JOURNAL OF
Management and
Development Studies
University of the Philippines
Open University

THE INFLUENCE OF LANDSCAPE AND VEGETATION STRUCTURES ON LAND SURFACE TEMPERATURE: THE CASE OF URBAN GREEN SPACES OF CITY OF CALAMBA, LAGUNA, PHILIPPINES

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Received in April 2020 • Revised in April 2021 • Accepted in May 2021 • Published in May 2021

ABSTRACT – Green spaces of the City of Calamba extracted from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite image data were used to determine the relationship of both landscape and vegetation structures on land surface temperature (LST). Based on regression analysis, results showed that LST of green spaces is linearly dependent on its area. Specifically, LST tends to decrease by 0.0058°C as the area is increased by one hectare. Shape metrics such as perimeter-area ratio and shape index showed non-linear relationship with LST. Similarly, normalized difference vegetation index (NDVI) was not significant in affecting LST linearly. Therefore, large patches of green spaces must be maintained or increased to mitigate heat islands. Shape irregularity and vegetation abundance have no strong influence on LST of green spaces. Given the limitation of the research, further studies on LST of green spaces must be conducted to validate the results.

Keywords: green space, landscape metrics, LST, NDVI, City of Calamba

INTRODUCTION

Urban areas are known to have higher density of human population and structures such as houses, commercial buildings, roads, bridges and railways as compared to rural areas (Weeks, 2010). Furthermore, these areas are continuously expanding as more and more people are moving out from rural areas (Du et al., 2017). Consequently, urban areas have higher atmospheric and surface temperature than their surrounding rural areas. This phenomenon is commonly called the urban heat island (UHI) effect. It is mainly caused by land surface modification where materials used effectively store short-wave radiation (Solecki et al., 2005).

To cite this paper: Rabena, M. A. F., Johnson, B. A., & Onishi, A. (2020). The Influence of Landscape and Vegetation Structures on Land Surface Temperature: The Case of Urban Green Spaces of City of Calamba, Laguna, Philippines. Journal of Management and Development Studies Volume Number 9 Issue 1, 1-17.

Other causes involve direct discharge of heat to the environment such as transportation, air-conditioning, and manufacturing. These lead to an increase in land surface temperature which poses negative impacts to air and water quality, species composition and distribution, and public health (Niemela, 1999; Patz et al., 2005).

To mitigate UHI effects, some strategies have been investigated like changing the albedo of surfaces from low to high (Radhi et al., 2014) and presence of open water (Steeneveld et al., 2014). Moreover, presence of green spaces or vegetation patches has also been tested and numerous studies concluded regarding inverse relationship of vegetation and temperature (Shashua-Bar and Hoffman, 2000; Wong et al., 2007; Hamada and Ohta, 2010; and Heinl et al., 2015). Vegetation shade and absorb radiation via photosynthesis and transpiration which leads to lower land surface temperature (Tiangco et al., 2008).

Meanwhile, several literatures on the influence of spatial composition and configuration of green spaces on land surface temperature have already been published (Weng et al., 2004; Chen et al., 2006). For example, Cao et al. (2010) reported that vegetation patches create a "cool island effect", with the size and shape of a patch affecting the amount/extent of the local cooling. Moreover, the spatial characteristics and configuration of vegetation patches within the urban environment have significant impacts on the distribution of the urban heat islands (Zhao et al., 2011). However, studies on the relationship between the spatial pattern of green spaces and land surface temperature in Philippine urban areas (i.e. in *barangay*s with at least 5,000 population size, or has at least one establishment with a minimum of 100 employees, or has 5 or more establishments with a minimum of 10 employees, and 5 or more facilities within the two-kilometer radius from the *barangay* hall) has not been published. Hence, this pioneering study attempts to understand how size and shape of vegetation patches, and also their associated vegetation structure, affects land surface temperatures in the tropics.

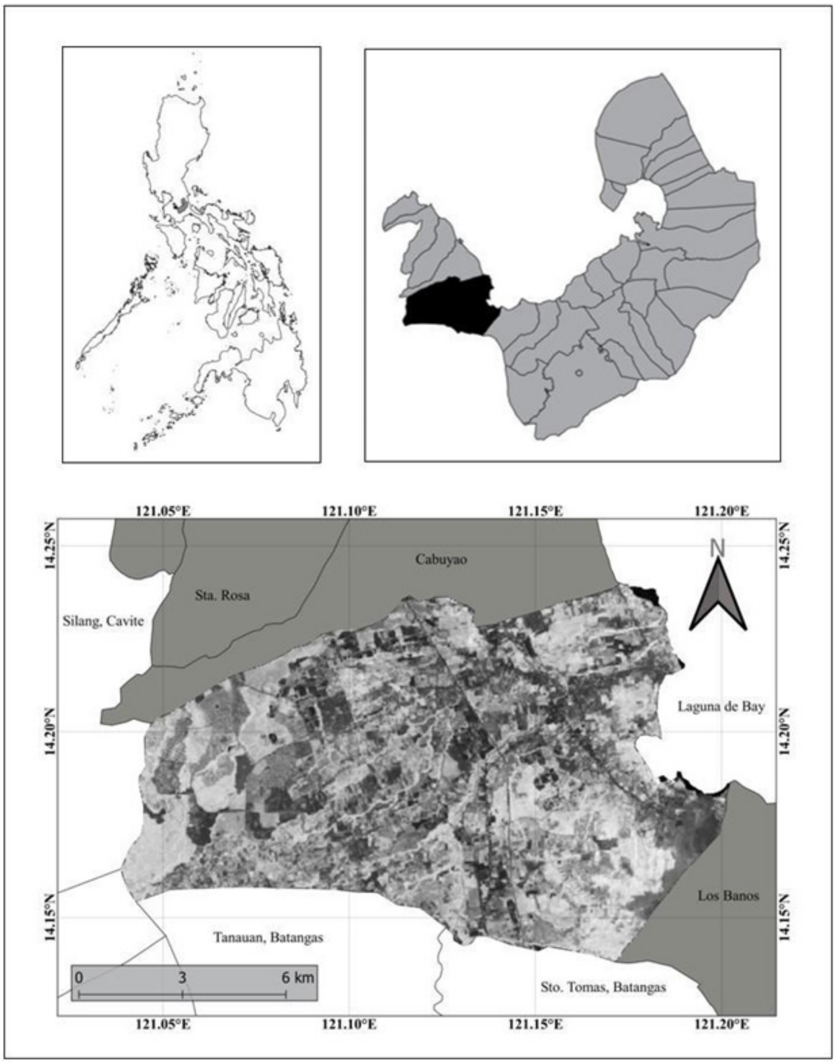
This study was designed to determine the relationships of vegetation patches' spatial and vegetation structures on its land surface temperature in the City of Calamba, Laguna, Philippines. This study was conducted during a two-month fellowship at the Global Cooperation Institute for Sustainable Cities, Yokohama City University in Yokohama City, Japan.

METHODOLOGY

Study Site

The City of Calamba is one of the urbanized cities of the Province of Laguna in the Philippines. It is situated at the western fringe of the Laguna de Bay, the largest lake in the Philippines, and is located about 45 kilometers south of Metro Manila (Figure 1).

Figure 1
Location map of the City of Calamba, Laguna in the Philippines



Note. Also shown is an NDVI image from a USGS satellite image acquired on April 4, 2017.

With an area of 14,480 hectares, the city accounts for about eight percent of the total land area of the province of Laguna. In 2015, its total population was 454,486 and its level of urbanization or proportion of urban population to total population was 91.7%. Based on Modified Coronas Classification, the City of Calamba has Type I Climate. It has two pronounced seasons, dry from January to April and wet during the rest of the year. In 2003, the city was declared the regional center of the Cavite – Laguna – Batangas – Rizal – Quezon (CALABARZON) region by virtue of Executive Order No. 246 of the President of the Philippines. At present, the City of Calamba is a first-class city and is an acknowledged tourism, industrial, commercial, service and administrative center in CALABARZON.

Land Cover Type Identification

Information on land cover of the City of Calamba were obtained from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite image data (courtesy of the U.S. Geological Survey). A Landsat 8 image acquired on April 4, 2017 was downloaded from Earth Explorer website. Land cover types were identified using the unsupervised classification method in QGIS environment (QGIS Development Team, 2018). Specifically, K-means clustering for grids (combined minimum distance) was applied to the satellite image to yield 10 initial (unlabeled) clusters. After which, visual interpretations were made and three land cover types were identified namely barren areas (i.e. soil, rocks, fallow land) , built-up areas (i.e. residential, roads, parking lots, commercial centers, industrial zones) and vegetation areas or green spaces (i.e. gardens, forest parks, vegetation on the side of the roads, grassland, shrubland, open forest and closed forest). Landscape statistics in QGIS were used to calculate landscape metrics for each cover type (Jung, 2016).

Landscape Structure Analysis

Green spaces, or patches, were extracted from the land cover map. To characterize these patches, the size and shape of each patch was calculated using patch metrics. These metrics include area metrics (e.g. patch area, m2) and shape metrics (e.g. perimeter to area ratio = the ratio of the patch perimeter in meter to area in square meter; and shape index = the ratio of perimeter to 2√[π*area]). See Mcgarigal et al. (2002) for detailed calculation equation and comments. All computations and analyses were done in QGIS (QGIS Development Team, 2018).

Vegetation Structure Analysis

\Normalized Difference Vegetation Index (NDVI) was used as a proxy parameter for vegetation structure or plant growth forms. Band 4 (red visible image band) and band 5 (near infrared (NIR) image band) of Landsat-8 image were analyzed in QGIS and NDVI was obtained using the formula as follows:
Very low values of NDVI (0.1 and below) correspond to barren areas of rock or sand. Moderate

$$\text{NDVI} = \frac{(\text{NIR - Red})}{(\text{NIR + Red})}$$

values represent shrub and grassland (0.2 to 0.3), while high values indicate tropical rainforests (0.6 to 0.8) (Weler and Herring, 2000).

Land Surface Temperature Assessment

The methodological framework of Avdan and Jovanovska (2016) was adopted to compute for the land surface temperature (LST). The same Landsat 8 image data downloaded from Earth Explorer website for land cover type classification was processed in QGIS. Band 10 (thermal infrared image band) was used to estimate brightness temperature and bands 4 and 5 were used to calculate the land surface emissivity. The two output images were then utilized as input data in QGIS to retrieve LST profile of the City of Calamba.

Statistical Analysis

Basic summary statistics for landscape metrics, NDVI values and LST were obtained through raster layer statistics, vector layer statistics and Landscape ecology statistics (LecoS) plug-ins of QGIS (Jung, 2016) and PAleontological STatistics (PAST) Software Version 3.21 (Hammer et al., 2001). To explore the bivariate relationship between landscape structure and LST, scatter plots were generated, and simple linear regression analysis was applied. Similar analysis was applied for the relationship between NDVI and LST. Analyses were also performed through PAleontological STatistics (PAST) Software Version 3.21 (Hammer et al., 2001).

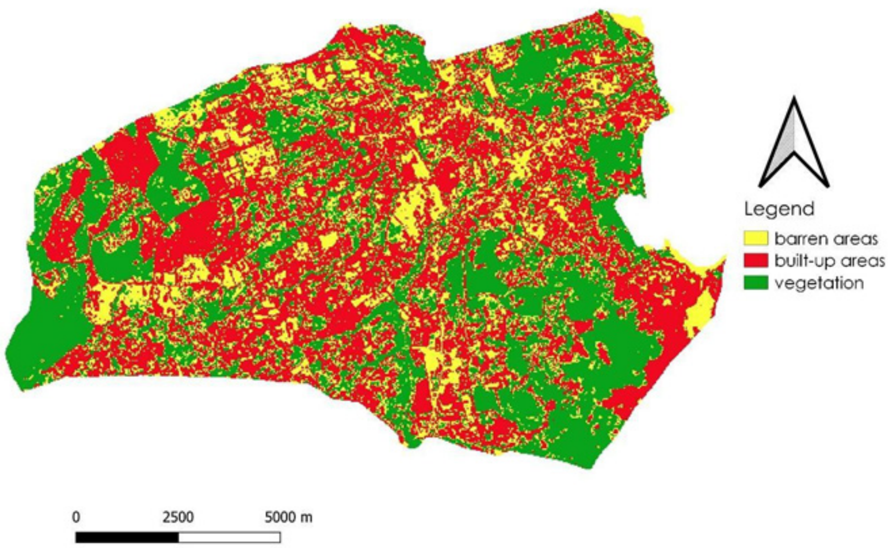
RESULTS AND DISCUSSION

Land Cover Types of the City of Calamba

Figure 2 shows a spatial mosaic model of the three major land cover types of the City of Calamba. The recorded total land area was 13,423 hectares. Built-up areas dominated the city with 43.4% coverage followed by 33.2% vegetation cover (Table 1). The remaining 23.4% cover type was comprised of barren areas. On the other hand, 71% of the 10766 patches were barren areas while the remaining 29% was covered by built-up areas and vegetation. The land cover type with the highest mean patch area were built-up areas (Table 1). The dominance of built-up areas in the City of Calamba has been reported by Bagarinao (2013) based on a 2010 land cover assessment. These results can be attributed to the on-going urbanization process of the city including but not limited to population increase, infrastructure development, land conversion, urban planning policies and local governance.

Figure 1

Land cover map of the City of Calamba based on Landsat-8



Note. Image acquired on April 4, 2017.

Table 1

Landscape metrics for the three land cover types based on Landsat-8 image of the City of Calamba dated April 4, 2017

Land Cover Type	Land Cover (Hectares)	Number of Patches	Mean Patch Area (Hectares)	Mean Perimeter-Area ratio	Mean Shape Index
Barren areas	3,135	7,653	0.4	0.111	1.26
Built-up areas	5,827	1,445	4.0	0.099	1.42
Green spaces	4,461	1,668	2.7	0.098	1.37
Total	13,423	10,766			

Note. Based on Landsat-8 image of the City of Calamba dated April 4, 2017

Landscape Structure of Green Spaces

Figure 3 shows the spatial distribution of 1,668 green patches, covering 4,461 hectares within the City of Calamba. The recorded patch area on the average was 2.7 hectares (Table 1).

Notably, the third quartile for the patch area was 0.5 hectares and the most frequently occurring area was 0.09 hectares. This means the city was dominated by smaller patches of green spaces. Meanwhile, the largest patch (949 hectares) was represented by a vegetated area proximal to and part of Mount Makiling Forest Reserve, an ASEAN heritage park (Fig. 3). Another large patch of green space was located near Tagaytay City which is known for its higher elevation and colder temperature. The other two patches with relatively larger areas were the annual cropland on the northern part of the city and a green corridor within a riverine channel.

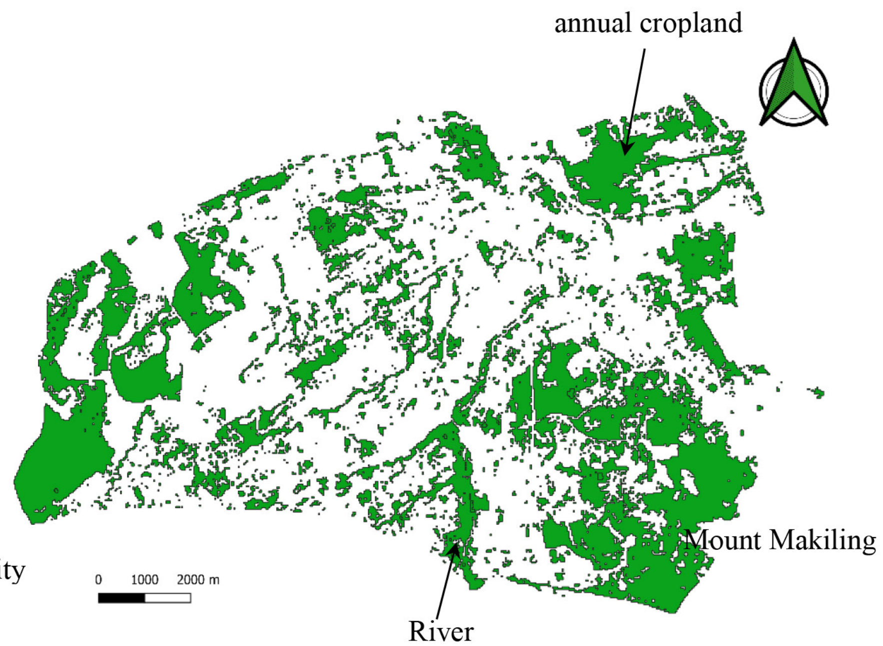
In terms of shape, green spaces recorded a mean perimeter-area ratio of 0.098 and a shape index of 1.37 (Table 1.) A mean shape index greater than one indicates an irregular and convoluted shape. Green spaces showed a certain degree of shape complexity. Krummet et al. (1987) reported that natural patches (e.g. forest areas) tend to be composed of more irregularly shaped units with less prominent boundaries. However, this is not the case in our study, as both natural and man-made patches showed irregularly shaped units without distinct borders (Table 1).

Vegetation Structure of Green Spaces

Vegetation structure describes the general life forms and vertical stratification of plant communities (Smith and Smith, 2001). In this study, the Normalized Difference Vegetation Index (NDVI) was used to determine whether a given green space is composed mainly of sparse herbaceous plants like grasses and crops or dense shrubs and woody trees. Figure 4 shows the spatial pattern of NDVI values among green spaces in the City of Calamba.

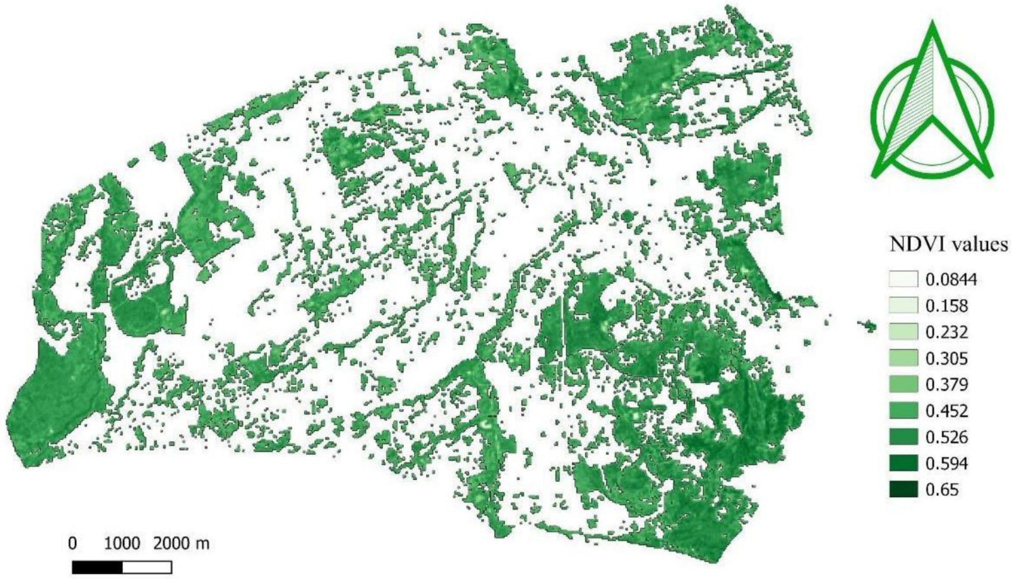
Figure 3

Green spaces map of City of Calamba



Note. Based on Landsat-8 image acquired on April 4, 2017.

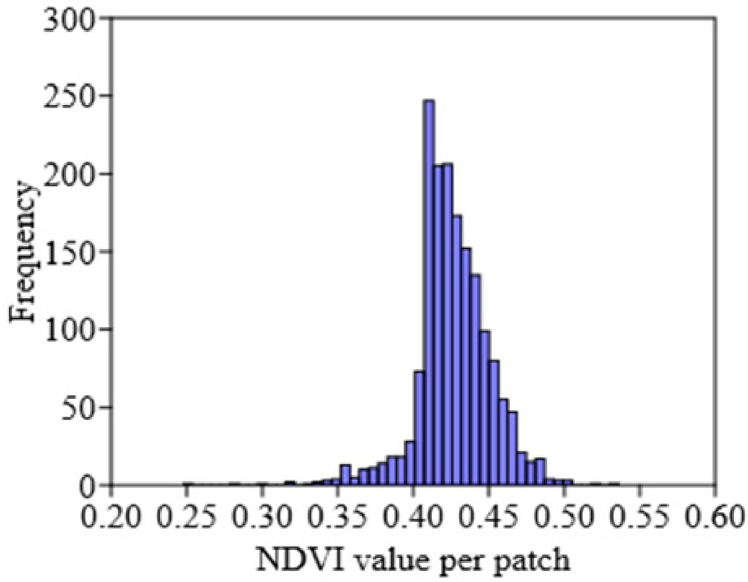
Figure 4
Normalized Difference Vegetation Index (NDVI) map of the City of Calamba



Note. Based on Landsat-8 image acquired on April 4, 2017.

The highest NDVI value was 0.65, a dense forested area while the lowest NDVI value was 0.08, a barren soil with negligible vegetation (Weler and Herring, 2000; Ozyavuz et al., 2015). When NDVI values within the patch were averaged, results showed that the highest mean NDVI value per patch is 0.54 while the lowest NDVI value is 0.25. Thus, patches of different vegetation types ranging from grassland to forest were evident in the city. Most of the patches had mean NDVI values of 0.40 to 0.45 (Fig. 5), indicating that green spaces of the City of Calamba are typically made up of sparse woody vegetation (shrubs or trees) intermixed with herbaceous plants. The large patch proximal to and part of Mount Makiling Forest Reserve had relatively high mean NDVI value (>0.5). This area was composed mainly of dense woody vegetation. The cropland identified previously showed moderate values of NDVI (0.48).

Figure 5
Frequency distribution of NDVI value per patch or green space of the City of Calamba.



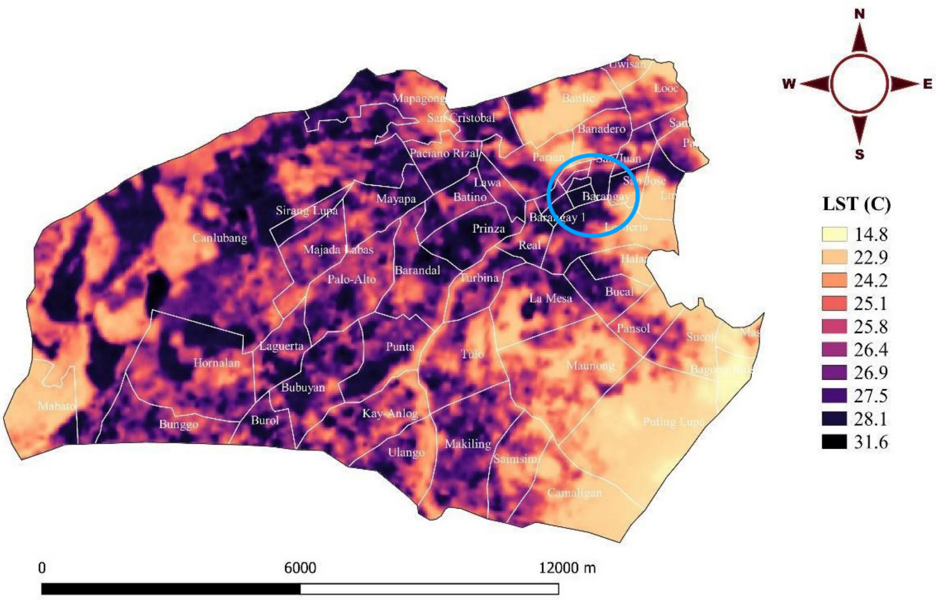
Land Surface Temperature of the City of Calamba

Figure 6 shows the spatial pattern of land surface temperature (LST) of the City of Calamba. The temperature ranged from 14.8 C to 31.6 C with a mean of 25.7 C and a standard deviation of 2.3. It is evident in the map that hot spots or heat islands ranging from 27.8 C to 31.6 C were not only concentrated in the urban center (or locally known as poblacion area) but rather spread out within the city. Moreover, these heat islands were most likely associated with built-up areas. For instance, *Barangay* Canlubang, one of the administrative units of the city located on the Northwestern part has five identified heat islands and these were mostly associated with residential subdivisions and manufacturing industries. Almost all *barangay*s or administrative units had heat islands, presumably due to the recorded 260 residential subdivisions, 234 manufacturing industries, and 8,437 business establishments throughout the city in 2015. This heat islands-built-up areas relationship can be attributed to the lower albedo of paving and building materials which reflect less and absorb more solar radiation (Li et al., 2012; Rasul et al., 2017; Mwangi et al., 2018).

On the other hand, a lower range of LST (14.8 C - 22.9 C) was found in southeastern *barangay*s namely Camaligan, Putinglupa, Bagong Kalsada, and Masili. These cold spots or cool islands were mostly covered by dense vegetation and found in relatively higher elevation. Also, these areas were near and part of the Mount Makiling Forest Reserve. Over-all, visual interpretation suggests that land surface temperature of the City of Calamba was affected by its land use / land cover (Forman, 1995; Weng, 2001; Arnfield, 2003; Chen et al., 2006; Xian and Crane, 2006 Zhou et al., 2011; Connors et al., 2013).

Figure 6

Land surface temperature map of the City of Calamba



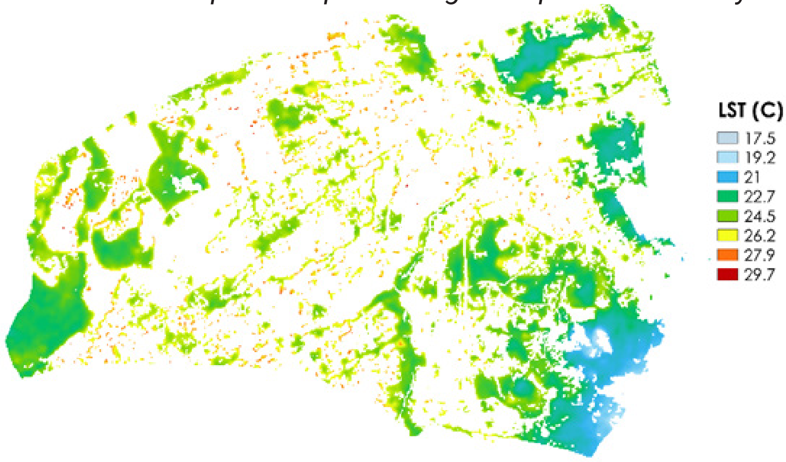
Note. Based on Landsat-8 image acquired on April 4, 2017. The boundary of *barangay*s is superimposed, and the encircled area is the urban center or población area.

Land Surface Temperature of Green Spaces

Land surface temperature of green spaces of the City of Calamba is shown in Figure 7. At the landscape level, the average temperature was 24.7°C with a range between 17.5°C to 29.7°C. The standard deviation was 1.6. Furthermore, at the patch level, the mean LST was 26.0°C with a range between 17.7°C to 29.5°C. The standard deviation was 1.2.

Figure 7

Land surface temperature profile of green spaces in the City of Calamba



Note. Based on Landsat-8 image acquired on April 4, 2017.

Land Surface Temperature and Landscape Structure of Green Spaces

The scatter diagrams of LST with three metrics of landscape structure are shown in Figure 8. After performing simple linear regression analysis, results showed that LST has a negative linear relationship with patch area. Based on statistical tests of significance of the regression coefficient, LST is linearly dependent on patch area (p-value = 2.7617E-08). Specifically, LST tends to decrease by 0.0058 C as the patch area is increased by one (1) hectare. On the other hand, based on computed coefficient of determination (denoted as R2), only about 1.84% of the variation in LST can be explained by variation in patch area. The other 98.16% can be attributed to some other factors not included in the model such as land cover type around the patch, spatial arrangement and types of vegetation in the patch, and patch shape (Chang et al., 2006). Similar findings on inverse relationship between LST and patch size of green space have been reported by Chang et al., 2006; Zhang et al., 2009; Cao et al., 2010; Li et al., 2012; Du et al., 2017; Naeem et al., 2018). Indeed, larger green spaces have cooler temperature than smaller ones.

Meanwhile, there seems to be a negative linear relationship between LST, and perimeter-area ratio as shown in Figure 8. However, this linear relationship is not statistically significant based on test of significance of the regression coefficient (p-value = 0.099217). In addition, the perimeter-area ratio of green space explains only about 0.16% of the variation in LST. Lastly, results on LST and shape index regression analysis showed non-linear relationship (p-value = 0.82027). The computed R2 was 0.003%. Hence, perimeter-area ratio and shape index, which are measures of shape complexity or irregularity of a given green space, did not affect LST linearly. This is consistent with the results reported by Yang et al. (2020).

Land Surface Temperature and Vegetation Structure of Green Spaces

The scatter diagram between LST and NDVI is shown in Figure 9. Results showed that LST is not linearly dependent on NDVI (p-value = 0.31105). Furthermore, NDVI explains only about 0.06% of the variation in LST. It appears that vegetation abundance or structure is not strong enough to influence LST of a given green space in the City of Calamba. As stated above, other factors might have affected LST and were not included in this study. It is important to note, however, about reports on the limitation of NDVI in providing a real estimate of the amount of vegetation (Small, 2001; Weng et al; 2004). NDVI may not be a good proxy of vegetation structure due to non-linearity between them (Asrar et al., 1984; Weng et al., 2004). Other measurements of vegetation structure other than NDVI can be explored and correlated to LST to infer meaningful inferences. In literature, LST-NDVI relationship is believed to be linearly related.

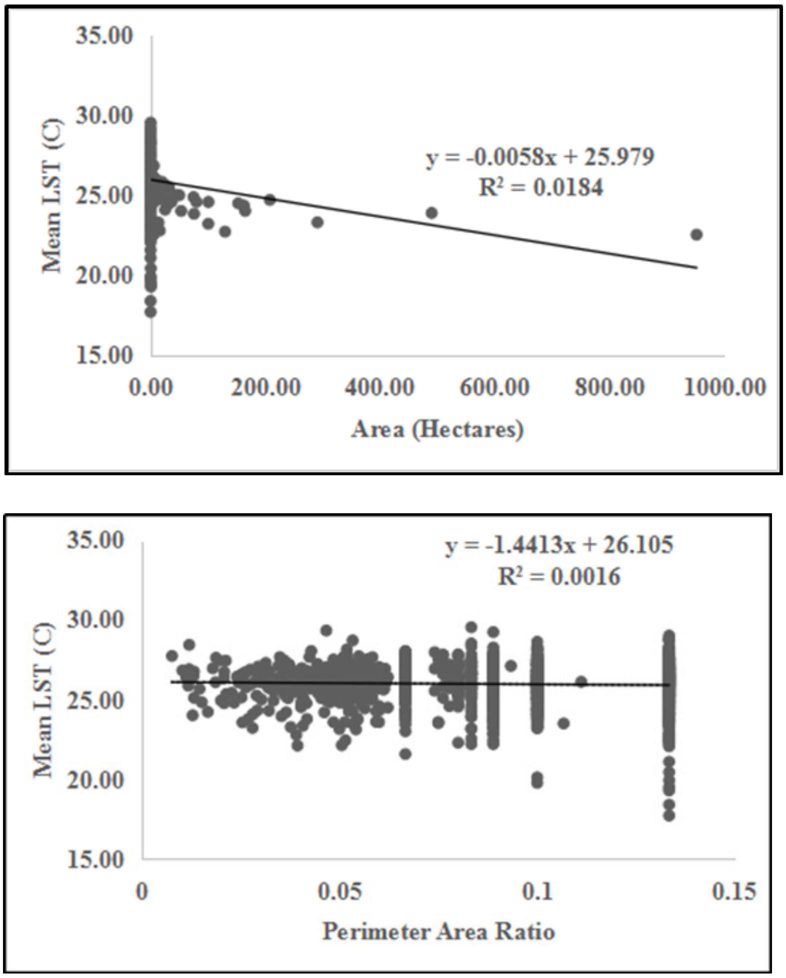
Implications for Environmental Management

Built-up areas are prevalent in the city. As the City of Calamba continuously progresses, the demand for land for commercial, industrial and residential purposes will also increase. This might exacerbate the thermal and health risks (Zhou et al., 2011).

Small green spaces are abundant in the city. The inverse relationship between size and LST necessitate larger green spaces to lower the green space profile of the city from dispersed unconnected heat islands to one distinct urban heat island (UHI). This UHI phenomenon has been regarded as an environmental issue since this may consequently increase water consumption and energy use. In addition, excess heat may also lead to discomfort temperature and to reduce heat islands. This can be achieved through local policy that promotes urban parks and green infrastructure especially in *barangay*s with high LST.

Figure 8

Relationship between LST and landscape metrics of green spaces in the City of Calamba



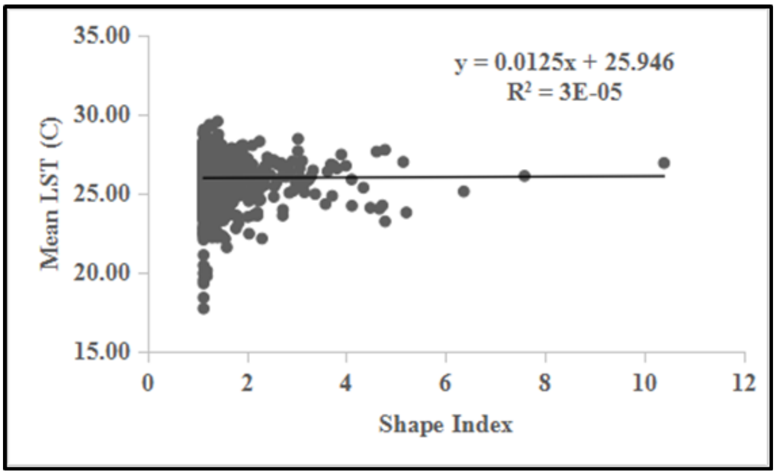
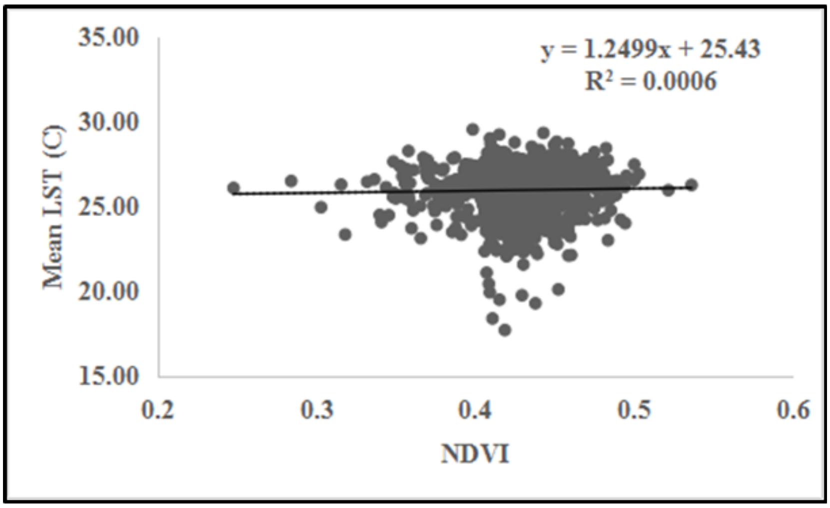


Figure 9

Relationship between LST and NDVI of green spaces in the City of Calamba



Promotion can be done through community-based and corporate-led projects. Another policy is to integrate forest and farmland conservation in the comprehensive land use plan (CLUP) of the city so green spaces will be maintained or increased in size and numbers. The City of Calamba must continue to support and cooperate with the University of the Philippines - Los Baños in preserving Mount Makiling Forest Reserve. For farmlands, the principle of local production for local consumption can be promoted so more communities or farmers will preserve their agricultural areas. Also, organic agriculture can be promoted especially in farmlands near Mount Makiling not only to add green spaces but also to protect biodiversity of the forestland. Moreover, urban parks can be established per *barangay* or implement green roofs and walls, green corridors, and roadside trees. Although vegetation structure does not influence land surface temperature of green spaces in the study, planting of different species of native trees adapted to the City of Calamba's climatic and edaphic conditions is advised.

Overall, other than cool islands formation, biodiversity can be improved and other ecosystem services such as flood regulation, air purification, source of materials, aesthetics, and recreation can be tapped from these forms of green spaces.

SUMMARY AND CONCLUSION

Land surface modification and microclimate change are known consequences of urban development. Specifically, proliferation of built-up areas results in heat islands while presence of green spaces forms cool islands. In this study, the relationship of both green spaces spatial pattern and vegetation structure with its land surface temperature (LST) was investigated. The City of Calamba, a regional center and first-class city of Laguna, was used as a case study for the Philippines. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images were used for land cover classification based on unsupervised classification method using combined minimum distance algorithm. Green spaces were extracted and characterized in terms of patch size, patch shape, vegetation structure and LST.

Results showed that built-up areas dominated the city (43%) in terms of land area while green spaces occupied 33% of the land. There were 11,668 green spaces identified with 2.7 hectares mean patch area and majority has smaller patch area (0.09 - 0.5 ha). Shape metrics suggests that green spaces have irregularly shaped units (mean shape index > 1). In terms of vegetation structure, green spaces composed mostly of few sparse shrubs and trees (mean NDVI = 0.40). On the other hand, the mean LST of green spaces was 26.0°C with a range between 17.7°C to 29.5°C.

The LST of green spaces was found to have a negative linear relationship with its size ((R^2 = 0.0184; p-value = 2.76E-08). LST tends to decrease by 0.0058°C as size increased by one (1) ha. On the other hand, both shape and vegetation structure did not show significant linear relationship with LST.

Thus, green spaces are indeed important in mitigating heat islands. However, the regression model suggests that it will be difficult to lower LST by just increasing the size of green spaces. Shape and vegetation characteristics do not seem to be a factor in affecting green spaces LST. Most likely, there are other factors not tested in this study which could influence LST of green spaces. Further studies on these factors must be done to substantiate the results.

RECOMMENDATION

This study used an unsupervised classification method for the identification of land cover types. In order to increase accuracy, supervised classification is suggested to verify the validity of results in this study.

In addition, the landscape analysis was only limited to patch level metrics. Landscape level analysis can be done to gain more insights on the relationship of spatial pattern of green spaces and its LST.

Besides size and shape, LST of green spaces is also influenced by other more variables worthy of investigation including morphology, land use around the green spaces, wind flow, and types and arrangement of vegetation. Although vegetation structure was considered through NDVI values, actual sampling of vertical stratification and growth form must be done.

In other words, further studies still need to be conducted to provide a more complete picture of the UHI effect on the city's urbanization plan. Nonetheless, the results of the study can serve as baseline information for decision-making and policy recommendations for the City of Calamba.

STATEMENT OF AUTHORSHIP

The first author conceptualized the research topic, conducted satellite data collection and analyses, and wrote the manuscript. The second and third authors provided substantial input on satellite data collection and analyses & reviewed the draft through comments and suggestions.

ACKNOWLEDGEMENT

This study was conducted as part of the Yokohama Urban Solutions Study (YUSS) Program of the Global Cooperation Institute for Sustainable Cities (GCI), Yokohama City University (YCU). We wish to thank the YUSS mentors namely Prof. Katsuhiko Yonezaki, Prof. Hidefumi Imura, Prof. Pei-I Tsai and Prof. Rui Ota and of GCI-YCU for their contributions to this study during weekly presentations. We also want to thank all the people of the International Affairs Division, Global Cooperation Institute for Sustainable Cities of YCU who contributed to this study through their logistic support. Finally, we are grateful to UPLB partners in the person of Mr. Donald A. Luna for his technical expertise on GIS and Remote Sensing and Dr. Damasa B. Magcale-Macandog for her excellent collaboration with Japan researchers which enabled the first author to participate in the 2018 YUSS Program of YCU.

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APPENDIX

Ordinary Least Squares Regression: Area-LST

Slope a:	-0.0057875	Std. error a:	0.0010367
t:	5.5826	p (slope):	2.7617E-08
Intercept b:	25.979	Std. error b:	0.030279

95% bootstrapped confidence intervals (N=1999):
Slope a: (-0.0072105, 0.0061065)
Intercept b: (25.916, 26.038)
Correlation:
r: -0.13547
r2: 0.018352
t: -5.5826
p (uncorr.): 2.7617E-08
Permutation p:0.0003

Ordinary Least Squares Regression: PA ratio-LST

Slope a:	-1.4461	Std. error a:	0.87668
t:	1.6496	p (slope):	0.099217
Intercept b:	26.106	Std. error b:	0.091482

95% bootstrapped confidence intervals (N=1999):
Slope a: (-3.1687, 0.1598)
Intercept b: (25.942, 26.278)
Correlation:
r: -0.040369
r2: 0.0016297
t: -1.6496
p (uncorr.): 0.099217
Permutation p:0.0977

Ordinary Least Squares Regression: SHAPE INDEX-LST

Slope a:	0.012708	Std. error a:	0.055925
t:	0.22723	p (slope):	0.82027
Intercept b:	25.946	Std. error b:	0.082406

95% bootstrapped confidence intervals (N=1999):
Slope a: (-0.093575, 0.13318)
Intercept b: (25.762, 26.108)
Correlation:
r: 0.0055654
r2: 3.0973E-05
t: 0.22723
p (uncorr.): 0.82027
Permutation p:0.8156

Ordinary Least Squares Regression: NDVI-LST

Slope a:	1.2525	Std. error a:	1.236
t:	1.0133	p (slope):	0.31105
Intercept b:	25.429	Std. error b:	0.52797

95% bootstrapped confidence intervals (N=1999):
Slope a: (-0.91843, 3.432)
Intercept b: (24.484, 26.365)
Correlation:
r: 0.024811
r2: 0.0006156
t: 1.0133
p (uncorr.): 0.31105
Permutation p:0.3091