City expansion and urban heat island in Bogor

A Nurwanda* and T Honjo
Graduate School of Horticulture, Chiba University, Matsudo-shi, Chiba, Japan

*Email: atiknurwanda@chiba-u.jp

Abstract. Bogor is a satellite city of Jakarta Metropolitan that experience rapid population growth and urban development. Urban landscape change for urban development affects the city expansion, development of urban heat island (UHI), and the increasing of land surface temperature (LST). The objectives of this study are to analyze the urban landscape change in 1990 and 2017, to analyze the LST change caused by city expansion, and to analyze the development of the UHI phenomenon. We used Local Climate Zone (LCZ) which is a classification system of urban surfaces. In LCZ classification, we used three categories in built-up area, three categories in vegetated area, bare soil, and water. Landsat 5 TM in 1990 and Landsat 8 OLI/TIRS in 2017 were used in this study. In 1990, the urbanized area was 9.38% and the vegetated area was 83.98%. The urbanized area continuously increased and become 27.24% in 2017 and the vegetated area decreased to 58.85% in 2017. By the comparison of LST in 1990 and 2017, the areas that show high LST is increased. As the result of the analysis, the changes from non-urban to urban surface highly affected the UHI in Bogor City through the rise of LST.

Keywords: city expansion, land surface temperature, local climate zone, urban heat island

1. Introduction
Urban Heat Island (UHI) is a condition or phenomenon where the atmospheric in the city is warmer than suburban area. Surface and atmospheric modifications due to urbanization generally lead to a modified thermal climate that is warmer than the surrounding non-urbanized areas [1]. To examine the UHI, UHI phenomenon can be observed by using remote sensing data [1, 2, 3]. Voogt and Oke [1] clearly reviewed and described the UHI phenomenon by utilizing remote sensing data.

UHI mainly caused by urban landscape change for urban development which resulted higher land surface temperature (LST) [4]. There are many factors which affect the surface change in urban areas: physical characteristics of the surface (albedo, thermal, and heat capacity), replacement vegetation by asphalt and concrete, urban land cover type [5]; vegetation abundance [6]; and landscape configuration [7]. Others researchers who concern in UHI studies also showed the relationship between LST and urban landscape changes which affect the UHI [6, 8, 9].

Interaction of the urban surfaces with the atmosphere is governed by surface heat flux [5, 10]. The surface energy balance is determined by downward and upward radiation flux, latent, and sensible heat fluxes. The downward flux is determined by the fraction of total radiation reflected and absorbed by the surface. The upward flux follows the Stefan–Boltzmann expression and is determined by the surface’s temperature and emissivity. The energy balance of the surface also determined the LST [10].

Based on the characteristic of the urban surface and its climate interaction, the urban surface is classified with new classification system: “Local Climate Zone” (LCZ) classification by Stewart and Oke [11]. They classified the urban surface based on the surface structure and surface cover...
characteristic related to the climate interaction which was explained previously. Surface structure affects the local climate through modification of airflow, shortwave and long wave radiation balances, and atmospheric heat transport. Surface cover modifies albedo, moisture availability, and heating/cooling potential of the ground.

Regarding the urban development process, population growth has an important role as an internal driving factor of city expansion. Population growth may lead the changes of social characteristics and the intensity of its activities led to rapid changes in urban utilization. Certainly, the rapid changes for urban development affected the higher LST, which then cause the development of UHI. UHI occur in almost all urban areas – large or small size city [11].

As a primary of residential purposes, Bogor City has a strategic location and comfortable climate. In 1745, the Dutch East Indies Governor (Baron Van Imhoff) built the Bogor Palace along with the construction of Daendels Highway which connecting Bogor with Batavia (now is Jakarta metropolitan). That period is the beginning of the development of Bogor City[12,13]. As a satellite city of Jakarta, Bogor City experienced population growth and urban development rapidly in 1990, the populations 272 thousand and in 2015 the population achieved more than one million[14]. This issue brings Bogor city into new environmental challenges; one of them is city expansion which may affect the UHI.

This study focused on utilizing remote sensing to investigate the city expansion and the UHI that reflected by the LST change in different period. The objectives of this study are (1) to analyzed the urban surface change in 1990 and 2017;(2) to analyze the LST change caused by the city expansion; and (3) to analyze the development of the UHI phenomenon. To obtain the LCZ and the LST maps, Landsat images were used in this study.

2. Method

2.1. Study area and materials
The analyzed area is shown in Figure 1. Landsat 5 TM (July 9th1990) and Landsat 8 OLI/TIRS (July 19th2017) were obtained from United State Geographical Survey web page (https://earthexplorer.usgs.gov/), path 122 and row 065. Band 1-5&7 (Landsat 5 TM) and band 1-7 (Landsat 8 OLI) were used for LCZ classification. In addition, band 6 (Landsat 5 TM) and band 10 (Landsat 8 TIRS) were used to analyze the LST. We used projection WGS-84 datum UTM zone 48 South.

2.2. Local Climate Zone (LCZ) classification system
We used LCZ classification system as urban surface categories. LCZ classification was developed and described by Stewart and Oke [11]. LCZ comprises a new and systematic classification of field sites for UHI studies. The classification divides urban and rural landscape, each defined by structural and land cover properties. Surface structure affects the local climate through modification of airflow, atmospheric heat transport, shortwave and long wave radiation balances. Surface cover modifies the albedo, moisture availability, and heating/cooling potential of the ground.

We conducted the classification process in Quantum GIS with Semi-Automatic Classification plug-in. Considering the purposes of this study, we divided LCZ classification into nine categories: (1) Compact low-rise building, (2) Large low-rise building, (3) Roads and paved, (4) Dense trees, (5) Scattered trees and bushes, (6) Low plants, (7) Bare soil, (8) Water, and (9) Cloud. To determine the categories, maximum likelihood classification (MLC) algorithm was used. MLC is a method for determining a known class of distribution as the maximum for a given statistic. Algorithm builds the probability density functions for each category. At classification process, unclassified pixels are assigned membership based on the relative likelihood of that pixel within each category’s probability density function.
Figure 1. Analyzed area. The map is a false color visualization of Landsat 8 OLI on July 19th, 2017. Cross section extractor (10x391 pixels) across the central city is used for investigating the UHI development due to city expansion.

2.3. Data post-processing and accuracy assessment of LCZ classification
Compact low-rise building, large low-rise building, roads and paved are merged as urbanized category. Dense trees, small trees and bushes, and low plants are merged as vegetated area. To identify the errors between categories, we conducted accuracy measurement of LCZ classification. Accuracy assessment of LCZ classification used error matrix which contain actual and predicted classification. Classification of an individual class is user’s accuracy and producer’s accuracy. User’s accuracy is the accuracy obtained by dividing the number of correct pixels of each category by the total pixels that classified in that category. Meanwhile, producer’s accuracy is the accuracy obtained by dividing the number of correct pixels of each category by the total pixels of training data in that category. Then, overall accuracy can be obtained. The formula of producer’s accuracy, user’s accuracy, overall accuracy, and kappa coefficient are described by Pal et al. [15].

2.4. LST measurement from the thermal band and UHI development
LST distribution from Landsat image was obtained by the following the steps below. The formula was obtained from USGS web page (https://landsat.usgs.gov/) and was clearly described in Pal et al. [15]. UHI intensity is calculated as a difference between the spatial temperature obtained from the LST maps. In order to evaluate whether the city expansion influence the UHI, the cross section area was extracted from LCZ and LST change between 1990 and 2017 with 10 x 391 pixels (see Figure 1). Then, the correlations of the LST change and the urban change in 1990 and 2017 was made.

3. Result and Discussion
3.1. Accuracy evaluation of LCZ classification
Table 1 shows the overall accuracy and kappa coefficient of LCZ classification. The overall accuracy of the classified images (1990 and 2017) respectively are 95.02% and 98.94% with kappa coefficient 0.83 and 0.97. Overall accuracy for each period is above 90%, it indicates that the accuracy is high. Overall accuracy in 2017 has the higher value, it is because of the availability of more detailed and higher resolution reference maps. On the other hand, kappa coefficient is above 0.8 for all period
classified images. When kappa coefficient is above 0.8, this value is classified as almost perfect [16] or very good agreement of the accuracy [17].

**Table 1. Accuracy assessment of LCZ classification**

| Year | Overall accuracy (%) | *Kappa coefficient |
|------|----------------------|---------------------|
| 1990 | 95.02                | 0.83                |
| 2017 | 98.94                | 0.97                |

*0-0.20 (slight), 0.21-0.40 (fair), 0.41-0.60 (moderate), 0.61-0.80 (substantial), 0.81-1.00 (almost perfect) [16].

*<0.4 (poor or very poor agreement), 0.4-0.55 (fair agreement), 0.55-0.70 (good agreement), 0.70-0.85 (very good agreement), and >0.85 (excellent agreement) [17].

3.2. LCZ analysis

LCZ classification maps over the entire period is shown in Figure 2 and LCZ statistical analysis in a different year is shown in Table 2. In 1990, vegetated area was predominant land use type (83.98%), but it continuously decreased to 58.85% in 2017. The annual rate of urban expansion is 0.7% (438.69 hectares per year) from 1990 to 2017. Dense trees, farm land, and bare soil are the main resource for city expansion. The city expansion was intense in the center of Bogor City. In suburban area, the city expansion was sparsely and broadly distributed.

![LCZ maps of Bogor](image)

**Figure 2. LCZ maps of Bogor**

**Table 2. LCZ statistical analysis in different years**

| LCZ                  | 1990         | 2017         |
|----------------------|--------------|--------------|
|                      | hectares     | %            | hectares     | %            |
| Urbanized area       | 5846.85      | 9.38         | 16979.4      | 27.24        |
| Vegetated area       | 52337.52     | 83.98        | 36677.79     | 58.85        |
| Bare soil            | 1881.45      | 3.02         | 3284.91      | 5.27         |
| Water                | 2068.38      | 3.32         | 3802.23      | 6.10         |
| Cloud                | 188.28       | 0.30         | 1578.15      | 2.53         |
Total area = 62322.48 hectares; A. Urbanized area is a merge of built-up areas (compact low-rise building, large low-rise building, roads and paved); B. Vegetated area is a merge of green areas (dense trees, small trees and bushes, and low plants).

3.3. LST maps
The spatial pattern of the LST in two periods is shown in Figure 3. The UHI (areas with relatively high LST) scattered in Bogor City. In 1990, mean LST of Bogor City was 23.28 °C and Bogor sub urban (the area without Bogor City in the analyzed area of Figure 1) was 22.51 °C. In 2017, the area that show high LST is increased. Mean temperature of Bogor City was 25.44 °C and Bogor sub urban was 23.75 °C. It indicated that the urbanized area became warmer than other areas and the LST is an impact of urbanization.

Comparing the LST maps with the LCZ maps (Figure 2), the LST change followed the pattern of the LCZ change. Urban heat island mainly concentrated in the central city. From 1990 to 2017, average LST has increased and the temperature difference between Bogor City and Bogor District (suburban) has also increased from 0.77 °C to 1.69 °C. Based on the LST maps, UHI phenomenon in 1990 already occurred at small area inside Bogor City. Thus, UHI phenomenon in 2017 almost covered Bogor City area and spread outside to Bogor sub urban area.

3.4. UHI expansion
The results of the urban change and the LST change are shown in Figure 4. Figure 4A shows the urban change between 1990 and 2017. The horizontal axis is a number of pixels and vertical axis is the degree of non-urban to urban change. The value of 10 vertical pixels is averaged to give the degree. Zero means non-urban in 10 pixels and one means 100% urban in 10 pixels. In 1990, the city area was located near Bogor Botanical Garden, especially in part X and part Yin Figure 4A. Then, there has been the change of the urban surface with the degree of change. The gap between the blue line (1990) and the red line (2017) on part of Z1&Z2 are the example that shows the biggest change of the surface from non-urban to urban. It indicated that the degree of changes from non-urban to urban in the old city center near Bogor Botanical Garden has saturated and it went out to the outer part of the city.

Figure 4 B describes the LST change between 1990 and 2017 (LST of 2017 – LST of 1990). When the gap between urban change degrees was bigger, the LST change increased (see Figure 4B on part of Z1&Z2, and compare with Figure 4A). Z part indicated that in those areas experienced the highest LST change.

The comparison of the LST change with the urban change (from non-urban to urban) from 1990 to 2017 is shown in Figure 4C. By this comparison, the LST increased following the land conversion from non-urban to urban. This result indicated that the surface UHI development has occurred with the city expansion and the increase of the LST.
Figure 4. Urban change and LST change. (A) Urban status in a degree, (B) LST change between 1990 and 2017, (C) Scatter plot of LST change and urban change (from non-urban to urban).

4. Conclusion
Based on the analysis of LCZ and LST, it is found that Bogor has experienced rapid city expansion in the last three decades. In 1990, urbanized area was a little part inside of Bogor City. From 1990 to 2017, the urbanized area continuously increased and the vegetated area decreased. By the comparison of LST between 1990 and 2017, the area that shows high LST increased and it is highly correlated with the city expansion. The changes from non-urban to urban surface highly affected the surface UHI in Bogor City through the rise of LST.
References

[1] Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. Remote Sensing of Environment, 86(3), 370–384. https://doi.org/10.1016/S0034-4257(03)00079-8

[2] Taylor, P., Roth, M., Oke, T. R., & Emery, W. J. (1989). International Journal of Remote Sensing Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology, (November 2014), 37–41. https://doi.org/10.1080/0143116890894002

[3] Streutker, D. R. (2002). A remote sensing study of the urban heat island of Houston, Texas. International Journal of Remote Sensing, 23(March 2015), 2595–2608. https://doi.org/10.1080/01431160110115023

[4] Estoque, R. C., Murayama, Y., & Myint, S. W. (2017). Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. Science of the Total Environment, 577, 349–359. https://doi.org/10.1016/j.scitotenv.2016.10.195

[5] Dousset, B., & Gourmelon, F. (2003). Satellite multi-sensor data analysis of urban surface temperatures and landcover. ISPRS Journal of Photogrammetry and Remote Sensing, 58(1–2), 43–54. https://doi.org/10.1016/S0924-2716(03)00016-9

[6] Weng, Q., Lu, D., & Schubring, J. (2004). Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies. Remote Sensing of Environment, 89(4), 467–483. https://doi.org/10.1016/j.rse.2003.11.005

[7] Patrick, J., Christopher, C., & Chow, W. T. L. (2013). Landscape configuration and urban heat island effects : assessing the relationship between landscape characteristics and land surface temperature in Phoenix , Arizona, 271–283. https://doi.org/10.1007/s10980-012-9833-1

[8] Chen, X. L., Zhao, H. M., Li, P. X., & Yin, Z. Y. (2006). Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. Remote Sensing of Environment, 104(2), 133–146. https://doi.org/10.1016/j.rse.2005.11.016

[9] Rhee, J., Park, S., & Lu, Z. (2014). Relationship between land cover patterns and surface temperature in urban areas. GIScience & Remote Sensing, 51(5), 521. http://doi.org/10.1080/15481603.2014.964455

[10] Benali, A., Carvalho, A. C., Nunes, J. P., Carvalhais, N., & Santos, A. (2012). Remote Sensing of Environment Estimating air surface temperature in Portugal using MODIS LST data. Remote Sensing of Environment, 124, 108–121. https://doi.org/10.1016/j.rse.2012.04.024

[11] Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. Bulletin of the American Meteorological Society, 93(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-0019.1

[12] Indra prahasta, G.S. (2004). The role of sustainable community on developing sustainable city (a case study on Kampoeng Bogor in Bogor City). Bogor: Center for Regional System Analysis, Planning, and Development

[13] Irianti, EF. (2008). The alteration of land use, land cover, and green open space in Bogor City 1905-2005. [Thesis]. Bogor (ID): Bogor Agricultural University

[14] BPS-Statistics of Bogor City. (2017). Bogor City in Figures 2017, 244. https://doi.org/32.710.16.01. Available online: http://bappeda.kotabogor.go.id/images/slidertabs/90f869bc2bc1549f849ce0f02e06f84cd.pdf (accessed on August 19th 2017)

[15] Pal, S., & Ziaul, S. (2017). The Egyptian Journal of Remote Sensing and Space Sciences Detection of land use and land cover change and land surface temperature in English Bazar urban centre q. The Egyptian Journal of Remote Sensing and Space Sciences, 20(1), 125–145. https://doi.org/10.1016/j.ejrs.2016.11.003

[16] Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. Biometrics, 159-174.

[17] Monstersud, R. A., & Leemans, R. (1992). Comparing global vegetation maps with the Kappa statistic, 62, 275–293.