Urban Heat Island Mitigation Strategy based on Local Climate Zone Classification using Landsat 8 satellite imagery

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Abstract. Appropriate strategies on urban climate mitigation should be formulated by considering the physical morphology of the urban landscape. This study aimed to investigate, analyze, and promote possible strategies to mitigate Jakarta's urban heat island (UHI) phenomena. Jakarta's local climate zone (LCZ) was classified into 17 classes using Landsat 8 data and the random forest method. Land surface temperature (LST) characteristic in each LCZ class was analyzed from 2018, 2019 and 2020. The result revealed that most of the local climate zone in Jakarta is dominated by LCZ 6 (open low-rise) and LCZ 3 (compact low-rise), which is the typical residential area in Jakarta. However, the mean LST in 2018, 2019 and 2020 showed that LCZ 3 (compact low-rise) and LCZ 7 (lightweight low-rise) are the areas that were most likely causing high surface temperature with the highest UHI intensity. During the COVID-19 pandemic in 2020, LST in Jakarta decreased drastically in some parts of the area, especially in public facility such as airport. However, the LST value in low-rise areas (LCZ 3 and LCZ 7) remains higher than the other LCZ classes. Materials of the building and land cover play a significant role in raising the land surface temperature. Therefore, mitigation strategies for urban heat islands in Jakarta should be focused on such particular areas mentioned.

1. Introduction

As a capital city, Jakarta faces several problems as an impact of massive urbanization [1]. One of the problems caused by urbanization is Urban Heat Island (UHI) phenomenon [2–4]. Researchers have stated that UHI is related to Jakarta's Open Green Space (OGS) degradation [5,6]. Many OGS and other natural features of the land in Jakarta have been converted into buildings in the past 30 years [7,8].

Mitigation strategies have been proposed to suppress the impact of Urban Heat Island in Jakarta by focusing on the area modification in the centre of UHI. The centre of UHI is determined by calculating the difference in air temperature or land surface temperature between urban and rural areas [9]. The mitigation strategy that can be pursued is the addition of urban forest in the built area [10], but the most important way is the application of appropriate urban planning that takes into account the physical and land morphology (building structures, density, and material) of the city itself, such as the use of green roofs which are proven to reduce surface temperatures [11].

Temperature increases indicating UHI generally occur in areas with the most significant landcover changes [12]. Most studies of UHI are still limited in analyzing the land cover of Jakarta simply by classifying Jakarta into a built and non-built area, using multispectral indices such as Normalized Difference Vegetation Index (NDVI) [13], Difference Built-up Index (NDBI) [14], and Normalize Difference Built-up Index (NDWI) [15]. The study of temperature differentiation between urban
surfaces indicating UHI has long been limited to describing differences between urban, suburban and rural landscapes [16]. UHI studies in Jakarta in previous studies generally only related land use changes to land surface temperatures. As done by Putra et al., who connected data on the increase in surface temperature in Jakarta to land cover data obtained from the Geospatial Information Agency (BIG) [12]. Rushayati, Prasetyo, Puspaningsih, & Rachmawati, also did the same thing with the land cover data obtained from Landsat Satellite [10]. Meanwhile, Estoque, Murayama and Myint using multispectral indices (MNDWI, NDBI and NDVI) to examined LST relationship with the land cover [7]. However, none of the studies mentioned clearly describe urban morphology of Jakarta.

Due to such limitations, a more standardized classification is needed by considering the physical morphology of an urban area. Understanding the physical morphology of the urban landscape can give a valuable insight to find the best solution for urban problems. The aims of this study are: 1) Classify the landscape of Jakarta by considering the urban morphology using the Local Climate Zone method. 2) Analyze the land surface temperature range of each class and calculate the UHI intensity. 3) Propose the possible strategy for mitigation and adaptation based on the actual condition.

1.1 Local Climate Zone

The latest land classification method that considers urban morphology and is specially designed to study UHI is the Local Climate Zone (LCZ). LCZ is a region with similar land surface cover, building construction materials, structures and human activities with a range of 100 meters to several kilometres on a horizontal scale [17]. The LCZ typology is applicable worldwide, in rural and urban environments, and could be very useful in selecting zones to be instrumented when developing urban temperature networks. It gives good results concerning the thermal coherence of its groups [18]. LCZ classification consists of 17 types, including ten types for the built area and seven types for land cover (Figure 1). In this study, LCZ was used in determining the LST variation in Jakarta.
1.2 Land Surface Temperature (LST)

The local climate zone (LCZ) has been widely used to study UHI phenomena combined with the Land Surface Temperature (LST) [19]. Satellite-derived LST from Landsat-8 is able to characterize the spatial heterogeneity of the urban thermal environment at the city level [3]. However, the observation time of Landsat for each city is fixed, which limits the records of temporal variations of LST [16]. Furthermore, Landsat does not obtain nighttime images. Therefore, the diurnal variations of LST at the community or neighborhood scale within city areas have remained unexplored due to the inherent data inadequacies. This gap could be addressed by integrating LST observation from fixed-point air temperature measurements. Fixed-point air temperature measurements such as from Automatic Weather Stations (AWS) generally have a high temporal resolution (10 minutes) with extensive time coverage and thereby can well explore the temporal variations of the thermal environment. However, due to the limited access and the number of observation instruments and stations available, in this study, the spatial analysis of spatial intra-urban temperature variation is only using LST data retrieved from the Landsat satellite.

1.3 UHI Intensity

The term of Urban Heat Islands intensity is equivalent to Urban Heat Signature, which explains different temperature built-up area and surface with vegetation [20]. Comparisons between the UHI intensity within different LCZ types revealed the significant influence of land coverage and surface structure properties on the local thermal environment [21]. According to the thermal characteristics of different urban structures, future cities will be managed and planned to mitigate the urban heat island.
The results of this study can be useful for city planners and decision-makers in developing appropriate spatial planning strategies for the city in a tropical climate similar to Jakarta.

2. Data and Methodology

2.1 Region of Interest (ROI)
Jakarta is the capital city of Indonesia, one of the megacities in Asia and has been rapidly urbanized. Jakarta is located between 5° 19’ 12” - 6° 23’ 54” S and 106° 22’ 42” - 106° 58’ 18” E. The land area of Jakarta is 662.33 km² with a population in 2019 reaching 11 million people [22]. The population predicted will reach more than 15 million in the next decade. With the rapid population increase, the urban area also expanded rapidly, which may have strongly affected the local climate of the area.

![Study Area](image)

**Figure 2. Study Area**

2.2 Data
This study uses Landsat 8 Collection 1 Tier 1 Top of Atmosphere Reflectance with 30-meter spatial resolution obtained from the United States Geological Survey (USGS). The Landsat 8 images in 2018, 2019 and 2020 were sorted to find the least percentage of cloud cover land to determine Jakarta’s LCZ and LST spatial distribution. Summer was the typical period employed to analyze LST and LCZ comparisons because cloud cover and their shadows can impact misclassification [23]. The images used are Landsat 8 on the recording as in the table at path 122 and row 64. The details of the Landsat 8 Satellite used in this study are described in Table 1.

| Image Date   | Sensor              | Cloud Cover Land Percentage (%) | Bands for LCZ Classification | Thermal Bands for LST |
|--------------|---------------------|---------------------------------|------------------------------|------------------------|
| 06/07/2018   | Landsat 8 OLI/TIRS  | 0.04                            | 1-7                          | 10                     |
| 25/07/2019   | Landsat 8 OLI/TIRS  | 0.06                            | 1-7                          | 10                     |
| 22/04/2020   | Landsat 8 OLI/TIRS  | 3.2                             | 1-7                          | 10                     |

2.3 Method
2.3.1 LCZ Mapping
The urban landscape classification in this study adopted the LCZ scheme by Stewart and Oke [17]. The recent and most widely used method for LCZ mapping was following the World Urban Data Access Portal Tools (WUDAPT) protocols [24–28]. WUDAPT is a tool to map the physical geography of cities worldwide using a standard classification scheme, Landsat data and crowdsourced knowledge [29]. The basic procedure of WUDAPT is to apply the Random Forest classifier to map LCZs from remote sensing data [30,31].
In this study, the multiband (band 1-7) Landsat 8 remote sensing data was retrieved and classified all at once by utilizing the online cloud platform named Google Earth Engine (GEE). The training sample area within the ROI was digitized from the Landsat 8 guided by the google earth view. There are 170 training area samples for all 17 classes of LCZ (10 samples for each class). Then, the rest of the area in ROI is classified by the random forest (RF) machine learning classifier. To validate the accuracy of the RF algorithm, cross-validation was conducted in this study. 70% of the training sample data are used for building the model, and 30% of the sample are used for validation. The performance of the RF algorithm was evaluated from the value of overall accuracy (OA). The workflow of the LCZ mapping can be seen in Figure 3.

2.3.2 LST Retrieval
A single channel approach using Band 10 of Landsat 8 was used to retrieve land surface temperature (LST) from thermal infrared data [32]. The procedures consist series of conversions, including digital numbers to radiances, radiances to brightness temperatures and finally, brightness temperature to land surface temperature (emissivity correction). These methods were also requiring normalized difference vegetation index (NDVI). NDVI value of 0.2 was used for a pure soil pixel and 0.5 for a pure vegetation pixel. LST obtained from Landsat-8 shows the current condition of the urban canopy layer and surface material in the study area. It causes different temperature values in the same LCZ classes. To establish the link between LCZ and LST, spatial overlay of the two maps and data extraction using the zonal statistics tool in ArcMap 10.7.1 was used. Using the zonal statistics tool, we retrieved the average LST for each LCZ [33]. The formula used for LST retrieval is given below [34]:

\[ LST = \left[ \frac{BT}{1 + W \left( \frac{p}{T} \right)} \right] - 273.15 \quad (1) \]

Where BT is the brightness temperature of Band 10 (K), W is the wavelength of emitted radiance (11.5µm), p is radiation Constanta (1.438 x 10^2 mK), e is emissivity. The result was subtracted by 273.15 to convert the LST value from Kelvin to Celcius.

3. Results and Discussion
3.1 Spatial distribution and performance evaluation of LCZ in Jakarta
Jakarta has various landcover with major fractions of built-up areas. The division of 17 LCZ classes spread throughout Jakarta. However, based on the composition area distribution, Jakarta is dominated by LCZ type 6 (open low-rise building) and LCZ 3 (compact low-rise). LCZ 6 and LCZ 3 was the predominant class covering up to 30% of the region. LCZ 6 (open low-rise) and LCZ 3 (compact low-rise) depict the typical housing building in Jakarta, representing a 1-3 stories tall building with few or no trees (LCZ 3) and low plants or scattered trees (LCZ 6). LCZ 3 is a prevalent residential area with
densed population which distributed largely in the central and north Jakarta around Kemayoran, Percetakan Negara, Cikini, Sunter, Mangga Besar and Tanjung Priok. In the west and east Jakarta, LCZ 3 is found in Kebayoran Lama, Cipinang, Pasar Minggu and along the side area of ciliwung river. Meanwhile, LCZ 6 is mainly found in southern Jakarta in the area around bintaro and menteng.

LCZ 7 (Lightweight low-rise) is an area of dense mix single-story buildings with few or no trees. This is the third predominant type of LCZ in Jakarta that occupies 59,1 Km² which spread largely in the north and west Jakarta region. Compact high rise buildings (LCZ 1) was identified in the heart of the city placed in the Sudirman Central Business District (SCBD) with an area of 44,8 km². Heavy Industry (LCZ 10) was identified in the eastern part located in pulogadung industrial centre. Comparison between built-up area (LCZ 1-10) and natural landcover type (LCZ A-G) is starkly different. The built-up area occupies 87% of the total area. Meanwhile, natural land cover only takes 13% (around 88,5 Km²). Natural landscapes such as trees (LCZ A and B) are generally found in southern and east Jakarta near Halim Perdanakusumah Airport. On the other hand, LCZ C (Bush, Scrub) and D (Low plants) were particularly discovered in northeast Jakarta.

Table 2. Landsat 8 Satellite Data Description

| LCZ | Types                  | Area (Km²) |
|-----|------------------------|------------|
| 1   | Compact High Rise      | 44,8       |
| 2   | Compact Midrise        | 12,7       |
| 3   | Compact Low-Rise       | 123,9      |
| 4   | Open High-Rise         | 11,9       |
| 5   | Open Midrise           | 50,1       |
| 6   | Open Low-Rise          | 191,8      |
| 7   | Lightweight low-rise   | 59,1       |
| 8   | Large low-rise         | 29,4       |
| 9   | Sparsely built         | 9,1        |
| 10  | Heavy Industry         | 21,6       |
| A   | Dense Trees            | 3,0        |
| B   | Scattered Trees        | 30,2       |
| C   | Bush, Scrub            | 17,7       |
| D   | Low Plants             | 12,3       |
| E   | Bare Rock or Paved     | 12,1       |
| F   | Bare Soil or Sand      | 5,7        |
| G   | Water                  | 7,5        |
| **TOTAL** |                       | **642,9**  |

Figure 4. LCZ Map of Jakarta
Figure 5 presents the classification confusion matrix to show the variation of the accuracy, including producer’s accuracy (PA), User’s accuracy (UA) and Overall Accuracy (OA) of each LCZ class. The classification was carried out using the random forest method with very good and reliable results, indicated by the overall accuracy value reaching 94.6% and the kappa coefficient value 0.95.

![Confusion matrix for LCZ Classification in Jakarta](image)

### 3.2 LST Spatial Distribution

The distribution of land surface temperatures obtained from Landsat 8 satellite imagery shows different ranges from 2018, 2019 and 2020. This could be due to differences in the month and date of data collection, which have an impact on differences in solar insolation. In 2018, the land surface temperature range was between 20-41 degrees Celsius, while in 2019, the LST ranged from 25-39 degrees Celsius. In 2020, the maximum of LST was much lower than the two previous years. Analyzed from the data acquired date, Landsat 8 image in 2020 was taken in April where the sun’s position was in the south near the equator, or closer to Jakarta than the previous two years, which was taken in July. In general, the smaller the latitude between the sun and a location, the greater the solar energy absorbed by the earth’s surface so that the LST on the surface tends to be higher. So, there is an assumption that the decrease in temperature in 2020 is influenced by anthropogenic factors related to the ongoing covid-19 pandemic.
In general, from the three datasets, high-temperature centres were observed specifically in several regions. While low temperatures are observed in areas with natural land covers such as trees and water bodies. The most striking temperatures are seen in residential areas and airports. However, in 2020, the temperature in the airport area decreased significantly due to reduced public transportation activities. This can be evidence that anthropogenic factors within the city strongly influence urban temperature.

### 3.3 Statistical Analysis of LCZ and LST

Each LCZ classes have different LST individual characteristic [17]. Therefore, the analysis of the LST signature for each LCZ type is essential to understand the relationship between LST and LCZ. The zonal statistic analysis carried out by ArcMap software is able to show the LST range, mean, standard deviation, minimum and maximum value from each LCZ class. Figure 7 below shows descriptive statistics of LST per LCZ in 2018, 2019 and 2020.
Figure 7. LST Map of Jakarta retrieved from Landsat 8 for (a) 2018, (b) 2019 and (c) 2020

It can be found that in 2018, the highest mean LST (35.6 °C) were recorded by compact low-rise (LCZ 3), followed by open midrise LCZ 5 (34.8 °C), lightweight low-rise LCZ 7 (34.7°C) and open low rise (LCZ 6) with 34.2°C. Landcover types tend to have lower mean LST than building types except for bare rock or paved (LCZ E) with 33.8 °C. Water (LCZ G) had the lowest mean LST (29.2 °C).

In 2019, the highest mean LST (33.4 °C) also occurred in compact low-rise buildings (LCZ 3), followed by open mid-rise buildings LCZ 5 (32.8 °C) and lightweight low-rise building LCZ 7 (32.5 °C). Bare rock or paved area (LCZ E) and bare soil or sand (LCZ F) as landcover types have mean LST as high as building types (32.4 °C and 32.1 °C), while dense tree (LCZ A) and water (LCZ G) corresponded to the two lowest mean LST (28.9 °C and 28.5 °C).

In 2020, the highest mean LST (30.5 °C) was again identified in compact low-rise building (LCZ 3) followed by lightweight low-rise building LCZ 7 (30.2 °C), open mid-rise LCZ 5 (29.8 °C), Bare rock or paved LCZ E (29.7 °C), large low-rise building LCZ 8 (29.6 °C) and Heavy Industry (29.6 °C). For natural landcover, water (LCZ G) had the lowest mean LST (26.0 °C).
3.4 UHI mitigation and adaptation strategy

Figure 8 shows the mean LST values for 2018, 2019 and 2020. It can be identified that the type of building (LCZ 1-10) has a higher mean LST compared to natural land cover (LCZ A-G), except for LCZ E (bare rock or paved) and LCZ F (bare soil and sand). Water (LCZ A) has the lowest LST, and dense tree (LCZ G) was the second-lowest mean LST.

Adaptation and mitigation strategies to the UHI phenomenon in Jakarta can be done by determining the centre of UHI intensity. Table 3 shows the order of the highest to lowest mean LST in each LCZ class.

![Figure 8. Mean LST for each LCZ classes in Jakarta](image)

| LCZ | Types                        | Mean LST |
|-----|------------------------------|----------|
| 3   | Compact Low-Rise              | 33.1     |
| 7   | Lightweight low-rise          | 32.5     |
| 5   | Open Midrise                 | 32.4     |
| E   | Bare Rock or Paved           | 32.0     |
| 6   | Open Low-Rise                | 32.0     |
| 8   | Large low-rise               | 31.8     |
| 2   | Compact Midrise              | 31.7     |
| 10  | Heavy Industry               | 31.7     |
| 1   | Compact High Rise            | 31.4     |
| 4   | Open High-Rise               | 31.4     |
| F   | Bare Soil or Sand            | 31.0     |
| 9   | Sparsely built               | 30.6     |
| B   | Scattered Trees              | 30.1     |
| D   | Low Plants                   | 29.6     |
| C   | Bush, Scrub                  | 29.5     |
| A   | Dense Trees                  | 28.4     |
| G   | Water                        | 27.9     |

It can be seen in table 3 that LCZ 3 (compact low-rise building) is the area with the highest temperature among others, or also known as UHI intensity. Compact low-rise consists of 1-3 stories tall buildings, commonly found in densely populated residential areas in Jakarta. There are few or no trees within the area and the land cover mostly paved. High LST in LCZ 3 can be caused by building materials and characteristics. The building material consists of stone, brick, tile and concrete construction material. This material usually absorbs heat during the day and emits the heat into the surface layer at night.
Figure 9. Compact low-rise (LCZ 3) buildings located in a residential area near Bendungan Jago, Central Jakarta

The next building type that contributes the highest LST is the lightweight low-rise (LCZ 7), followed by an open mid-rise building (LCZ 5). Lightweight low-rise (LCZ 7), as seen in figure 10, is an area of a dense mix of single-story buildings with few or no trees. Land cover is mostly hard-packed, and the construction materials are composed of wood, thatch, or corrugated metal. Materials made of metal can reflect more heat into the air, thereby increasing the heat stress. Open mid-rise buildings (LCZ 5), as seen in figure 11, is an open arrangement of mid-rise buildings (3-9 stories) with an abundance of previous landcover (low plants, scattered trees). The material of LCZ 5 consists of concrete, steel, stone, and glass construction materials.

Figure 10. Lightweight low-rise (LCZ 7) buildings as seen in residential area near Kapuk, West Jakarta

Figure 11. Open mid-rise (LCZ 5) buildings in the governmental office area near the veteran street, Central Jakarta

Thus, implementing urban planning for central areas of this mega-urban region should be paid more attention to, particularly for compact low-rise types and lightweight low-rise, since this type has extensive coverage and relatively have higher LST among the built types. It also potentially has more
impact on the thermal environment. The areas of LCZ 3 (compact low-rise) and LCZ 7 (lightweight low-rise) should be modified with a proper greenery plan in between.

Mitigation strategies, including a combination of shading and ventilation, green roofs option, garden cities, maintaining air quality, and anthropogenic heat, can be considered to reduce the impact of Urban Heat Island in Jakarta. Shading and ventilation are the typical approaches to mitigate the UHI impact in the tropics [35]. Shading from buildings or trees in the tropics is very important. High-rise compact building forms such as a block of towers have a great potential to shade the urban environment [36]. Scattering tall buildings also give better ventilation at pedestrian level. Careful arrangement of the nature and scope of shading may be needed to minimize the nighttime heat island effect and maximize ventilation. As a matter of fact, Jakarta only has a few high-rise buildings and is only located centrally in the SCBD area.

Nevertheless, the interaction between many mitigation strategies should consider the state of air pollution and internal heat gain within the city. The windows will be shut in the absence of good air quality, and internal and solar gains will rise. Anthropogenic heat in the urban area is also one of the significant factors that contributed to the UHI. In this study, the anthropogenic effect has been pointed out by the differences of LST in Halim Perdana Kusuma Airport before and during pandemic Covid-19. The temperature in the airport and surrounding area was decreased 8 °C (Figure 12).

![Figure 12. LST temperature difference during (2020) and before the pandemic Covid-19 (2018).](image)

In compact low-rise buildings such as LCZ 3 and LCZ 7, the solar gain will largely occur via the roof, and the application of cool building material is very essential. A well-designed roof and building material could have a significant impact on the anthropogenic heat released. The experimental study in Singapore found that using cool roofs material could lead to daytime temperature reduction [35]. The efforts of UHI mitigation in urban planning requires support from local government and institutional framework. LCZ method could be used practically to identify the characteristics of the city landscape by defining LCZ based on the specific morphology and planning the maximum future development. This study still requires a lot of supporting data to be able to describe urban conditions in more detail, namely: building height, sky view factor (svf), meteorological data (wind, humidity and air temperature). Simulations are also needed to have a better understanding of the impact of the various mitigation efforts mentioned above. It is necessary to find out the effectiveness of the mitigation strategies.

4. Conclusion

The spatial distribution of LCZ in Jakarta can be identified using Landsat 8 satellite by employing the random forest algorithm. The spatiotemporal relationship between LCZ and LST is beneficial for understanding the urban structure and characteristics to minimize the negative impact of urbanization. UHI mitigation in Jakarta to prevent the negative impacts of climate change must focus on densely
populated areas (LCZ 3 and LCZ 7). These areas have a relatively higher temperature among others, due to miss-arrangement of spatial layout and poor selection of building materials. The addition of green space and cool roofs material is likely can be beneficial to reduce the daytime temperature within the area.

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