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THE CONTRIBUTION OF HOUSING AREA TO LAND SURFACE TEMPERATURE IN BANDUNG

RIFIATI SAFARIAH*, M. RAFEE MAJID AND NORADILA RUSLI

Urban and Regional Planning, Jalan Lingkaran Ilmu, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.

**Corresponding author: srifiati2@graduate.utm.my*
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Abstract: Following the development of built-up areas in Bandung predominantly for housing purposes, the land surface temperature (LST) in the region has increased significantly. In urban planning, particularly in housing, environmental aspects related to LST have yet to be widely considered. The aim of this study is to identify the relationship between housing densities and LST. The information regarding elevation, density, LST and tree cover (vegetation coverage) in housing areas in Bandung have been collected. Landsat 8 satellite images were used to assess LST levels and to calculate the normalised difference in vegetation index (NDVI). Statistical analyses have been conducted to determine whether the NDVI and the housing density are factors that influence LST values. A correlation analysis demonstrates a strong inverse relationship between LST and NDVI while controlling for elevation of the housing area, with Pearson correlations of -0.575, -0.612 and -0.754. Meanwhile, an ANOVA test showed that LST comparisons at each elevation were statistically significant ($p<0.05$), it presents the idea that LSTs for high-density housing and medium-density housing have significant differences. The statistical test results indicate that the housing densities and the lack of urban tree cover contributes to LST. These findings are an invaluable source for spatial planning in housing areas and support sustainable development in Bandung city.

Keywords: Housing area, land surface temperature, vegetation coverage, sustainability.

Introduction

Rapid urbanisation has become common in developing countries (Zhang *et al*., 2011; Ishtiaque *et al*., 2017) including Indonesia. Rapid urbanisation in Indonesia notably occurs in large cities concentrated on the island of Java (Mardiansjah & Rahayu, 2019). Urbanisation has led to changes in land use and increase in the built-up areas (Guo *et al*., 2012; Morabito *et al*., 2016; Zheng *et al*., 2019).

The changes in land use and expansion of the built-up areas have affected the characteristics of the thermal environment (Kim *et al*., 2016; Yang *et al*., 2017; Sejati *et al*., 2019). The impact of urbanisation on the thermal environment has been discussed in previous studies, particularly on land surface temperature (LST) (Chen *et al.*, 2017; Mathew *et al.*, 2017; Yu *et al*., 2018; Gui *et al*., 2019). The results of their studies concluded that rapid urbanisation is one of the drivers of the increase in LST.

LST values have been extensively used to explain Urban Heat Island (UHI) intensity. The the UHI phenomenon could be seen in the increasing LST values and the increase in air temperature. UHI is the occurrence of higher temperatures in urban areas compared with the surrounding rural areas (Liu & Zhang, 2011). The UHI phenomena can have a severe impact on urban environments and quality of life in the cities, urban areas. UHI may cause discomfort and even affect human health.

In Bandung City, the UHI phenomenon has begun to occur, evidenced by the average annual temperature increase (Puspita & Saputra, 2019). By considering changes in the land use in Bandung City, the UHI looks to be more intense in the future. Therefore, the implementation of UHI mitigation strategies is a necessity in Bandung City today.

Bandung belongs to a group of urbanised cities in Java with a rapid population growth. It had a total population of 2.45 million people in 2018, with an average growth rate of 1.01% per year at the time of this research report (BPS Bandung[a], 2021). The rapid urbanisation in Bandung has changed the land use from green lungs and agriculture to built-up areas and urban centres.

Housing accounts for the bulk of the built-up area in Bandung at 53.38% of the total area (Dinas Tata Ruang & Cipta Karya, 2011). Meanwhile, the availability of green spaces in Bandung is still very limited the ratio between non-built-up areas (including green spaces) to built-up area in 2018 was around 22.42%. The expansion of the built-up areas in Bandung is correlated to an increase in LST (Ramdani & Setiani, 2014).

The phenomenon of increasing LST in the area has been documented by Wardana (2015) and Puspita and Saputra (2019). In line with this, the prevailing air temperature has also escalated. In 2014, the maximum temperature reached was 29.1°C, which then increased to 33.4°C in 2018 (BPS Bandung[b], 2021). Although studies on LST in Bandung have been conducted by several researchers, the focus on LST within housing areas has been quite limited.

The increasing LST in housing areas potentially exacerbates the effects of urban warming and has affected the quality of the residential environment. Thus, an understanding of the factors related to LST is important, to assist in the efforts to mitigate the effects of increasing LSTs within housing areas. There have been many studies on factors related to LST in urban areas, however research that focuses on the scope of urban housing areas is still limited. Previous studies that have been carried out were conducted in Tehran which considered vegetation, cool pavements and the orientation of buildings (Farhadi *et al*., 2019); a study in Beijing considered the residential landscape composition (building density and tree cover) and vertical structures of urban residential (building height) (Zheng, 2019) in Austin, Texas, the factors used looked at the neighbourhood landscape spatial pattern (Kim, 2016). In this study, the observed factors were limited to housing characteristics namely density and vegetation coverage and the housing landscape composition. Additionally, the elevation of the housing area was used as the controlling variable in this study.

This study aims to identify the contribution of housing area characteristics to LST. The characteristics in focus were housing density and vegetation coverage, while elevation factor was a controlling factor. The analysis of density and vegetation coverage factors have been conducted to identify the relationship between normalised difference vegetation index (NDVI), as indices of vegetation coverage and LST in housing areas.

As density and NDVI are related, it is also pertinent to find out the relationship between density and LST. Both analysis have been carried out with elevation as a controlling factor. The findings of this study are expected to be an input for sustainable development plan in Bandung City, especially in the formulation of plans to mitigate the impact of high LST levels.

Materials and Methods

Study Area

The study area, Bandung City, is the capital of West Java Province. It is the third largest metropolitan area in Indonesia after Jakarta and Surabaya. In 2018, the population of Bandung was 2.45 million inhabitants and it had a growth rate of 1.01%. Bandung City covers an area of approximately 16,731 hectares and has an average elevation of 712 meters above sea level (m a.s.l.), with the highest point in the north and the lowest point in the south. The topography in the northern area of the city is hillier than other parts of Bandung City.

Being its capital, Bandung city functions as the civic centre, education centre, service centre and trade centre of the West Java Province. These functions drive a rapid population growth, which triggers the development of built-up areas including housing areas and an increase in temperature.

Data

Satellite images derived from Landsat 8 OLI/TIRS and Digital Elevation Model Nasional (DEMNAS) are the main data used to assess the LST, NDVI and elevation. The satellite images were obtained from the United States Geological Survey (USGS) on October 10, 2018. DEMNAS was obtained from Geospatial Spatial Agency of Indonesia. Out of the 13 bands of Landsat 8 OLI/TIRS, only three bands were used for this study. Band 10, band 5 and band 4 of Landsat 8 OLI/TIRS were processed to create the LST map and NDVI map while DEMNAS has been processed to create elevation map.

Additional data used in this research includes the Bandung City Master Plan 2011-2031 and data of land use classification of Bandung City 2011. The housing density map is obtained from the Master Plan of Bandung City 2011-2031, which has been crosschecked against the existing housing density.

LST and NDVI Calculation

The multiple-step calculation used to derive LST in this study was based on the method developed by previous researchers (Guha *et al.,* 2018; Malik *et al.,* 2019). The first step is conversion of Landsat-8 TIRS band 10 data to spectral radiance, using the following equation:

$$L_\lambda = 0.0003342^* DN + 0.1 \quad (1)$$

where L_λ is the spectral radiance in $Wm^{-2}sr^{-1}mm^{-1}$. Brightness temperature is then calculated by converting the spectral radiance to brightness temperature value. The equation used to convert spectral radiance to brightness temperature was as follows:

$$T_B = \frac{K_2}{ln\left((K_1/L_\lambda)+1\right)} \quad (2)$$

where T_B is the brightness temperature in Kelvin (K), K_1 is calibration constant 1 and K_2 is calibration constant 2. For Landsat 8 OLI, K_1 is 774.89 and K_2 is 1321.08.

The next step is brightness temperature adjustment based on the surface emissivity (ε), which was estimated using the NDVI thresholds method developed by Sobrino *et al.* (2004). The surface emissivity (ε) may be determined by the following equation:

$$(\varepsilon) = 0.004^* F_v + 0.986 \quad (3)$$

where:

$$F_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (4)$$

where $NDVI_{min}$ is the minimum NDVI value (0.2) and $NDVI_{max}$ is the maximum NDVI value (0.5).

In the last step, the LST was calculated using the following equation:

$$LST = \frac{T_B}{1+(\lambda\sigma T_B/(hc))ln\varepsilon} \quad (5)$$

where λ is the effective wavelength (10.9 mm for Band 10 in Landsat 8 data), σ is Boltzmann constant (1.38 x 10_{-23} J/K), h is Plank's constant (6.626 x 10^{34} Js), c is the velocity of light (2.998 x 10^8m/sec) and ε is emissivity.

Furthermore, the estimation results of brightness temperature value in Kelvin unit are then converted to Celsius. As a result, the LST (in unit Celsius) map of Bandung is generated.

NDVI has been employed as an indicator to estimate the vegetation coverage in housing area. The NDVI value is determined using near infrared band and visible red band. The values of NDVI range between -1 and +1. NDVI can be estimated by the following equation (Mathew *et al*., 2018).

$$\text{NDVI} = \text{NIR} - \text{RED}/\text{NIR} - \text{RED} \quad (6)$$

where:

RED = Spectral Reflectance acquired in Red,
NIR = Spectral Reflectance acquired in Near Infrared.

Statistical Analysis Method

Analysis of Variance (ANOVA) testing is carried out to examine whether LST differed among high-density housing area and medium-density housing area. This method was used to determine whether there was a statistically significant difference between means of two or more groups. Then Pearson's correlation analysis is applied to investigate and determine the strength and the direction of correlation between LST and NDVI in Bandung City housing areas.

The sample size used was 180 observation points of LST from housing areas at elevation 1 and 2, respectively and 60 observation points of LST from housing areas at elevation 3. Samples taken in elevation 1 and 2, respectively, consisted of 90 LST points from 6 medium-density housing areas and 90 LST points from 6 high-density housing areas.

Whereas samples taken in elevation 3 consisted of 30 LST points from two areas of high-density housing area and 30 LST points from two areas of medium-density housing areas.

Results and Discussion

Identification of Housing Area Characteristic

In 2011, housing areas in Bandung covered an area of 8,971,959 hectares, approximately 53.38% of the total area of the city. The increasing demand for residential units has caused housing areas to expand and resulting in changes of land use in Bandung.

This expansion has led to an increase in impervious areas, also at the same time reducing green space. Moreover, the need for housing also increases the density of housing areas (Triyuly *et al*., 2018). The following sections describe the factors affecting LST of housing areas in Bandung:

a. Elevation

Previous studies discovered that elevation factor has negative correlation with LST (Khandelwal *et al*., 2017; Phan *et al*., 2018; Khan *et al*., 2020; Zhi *et al*., 2020). In this study, elevation is one of the factors that are considered in observing the relationship between the characteristics of housing area and LST.

Bandung is located at 654.754-1077.85 m a.s.l. Using 40 m range intervals, the elevation of Bandung was categorised into nine classes (Figure 1). However, observations were only carried out at elevation 1 (654 – 694 m a.s.l.), elevation 2 (694,0001 – 734 m a.s.l.) and elevation 3 (734,0001 – 774 m a.s.l.). The observations were only conducted at three elevations because most of housing areas are located at these three elevations.

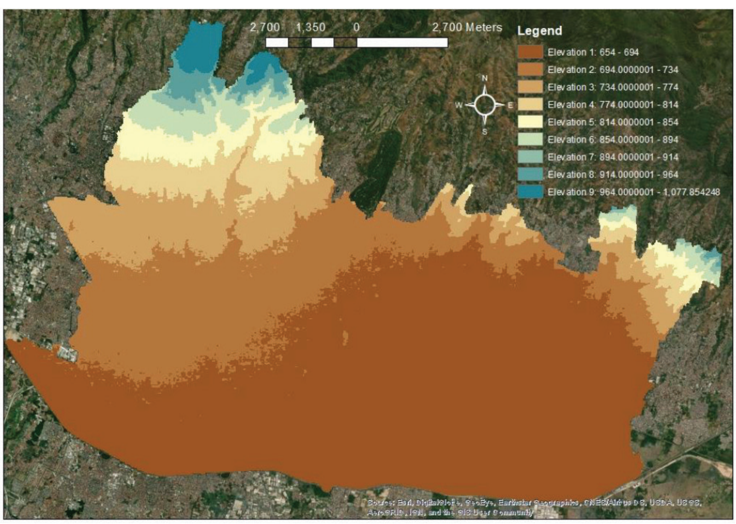

Figure 1: The elevation map of Bandung City

b. Density

Based on the Bandung Master Plan 2011-2031, housing areas are classified into three density groups, i.e., high, medium and low. The distribution of high and medium density is mainly at elevation 1, 2 and 3.

Meanwhile, the low-density distribution is mostly in elevation 4 and above. The observed areas for the purpose this study are the areas with high and medium housing densities at elevation 1, 2 and 3. The classification of housing density and the distribution of housing areas used as sample observations can be seen in Figure 2.

Two sample images of high and medium density housing areas are illustrated in Figure 3. The percentage of impervious areas for high-density housing in the sample areas ranges between 75% and 95%, meanwhile medium-density housing areas range between 40% and 70%.

c. Vegetation Coverage (Urban Tree Cover)

The relationship between vegetation coverage and LST has been widely discussed in previous research papers (Grover & Singh, 2015; Santos *et al*., 2017; Ferreli *et al*., 2018). The urban tree cover in Bandung is as depicted in the following NDVI map (Figure 4). The maximum, minimum and mean values of NDVI are 0.553, -0.028 and 0.144, respectively. Meanwhile, the mean NDVI in the sample housing areas at each observed elevation are tabulated in Table 1. As expected, due to higher impervious surface, high-density housing areas have lower mean NDVIs at each elevation compared with medium-density housing at the same elevations.

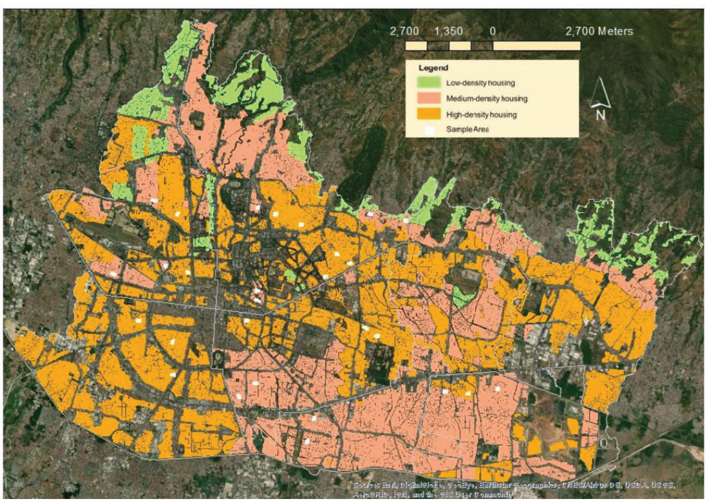

Figure 2: Map of the classification of housing density and the distribution of sample area

High-density Medium-density

Figure 3: Two sample images of high-density and medium-density areas

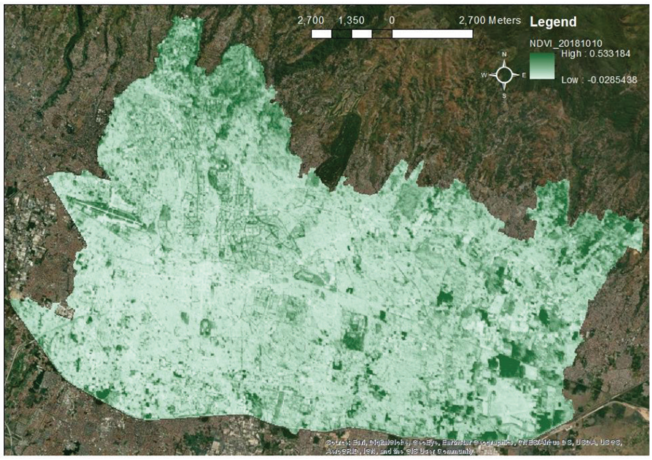

Figure 4: Map of NDVI in Bandung city

Table 1: Mean NDVI in housing area at different elevations

Elevation	Mean NDVI	
	High-density	**Medium-density**
Elevation 1 (654-694 m a.s.l.)	0.084871	0.118017
Elevation 2 (694.0001-734 m a.s.l.)	0.082445	0.109044
Elevation 3 (734.0001-774 m a.s.l.)	0.087233	0.163446

LST in Housing Area

The results of LST calculations are illustrated in Figure 5. Map of LST distribution in Bandung in October 2018 shows that the minimum, maximum and mean LST are 22.88^{0}C, 38.54^{0}C and 32.11^{0}C, respectively. The map also presented that, high LST in Bandung are scattered in the central, western, eastern and southern regions.

These regions are dominated by built-up areas including housing areas. Meanwhile, lower LST are found in areas covered with vegetation such as in the northern region and rice fields in southern region of Bandung.

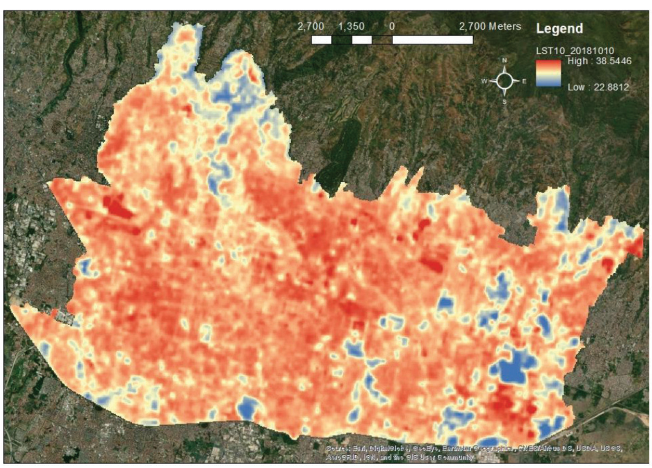

Figure 5: Map of LST distribution in Bandung

Table 2 shows the mean LST for high-density and medium-density housing areas observed at each elevation. The comparison at each elevation shows that the mean LST in high-density areas is higher compared with that of medium-density areas. Meanwhile, the comparison between the mean LSTs based on elevations shows that the higher the elevation, the lower the mean LST. The highest mean LST is at elevation 1, followed by elevation 2 while elevation 3 has the lowest LST.

Correlation between LST and NDVI in Housing Area

Pearson correlation of NDVI and LST is shown in Table 3 while scatterplot of NDVI and LST is shown in Figure 6. Regression line, equation and R^2 value are also shown in Figure 6. From the scatterplots, correlation between NDVI and LST appear to have linear, strong and negative correlation in each elevation.

However, anomalies can be seen in many observation points with a low NDVI have a low LST. For the overall observations, the correlations are statistically significant in each elevation, which the significant values are always smaller then 0.001. The lowest correlation coefficient is found in elevation 1 while the highest correlation coefficient was found at elevation 3.

The correlation coefficient has a range of between -0.57 and -0.75. Thus, NDVI has strong and negative correlation with LST. Similar results were found by Santos *et al*. (2017) and Zheng *et al*. (2019) as was found in this study.

A strong and negative correlation between NDVI and LST means that the higher the NDVI value, the LST tends to be lower. Tree cover and vegetation is an important factor in decreasing LST.

Increasing the coverage of green open space, will lead to a cooler residential environment.

Table 2: Mean LST in housing area at different elevations

No.	Elevation	Density	Mean LST
1	Elevation 1 (654-694 m a.s.l.)	High	32.018
		Medium	31.055
2	Elevation 2 (694.0001-734 m a.s.l.)	High	31.977
		Medium	30.507
3	Elevation 3 (734.0001 -774 m a.s.l.)	High	31.893
		Medium	29.513

Table 3: Pearson correlation between NDVI and LST at different elevation

Case	N	Pearson Correlation	Sig.
Elevation 1 (654-694 m a.s.l)	180	-0.575	.000
Elevation 2 (694.0001-734 m a.s.l)	180	-0.612	.000
Elevation 3 (734.0001-774 m a.s.l)	60	-0.754	.000

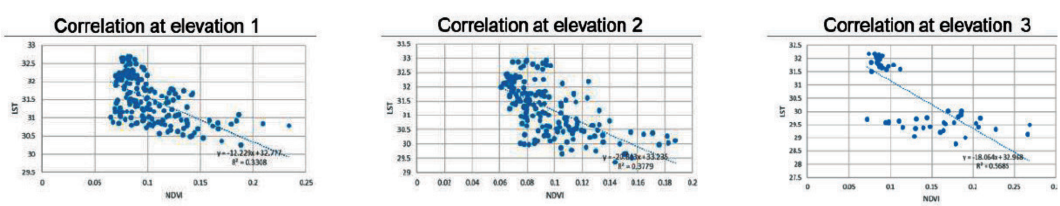

Figure 6: Scatterplots of LST vs NDVI

Hence, the relationship between LST and NDVI emphasises the fact that a prominence of tree covering housing areas reduces surface temperatures.

LST Comparison in Housing Area

The ANOVA test results, tabulated in Table 4, present that the density of housing areas has substantial contribution to LST value. There is a significant difference in LSTs values for high and medium density housing areas at each elevation.

This result is in line with research conducted by Keeratikasikorn *et al*. (2018) which analyzed the surface urban heat island (SUHI) in Bangkok. The results from the research shows that the mean intensity of SUHI (where SUHI = $LST_{urban} – LST_{rural}$) in high-density residential areas was higher than that of low-density residential areas. Similar findings were also reported in research conducted by Fonseka *et al*. (2019). That study revealed that the density in Colombo metropolitan area has a positive relationship with LST.

High-density housing areas present higher percentage of impervious areas compared to medium-density areas. Normally as a consequent, vegetation coverage in high-density housing areas is lower than vegetation coverage in medium-density areas.

It can be concluded that high percentage of impervious areas and low vegetation coverage contributes to higher LST levels in high-density housing areas.

Conclusion

Based on analysis of the housing density and vegetation cover factors, this study found out that LST is directly proportional to housing density and inversely proportional to the amount of urban tree cover at each observed elevation. LST values increase with the increasing density, meanwhile, decrease with increasing vegetation coverage. This indicates that density and vegetation coverage have a significant influence on LST in housing areas in Bandung.

Therefore, to mitigate the impact of the increasing LST in housing areas, the factors of housing density and conditions of vegetation cover should be considered. By increasing the quality of tree cover, especially in high-density housing areas, city planners and policymakers can reduce LST values and improve the quality of housing environment.

This mitigating factor needs to be accommodated in urban planning in Bandung, especially in housing area to support the sustainable development of Bandung city.

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Table 4: Result of the homogeneity of variances and ANNOVA test

Case	Test of Homogeneity of Variances		ANOVA	
	Levene Statistic	Sig.	F	Sig.
Elevation 1 (654-694 m a.s.l)	1.482	.225	266.349	.000
Elevation 2 (694.0001-734 m a.s.l)	.886	.348	409.062	.000
Elevation 3 (734.0001-774 m a.s.l)	2.450	.123	1344.305	.000

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