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INFLUENCES OF URBAN GROWTH ON URBAN HEAT ISLAND IN KUCHING CITY IN YEAR OF 2005 UNTIL 2017

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Abstract:

Urbanization has contributed significantly to global warming. Kuching city has grown rapidly in recent years as a result of favourable socioeconomic, political, and physical factors that will undoubtedly affect the urban climate and environment. Landsat Thematic Mapper (ETM+) imagery from 2005, 2010, 2016, and 2017 was used to determine the urban heat island effect by examining the relationship between land-use changes and land surface temperature (LST). The study discovered a significant increase in the built-up area of about 17.1 percent between 2005 and 2017 and a decline in barren land and vegetation areas of about 41.6 percent and 5.1 percent, respectively. Additionally, this study discovered that as land use changed from 2005 to 2017, the LST increased year after year. The findings of this study demonstrate that they are effective tools for urban planners and environmental scientists because they provide critical data for monitoring urban growth patterns and their impact on urban climate.

Keywords:

Urban Heat Island (UHI), Land Surface Temperature (LST), Landsat Thematic Mapper (ETM+)

Introduction

In many developing countries today, urban growth is viewed as a series of unresolved problems as a result of a variety of intense factors, including socioeconomic patterns, physical characteristics, and political dynamics. When there is urban growth, it indicates a tremendous

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increase in the city's population and built environment. Kuching's population increased from 580,634 peoples in 2000 to 705,546 peoples in 2010. In 2020, more than 75% of Malaysia's population will live in urban areas, illustrating how people will demand basic facilities and infrastructures. Due to Kuching's rapid growth, urbanized areas may have significantly higher daytime surface temperatures than rural areas. Urban heating can create a slew of issues and problems for city dwellers, particularly those who live in tropical climates. In other words, urban heating has the potential to degrade our living environment, increase mortality (heat hazard), elevate ground-level ozone (urban heat island), and increase energy consumption. Thus, it is critical to understand the pattern of UHI intensity in Kuching and their relationship to urban growth characteristic to mitigate the worsening effect of the urban climate problem in the local context. Environmental and urban climate studies have analysed land surface temperature (LST) patterns and their relationship to surface characteristics, forecasting urban heat islands, and serving as a good indicator of the earth's surface energy.

Land surface temperature (LST), aided by thermal infrared bands of remote sensing data from space-borne sensors, is a critical application of remote sensing in urban climate studies, as it aids in land use and occupation planning (Chen et. al, 2006). Thermal infrared (TIR) remote sensing is used to obtain regional and global LST data; this is a unique approach because sensors in this spectral region detect energy emitted directly from the land surface (Yu et. al, 2014). The significance of this study it may help the profession of urban planning and even policymakers in the macro planning context, particularly in terms of physical development, such as zoning, land use planning, feasibility studies, mitigation measures, and risk management. For example, one possible mitigation measure is to enact zoning by-laws or building codes requiring new industrial or commercial development to incorporate green spaces and high-albedo or green roofing. Another potential mitigation strategy is to use water features or bodies of water to help moderate and neutralise the temperature in urban areas. Thus, it is critical to preserve water bodies not only for the benefit of the city's residents, but also so that parks and trees can be planted as recreational areas that contribute to lowering the ambient temperature.

The purpose of this study is to examine the land use pattern in a rapidly changing area of Kuching in relation to urban growth since 2000 and to ascertain the effect of such changes on the intensity of the UHI effect in the study area. Landsat image bands 2,3, and 4 were used to extract land cover information from remote sensing images taken at various time periods, and thermal infrared band 6 was used to analyse land surface temperature. The objectives of this research are to: (1) derive land surface temperatures from the Landsat ETM+ thermal band for the years 2005, 2010, 2016, and 2017; (2) determine the spatial pattern of land use cover and its changes over time from 2005 to 2017; and (3) examine the relationship between land surface temperature (LST) and land use changes in Kuching.

Study Area
The location is primarily in the Kuching city area. The increasing trend and greater changes in the urbanisation process in the Kuching areas in recent years are one of the primary reasons it was chosen as the study area. Kuching is Sarawak's most populous municipality and the epicentre of all economic, commercial, industrial, social, and administrative activities. As is the case with the majority of towns and cities in Malaysia, Kuching, the capital of Sarawak, is undergoing rapid growth.

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Kuching is the largest city in the Malaysia state of Sarawak, covering an area of 431.02 km^2. It is situated on the banks of the Sarawak River in the south western part of Borneo Island (located between latitudes 1.3°N and 110.4°E and has an elevation of 27m above sea level). The Sarawak River divides Kuching into North and South, with Kuching North City Hall (DBKU) covering area of 369.48 km^2 and Kuching South City Council (MBKS) covering area of 61.54 km^2. Kuching the capital state of Sarawak, is also experiencing rapid growth with the population increasing from 580,634 in 2000 to 812,900 in 2020. (Population and Housing Census of Malaysia, 2020). The rapid expansion is expected to continue for the next ten to twenty years.

Methods and Materials

The primary data set for this study is Landsat images from the years 2005, 2010, 2016, and 2017. All the satellite images were downloaded from the United States Geological Survey (USGS) by the navigation tools of Global Visualization Viewer (GloVis). The particular band 6 (thermal band) and band 2-4 (RGB) were used in this study to identify LST and land coverage (Table 1). Secondary data such as cadastral map, municipal boundaries and master plan map were obtained from the local authority of Kuching.

The navigation tools that are used in this research study are probably the remote sensing software such as Erdas Imagine 14.0 and ENVI 5.0 for the purposes of image pre-processing and data analysis at the earlier stage. Later, ArcGIS 10.1 was used for the data arrangement and maps composition. Lastly, Microsoft Office 2016 (Word and Excel) was used for report writing and tabulation of data.

Derivation of Land Surface Temperature (LST)

One of the objectives of this research is to simulate the land surface temperature which being derived from thermal infrared band of Landsat images. Plus, to determine its relationship to the land use changes from the period of 2005 until 2017. There are three (3) steps requires to derived the LST from Landsat 7 ETM+ images. First, spectral radiance was gained from DN of Landsat images with this following formula:

Step (1): Conversion of the Digital Number (DN) to Spectral Radiance (Lλ)

As to convert DN value to spectral radiance, the Band Math analysis was done in ENVI by key in the value in the equation. The following equation was used to convert the digital number (DN) of TIR bands of Landsat data into spectral radiance (Landsat 7 Science Data User's Handbook, 2002).

$$Radiance\ (L\lambda) = \left[\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right] x\ (QCAL - QCALMIN) + LMIN\lambda$$

whereas:
Lλ = the spectral radiance at the sensor's aperture in watts/ (meter squared * ster * µm).
QCAL = the quantized calibrated pixel value in DN.
LMINλ = the spectral radiance that is scaled to *QCALMIN* in watts / (meter squared * ster * µm).

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LMAXλ = the spectral radiance that is scaled to *QCALMAX* in watts/(meter squared * ster * µm).
QCALMINλ = the minimum quantized calibrated pixel value (corresponding to *LMINλ*).
QCALMAXλ = the maximum quantized calibrated pixel value (corresponding to *LMAXλ*).

Step (2): Conversion of Spectral Radiance to temperature in Kelvin

To convert the spectral radiance values to brightness temperature, the equation below was used.

$$\text{Kelvin Temperature } (T_k) = K2 \div \ln(K1 \div L\lambda + 1)$$

whereas:
Tk = the effective at satellite temperature in Kelvin.
Lk = the spectral radiance in W/ (meter squared *ster *µm).
K2 and *K1* = the pre-launch calibration constants.

Step (3): Conversion of Kelvin to Celsius

The final apparent surface temperature in Celsius (˚C) was calculated with the following equation:

$$\text{Celsius Temperature } (T_c) = T_k - 273.15$$

whereas:
**Tc* is the temperature in Celsius (˚C) and *Tk* is the temperature in Kelvin (*K*).

This research found that the temperature values ranged from 18˚C to 35˚C which were subsequently categorized into six (6) classes (18˚C to ≤ 23˚C, 23˚C to ≤ 24˚C, 24˚C to≤ 25˚C, 25˚C to ≤ 26˚C, 26˚C to ≤ 30˚C and 30˚C to ≤ 35˚C).

Main Results

Spatial Analysis

The spatial analysis consists of the derivation of land use map by identified and classified the current land cover types within the study areas. The total area of interest is approximately 21,440.70 hectares where the exact area of LULC is listed in Table 1 and land use map shown in Figure 1. Based on the land cover classification for satellite image 2005 indicates that the dominant class types within the study areas was under urban built up for 7,782.6 ha (36.3%) followed by vegetation which occupied 5123.1 ha (23.9%), while green parks and barren land comprises of 3,777.4 ha (17.6%) and 3,454.8 ha (16.1%) respectively. The water body such as river and lake covered up of 6.1% (1302.8 ha) from the total areas.

In 2017, the image classification result shows an increment in urban built up class which is up to 9,116.9 ha (42.5%). The green parks class also showed the increment of areas which amounted to 4,140.1 ha (19.3%). These two classes are showing an increment of areas as the urban are growing and a new development was coming in Kuching city especially the construction of new township comprising of all the facilities such as housing, commercial and

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meanwhile the provision of green parks for recreational purposes. While the other two classes showing decline in their areas includes vegetation which is 4,862.5 ha (22.7%) and barren land with 2,018.4 ha (9.4%). Apart from that, waterbody class remains the same and unchanged in 2017 which is 1,302.8 ha (6.1%).

Thermal Analysis

The thermal analysis consists of the computation of land surface temperature (LST) which derived from the Band 6 thermal infrared (TIR) of the satellite images. The band 6 commonly records the radiation with spectral range in 10.4-12.5 µm from the surface of the earth. As to obtain the final thermal map, the thermal infrared band are carried out in three stages of analysis in ENVI which is digital number (DN) to spectral radiance, radiance to Kelvin and Kelvin to Celsius. The LST was measured for the individual thermal images (4-images) and were compared based on its minimum, maximum and average temperatures of different time periods. The computed LST map is illustrated in Figure 2 respectively in years 2005, 2010, 2016 & 2017 with different values ranges between 113-144 (2005), 124-150 (2010), 121-155 (2016) and 120-156 (2017). The increase of the range values over the years is due to times frames of the images was captured.

Class Types	Year 2005			Year 2017		
	Acreage (ac)	**Hectare (ha)**	**Area (%)**	**Acreage (ac)**	**Hectare (ha)**	**Area (%)**
Urban Built Up	19231.3	7782.6	36.30	22528.4	9116.9	42.52
Green Parks	9334.2	3777.4	17.62	10230.5	4140.1	19.31
Vegetation	12659.5	5123.1	23.89	12015.5	4862.5	22.68
Barren Land	8536.9	3454.8	16.11	4987.5	2018.4	9.41
Water Body	3219.2	1302.8	6.08	3219.2	1302.8	6.08
Total	**52981.1**	**21440.7**	**100.0**	**52981.1**	**21440.7**	**100.0**

Table 1: Statistic of Land Cover Types Areas

Source: Author's Analysis (2021)

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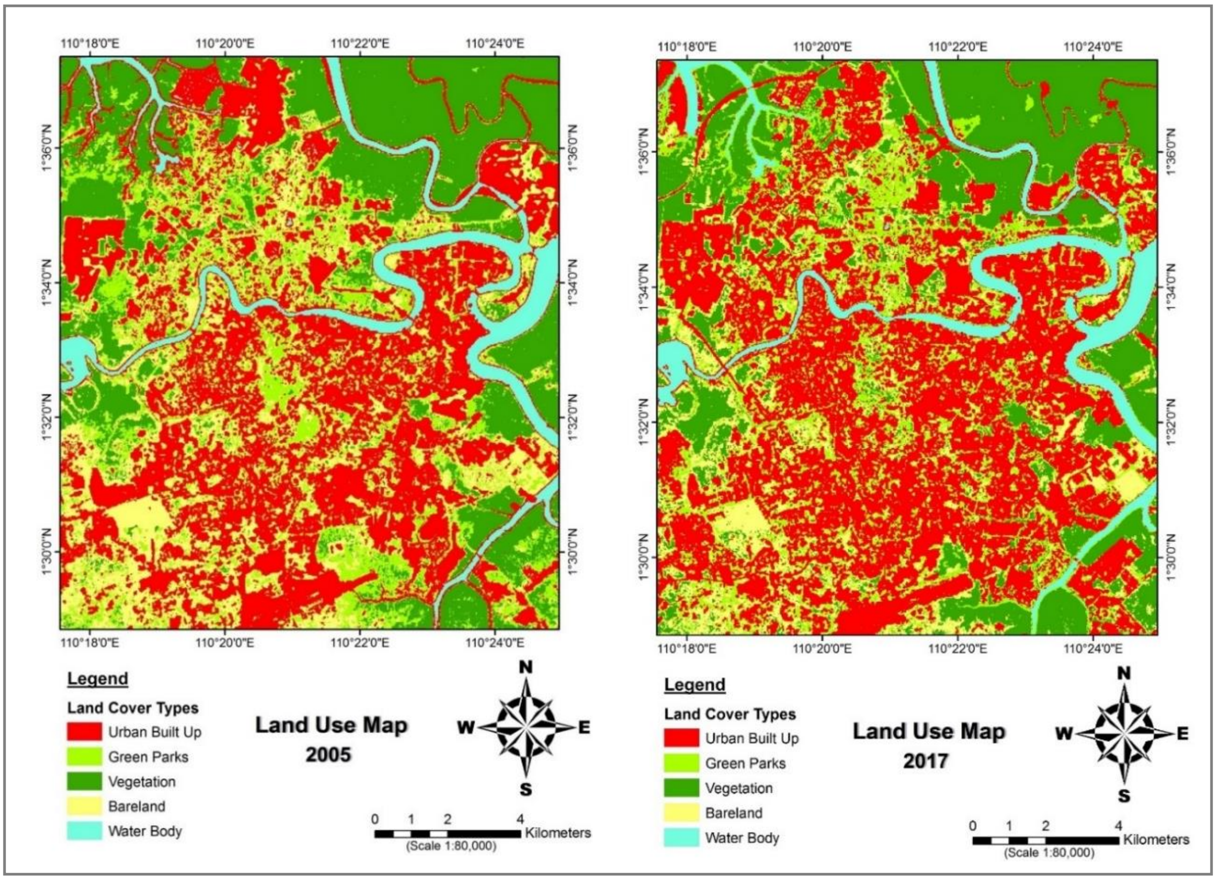

Figure 1: Land Use Maps of 2005 and 2017
Source: Author's Analysis (2021)

These changes could be the significant reason of the climate change happen over the past few years. Extreme season such as drought, heavy rain, flood particularly gives a great effect to this phenomenon. The thermal maps of the study area for year 2005, 2010, 2016 and 2017 were generated in GIS and presented in Figure 2 showing up the temperature distribution across the study areas which the range of temperatures was divided into six (6) categories. It could be seen that the trends for minimum and maximum value of LST are keep increasing over the years. The highest temperature was recorded in 2017 which is 35.5°C and the lowest was in 2005 with 21.8°C. In 2005, the minimum and maximum LST is 21.8°C and 29.8°C respectively where the change is 8°C. While, in 2010 the minimum and maximum LST is 26.2°C and 32.7°C with increment of 6.5°C. For 2016 and 2017 is not much different as the gap is only within one year as the minimum and maximum value was 26.6°C and 35.1°C to 35.5°C. In overall, the highest average temperature was recorded in 2017 which is 26.6°C compared to the other years.

Relationship between Spatial and Thermal Analysis

The investigation towards the thermal signature of each land use type is essential as to understand the relationship between land use and LST. In this study, the third objective is to determine the impacts of land use change (urban growth) towards the temperatures surrounding in Kuching. Therefore, a comparison of land use and LST was carried out where the sampling points for each land use category and spatial subset were selected to compare all the LST retrieval which being represented in terms of minimum, maximum and average (mean) values.

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The mean values were calculated by averaging all consistent pixels of given LST retrieval. The sampling points were chosen based on the different land use on the site study such as residential, commercial, open spaces and others as to see clearly the variations of LST values. Figure 3 summarized the average (mean) LST values by land cover types for 2005, 2010, 2016 and 2017.

The surface temperature pixels were ranged from 18°C to 35°C. The results indicated in graph line below clearly shows the built up land exhibited the highest LST where the highest value was 28.8°C in 2017 followed by green parks, barren land, vegetation and water body in all four periods. The low values of LST were observed in vegetated areas and water bodies. The findings trend also signified that built-up areas increased the land surface temperature by replacing the natural vegetation with non-evaporating and non-transpiring surfaces (Weng, 2001). In addition, it is noticeable that the LST was increased for all the land cover types over the four periods of time except water body class which declined from 2010 until 2016. Generally, the changing of LST was caused by the land changes from 2005 until 2017 due to each type of land has its own qualities in terms of energy radiation and absorption (Ibrahim F. & Rasul G., 2017). The urban built-up surfaces may dominate high albedo and absorption than barren lands due to the surrounding environment that having higher temperatures than urban areas.

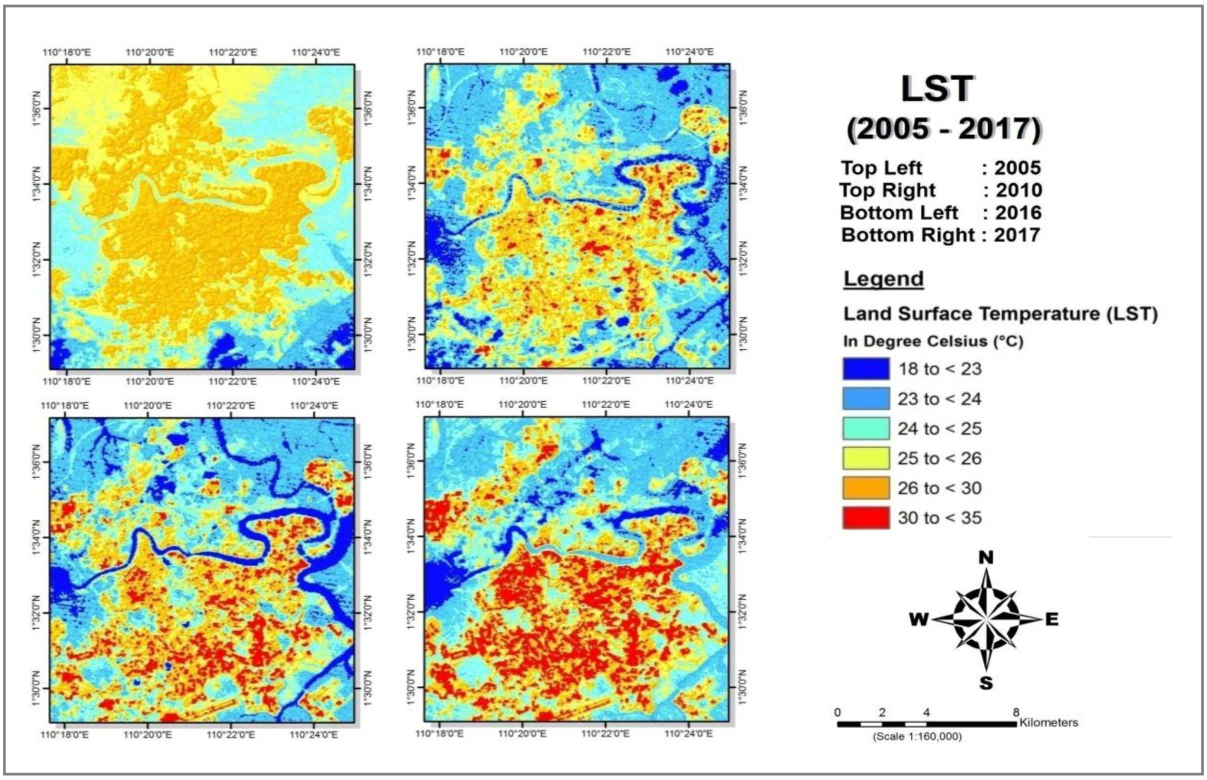

Figure 2: Thermal Maps of 2005, 2010, 2016 and 2017
Source: Author’s Analysis (2021)

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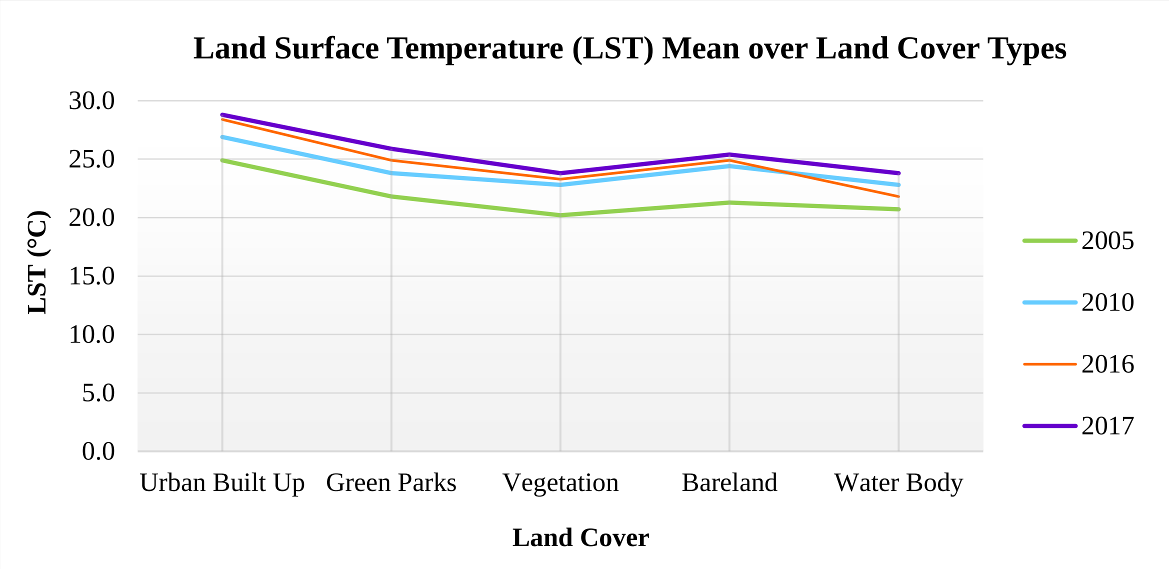

Figure 3: Relationship Between of Mean LST Over Variations of Land Cover Types
Source: Author's Analysis (2021)

Conclusion

This study primarily used remote sensing and GIS to assess the effect of urban growth on land surface temperature (LST) in Kuching, Sarawak. The land cover classification revealed that between 2005 and 2017, urban built-up areas and green parks increased by 17.1% and 9.6%, respectively, while vegetation and barren land decreased by 5.1 percent and 41.6 percent, respectively. The dramatic changes in barren land are a result of land being used for development purposes as a result of political and socioeconomic factors. Overall, the accuracy of the 2005 and 2017 land use maps was 75% and 90%, respectively. The findings indicated that the relationship between land use changes and LST increased proportionately over time. In 2017, urban built-up areas had the highest mean LST of 28.8°C, while water bodies had the lowest mean LST of 23.8°C. Remote sensing and GIS have been shown to be an effective method for detecting land use changes and have a significant impact on LST. This could result in additional research on the specific effect of human activities and environmental modification on climate change or global warming. In future research, it is critical to assess the impact of urban growth on climate change and to investigate the adaptation of climate-responsive urban planning in decision or policy making.

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