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Local Climate Zone classification for climate-based urban planning using Landsat 8 Imagery (A case study in Yogyakarta Urban Area)

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Abstract. Urbanization of the last decade contributed to the urban morphological changes in Yogyakarta Urban Area (YUA). These conditions have an impact on local climate zone variations. There is an urgent need for enhanced climate-based urban planning. This study aims to: 1) Classify the Local Climate Zone (LCZ) in YUA using the World Urban Database Access and Portal Tool (WUDAPT) method, and 2) develop climate-based urban planning recommendations of the classification results. WUDAPT method used in this research based on the concept of LCZ framework by utilizing Landsat 8 imagery. LCZ classification of the whole area is determined using random forest classifier algorithm by SAGA GIS. The results of this study indicate that there are 12 LCZs in YUA, consisting of 6 types of LCZ based on building type and 6 LCZs based on land cover type. The highest increase of LST are in LCZ 3 and LCZ 5. Consequently, there's a change in diurnal temperature from low to medium. Therefore, the thermal comfort aspect define by four components of LCZ is important in YUA urban planning strategy.

1. Introduction

Over the past three decades, Indonesia has experienced a substantial urbanization. The number of Indonesian people living in urban areas has increased from 42% in 2000 to 49.8% in 2010 [1]. Based on National Development Planning Agency (Bappeda), 66.6% of Indonesian population will live in urban areas by 2035. The level of urbanization for some provinces, especially in Java and Bali are already higher than in all of Indonesia. The highest urbanization rate with percentage above 80% is in four provinces in Java; DKI Jakarta (100%), West Java (89.3%), Banten (84.9%), and Yogyakarta Special Region (84.1%) [2].

In the Special Region of Yogyakarta, a high level of urbanization goes according to its function as a student and tourist city. Therefore, population growth and urban activities are also increasingly high, demand greater land requirements. Land use change in the term of urban physical development become undeniable. Yogyakarta City experienced massive acceleration of physical development in urban areas due to the urbanization process. From 2006 to 2009, the changes of open land into settlements and built land reached 442.61 ha [3].

The characteristics of urban development during the urbanization process are identical with extensive paving, intensive physical development both vertically and horizontally, accompanied by emissions from various pollutants that have a major influence on changes in the natural conditions of urban areas. As a result, several environmental problems such as Urban Heat Island (UHI), pollution and air quality degradation will directly affect the lives of urban residents. The vulnerability to



disasters will be higher along with the high concentration of population, infrastructure and socio-economic activities, especially the vulnerability to climate disasters. If mitigation is not immediately carried out, this condition can lead to the emergence of various climate disasters [4].

1.1. The need of applying the LCZ classification system in Yogyakarta Urban Area

In mitigating climate disasters and undesirable changes during the urbanization process, every urban area in the world has a different capacity and response. This is due to the differences in the background of political culture, economic base, and social conditions of the population. Likewise in climate-based urban planning. Developed countries and developing countries have significant differences in spatial planning in urban areas. In supporting the planning process, developing countries generally have limited availability of urban data, while in developed countries urban data is easily accessible by open source. Therefore, standardization of the information is needed regarding urban data that can describe urban landscape, globally implemented in all urban areas both in developed or developing countries. This standardization is then used as a guide in the study of urban climate and planning throughout the world.

Although there are plentiful of previous studies have revealed the impact of urban physical development on the local climate, the findings of the study have limited influence on the urban planning process [5][6]. This is because there are obstacles between researchers and planners, specifically the differences in the availability of information at different scales [7]. In a climate perspective, the information needed to determine differences in the spatial characteristics of the region's climate in urban areas are the form of the city and the function of the city. The form of the city is described through land surface cover, building construction material, and urban morphology. The function of the city is described based on its function, for example as a residential, commercial building, or industrial area. Ideally, both information are spatially-temporally collected and analysed. In the final stage, the right recommendations were found to overcome changes due to the urbanization process.

Yogyakarta is one of the city in a tropical country with a high level of urbanization, the role of LCZ in determining LST variations in YUA is interesting. The higher the level of urbanization, the higher the growth of urban areas. This will also increase LST. The threat of stress, thermal discomfort, increased energy demand because the use of air conditioning has a direct impact on the lives of residents of the YUA region. The threat is not only for now, but also in the future.

1.2. LCZ Mapping Method

The World Urban Database and Portal Tool (WUDAPT) is a community-based project collecting data in urban areas around the world using the Local Climate Zone (LCZ) scheme. 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 [8]. Tools and materials used in the LCZ classification can be obtained free of charge (open source), namely Landsat, Google Earth Pro, and SAGA GIS. LCZ has been widely applied, developed and modified in urban areas in various countries, both developed and developing countries.

Developed countries usually apply LCZ level 1 (detail) and level 2 (very detailed), while in developing countries it is better to apply LCZ level 0 because of the limited data availability and government policies [9]. There are 17 types of LCZ, including ten built types (LCZ 1-10), and seven land cover types (LCZ A-G) [10]. The selected training areas used by SAGA GIS [11] to automatically classify the pixel using random forest classifier algorithm [12].

Considering that Yogyakarta is one of the cities in a tropical country with a high level of urbanization, the role of LCZ in determining the local climate of the urban area of Yogyakarta and its surroundings is quite interesting. The final results of this study are to classify the LCZ in Yogyakarta Urban Area and its surrounding using the World Urban Database Access and Portal Tool (WUDAPT) method and develop climate-based urban planning recommendations of the classification results.

2. Data and Methodology

2.1. Study Area

This research was conducted in urban areas of Yogyakarta City and the expansion of the surrounding area (7°32'24.30"S - 8°2'50.02"S and 110°6'31.63"E-110°39'1.77"E) which was influenced by urbanization, precisely inside the ringroad area. This boundary is used to determine Region Of Interest (ROI). Based on the WUDAPT protocol, the ROI should contain the entire urbanized area with a buffer of about 20 km around this area. The ROI should not be smaller than 50 km in each direction. The study area in the research that has been described above is called Yogyakarta Urban Area (YUA) and its surroundings.

2.2. Data

Landsat 8 Level 1 image with 30 m spatial resolution downloaded from the United States Geological Survey (USGS) page. Since Landsat 8 was launched in 2013, not all the images at each recording time are good and right to use. Those which have less cloud coverage are better. The presence of the clouds and their shadows can cause misclassification and false detection of land cover [13].

Table 1. Description of Landsat images that were used in this study

Image Acquisition Date	Sensor	Bands for LCZ Classification	Thermal Bands
18 May 2017	Landsat 8 OLI/ TIRS	1-7	10
5 May 2018	Landsat 8 OLI/ TIRS	1-7	10

To determine changes in LCZ and LST spatial distribution for one year, the images used are Landsat 8 on the recording as in the table at path 120 and row 65. This satellite images were preferred due to the less cloud coverage leading to more intensified results of this LCZ and LST mapping [14].

2.3. LCZ mapping and validation

2.3.1. LCZ Mapping method

Basically, the LCZ classification requires detailed urban morphological data. However, these data are often difficult to obtain due to the limitations of technology and government policies, especially in developing countries such as Indonesia. This study follows the World Urban Database and Access Portal Tools (WUDAPT) methods proposed by Bechtel et al. [15] using SAGA GIS to do LCZ classification. The LCZ classification mapping workflow starts with determining the Region of Interest (ROI) in Google Earth Pro. After ROI was determined, the next step is to digitize the training area. In the process of digitizing the training area, aspects of the shape and function of the city must be considered, then categorize into one of the 17 categories of LCZ according to the type of building and land cover [16]. Users only need to digitize several training areas in each category, because the overall area is classified by the random forest classifier algorithm based on the specified training area. The more training areas, the more accurate the classification results.

2.3.2. LCZ Classification

In the process of digitizing the training area, aspects of the form and function of the city must be considered. Below (table 2) are 17 LCZ categories according to building type and land cover type.

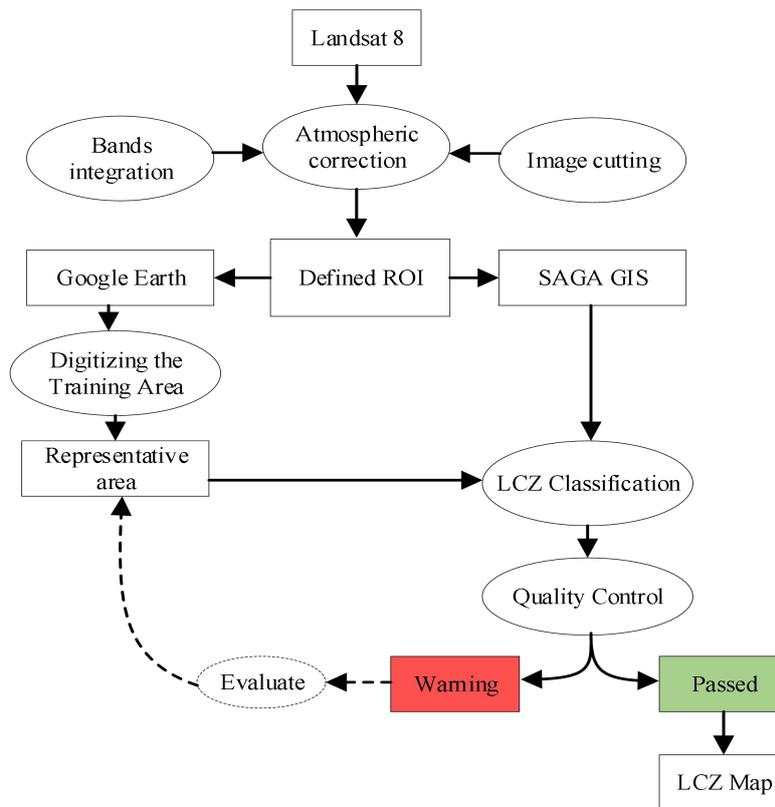
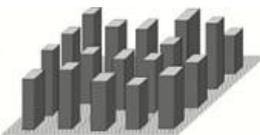
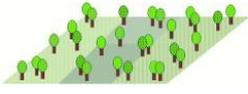
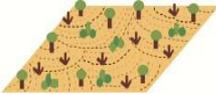


Figure 1. Research flowchart

Table 2. LCZ Classification
(Source:Steward & Oke (2012))

Building Type	Definition	Land Cover Type	Definition
LCZ 1: Compact high-rise 	<ul style="list-style-type: none"> - tightly packed buildings to tens of stories tall - few or no trees - little or no green space - concrete, steel, stone and glass construction materials - small diurnal temperature range 	LCZ A: Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
LCZ 2: Compact mid-rise 	<ul style="list-style-type: none"> - tightly packed buildings of 3 to 9 stories tall - few if any trees - little or no green space - stone, brick, tile and concrete construction materials - small diurnal temperature range 	LCZ B: Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
LCZ 3: Compact low-rise 	<ul style="list-style-type: none"> - tightly packed buildings of 1 to 3 stories tall - few or no trees - little or no green space - concrete, steel, stone and glass construction materials - diurnal temperature range is medium 	LCZ C: Bush, scrub 	Open arrangement of bushes, shrubs and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture

LCZ 4: Open high-rise	<ul style="list-style-type: none"> - openly arranged buildings tens of stories tall - abundance of trees and pervious cover (low plants) - concrete, steel, stone and glass construction materials - small diurnal temperature range 	LCZ D: Low plants	<p>Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.</p>
LCZ 5: Open mid-rise	<ul style="list-style-type: none"> - openly arranged buildings of 3 to 9 stories tall - abundance of trees and pervious cover (low plants) - concrete, steel, stone and glass construction materials. - medium diurnal temperature range 	LCZ E: Bare rock or paved	<p>Featureless landscape of rock or paved cover. Few or no trees. Zone function is natural desert (rock) or urban transportation.</p>
LCZ 6: Open low-rise	<ul style="list-style-type: none"> - openly arranged buildings of 1 to 3 stories tall - abundance of trees and pervious cover (low plants) - wood, brick, stone, tile and concrete construction materials 	LCZ F: Bare soil or sand	<p>Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.</p>
LCZ 7: Lightweight low-rise	<ul style="list-style-type: none"> - lightweight building materials of 1 to 2 stories tall - few or no trees - land cover hard-packed - large diurnal temperature range 	LCZ G: Water	<p>Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs and lagoons.</p>
LCZ 8: Large low-rise	<ul style="list-style-type: none"> - large, openly arranged buildings of 1 to 3 stories tall - few if any trees - land cover mostly paved - medium diurnal temperature range 	Variable Land Cover Properties	
		<p>Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.</p>	
LCZ 9: Sparsely built	<ul style="list-style-type: none"> - sparse arrangement of small or mid-sized buildings - natural setting - abundance of pervious cover - large diurnal temperature range 	b. bare trees	
		<p>Leafless deciduous trees (e.g. winter). Increased sky view factor. Reduced Albedo.</p>	
LCZ 10: Heavy industry	<ul style="list-style-type: none"> - Low-rise and mid-rise industrial structures (towers, tanks, stacks) - few or no trees - land cover mostly paved or hard-packed - metal, steel and concrete construction materials 	s. snow cover	
		<p>Snow cover > 10 cm in depth. Low admittance.</p>	
		d. dry ground	
		<p>Parched soil. Low admittance. Large Bowen ratio. Increased albedo</p>	
		w. wet ground	
		<p>Waterlogged soil. High admittance. Small Bowen ratio. Reduced Albedo.</p>	

2.3.3. Validation of LCZ

Choosing the right method and representative training area is very important for LCZ classification and subsequent accuracy assessment. The selection of training area polygons is very dependent on the knowledge of local experts. Everyone has various cognitive interpretations of the urban landscape, this can significantly affect the results of classification and accuracy. Bechtel et al. [17] shows this in the LCZ HUMINEX (Human Influence Experiment). Validation in this study was carried out by reviewing the results of the LCZ generating from SAGA GIS by random forest classifier algorithm. Random forest classifier algorithm chosen due to its high accuracy and computational performance

[18]. Validation is done to get a good distribution, therefore the role of local expertise here is highly important. Checking the LCZ results is done by validating the results of the LCZ mapping with the existing conditions in Google Earth Pro to obtain a good LCZ distribution.

2.3.4. LST retrieval

Remote sensing is a method commonly used for analysis and visualization of LST in a relatively wide area of observation due to its ability to provide tight spatial data with good accuracy and wide area coverage [19]. Previous research uses a single channel algorithm to retrieve LST from satellite image data because it is relatively simple and has high accuracy [20]. In this study, LST acquisition was obtained using SAGA GIS. Here are the equations in LST calculations.

$$LST = TB_{10} + C_1(TB_{10} - TB_{11}) + C_2(TB_{10} - TB_{11})^2 + C_0 + (C_3 + C_4W)(1 - X_\varepsilon) + (C_5 + C_6W)\Delta\varepsilon \quad (1)$$

Where the $C_0 - C_6$ are *Split Window Coefficients*, TB is the number of the thermal band (K), X_ε is the number of LSE mean of thermal band, W is the atmospheric water vapour content = 0,013 and $\Delta\varepsilon$ is the difference between LSE.

3. Results and Discussion

3.1. Result

Based on the classification results, Yogyakarta and its surroundings consist of 13 LCZs. The description is at the point below.

3.1.1. LCZ Maps

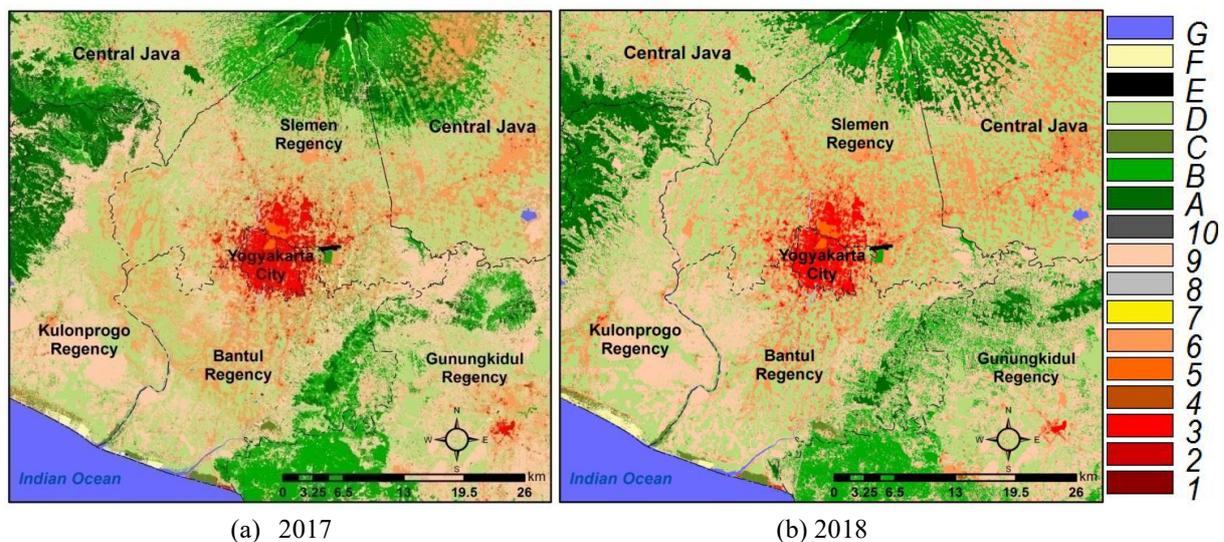


Figure 2. LCZ Maps Yogyakarta and its surrounding area

On the map, it may not seem obvious that there is a difference if seen at a glance. But more thoroughly, there are clear differences. The following (table 3 and table 4) are the description.

Table 3. LCZ percentage in Yogyakarta and its surrounding area 2017

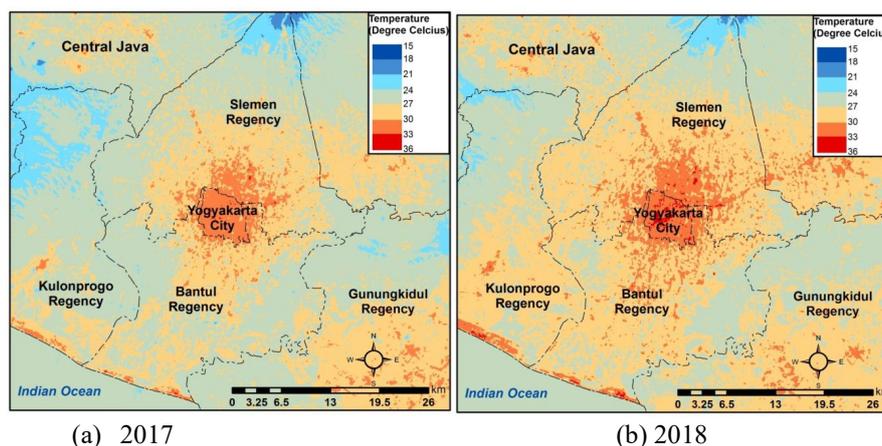
LCZ 2017	Area (%)		
	Yogyakarta City (Administrative)	Inside the ring road	Outside the ring road
LCZ 2	4.66%	0.5%	0.1%
LCZ 3	76.71%	35.3%	7.0%
LCZ 5	8.58%	11.9%	2.3%
LCZ 6	4.95%	27.3%	34.9%
LCZ 8	1.69%	7.2%	3.1%
LCZ 9	0.12%	2.6%	17.2%
Σ Building Type	96.72%	84.82%	64.5%
LCZ A			0.3%
LCZ B	0.11%	1.4%	2.3%
LCZ C	1.43%	2.5%	1.9%
LCZ D	0.31%	6.5%	27.4%
LCZ E	0.59%	0.2%	0.6%
LCZ F	0.81%	4.3%	3.0%
LCZ G	0.03%	0.3%	0.3%
Σ Landcover Type	3.28%	15.18%	35.5%

Table 4. LCZ percentage in Yogyakarta and its surrounding area 2018

LCZ 2018	Area (%)		
	Yogyakarta City (Administrative)	Inside the ring road	Outside the ring road
LCZ 2	4.76%	0.49%	0.06%
LCZ 3	70.23%	29.17%	5.94%
LCZ 5	8.35%	10.14%	1.56%
LCZ 6	11.18%	38.09%	39.84%
LCZ 8	2.25%	5.48%	2.36%
LCZ 9	0.20%	2.36%	12.59%
Σ Building Type	96.97%	85.72%	62.36%
LCZ A			0.05%
LCZ B	0.09%	0.88%	1.67%
LCZ C	1.48%	1.50%	1.11%
LCZ D	0.38%	9.85%	32.71%
LCZ E	0.37%	0.17%	0.62%
LCZ F	0.61%	1.71%	1.30%
LCZ G	0.10%	0.16%	0.18%
Σ Landcover Type	3.03%	14.28%	37.59%

Generally, Yogyakarta and surrounding areas have 13 LCZs classes consisting of 6 LCZs based on building type, and 7 LCZs based on land cover. Urban areas (administrative and inside the ring road) do not have LCZ A in the form of dense tress. Dense trees are only in the outside of ring road area. Based on the table above, the three areas are dominated by LCZ based on the building type. In 2017, the developed area of Yogyakarta City increased by 0.25% from 96.7% in 2017 to 96.97% in 2018. Conversely, the type of natural land cover decreased by 0.25% from 3.28% in 2017 it became 3.03% a year after that.

3.1.2. LST Maps

**Figure 3.** LST Maps of Yogyakarta Urban Area and its surrounding

In just one year, Yogyakarta and surrounding areas experienced a temperature increase. From figure 3, the Urban Heat Island (UHI) phenomenon is also clearly visible. By using LCZ and LST schemes, this can be further investigated in the future studies.

Table 5. LST in each area

Area	LST 2017	LST 2018	Temperature Increase (°C)
Yogyakarta City (Administrative)	32.1	32.7	0.6
Inside the ring road	30.6	31.3	0.7
Outside the ring road	28.8	29.7	0.9

3.1.3. LCZ and LST Map in Yogyakarta City Administrative and Inside the Ring road

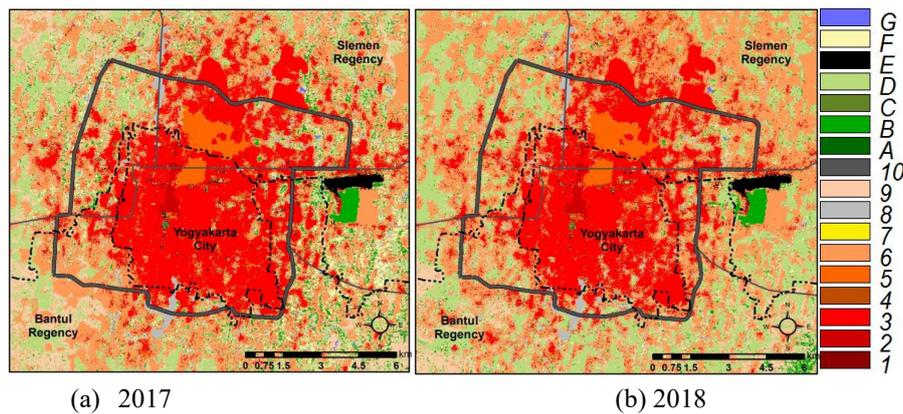


Figure 4. LCZ maps in Yogyakarta City Administrative and Inside the Ring road

This part is the focus of analysis in urban areas of Yogyakarta (administrative and in the ring road) without the area outside the ring road. If analyzed in depth only in urban areas, namely the administrative area of Yogyakarta and inside the ring road of Yogyakarta, LCZ percentage can be observed in the following table.

Table 6. LCZ percentage in Yogyakarta City Administrative and Inside the Ring road

LCZ Classes	Area (%)			
	Yogyakarta City (Administrative)		Inside the Ring road	
	2017	2018	2017	2018
Building Type				
Compact midrise (LCZ 2)	4.66%	4.76%	0.49%	0.53%
Compact low-rise (LCZ 3)	76.71%	70.23%	29.17%	35.26%
Open midrise (LCZ 5)	8.58%	8.35%	10.14%	11.91%
Open low-rise (LCZ 6)	4.95%	11.18%	38.09%	27.29%
Large low-rise (LCZ 8)	1.69%	2.25%	5.48%	7.24%
Sparsely built (LCZ 9)	0.12%	0.20%	2.36%	2.58%
Total of Building Type	96.72%	96.97%	85.72%	84.82%
Land Cover Type				
Dense trees (LCZ A)	0.00%	0.00%	0.00%	0.00%
Scattered trees (LCZ B)	0.11%	0.09%	0.88%	1.45%
Bush, scrub (LCZ C)	1.43%	1.48%	1.50%	2.47%
Low plants (LCZ D)	0.31%	0.38%	9.85%	6.50%
Bare rock or paved (LCZ E)	0.59%	0.37%	0.17%	0.20%
Bare soil or sand (LCZ F)	0.81%	0.61%	1.71%	4.29%
Water (LCZ G)	0.03%	0.10%	0.16%	0.26%
Total of Land Cover Type	3.28%	3.03%	14.28%	15.18%

In the administrative area of the city of Yogyakarta, it can be seen that >96% is in the form of buildings, and the rest is natural land cover. While inside the ring road, >84% are also in the form of

buildings and the rest is natural land cover. There were no dense trees in the two regions. If we look at the LCZ distribution pattern with the LST distribution map in Yogyakarta and its surroundings, LCZ has a relationship with LST. The more intense the LCZ by type of building is, the higher the LST will be. For more details, let's look at the following table.

Table 7. LST in YUA (Administrative and Inside the Ring road)

LCZ	LST of Yogyakarta Administrative Area		Temperature Increase	LST Inside the Ring road		Temperature Increase
	2017	2018		2017	2018	
Compact midrise	32.4	33.1	0.6	32.3	32.9	0.7
Compact low-rise	32.3	33.0	0.7	31.8	32.6	0.9
Open midrise	31.6	32.4	0.8	30.9	31.7	0.8
Open low-rise	30.6	31.7	1.1	29.9	31.0	1.0
Large low-rise	30.9	31.5	0.6	30.3	31.0	0.7
Sparsely built	29.2	29.6	0.4	28.3	29.2	0.9
Scattered trees	29.2	29.2	0.0	28.6	29.3	0.7
Bush, scrub	31.9	32.5	0.6	30.0	31.1	1.0
Low plants	29.9	29.7	-0.3	28.5	29.1	0.6
Bare rock or paved	32.7	33.2	0.5	31.9	32.4	0.5
Bare soil or sand	31.1	31.6	0.5	29.6	30.6	1.1
Water	29.7	30.7	1.0	28.8	30.4	1.6
Average	32.1	32.7	0.6	30.6	31.3	0.7

Based on the table, the highest temperature increase in the administrative area of Yogyakarta City is LCZ 5 or Open Midrise (0.8°C) and LCZ 3 or Compact Low-rise (0.7°C). While in the ring road range, the highest increase is at LCZ 3 (0.9°C) and LCZ 5 (0.8°C). The distribution of the two LCZs can be seen in figure 4.

3.2. Discussion

The graph below (figure 5) shows how LST is in each LCZ, in urban areas of Yogyakarta. Above has also been explained that the most significant increase in LST is LCZ 3 and LCZ 5. LCZ is based on four main components of urban landscape, namely the height of roughness feature, packing of roughness, surface cover around roughness feature, and thermal admittance of materials. Therefore, climate-based urban planning can be planned based on LST and LCZ. Through this concept, climate-based urban planning can be carried out in the LCZ region which has high temperatures by observing and mitigating through the components of the LCZ compiler.

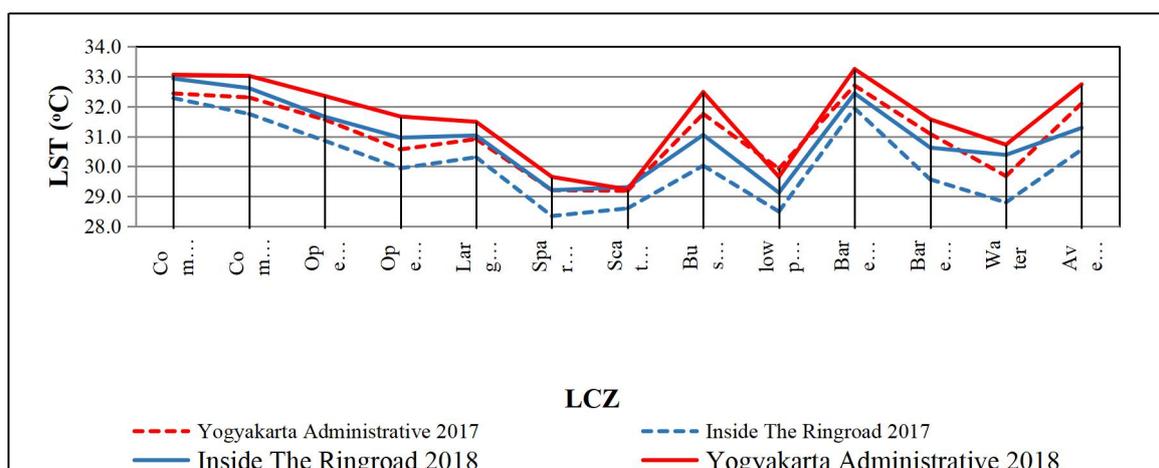


Figure 5. Graphic of each LST in LCZ in Yogyakarta Urban Area 2017-2018

4. Conclusion

Yogyakarta Urban Area have 12 LCZs consist of 6 LCZs based on building type and 6 LCZs based on landcover type. The highest increase of LST occurs in LCZ 3 (Compact low-rise) and LCZ 5 (Open midrise). LCZ 3 has characteristics; tightly packed buildings of 1 to 3 stories tall, few or no trees, little or no green space, concrete, steel, stone and glass construction materials, diurnal temperature range is medium. While LCZ 5 has characteristics openly arranged buildings of 3 to 9 stories tall, abundance of trees and pervious cover (low plants), concrete, steel, stone and glass construction materials, medium diurnal temperature range. Climate-based urban planning can be done by adding greenspace, replacing material that absorbs heat more throughout the area, spread out LCZ 3 and LCZ 5 according to those in the map. This will be quite effective because any area that needs the climate-based urban planning has been displayed on the map.

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