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Impact of vegetation growth on urban surface temperature distribution

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Abstract. Earlier studies have indicated that, the temperature distribution in the urban area is significantly warmer than its surrounding suburban areas. The process of urbanization has created urban heat island (UHI). As a city expands, trees are cut down to accommodate commercial development, industrial areas, roads, and suburban growth. Trees or green areas normally play a vital role in mitigating the UHI effects especially in regulating high temperature in saturated urban areas. This study attempts to assess the effects of vegetation growth on land surface temperature (LST) distribution in urban areas. An area within the City of Shah Alam, Selangor has been selected as the study area. Land use/land cover and LST maps of two different dates are generated from Landsat 5 TM images of the year 1991 and 2009. Only five major land cover classes are considered in this study. Mono-window algorithm is used to generate the LST maps. Landsat 5 TM images are also used to generate the NDVI maps. Results from this study have shown that there are significant land use changes within the study area. Although the conversion of green areas into residential and commercial areas significantly increase the LST, matured trees will help to mitigate the effects of UHI.

Keyword: *NDVI, LST, mono-window algorithm, UHI and GIS*

1. Introduction

UHI occurs when the air and surface temperatures are hotter than their rural surrounding [1]. One of the possible causes of UHI is a drastic reduction of the greenery areas to built-up surfaces. The natural land cover that are converted to built surfaces trap incoming solar radiation during the day and then re-radiate it at night [2]. Several studies have been carried out to investigate the impacts of UHI on the energy consumption, storm water run-off, environmental disturbance, community health, and altering climatic conditions [3–7]. The mitigation strategies call for the use of lighter-coloured, reflective surfaces on new developments, as well as the replacement of existing dark-coloured surfaces with lighter ones. A more practical method of mitigating the UHI is strategic planting of vegetation in urban areas [8]. Previous researchers have used remotely sensed image such as Landsat image and Geographical Information System (GIS) technique to develop the land use map, to monitor the land use changes and as well as to generate surface temperature map [10]. Earlier studies clearly demonstrated that the implications of rapid urban growth are decreased vegetated areas, increased the surface temperature and modified the urban microclimate [14]. Thus, this study investigates the impact of vegetation growth on the urban surface temperature distribution.

2. Study Area and Datasets

The study area consists of part of the Shah Alam City. The area is selected due to rapid urban development activities over the last 30 years. The extent of the study area is shown in Figure 1 a). For a more detailed study on the effects of vegetation growth on the land surface temperature, a small area surrounding the Shah Alam Lake (which include sections 2, 4 and 14) is selected (refer to Figure 1 b). The data (i.e. temperature and water vapour content) of nearby weather station (Subang Meteorological Station) is obtained from the Malaysia Meteorological Department (MMD). The data

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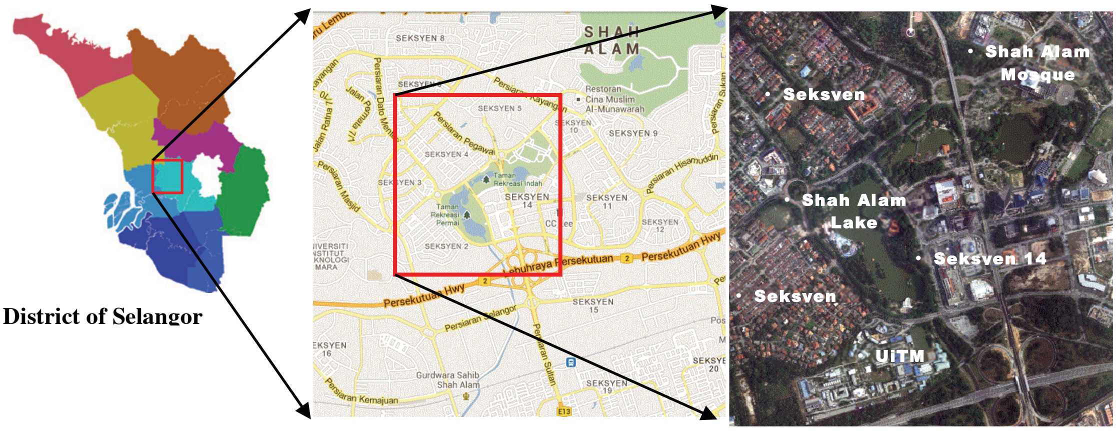
obtained coincide with the time and date of the Landsat TM satellite pass. Landsat TM images dated 21st February 1991 and 21st January 2009 are used.



a) b)

Figure 1: Location of the study areas a) part of the Shah Alam City and b) detail study area (Shah Alam Lake Garden) (Source : Google Map, 2013)

3. Methodology
The methodology adopted for this study is divided into four main stages; i.e. generation of land use/land cover map, land surface temperature (LST) retrieval, NDVI assessment and determination of the relationship between NDVI and LST.

3.1. Generation of land use/land cover maps
Satellite images are used to generate the land use/land cover maps of two different dates. The 18 year period is selected to ensure the vegetation growth within this study area is matured. The process of generating land use maps is done using the ERDAS Imagine digital image processing software. The unsupervised classification method is used to generate land use/land cover maps. The percentages of land use/land cover changes are later calculated.

3.2. Land Surface Temperature (LST) retrieval
The mono-window algorithm method is used to generate the LST map [11]. The mono-window algorithm requires three parameters; emissivity, transmittance and effective mean atmospheric temperature. These two parameters (i.e. atmospheric water vapour content and the near surface air temperature) are then used to calculate the air transmittance and effective mean atmospheric temperature [12]. The third parameter is emissivity, which is calculated from the normalized difference vegetation index (NDVI). The mono-window algorithm equation is given as:-

$$T_s = \{a(1-C-D) + [b(1-C-D) + C + D]T_i - DTa\} / C \qquad (1)$$

where:- Ts is LST in Kelvin; a = -67.355351; b = 0.458606; C = ε_i x T_a ;where emissivity (ε_i) can be computed from NDVI ; D = (1- T_a) [1+(1- ε_i)x T_a]; T_i is the brightness temperature (K) and T_a is the effective mean atmospheric temperature.

3.3 Generation of Normalized Difference Vegetation Index (NDVI)

GIS spatial analysis and zonal statistical analysis technique are used to visualize the vegetation fragmentation and surface temperature distribution. Equation 2 is used to calculate the NDVI of the study area. The proposed emissivity values from different NDVI range; i.e.; NDVI<0.2 (bare soil), 0.2<NDVI<0.5 (mixture of bare soil, vegetation and hard surfaces) and NDVI> 0.5 (fully vegetated) are 0.99, 0.98 and 0.98 respectively [13].

$$NDVI = (NIR - R) / (NIR + R) \quad (2)$$

Where NIR - the pixel digital number (DN) of TM Band 4 and R – DN of TM Band 3

3.4 Relationship between NDVI and LST

To obtain the relationship between NDVI and LST, 25 sample points are measured within the detailed study area. Regression analysis is carried out to determine the correlation between these two parameters. The regression equation models are retrieved by fitting the trend line using Microsoft Excel.

4. Results and Analysis

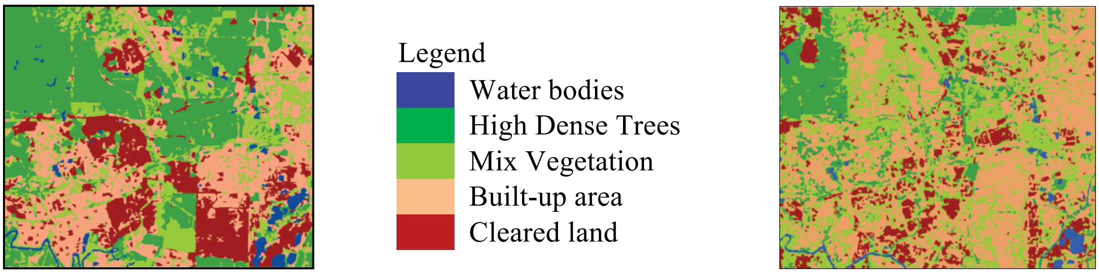
The results and analysis are given in the following sub-sections.

4.1. Land Use/ Land Cover Changes

The land use/land cover maps for the two dates of part of the Shah Alam City are shown in Figure 2. The total acreage of the study area is 16,904.547 hectares. The detail acreage of individual land cover of the study area is listed in Table 1. Over the period of 18 years, there is significant decrease in the high dense trees (i.e. forest and agricultural land) land cover category. The total area for the mixed vegetation category (i.e. crops, parks and bushes) and built-up areas (i.e. commercial, residential and administrative building) increased by 11.24% and 13.63% respectively. The cleared land decreased due to its conversion to built-up areas. Although there is significant increase in built-up areas, the mixed-vegetation area also increased. This is due to more trees being planted to replace the lost of natural greenery within the study area.

4.2 Land Surface Temperature (LST)

The LST distribution of 1991 and 2009 are shown in Figure 3. The mean temperature for individual land use/land cover is summarized in Table 2. Based on Figure 3 and Table 2, the lowest and highest radiant temperature for 1991 are 25.8°C (in high density tree area) and 30.8°C (in the built-up area) respectively. Meanwhile, for 2009 the radiant temperatures range between 24.0°C and 38.0°C. The highest mean temperature is within the built-up area while the lowest is within water bodies. The implication of urban development by replacing natural vegetation (forest) to built-up surfaces such as concrete, stone, metal and asphalt clearly can increase the surface radiant temperature. Although there is significant increase in the built-up areas, the surface temperature is still relatively lower (refer to Figure 3 b). This could be due to the vegetation growth within the study area.

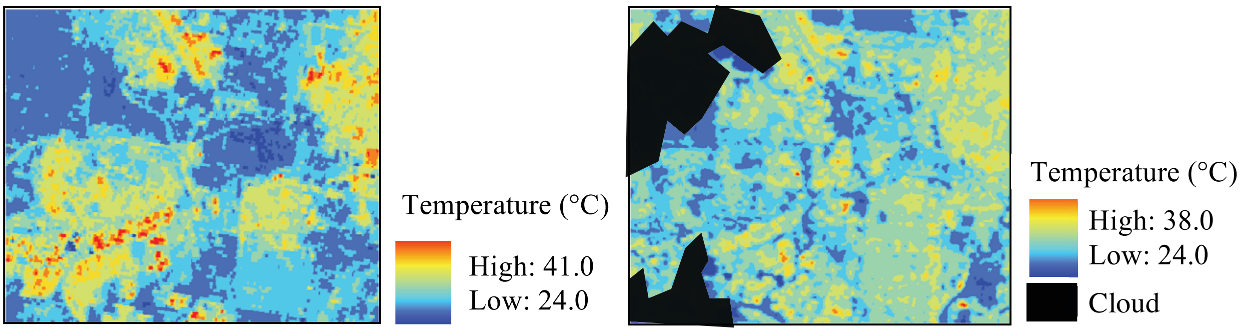


a) Land Use Map of 1991 b) Land Use Map of 2009

Figure 2: Land use/ Land cover maps of a) 1991 and b) 2009

Table 1: Land use/land cover coverage

Land Use/Land Cover Class	Area in Hectare 1991	Percentage (%)	2009	Percentage (%)	Changes (%)
(1) Water bodies	464.554	2.75	317.827	1.88	-0.87
(2) High Dense Trees	5726.516	34.09	2807.432	16.61	-17.48
(3) Mix Vegetation	3503.806	20.73	5403.899	31.97	+11.24
(4) Built-up area	4300.606	25.44	6608.361	39.09	+13.65
(5) Cleared Land	2873.065	17.00	1767.028	10.45	-6.55
Total	16,904.547	100	16,904.547	100	



a) b)

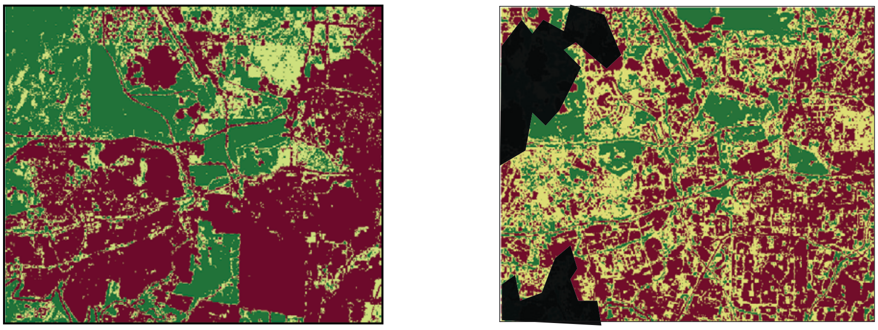
Figure 3: Land surface temperature for a) 1991 and b) 2009

Table 2: LST distribution within different land use/land cover

Land use/ Land Cover	1991 (Temperature °C)	2009 (Temperature °C)
Water	26.3	25.3
High Dense Tree	25.8	25.4
Mix Vegetation	28.2	28.0
Built-up area	33.1	30.8
Cleared Land	28.7	28.7

4.3. Analysis of Normalized Difference Vegetation Index (NDVI)

Figure 4 a) and b) show the NDVI maps generated from the Landsat 5 TM imagery for the year 1991 and 2009. The increase in the vegetation growth coverage within the study area can clearly be seen. This could be due maturity of the trees grown within the built-up areas. As the more trees and vegetation within the study area are getting matured, the NDVI value increase and hence lowering the LST (refer to Figure 3).



a) b)

Legend:

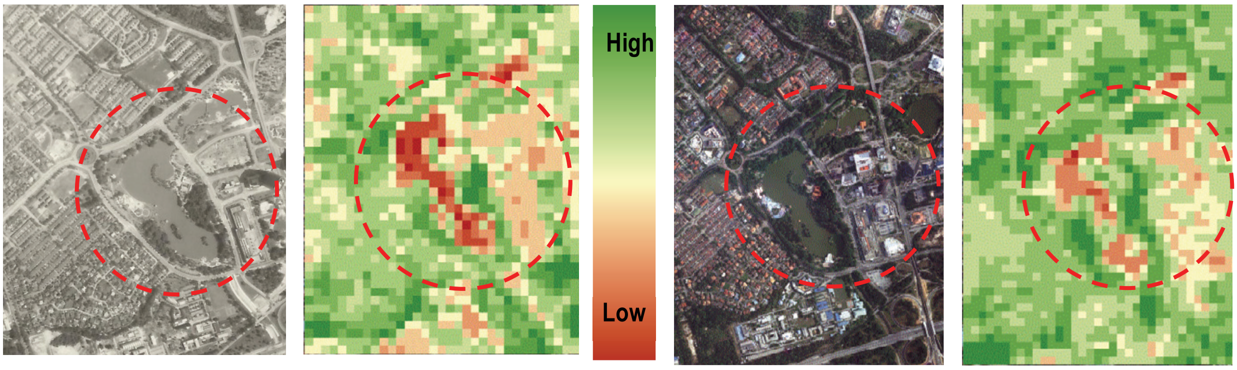
<0.2 : Cleared Land and Built-up Area
0.2≤NDVI<0.5 : Mix of Built-up/ Bare Soil and Vegetation
≥ 0.5 : Fully Vegetated
Cloud Cover

Figure 4: Vegetation growth in a) 1991 and b) 2009

Scanned aerial photo of 1992 (Figure 5 a) and digital orthophoto of 2009 (Figure 5 c) are used to visualize the urban growth of the detailed study area. The lake garden area is surrounded by residential, high rise building, road and commercial areas. Figures 5 b) and d) show the NDVI maps of two different dates. Referring to Figure 5 b), lower NDVI values are clearly evident water bodies and built-up areas. However, over the period of 18 years, NDVI in these areas significantly increased although there is no significant change in the coverage of the water bodies and built-up areas. This situation occurred due to the significant vegetation growth within this area. Thus, vegetation can help to reduce of the hard surface emissivity and lowering the solar exposure of the building envelope as well as cooling down the high temperature in built-up area. Figure 6 shows the NDVI pattern of the year 1991 and 2009. The lower NDVI value is mainly located in the water bodies. Although there is not much difference between the highest NDVI values, the pixel count for the NDVI higher values in the built-up and vegetated areas significantly increased over the 18 year period.

4.3. Correlation between NDVI and LST

Figure 7 a) and b) show the correlation of LST and NDVI on detail study area in 1991 and 2009. Strong correlation between surface temperature and NDVI values are found in study area. Thus, the surface temperature can be estimated with reasonable accuracy using NDVI values. Precisely, replacing vegetation and landscaping the new urban area can help to reduce the high radiant temperature of the built-up area.



a) Scanned aerial photo of Shah Alam Lake Garden in 1992

b) NDVI Image1991 (High:0.457; Low: -0.527)

c) Digital Orthophoto of Shah Alam Lake Garden in 2009

d) NDVI Image 2009 (High:0.464; Low: -0.192)

Figure 5: Aerial images and NDVI maps of the detailed study area

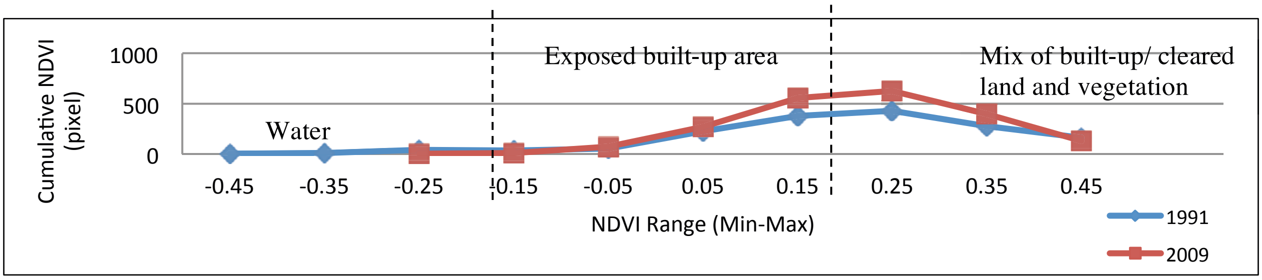
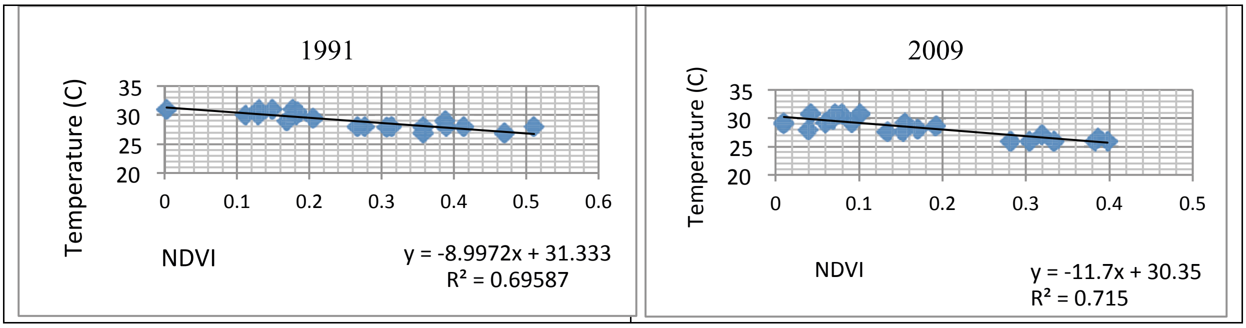


Figure 6: Comparison of NDVI pattern in the Shah Alam Lake Gardens



a) b)

Figure 7: Relationship between NDVI and LST of the study areas in a) 1991 and b) 2009.

5. Conclusion and recommendation

Although this study is not conclusive, initial findings have shown that there is significant increase in the built-up areas in the Shah Alam City over a period of 18 years which resulted in higher LST in built-up areas as compared to water bodies or the vegetated areas. There is strong negative correlation between LST and NDVI, which indicates vegetation helps to reduce the LST of an area. Although urbanization significantly increase the LST, the initiative taken by the Shah Alam City Council to plant more trees helps to mitigate the UHI effects within a developed urban area. Comprehensive ground observations are needed to validate the results obtained from satellite images.

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