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Application of Thermal Remote Sensing in Study of Urban Green Space Mitigation of Urban Heat Effect at Small Medium Size City: Case Study

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Abstract

Urban Heat island is phenomena when the temperature in urban areas higher than rural or suburban. Urban heat island negative effect such a high emission of green gasses, increase of demand energy consumption, air pollution, heatstroke, and decrease of population comfort. Green areas are very important in reducing the impact of urban heat islands. This is because plants can lower the ambient temperature through the process of Evo transpiration. Many studies on the use of plants in reducing the effects of urban heat islands. However, there is still a lack of studies on the effect of changes in the area of green areas on the effectiveness of green areas to lower the temperature due to urban heat islands. In tropical climates, there is still a lack of research on the effects of changes in green area on surface temperature, especially in Malaysia. The existing study only focuses on studying the relationship between green areas and surface temperatures in the city. To increase knowledge about urban heat island this study will use two different year data to study the effect of changes in the area of green area on the surface temperature in the city. Beside that central literature reviews strongly advised the location of area study should be at small-medium city such Kuching with population below one million. The Land Surface Temperature (LST) maps were retrieval from Landsat 5 Thematic Mapper (TM) on year 1988 and Landsat 8 Thermal infrared sensor (TIRS) on year 2019. Next step this study applied the red and infrared wavelength to generate NDVI (Normalized Difference Vegetation Index). The last step of the method applied the correlation between NDVI, distance cooling extent, and area of urban green space with LST. The results show a negative correlation between NDVI and area urban green space. However, there is a positive correlation between distance cooling extent with LST. The finding of studies provides new perspectives in tropical urban heat island studies in mitigation urban heat effects. The finding provides also valuable information to urban planners, policymakers, and a municipal council in future planning mitigation to reduce the urban heat island effect to achieve low city carbon.

Keywords**:** Thermal remote sensing; Urban heat effect, Urban green space,

Introduction

The United Nations in 2014 predicts 54% of the world's population will live in cities. This percentage will increase to 66% by 2050. This states the need for more in-depth and extensive research on urban heat islands due to the negative impact on the population living in the city (Yang, He, Wang, Yan Yu, Bu, Yang, Chang, & Zhang, 2017). Rosenfeld, Akbari, Romm, and Pomerantz (1998) reported of the urban heat island effect

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can cause urban pollution, an increase in energy and water consumption (Aggarwal, Ghaghara, Grossman-Clarke, & Lathey, 2012; Akbari & Konopacki, 2005), extra heat stress on the population (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006) and can cause of morbidity and mortality (Barnett, 2007). Due to the negative effects as stated above, it is a need for researchers to study ways to reduce the impact of urban heat islands. Green areas that are growing areas are an important component in reducing the impact of urban heat islands. The urban green spaces such an urban forest, parks, grassland, and sports field or sports recreation e.g. golf, football, and jogging track (Wolch & Bryne, 2014) vital component in reducing urban heat effect (Park, Kim, Lee, Park, & Jeong, 2016).

Urban green space provides important ecosystem services in enhancing urban population quality of life, health and comfort (Akpinar, Barbosa-Leiker, & Brooks, 2016). The function of urban green space can reduce the LST with two primary processes. The first by shading and provide higher evapotranspiration. Many studies on the relationship of green areas with the effects of urban heat islands in reducing heat (Wolch, Byrne, & Newell, 2014; Chen, Su, Li, Huang, Chen, & Chen, 2012; Susca, Gaffin, & Dell'Osso, 2011; Hamada & Ohta, 2010; Santamouris, 2001; Shashua-Bar & Hoffman, 2000). In Malaysia, there are only two studies studying the relationship of green areas with surface temperature in cities. But their study uses only one remote sensing data (Sheikhi, Kasturi & Ho, 2018; Afzan, Wan Mohd & Misni 2016).

This study will use two remote sensing data to see the effect of green area change with surface temperature in the city. The first examined the relationship between NDVI and LST, second discovers of cooling effect distance of urban green space. A third of the objective to examine the relationship between urban green space areas in hectares with LST surrounding. The last objective this study will examine the relationship of surface temperature with changes in the area of green area. The output of this study able gives the image degree of significant vegetation in the mitigation of urban heat effect. Urban planners and policymakers shall be considered during makes decisions in urban development to achieve low carbon city and upgrade the wellbeing of the urban population.

Literature review

The following is a literature review study that examines the relationship of green areas in lowering surface temperatures in cities due to urban heat islands (Le, Cao & Tran, 2019; Hong, Carib, Zhou, Jiang, & Xue, 2019; Zhang, Zhan, Yu & Ren, 2019; Sheikhi, Kasturi, & Ho, 2018; Ren, Deng, Zuo, Song, Liao, Chen, Hua & Li, 2016; Asgarian, Amiri & Sakieh, 2015; Buyadi, Wan Mohd, & Misni, 2014; Bowler, Buyung-Ali, Knight & Pullin, 2010). Besides that, there have studies was done use the indexes vegetation such like Normalized Difference Vegetarian Index (NDVI) and Leaf Area Index (LAI) (Cai, Chen, & Tong, 2019; Yang, Yu, Jørgensen & Vejre, 2020; Zhen et al., 2019; Huang & Cadenasso, 2016; Kuang, Liu, Dou, Chi, Chen, Gao, Yang, Liu, & Zhang, 2015; Yu, Guo, & Wu, 2014; Yu & Hien, 2006). However, the relationships between green space and LST are hard to support urban planning and management practicality (Huang et al., 2016; Sun & Chen, 2012). Consequently, many scholars focused on the quantification of the cooling scope and intensity of green spaces. Lin, Yu, Chang, Wu, and Zhang (2015) discussed in this category is a study conducted on 30

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parks in Beijing, where it was found that the size of the parks has an impact on cooling effect creation. The parks investigated in this study had an average of between 85m and 284m, and could reduce the average temperature by about 2.3 until 4.8-degree celcius. Yu, Guo, and Sun (2017) examined that green spaces cooling effective distance at 104m which can reduce the LST 1.78 degree Celsius. A study by Oliveira, Andrade, and Vaz (2011) recognized that while the temperature decrease in Lisbon can reach 6.9 °C on a hot summer day. The cooling effect of green spaces also has a connection with the different climate zones, which was also proven by other studies (Zhao, Lei, Smith, & Oleson, 2014). All the studies mentioned have been conducted in countries with a climate of four seasons. There is still a lot to be understood about the relationship between green areas and surface temperatures in urban areas, especially in Malaysia and small to medium sized cities. There only three study at tropical, which was done by Jauregui (1991) in Mexico City within-site measurement, which they found cooling extent reached over 2 km. In the context of Malaysia, as far as we know, two research has investigated the cooling extent of urban green space which by Buyadi et al. (2014) and Kasturi et al. (2018). However, their study used only one remote sensing data. This study will use two different remote sensing years to study the effects of green area changes on the ambient temperature in the city.

Study Area

Kuching is the capital city of the state of Sarawak, Malaysia. The annual precipitation 4200 millimeters (Thomas, 2013) and the standard temperature value of 19 ◦C to 36 ◦C (MOSTI, 2014). The Northeast season in September until March and the southeast from May until August. The northeast season significant wet season at Kuching and the southeast season is dry. United Nations (2018) reported that the total population of 570, 407. Selection of Kuching city as a study area because the literature paper (Zhou, Xiao, Banafoni, Berger, Deilami, Zhou, Frolking, Yao, Qiao, & Sobrino, 2019) has been strongly suggested the future studies of urban heat should focus on small-medium small cities which a population below 2 million. This study is an excellent deal to infill the gaps in the research of applied thermal remote sensing in urban heat studies.

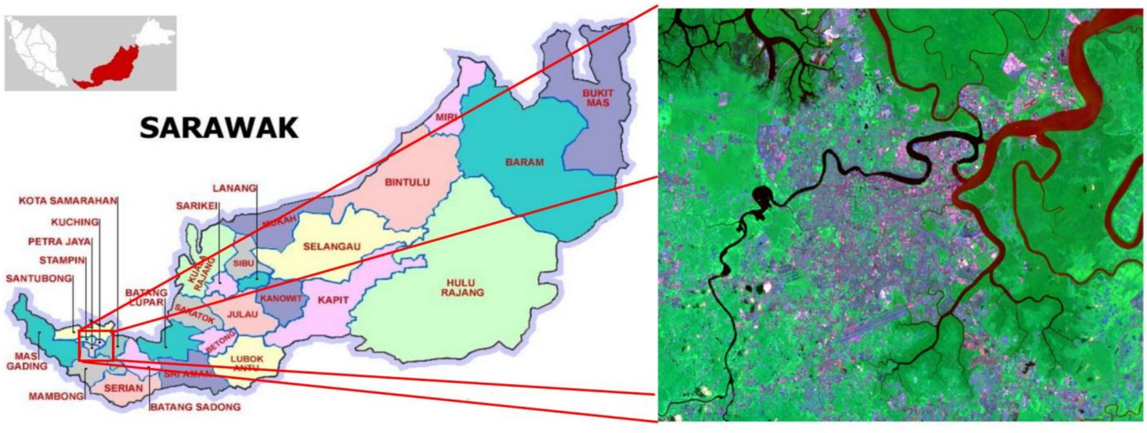

Figure 1 show of location of the study area.
Source: Author

Dataset

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Table 1 Dataset Detailed

Sensor	Thermal Band	Resolution (Meter)	Data Acquisition
Landsat 5	Band 6	100 resample to 30 meters	25 May 1988
Landsat 8	Band 10	120 resample to 30 meters	15 May 2019

Source: Author

The first steps are as follows for pre-processing environment correction, geometric correction, and radiometric correction. The next step is taking the ground surface temperature (LST) in Landsat 8. This study does not focus on the algorithms produced by LST. This study will use the method once used by Ricky and Oliver (2019) in converting digital value of numbers to LST and NDVI.

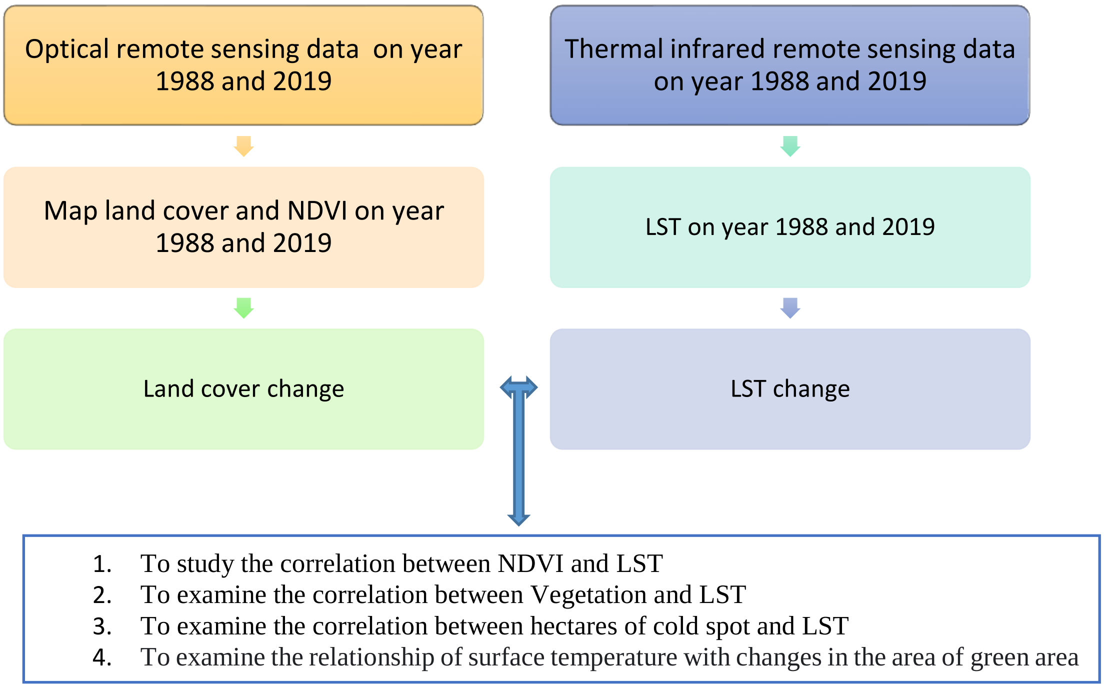

Figure 2: The flow method to achieve the objective of study.

Source: Author

NDVI

Ogashawara and Bastos (2012) denote the Normalized Difference Vegetation Index (NDVI) live green vegetation indicator. NDVI was able to separate vegetation from water and soil. The value of NDVI forms 1 to –1. The value of 1 represents most health of vegetation, and the negative denotes not contain vegetation. Formula below shows the calculation to procedure NDVI at remote sensing. At Landsat 8 Near Infrared (NIR) was at Band 5 and Red (R) wavelength was denoted at Band 4. However, for Landsat 5 the NIR was at Band 4 and R at band 3.

$$NDVI = \frac{NIR + R}{NIR + R}$$

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Table 2 The selection band for calculated NDVI

Sensor	Selection band for calculated NDVI
Landsat 8,	(Band 5 – Band 4) / (Band 5 + Band 4)
Landsat 5	(Band 4 – Band 3) / (Band 4 + Band 3)

Source: Author

This study used 100 sample points. The sampling method is systematic sampling as seen in the picture below (Figure 3). The first sampling to find out the study relationship between NDVI and LST. The next step is to study the relationship between cold distance (urban green space) and LST. To achieve this objective the author takes a sample every 30 meters from plants to reach 300 meters. The next objective is to calculate the area in the green hectares of urban space. This requires two different data dates. The area of green areas in 1988 and 2019 will be calculated. Subsequently changes in the area of the green area will be calculated.

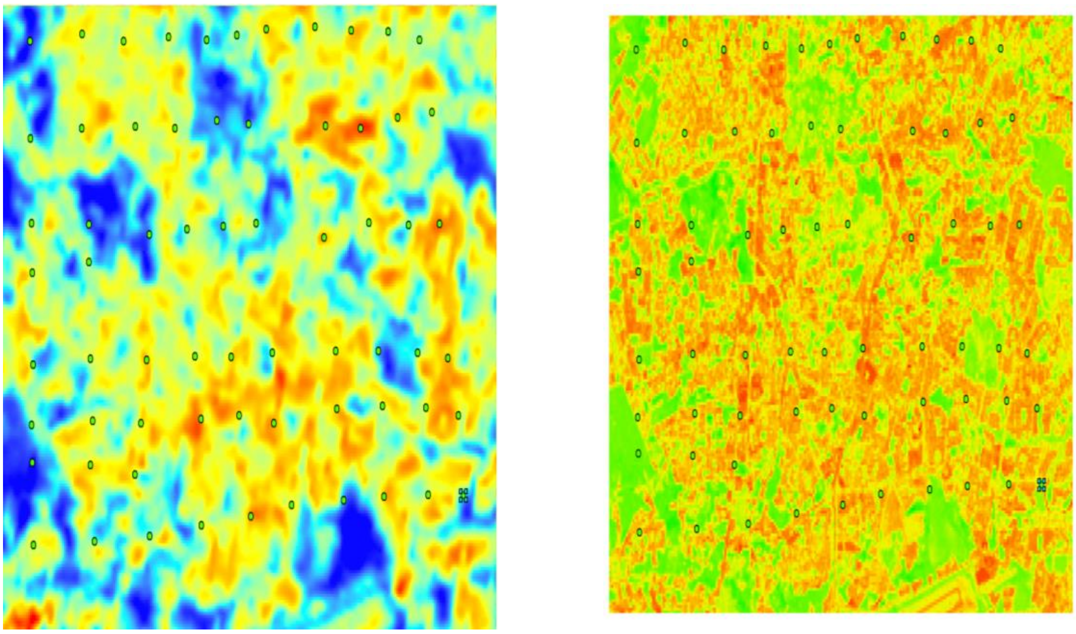

Figure 3: The location of the Sampling Location for the 100-point location on the LST and NDVI maps.
Source: Author

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Results and Discussion

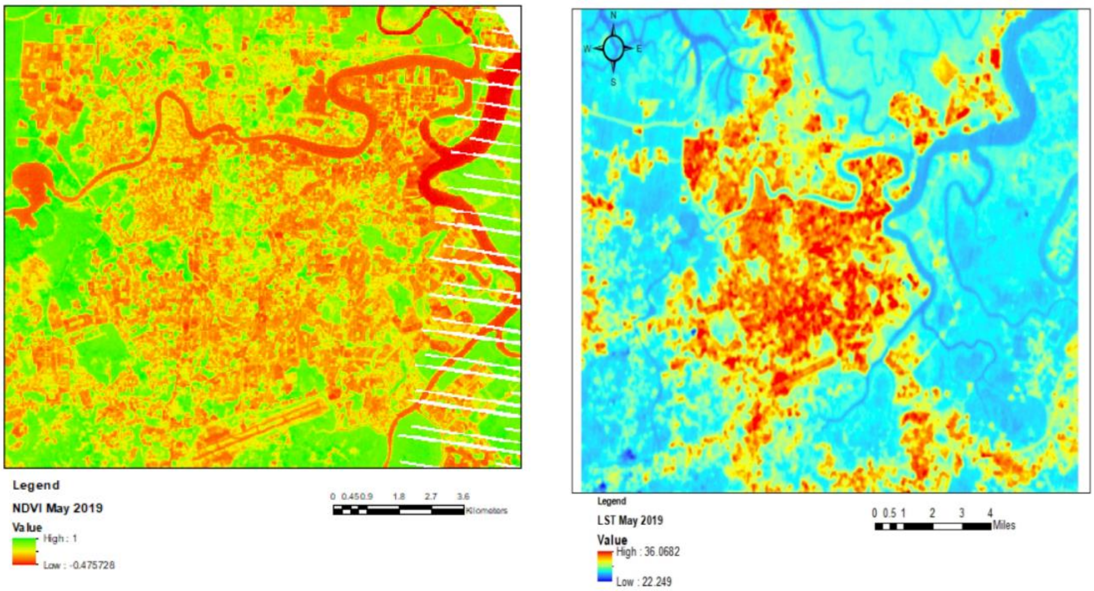

Figure 4: The map of LST (Left) and NDVI (Right) on year 2019.
Source: Author

Figure 4 presents that the mean of NDVI 0.274, value of minimum is a -0.107, and maximum 0.628. The mean value for LST 29.58 degree Celsius, minimum is a 25.25 degree Celsius and the maximum 33.39. The maximum value of LST relocated at the lowest value of NDVI, which represents urban areas. The minimum of LST represents green space urban. The detailed regarding the result was show at Table 2. This clearly states that green areas have low LST compared to areas with negative or low NDVI values. The result similar to literature reviews (Yuan et al., 2019; Gao et al., 2019). The vegetation provides ecological services such Eva transpiration which able to reduce the value of LST.

Table 3 The statistic information regarding value NDVI and LST for year 2019.

Data statistics	NDVI	LST
	NDVI Value	Value (Degree Celsius)
Min	-0.107	25.25
Max	0.628	33.39
Mean	0.274	29.58

Source: Author

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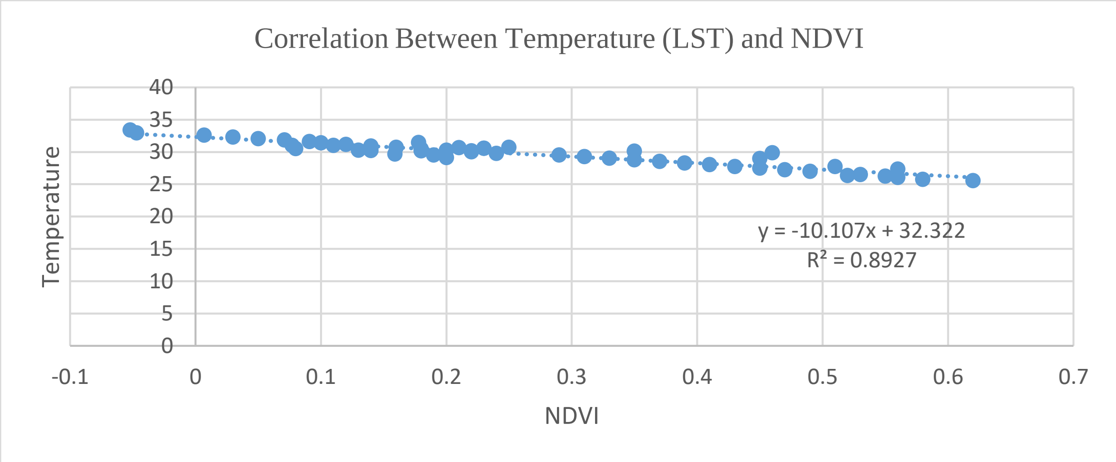

Figure 5: Scatter plot correlation between LST and NDVI.
Source: Author

Figure 5 stated there was a strong negative correlation observed between NDVI and LST with the value of R 0.8927. The result of this study found similar with pervious literature review (Yuan et al., 2019; Yang et al., 2019; Zhen et al., 2019; Huang et al., 2016; Kuang et al., 2015; Yu et al., 2014; Yu et al., 2006;). That explain the green space at urban has potential to reducing the LST which effect from urban heat island.

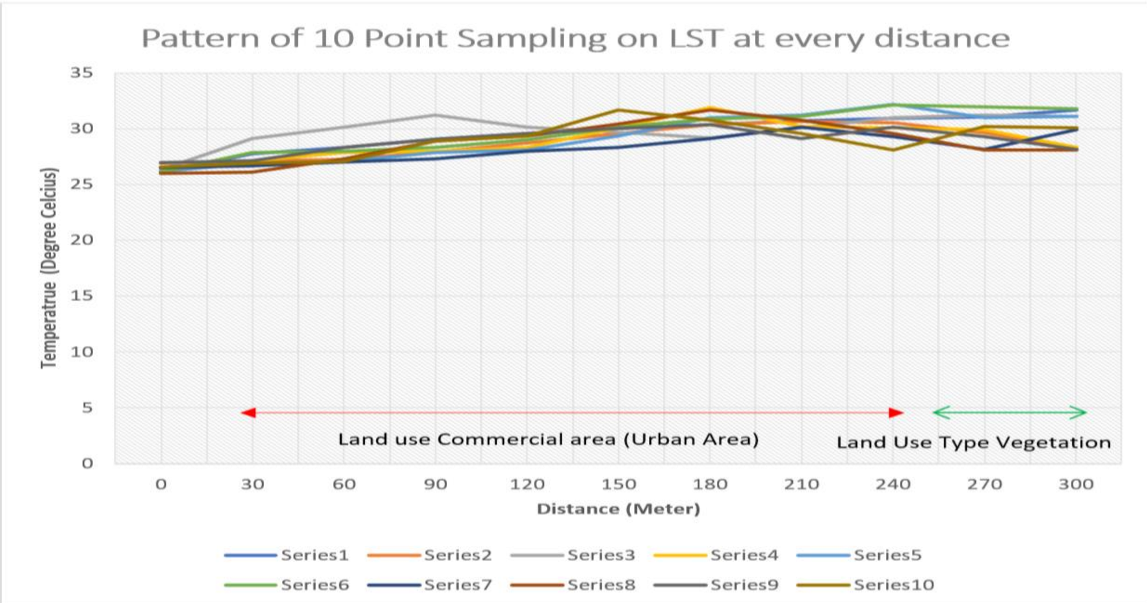

Figure 6: Pattern of 10 sampling point LST at every distance (meter).
Source: Author

Figure 6 demonstrates the pattern of 10-point sampling LST at every distance. The detailed explanation following in Figure 7.

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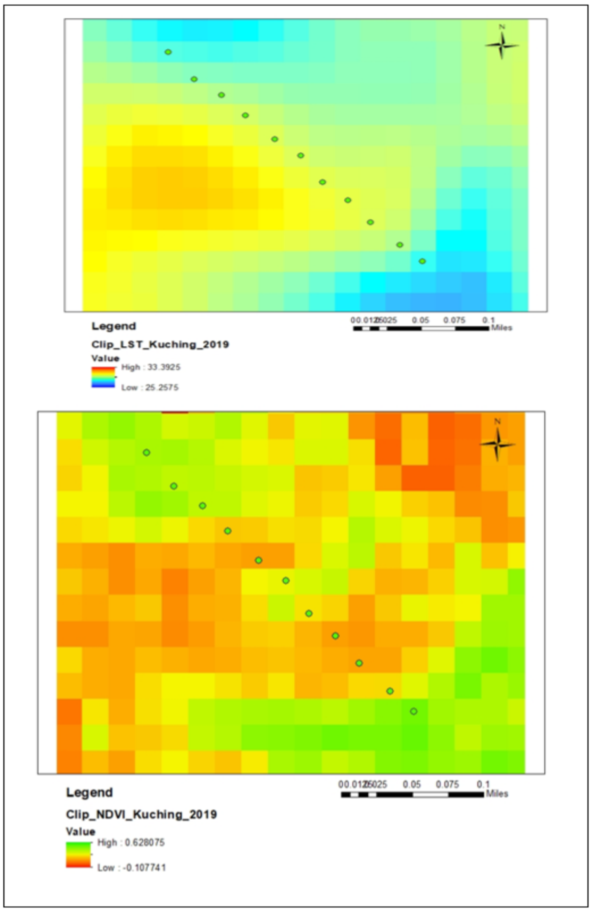

	The year 2019	
Distance (m)	Temperature (Celsius)	Land Use
Vegetation (0)	27.89	Vegetation
30	28.50	Commercial areas
60	29.56	Commercial area
90	30.14	Commercial area
120	30.32	Commercial area
150	30.23	Vegetation
180	30.41	Commercial area
210	29.56	Commercial area
240	29.07	Vegetation
270	28.66	Vegetation
300	28..51	Vegetation

Figure 7: The correlation between land use type and land surface temperature.
Source: Author

Therefore, it appears that land-use type is vital to factor in terms of the influence of the LST at every distance. The role of land use is the strongly significant influence of LST at point 150 meters which the LST decrease to 30.23 degree Celsius. The effect of urban green space is useful at a distance of 150 meters below. After 150 meters, the pattern of LST following the type of land use. The example, at point 180, the value of LST increase to 30.41 and decrease to 29.56 at point 210, which represents the land use type commercial because of the influence of vegetation land-use type at point distance 240 and 270. The result almost similar to the literature review Zhao et al. (2014), Oliveira et al. (2011), Bowler et al. (2010), Hamada (2010), and Jauregui (2001). However, the distance was achieved below 150 meters the cooling extent effective in reducing the temperature of the urban heat effect. The differences in the effectiveness of the distance of the green area with LST the probability of the above study area factors being in the four-season climate area and the building density factor. Back to the comparison of the results of this study with the study that has been conducted in Malaysia. Buyadi, Wan Mohd, and Misni (2014) found the intensity value increases as distance from green space. The LST increase 1 – 1.7 degree Celsius every 50 m. At a distance of 400 meters the influence of the green area on the temperature is ineffective. Their study also found that the type of soil use affects the surface temperature.

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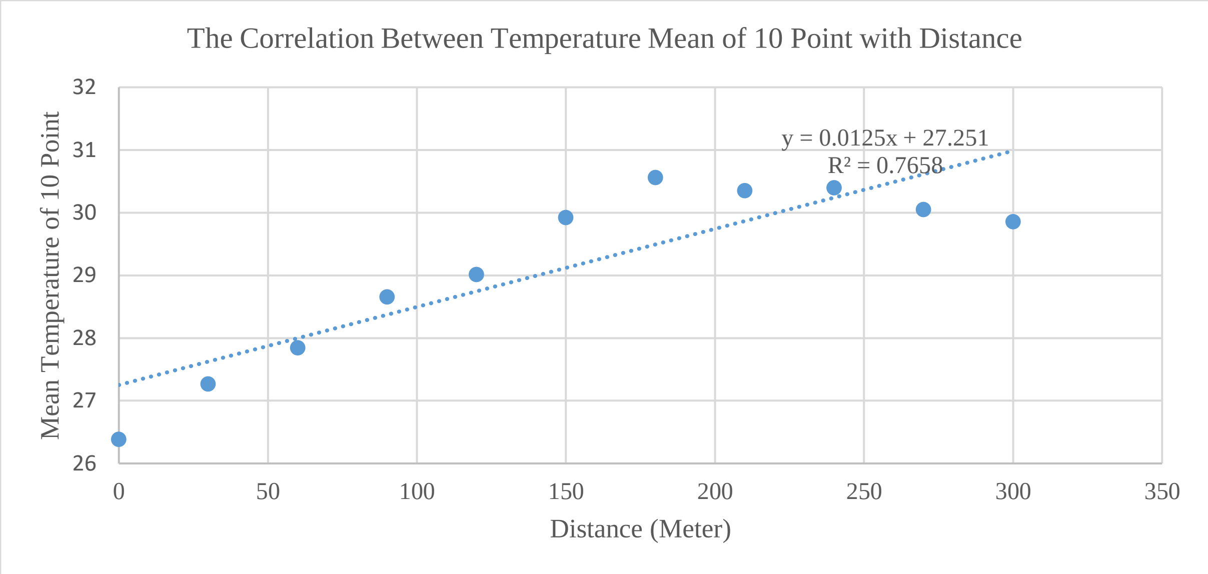

Figure 8: The correlation between temperature mean of 10 point with distance.
Source: Author

There was a slight significant positive correlation between the distance of urban space green and LST with R^2 0.7658. The LST increase when the distance from urban green space increase. At a distance, 30 meters from urban green space can cool the urban heat effect 0.88-degree Celsius. The value of cooling of the urban heat at 60-meter decreases to 0.58 degrees Celsius. This because of sufficient urban material that has low evapotranspiration. That well explains the urban green space significantly valuable in the mitigation of the urban heat effect. The cooling extent of urban green space-effective at 170 meters and below. The degree of active cooling urban green space significantly can influence land-use type.

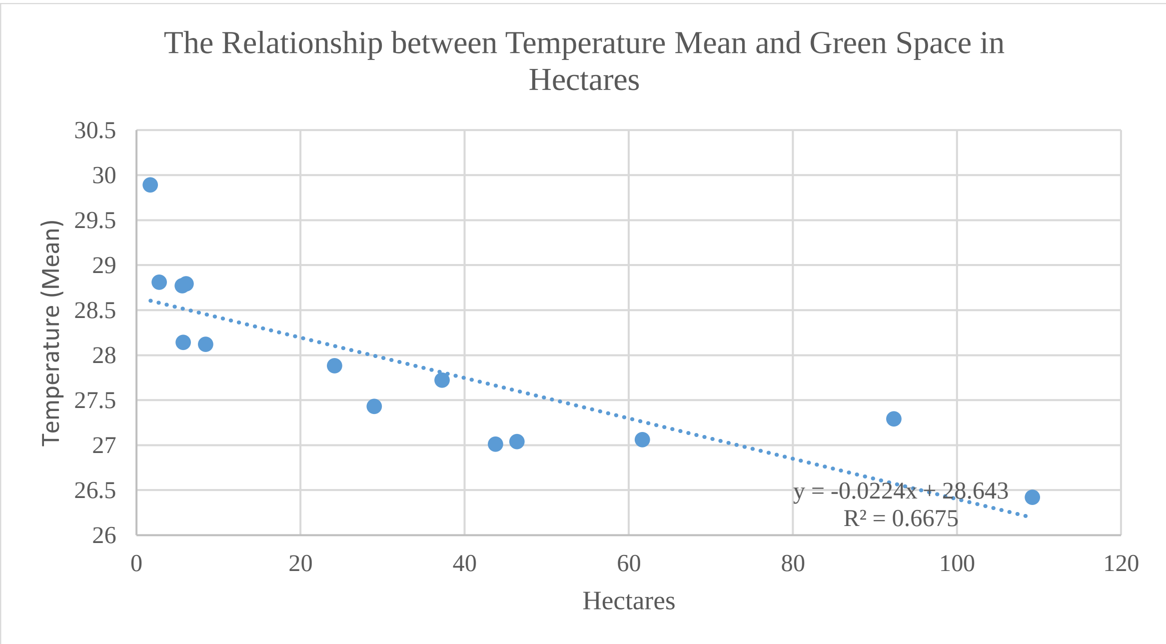

Figure 9: Relationship between temperature mean with green space in hectares.
Source: Author

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There was close negative correction exists between areas of hectares with LST with R^2 0.6675. The size of the urban space green influence of LST surrounding. The more prominent area green will be reducing of LST surrounding. This result similar to the previous study (Min et al., 2019; Hong et al., 2019; Yuan et al., 2019; Yang et al., 2019; Zhen et al., 2019).

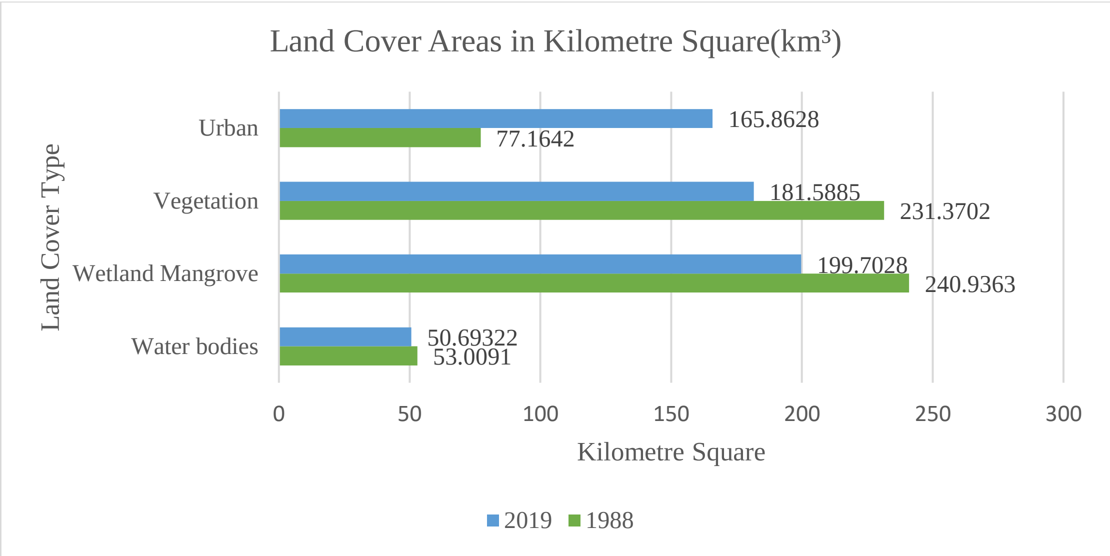

Figure 10: Land cover areas for year 1988 and 2019
Source: Author

Figure 10 displays the land cover areas for year 1988 and 2019. In the year 1988 shows the area of land cover wetland mangrove is the highest with 240.94 km². The second highest of the area is vegetation land cover with 231.37 following urban area with 77.16 km² and the last water bodies land cover with 53 km². The trend of highest for the year 2019 was similar to 1988 with wetland 199.70 km², other vegetation with 181.58 km² and third urban area with 165.86 km² and lastly water bodies with 50.69 km². From the graph 7 the areas of vegetation cover decrease from 231.37 km³ to 181.58 km³. Beside that the land cover wetland mangrove also decrease from 240.93 km³ to 199.70 km³. The highest increase land cover areas are an urban area which from 77.16 km³ increase to 165.86³. Figure 11 explains detailed the amount land cover change between year 1988 and 2019.

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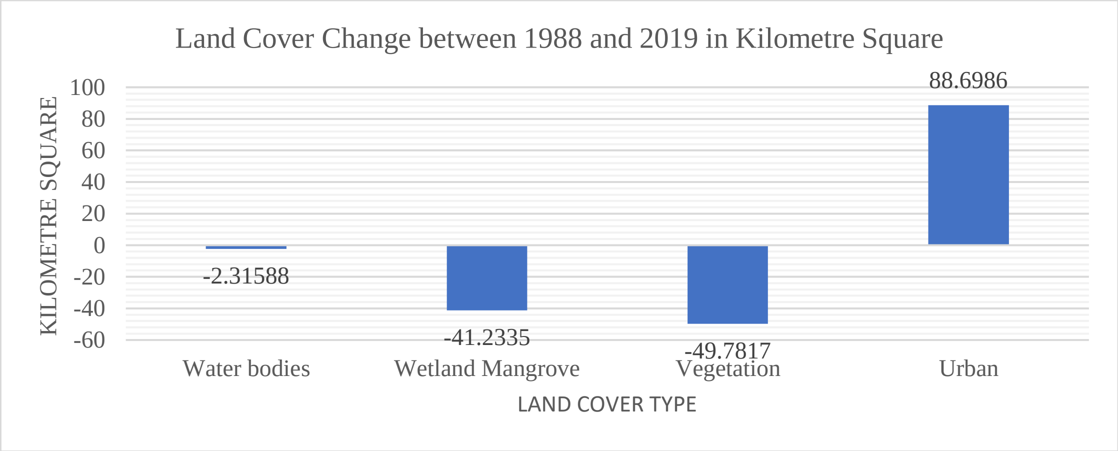

Figure 11: Land cover change areas for year 1988 and 2019.
Source: Author

Figure 11 shows the land cover change between 1998 and 2019 in kilo meter square. The most significant change between land cover for the years 1988 and 2019 is an urban with an increase of 88.69 km². The urbanization replaces wetland mangrove at the area at Sama Jaya Free Industrial Zone, Pending Industrial Estate, Demak Laut Industrial Phase 1, 2, and 3. The water bodies to build up, namely at Sama Jaya Port and Kuching Port. The next transformation from vegetation to build up human for settlement at Tabuan Height, Kota Sentosa, Tabuan Desa, Petra Jaya, and Kampung Rampangi. The second biggest land cover change of vegetation decrease from 49.78 km², following wetland mangrove with 41.23 km², and lastly water bodies with 2.31 km².

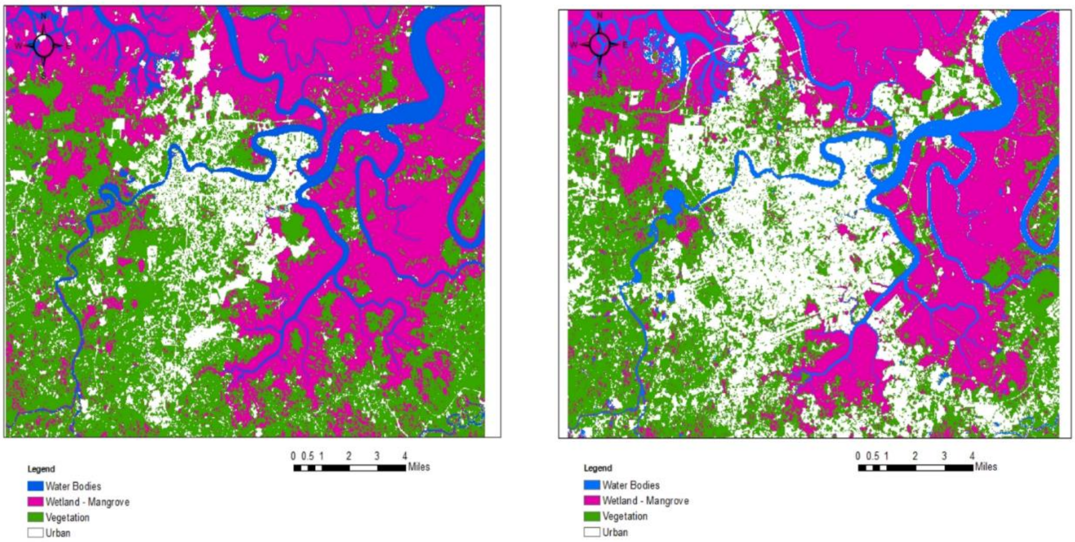

Figure 12: Land cover map of the year 1988 (Left) and Land cover map of the year 2019 (right).
Source: Author

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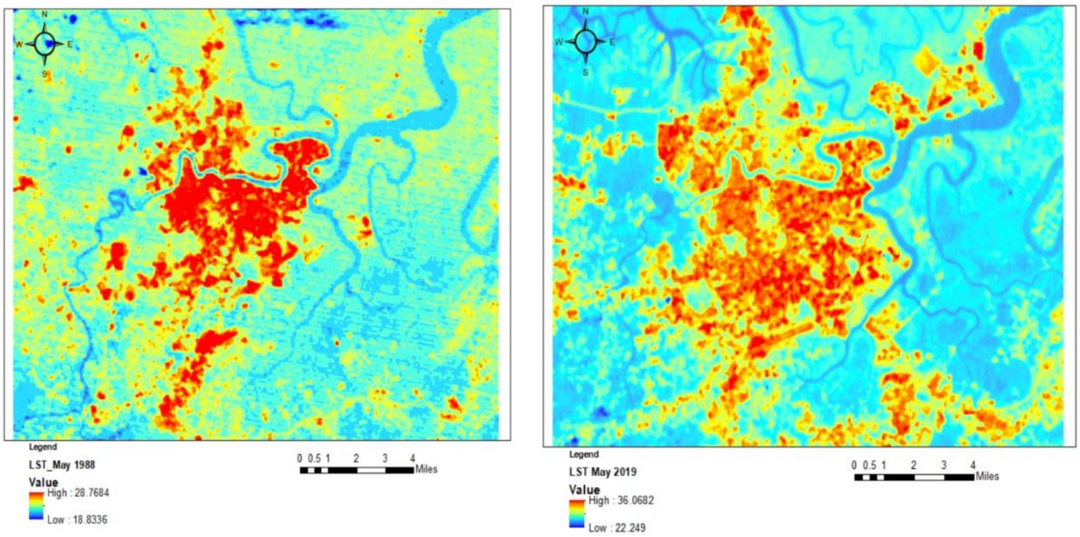

Figure 13: LST map of the year 1988 (Left) and LST map of the year 2019 (right).
Source: Author

Figure 13 shows the map of LST for the years 1988 and 2019. The maps show the increase of Surface urban heat effect island (SUHI) pattern from 1988 to 2019. The SUHI pattern increase from the center of the city to the suburban area. The increasing of SUHI significant increase the LST statistics as mentioned in Table 4: The min of LST in 1988 with value 18.83 increased to 22.24 and following the max of value LST 28.76 in 1988 rise to 36.06 at 2019. The data mean of LST also increases from 23.00 to 26.64. The increase in data statistics because of influence growing the SUHI at area study. The result was confirmed by Ricky and Oliver (2019), Zhang et al., (2014), and Bowler et al., (2010), that the urbanization causes the increase of LST. The transformation from natural areas to build up a significant rise in LST surrounding area study. The data was captured both in May, which no significant influenced by the monsoon season.

Table 4 The data statistic of minimum, maximum and mean of LST for year 1988 and 2019

Data statistics	**The year 1988**	**The year 2019**
	Value (Degree Celsius)	**Value (Degree Celsius)**
Min of LST	18.83	22.24
Max of LST	28.76	36.06
Mean of LST	23.00	26.64

Source: Author

Table 5 Data statistics of LST every land cover for the year 1988 and 2019

Data statistics	**The year 1988**	**The year 2019**
	Value (Degree Celsius)	**Value (Degree Celsius)**
Mean of LST at Urban Areas	26.83	33.24
Mean of LST at Vegetation Areas	22.54	26.78
Mean of LST at Water bodies	21.20	25.93
Mean of LST at Wetland - Mangrove	22.40	26.20

Source: Author

Table 4 shows the mean of LST at every mainland cover at area study. The urban areas value highest is 26.83 and 33.24 for the year 1988 and 2019, following the means of LST at vegetation areas 22.54 for the year 1988, 26.78 for the year 2019. The wetland

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mangrove for a mean of LST at 1988 22.40 and increase in 2019 with value 26.20. The lowest is water bodies with 21.20 for the year 1988 and 25.93 for the year 2019. Transformation of from nature to build up building was the modification of surface properties cause to more absorption of solar radiation, reduce convective cooling, and lower water evaporation rates. Because of this, the LST at urban higher than vegetation and water bodies (Gunawardena, Wells, & Kershaw, 2017). Table 5 explains the decrease of area vegetation and wetland 100 km³ cause of increase of LST from 4 degree Celsius to 6 degree Celsius depend on the land cover type. Amani-Beni et al. (2018) stated for every 10% increase in the green space ratio, the land surface temperature drops by 0.4 degree Celsius. Voogt and Oke (2003) and Oke (1995) applied the ground measurement for study impact of ratio of green space coverage in urban areas to LST. The result shows the increase of ratio of green space coverage can efficiently reduce the ambient air temperature and the land surface temperature.

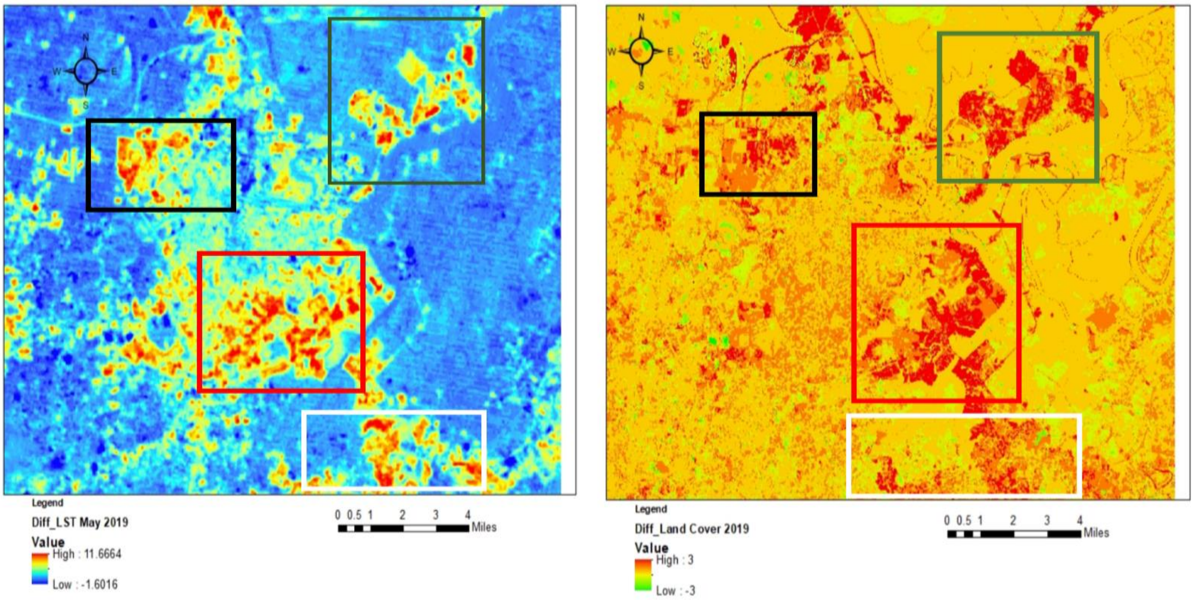

Figure 14: Map of change between LST for the year 1988 and 2019 (left) map of change detect for land cover for the year 1988 and 2019 (right).
Source: Author

The square white in the year 1988 was a wetland, and vegetation converts to settlement at Tabuan Baru, Riveria, and kampung Stutong. The red square relocated at Sama Jaya Free Zone Industrial, Muara Tabuan Light Industrial park, and Pending Industrial Estate. The wetland mangrove has been destroyed and replaces with build up such industrial area and Port. The green square relocated at Demak Industrial Park Phase 1, 2, and 3. At here, relocate of Power Plant Sejingkat and settlement of Senari, Sejingkat, and Muara Tebas. The more significant change in this area, which previous in 1988, the most place contains vegetation and wetland mangrove. The last, which black square relocated at Kampung Semerah Padi Matang, Petra Jaya and Kampung Rampangi (settlement). The most of land cover in the area here in 1988 is vegetation, and wetland transformed into the settlement. The change of land cover from vegetation and wetland to urban/built area significant increase of LST.

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Conclusion

The urban green space's effects on LST in small, medium-size cities, Kuching has been studied by utilized Landsat 8 thermal band. The vital vegetation component in reducing urban heat effect. The correlation between NDVI and LST proven vegetation can be reducing LST in the mitigation of urban heat effects. The second result shows the cooling extent of urban green space-effective at 170 meters and below. The degree of active cooling urban green space significantly can influence land-use type after 170 meters and above. Besides, the reduction of green space area can cause of increase the LST. The result state decrease of area vegetation and wetland 100 km^3 cause of increase of LST from 4 degree Celsius to 6 degree Celsius depend on the land cover type. Local government, such as the municipal council, shall take incentive in the development of urban green space in reducing of temperature cause of urban heat effect. With the increase of demand for expansion of urban areas, mitigation of urban heat effect become vital for reducing the adverse effect of urban heat such as extra heat, increasing energy and water consumption, pollution, and the most important of urban population health. The policymaker, urban planner, and designers shall value the existence of urban green space cooling effects on neighboring areas. The improvement of knowledge by the quantity of spatial variation of LST can help understand the duty of the water body with the urban ecosystem in services urban heat effect mitigation for Malaysia achieve Low Carbon city / Nation besides reducing the negative effect of urban heat effect.

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Thank NASA for freely access to Landsat 8.

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