, followed by Jakarta, Tangerang, and Depok.

![LST maps](image)

**Figure 5. LST maps**

![Mean LST by land cover type](image)

**Figure 6. Mean LST by land cover type**
The city that has the most significant difference between mean LST in the initial and the recent year is Bekasi with 12.66 °C, then followed by Tangerang (11.05 °C), Jakarta (8.34 °C), and Depok (6.43 °C). Bekasi shows the highest LST difference although the highest built-up expansion proportion belongs to Tangerang. It might be caused by higher proportion of built-up area combined with higher loss of vegetated area in Bekasi compared to Tangerang (Figure 3). Further study is needed to confirm this finding.

Bekasi and Tangerang underwent major developments between the initial and the recent year. There is a significant increase in family shopping malls in Bekasi to the point where the government’s income from the shopping mall’s taxes in 2014 doubled from 2011 [14]. These shopping malls are built in the center part of the city near the Bekasi railway station (initial built-up area in 1989).

4. Conclusion
The land cover change that occurred in Jakarta and its satellite cities is mostly vegetated area conversion to built-up area. The urbanization in started from Jakarta and then spread to the surrounding cities. According to the built-up expansion proportion of each city’s total area, the expansion occurred most extensive in Tangerang, followed by Bekasi, with a slight difference, Depok, and lastly Jakarta. The main cause of built-up area expansion in every city was construction for residential purposes and shopping malls to accommodate the continuously growing population.

The land cover changes resulted in significantly higher mean LSTs of the analyzed cities. The LST difference ranged from 6.43 °C to 12.66 °C. The highest LST difference belongs to Bekasi, meanwhile, the lowest belongs to Depok. If observed by land cover types, a high LST area is mostly distributed in the built-up area. The increase of the high LST area is highly affected by the land conversion to the built-up area.

Table 5. Means LST (°C) in different land cover types

| Land cover | Jakarta 1990 | Jakarta 2015 | Jakarta 1989 | Jakarta 2018 | Depok 1989 | Depok 2015 | Tangerang 1989 | Tangerang 2015 | Bekasi 1989 | Bekasi 2015 |
|------------|--------------|--------------|--------------|--------------|------------|------------|---------------|---------------|-------------|------------|
| Water      | 23.29        | 29.44        | 19.86        | 25.81        | 20.40      | 20.79      | 30.03         | 20.79         | 33.00       | 30.03      |
| Grass      | 23.85        | 32.41        | 20.44        | 26.55        | 20.89      | 31.76      | 20.91         | 32.98         | 20.68       | 33.38      |
| Trees      | 23.76        | 32.43        | 19.85        | 26.70        | 20.49      | 31.96      | 20.68         | 33.38         | 20.68       | 33.38      |
| Built-up   | 25.29        | 34.45        | 21.21        | 28.69        | 21.73      | 33.52      | 22.09         | 34.82         | 22.09       | 34.82      |
| Bare land  | 23.53        | 32.72        | 21.55        | 27.27        | 21.27      | 33.01      | 20.88         | 34.46         | 20.88       | 34.46      |

Mean 23.95 32.29 20.58 27.01 20.96 32.05 21.07 33.73

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