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Urban Heat Islands analysis towards topographic based land use change and daily commute effect along the Kaliurang Street in Yogyakarta

Urban Heat Islands analysis towards topographic based land use change and daily commute effect along the Kaliurang Street in Yogyakarta

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Abstract. This paper's aim is to analyse the correlation between land change pattern and its topography with Urban Heat Islands (UHI) in Kaliurang Street and surrounding area. Secondly, the effects of daily commuting activities from rural or sub urban area towards urban area are well identified. Kaliurang Street is one of the major streets in Sleman that uniquely represented the transition between rural, suburban, and urban area. Rural area is located in the furthest north, suburban located in the center, while the urban area is located in the southern part. Transect method carried out along Kaliurang Street to obtain primary data mainly temperature and vehicles number. Data collected during daytime (between 12-2 PM) and afternoon (between 3 to 5 PM). Furthermore, LANDSAT 8 OLI/TIRS satellite imagery was analyzed to obtain the Land Surface Temperature (LST) Information, while ALOS PALSAR was analyzed to obtain elevation data. One of the causes of temperature differences is the commuting which affects the variation of surface temperature along Kaliurang Street. Therefore, strong correlation between commuting and the UHI phenomenon are expected.

Keywords : urban heat island, Landsat, topography, land surface temperature.

1. Introduction

Road geometry affects the occurrence of UHI phenomena in an area[1] because the road determines the accessibility of a built land. Kaliurang Street is one of the collector roads in Sleman Regency, Yogyakarta Special Province, which stretches from the volcanic cone landform with steep topography area on the north to the volcanic slope landform with flat topography on the south. The topography of the Kaliurang Street, which is flat in the southern part, stretches into steeper area to the north associated with its regional status. Urban area located in flat topography areas, while sub-urban to rural areas are located in sloping to very steep topography areas. This condition underlies that the topography of the Kaliurang Street influences the land change patterns over the past 10 years. From the 10 years land change patterns in Kaliurang Street, the distribution of temperature over the ten years can be found.

Kaliurang Street area is influenced by the diffusion phenomenon of urban areas in Yogyakarta City which has begun to be seen since 2005 [2]. This condition shows that there is a tendency of urbanization in Kaliurang Street since 2005 which started from the south to the north, subsequently occurs along Kaliurang Street topography patterns. The urbanization then followed by the increasing of built-up area and the increasing of the rate of transportation which led into surface and land temperature increases. The first objective of this study is to identify the pattern of UHI in the Kaliurang Street area for the past 10 years (2008-2018) through the UHI approach based on its urbanization pattern. The second objective is to identify the correlation between the commuting as a result of urbanization along Kaliurang Street with the increase of air temperature as the indication of UHI phenomenon.

This study examines the urban heat island phenomenon on Kaliurang Street as a road that has unique road geometry. The geometry of Kaliurang Street is subsequently located along with its topographical patterns from south to the north, which is led into urbanization pattern that occurred in Kaliurang Street surrounding area from year to year. Temperature change over years is a phenomenon of climate change that needs temporal analysis [3], therefore the study of land changes, changes in vegetation density, and changes in land surface temperature were studied spatially and temporally using Landsat 7 ETM+ and Landsat 8 OLI / TIRS imagery with LST analysis. Urban Heat Island in Kaliurang Street occured in 2018 then further studied by correlate it with the commuting phenomenon of Kaliurang Street. Commuting in urban area considered as primary activity that also happened as one of the factors of increasing temperature.

2. Method

2.1. Study area

The measurement was carried out along Kaliurang Street as a representative transect from the surrounding area. The location of measurements is shown on Figure 1. The measurement location represents the village administration area located on Kaliurang Street, including Sinduadi, Condongcatur, Minomartani, Sinduharjo, Sardonoharjo, Sukoharjo, Wedomartani, Umbulmartani, Umbulharjo, Harjobinangun, Pakembinangun, Wukirsari, and Hargobinangun Village.

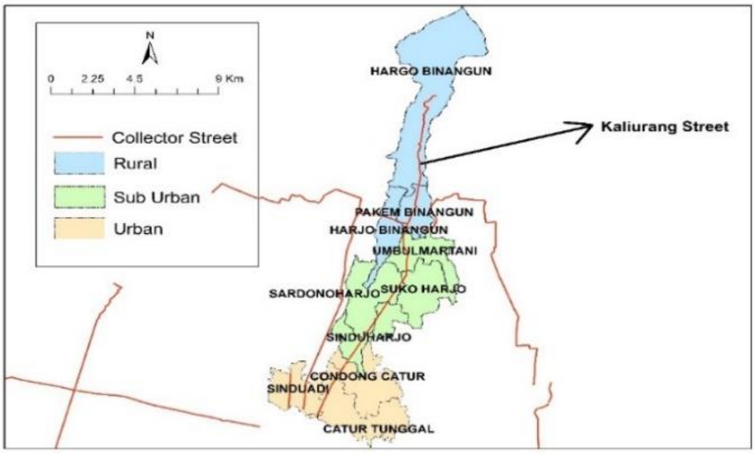

Figure 1. Study Area

2.2. Data Collecting and Analysis

Temperature and number of vehicles that represent the condition of current condition was obtained by direct measurement that was conducted for eight days in two timeframes which are 12:00 AM to 2:00 PM and 3.00 PM to 5.00 PM.

The land cover change of 2008-2010 causes land cover distribution of 2008 and 2018. Land Surface Temperature (LST) of 2008-2018 obtained by land surface temperature extraction from Landsat 8 OLI/TIRS (2018) and Landsat 7 ETM+ (2008). Topography analysis was carried out using landform slope data and ALOS PALSAR DEM (Figure 2).

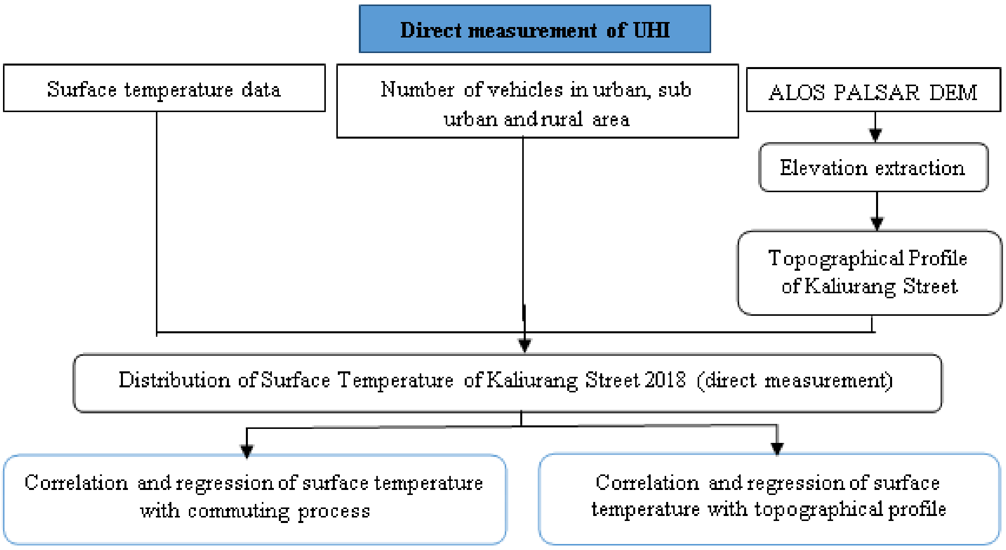

Figure 2. Research methodology

3. Result

3.1 Land use changes along Kaliurang Street and topography function

Urban areas are geographic manifestations which will always experience changes due to population (demographic) and demographic factors [4]. Demographic factors are the most important factor in urban studies because they are related to population growth. Urban areas, over time, are no longer able to provide built-up land for residents which quantity continues to increase, so there is a shift in urban activities in the area around urban areas called function shifting. Shifting the functions of urban areas to the surrounding region is called diffusion of urban areas.

The concept of the urban area of Yogyakarta is known through the Yogyakarta Urban Development Project concept which began in 1990. The concept explains that the area covered by the Yogyakarta Urban Development Project has the potential to carry out urban functions because it includes access to education, housing and services. This concept also explains the development of the urban area of Yogyakarta that leads to the north area of Yogyakarta that is half of some parts of Sleman Regency area and to the south area of Yogyakarta, which is half parts of Bantul Regency area. Diffusion of urban function happened to these areas because in some parts of Sleman Regency and part of Bantul Regency are already have proper access to shelter, education, trades, and services [5].

Kaliurang Street is one of the main roads in Sleman Regency which stretches along Sleman Regency with a length of about 23 km from Mlati Sub District to the Pakem Sub District. The area around Kaliurang Street is one of the areas in the Special Province of Yogyakarta that has experienced diffusion of urban areas. The tendency of diffusion of urban areas in the area around KaliurangStreet is due to accessibility as the main factor [6]. Accessibility conditions for Kaliurang Street services considered accessible until sub urban area in the past 10 years because it is supported by the location of recognized universities located in Kaliurang Street.

The diffusion of urban areas on Kaliurang Street for the last 10 years shows the tendency of spreading into north area of Yogyakarta. Some village areas classified as sub-urban areas, including the area of Sinduharjo Village, Sardonoharjo Village, Sukoharjo Village, and Umbulmartani Village. Sub-urban area happened as the most intensive land conversion area over the past 10 years, as shown in Figures 3a and 3b. The tendency of land conversion in the sub-urban areas is due to several causes, the first condition is due to the increasing number of local residents that the demand for houses with good access also increases. The

Kaliurang Street area in the sub-urban area is still considered as an area with good and very proper accessibility. The next condition is sub urban areas, more precisely at Umbulmartani Village. There is a university located in Umbulmartani Village, therefore its surrounding considered as educational area and followed by large number of non-permanent migrants, which is university students from other areas in Indonesia. Nevertheless, the presence of university campuses then soonfollowed by business service as supporting facilities to the students who reside around the campus. This condition resulted in the increasing of built up area around the campus.

Land use over the past decade has experienced a significant change in land use, especially from paddy fields to residential land. These changes can be seen in the land use map in 2008 (Figure 3a), where the paddy fields are still on topography that has a flat slope, sloping slope, and rather-steep-slope. After 10 years, the changes in paddy fields continue to be intensive until the settlements dominating sloping topography area, rather steep topography area, and steep topography area. Besides paddy fields, the land cover of forest also decreases its functions into settlements, as shown in Figure 3a and 3b.

The diffusion of urban areas on Kaliurang Road for the last 10 years has occurred to reach rural areas, with intensive land use changes in urban areas and sub-urban. Urban diffusion on Kaliurang Street is associated with topographic paths. Land conversion in Kaliurang Street happened to be intensive in areas with sloping topography and decreases its intensity in areas with steeper topography. Spatial distribution of land use with topography is shown in Figure 3a and 3b.

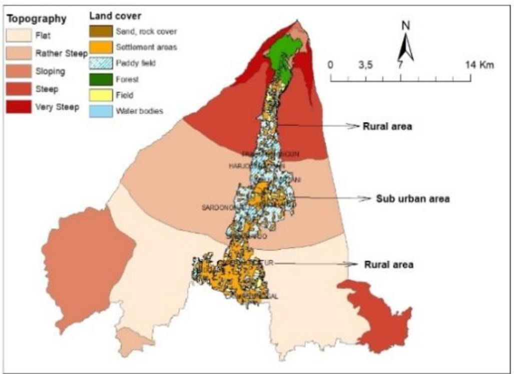

Figure 3a. Distribution of Land use in study area (2008) based on slope aspect in Sleman Regency

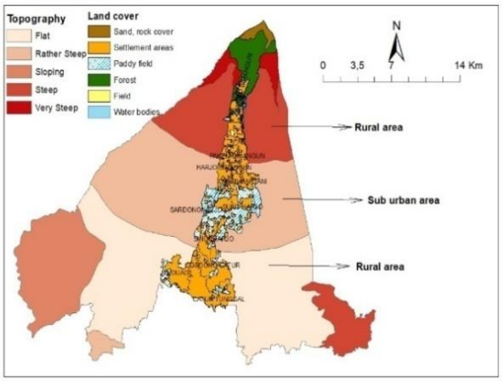

Figure 3b. Distribution of Land use in study area (2018) based on slope aspect in Sleman Regency

3.2. The pattern of temperatures along Kaliurang Street

The characteristic of UHI in Kaliurang Street could be seen periodically and directly. Periodically study of UHI associated with the influence of change of land uses across the years, which is the increase of building area land cover. Periodic study of UHI dealing with the increasing of temperature due to the change of land cover, while in fact the study of UHI dealing with the surface temperature with the environmental conditions. One of environmental condition that has prominent differences at Kaliurang Street is topography, which also describing the pattern of urban diffusion in Kaliurang Street.

Study of periodic UHI of Kaliurang Street obtained from the Land Surface Temperature (LST). The increase of LST showed that the influence of urban diffusion continues to support the process of the increasing of built area that followed by the reduction of vegetation land cover. Reduction of vegetation land cover reduces the effect on reducing the shadow canopy on the ground surface and reducing the supply of moisture in the air [7], resulting the increase of LST over the years.

Calculation of LST 2008 is obtained from the extraction of Landsat 7 ETM that recorded on July 8, 2008. While the calculation of LST 2018 using the extraction of Landsat 8 OLI / TIRS data that recorded on July 20, 2018. Landsat 7 ETM imagery suffered sensor damage in 2003, so the recording results

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experienced stripping which eliminated imagery data by 24% [8]. Stripping removal on Landsat 7 ETM + imagery is done by filling the gap stripping using image data with the same recording lane but on different recording dates and patterns that recorded in the same year (2008).

Table 1. Average of LST value in sub urban and urban area.

	Year		
	2008	2018	Status
Village	LST average (°C)	LST average (°C)	
Sinduadi	27.44	27.5	Urban
Caturtunggal	28.48	29.11	
Condongcatur	28.08	28.63	
Sinduharjo	26.17	25.75	Sub urban
Sardonoharjo	25.38	24.84	
Sukoharjo	26.22	25.15	
Umbulmartani	25.77	24.30	

The average LST in urban areas has increased in the last 10 years, but there has been a decline in the average temperature in the sub-urban areas (Table 1). LST in sub-urban areas experienced an average decline, but if spatially reviewed, there was an increasing distribution of LST in the past 10 years (Figure 4a and Figure 4b) in sub-urban area. The results of LST extraction in 2008 showed that the surface temperature range is 12.4^{O}C to 34.9^{O}C, while in 2018 it was shown that the surface temperature range is 14.9^{O}C to 32.1^{O}C. A higher temperature range in 2008 can be caused by Landsat 7 ETM + that experiencing the filling gap process beforehand. Filling gap process might use imagery with different weather condition due to its better resolution, so that process resulting higher temperature than it should be.

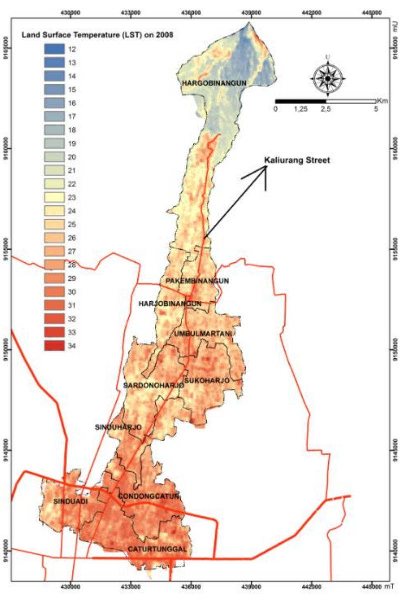

Figure 4a. Spatial distribution of LST (2008).

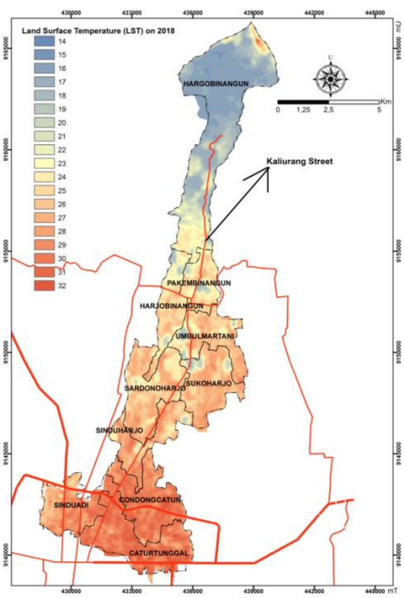

Figure 4b. Spatial distribution of LST (2018).

Average LST in sub-urban areas which decreased over the last 10 years can be caused by the cloud cover in 2018. Cloud cover is disguised as noise in LST extraction. Extraction of LST affected by cloud cover is resulting in lower LST value than it supposed to be due to the presence of water vapor in the cloud. The presence of cloud disturbances in LST extraction results is shown in areas with low temperatures (14- 17^{O}C) in suburban areas (shown with blue colour) (Figure 4b). The sub urban area is considered as settlement complex area which is impossible to experiencing low LST distribution.

Urban diffusion on Kaliurang Street has reached to the Sub-urban area which includes Sinduharjo Village, Umbulmartani Village, Sardonoharjo Village, and Sukoharjo Village. The 10-year increase of LST that is most spatially visible in sub-urban areas occurs in Sinduharjo Village. The increasing conditions of LST in other suburban areas, such as in Sukoharjo Village, Sardonoharjo Village, and Umbulmartani Village are biased due to cloud cover in the 2018 image.

One of environmental factors that influence the spatial distribution of temperature is topography, because it controls the amount of sun radiation received on the surface [9]. Recent surface temperature and topography condition of Kaliurang Street brought by direct study of UHI. Topographic pattern of Kaliurang Street was extracted from the elevation. Elevation data of Kaliurang Street is obtained from ALOS PALSAR DEM. In order to divide elevation profile of Kaliurang Street into slope segments, the landform data of Sleman Regency obtained from Spatial Planning Agency (*Bappeda*) of Yogyakarta Province was also used. The landform data of Sleman Regency divided the topographical of Kaliurang Street based on volcanic typological landform. The topographical profile of Kaliurang Street is shown in Figure 5. The profile divided into 4 segments based on volcanic landform associated with the break of slope.

Distribution of surface temperature obtained from direct measurements along Kaliurang Street at daytime and evening. Daytime measurement represents maximum temperature due to maximum sun radiation throughout the day, while evening measurement represents the decreasing temperature after maximum condition. The temperature profile shows the mean of surface temperature from 4 segments, while every segment has 3 sub segment points. The sub segment points take role as sampling point that represents surface temperature in different topography along Kaliurang Street. The result of temperature along Kaliurang Street is shown in Figure 6.

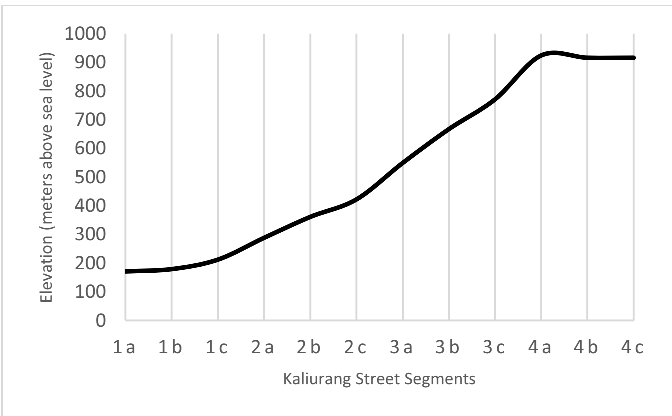

Figure 5. Topographical profile of Kaliurang Street based on elevation and landform.

Based on Figure 6, the highest temperature along Kaliurang Street on daytime and evening located in segment 1. Highest temperature on daytime and evening that occurred at segment 1 mainly caused by the amount of sun radiation in building area with minimum vegetation land cover that also supported by the commuting pattern. The commuting pattern in segment 1 happened as the most crowded traffic out of all

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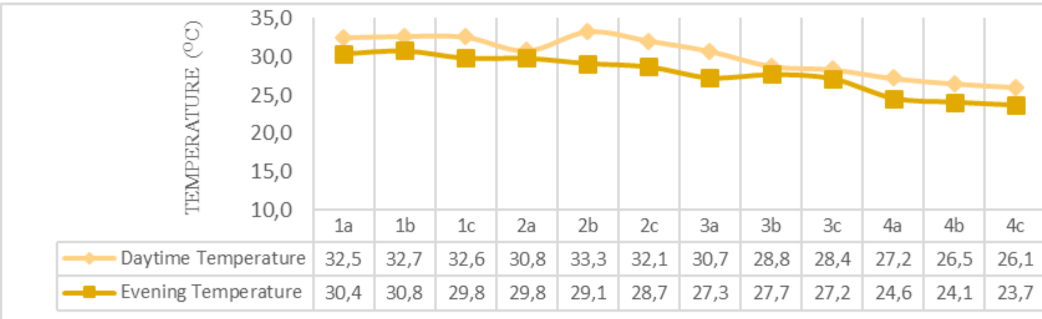
these segments. This condition also shows that the most intensive urban diffusion at Kaliurang Street still occurred at urban area, following at the sub urban area. The correlation score (r) of elevation and surface temperature in the daytime is 0.446 and in the evening is 0.4461 which means that the relation between elevation and surface temperature is not strongly related. The UHI pattern of 2018 showed by image and direct measurements basically show the same results. The results concluded that urban area still remains as the centre of the heat island, followed by sub urban area as the second area that dealing with the increasing of temperature.



	Segment 1	Segment 2	Segment 3	Segment 4
Elevation (meter)	171-251	252-485	486-817	818-916
Area status	Urban	Suburban	Rural	Rural
Landuse	-Building area	– Building area – Open green area	– Open green area – Building area	– Open green area – forest – Building area
Commuting	Most crowded	Crowded	Crowded-not too crowdeed	Deserted

Figure 6. Distribution of surface temperature of Kaliurang Street.

3.3 Urbanization and correlation between the number of vehicles and atmosphere temperature

Urban Heat Island or UHI is closed isotherms indicating an area of the surface that is relatively warm; most commonly associated areas of human disturbance such as towns and cities. The physiographic analogy derives from the similarity between the pattern of isotherms and height contours of an area on a topographic map. The annual temperature of a city may be 1- 2 ^{O}C warmer than before the development occurs [10]. Figure 4a and 4b can illustrate that some villages like Sinduadi, Condongcatur, and Caturtunggal experiencing an increase in temperature which reached more than 2^{O}C. For example some area in Caturtunggal and Condongcatur which have range of temperatures from 25-26 ^{O}C in 2008, have risen to 29-31 ^{O}C in 2018. Thus, it can be seen that the UHI phenomenon along Kaliurang Street occurs at Sinduadi, Caturtunggal, and Condongcatur.

The large temperature difference between a village and a city that has a high population density and activity indicates the phenomenon of Urban Heat Island. The measurement of UHI in an area cannot only be measured based on the characteristics of the city[11]. Emissions, pollution and greenhouse gases in urban areas encourage the UHI phenomenon [12]. Commuting activities in the study area which included urban, suburban, and rural area were shown in the average number of passing vehicles.

The increased activity of people that use transportation caused the increase of emissions from fossil fuels in the form of carbon emissions [12]. Carbon emissions encourage the UHI phenomenon including the area around Kaliurang Street, which is characterized by the increase of its atmospheric temperature. The results of the measurements show that the highest temperature is in urban areas with maximum temperatures recorded reaching more than 33 ^{O}C. The highest temperature in the urban area has a fairly large difference with the highest temperature in the rural area, which is 31.9 ^{O}C.

The correlation between the numbers of passing vehicles at measured temperatures can be found by calculating the correlation value. Positive correlation values indicate that there is a correlation between increased temperatures and an increase in the number of passing vehicles. The correlation value between the temperature and the number of passing vehicles is shown in Table 2 and Table 3.

Table 2. The value of correlation between number of vehicles and atmosphere temperature on the first week of measurement.

	Time of Measurement							
	Monday 16/07/2018		Tuesday 17/07/2018		Saturday 21/07/2018		Sunday 22/07/2018	
	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00
Urban	0,129	0,775	0,386	Negative value	0,531	0,363	0,431	0,404
Suburban	Negative value	0,847	Negative value	0,607	0,521	Negative value	0,210	0,784
Rural	0,884	0,865	0,789	0,794	0,867	0,683	0,749	0,840

Table 3. The value of correlation between number of vehicles and atmosphere temperature on the second week of measurement.

	Time of Measurement							
	Monday 23/07/2018		Tuesday 24/07/2018		Saturday 28/07/2018		Sunday 29/07/2018	
	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00	12.00-14.00	15.00-17.00
Urban	Negative value	Negative value	0,377	Negative value	Negative value	0,186	0,132	Negative value
Suburban	Negative value	0,745	0,532	0,474	Negative value	0,876	0,664	0,818
Rural	0,384	0,892	0,903	0,849	0,689	0,851	0,728	0,704

The results of the correlative value measurement between the increase in air temperature and the number of passing vehicles in urban, suburban, and rural areas showed that the positive correlations value were dominated. This shows that there is a correlation between the increase in atmospheric temperature and the number of passing vehicles. The positive correlation is in accordance with the carbon emission. The more the number of vehicles passing by will lead more carbon emission emitted to the air.

The weakness of the device causes a bias at the measured temperature. The temperature measurement tool that was used has a resolution of 0.2 with an accuracy of ± 2^{O}C. This level of accuracy affects the accuracy of the temperature measurement results. In addition, temperature gauges have a weakness that is easily heat when it was exposed to the sunlight for too long. Tools that heating due to sunlight can affect the measured temperature result. The results of temperature measurements that are less precise affect the correlation value.

4. Discussion

4.1. Land cover change, topography, and surface Urban Heat Island

Land-surface temperatures are known to be sensitive to changes in latitude, topography, vegetation, land-use, and moisture. The preceding research about the effects of topography on temperature conditions was conducted on Zagreb Greater Area. The UHI development modelling on Zagreb Greater Area was implemented on 9-10 June and 17-23 July 2004 with the temperature represented the UHI magnitude was expressed at 150 m height. The study shows that the temperature pattern in the afternoon found in the south-facing slopes of the Medvednica Mountain. The temporal evolution of the UHI halted in the afternoon. The condition caused the spatial distribution of temperature over urban area was homogeneous during the night. The presence of katabatic movements from the southern slopes of Medvenica and from the Pannonian valley caused convergence [13]. The convergence turned the wind flow to the west and removing the warm air masses over urban area and preventing further evolution of the UHI. The adiabatic lapse rate of air is to estimate topography-dependent empirical corrections for known ground-surface temperatures. However, air temperature is only one of the variables influencing ground temperature [14].

This research shows that the topography, specifically slope results in temperature variation. Kaliurang Street has less topography variation than Zagreb Greater Area. Topographic variation of Kaliurang Street is influenced by the landforms of Mount Merapi. The landforms of Mount Merapi that influenced the elevation of Kaliurang Street is Volcanic cone (818 m - 916 m), volcanic slope (486 m - 817 m), volcanic foot (252 m – 485 m), and volcanic foot plain (171 m - 252 m), while the variation of elevation in Zagreb starting from 86 m – 1100 m. The less variation of topography causing the relationship of topography and landform in Kaliurang Street is weaker than in Zagreb Greater Area.

4.2. *Surface Urban Heat Island and commuting patterns*

The correlation between commuting phenomena and air temperature directly shows the influence of urban activity with the UHI phenomenon. This condition based on the fact that the commuting phenomenon produces emissions that also produce heat energy. Vehicles that use fossil fuels are one source of carbon emissions in the world. These carbon emissions have an impact on increasing UHI in an area. The results of this research showed an increase in carbon emissions by 72.97% in Surabaya over the past 20 years[11]. Over the past 20 years, 137 x 106 tons of carbon matrix have been produced by 28 x 106 motorized vehicles. The increase in carbon emissions has positive correlation to the increase in the number of vehicles used in Surabaya. Furthermore, the carbon emission is one of the temperature increasing factors.

The research about emission in Surabaya is not dealing with the condition of temperature, but the research emphasizing that the increasing number of commuting will produce the increase of emission, which brought the increasing of surface temperature later. Urban diffusion is a factor that brought the increasing number of commuting in Kaliurang Street. Commuting process in Kaliurang Street influenced the surface temperature condition in daytime and evening. The correlation value (r) of commuting and temperature on the daytime reached 0.903 in rural area, while on the evening reached 0.876 in the sub urban area.

5. Conclusion

The first conclusion of this research including the change pattern of land use in Kaliurang Street in the past 10 years with its relationship with topography and its connection with the change pattern of spatial distribution of LST. The change pattern of land use due to urbanization in Kaliurang Street is reaching sub-urban area, while the sub-urban area is used to be not considered as settlement complex area in 2008 due its accessibility. Land use changing into building land cover in sub urban area happened as the most intense land use change in the past 10 years that followed by the decreasing of vegetation land cover and resulting the increasing of LST in all over sub urban area. The second conclusion of this research is dealing with commuting as the primary activity in urban area. Positive correlation between commuting and UHI in urban area, sub urban area, and rural area are found in the research. Highest correlation between commuting in afternoon and UHI found in rural area, with r = 0.903 while the highest correlation between commuting in the evening and UHI found in sub urban area, with r = 0.876.

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