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Green Spaces Growth Impact on the Urban Microclimate

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Abstract

Urban heat island (UHI) is one of the urban climatology problems arising in the urban development. Trees and vegetation play vital role to mitigate UHI effects. This study attempts to assess the effects of vegetation growth on land surface temperature (LST) distribution in urban areas. Green spaces 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. A 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 natural green areas into residential and commercial areas significantly increases the LST, matured trees in urban green space will help to mitigate the effects of UHI and it is important to sustain urban development as well as to provide better quality of life on the urban population.

Keywords: UHI; urban green space; green space characteristic; cooling effect

1. Introduction

The urban heat island (UHI) phenomenon has been found in cities throughout the world. It is defined when the air and surface temperatures are hotter than their rural surroundings (Shahmohamadi, Maulud, Tawil, & Abdullah, 2011). Due to urbanization demand, the rapid growth of urbanization caused reduction of vegetated areas and increased the built-up surfaces. One of the possible causes of UHI is a drastic reduction of the greener areas to built-up surfaces. The natural land cover was converted by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Solecki, Rosenzweig, Pope, Chopping, & Goldberg, 2004). Several studies have been carried out in investigating the UHI impacts (Choi, Lee, & Byun, 2012; Mallick & Rahman, 2012; Yan, Wang, Hao, & Dong, 2012).

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Thus, the seriousness of UHI phenomena cannot be denied and the mitigation strategy should be applied to combat the UHI effects at the macro and micro level.

The impact of the heat island suffered so many people in many ways. The investigation of UHI impacts such as in energy consumption, management of storm water run-off, environmental disturbance, community health, and altering climatic conditions. The UHI project is to produce historic air temperature maps based upon satellite and derived land surface temperature data for multiple years as well as the land use change monitoring. Based on the previous research, the UHI mitigations are discovered and have been applied in sub-tropic countries (e.g.: China and Hong Kong). The mitigation strategies call for the use of lighter-colour, reflective surfaces on new developments, as well as the replacement of existing dark-colour surfaces with lighter ones. A more practical method of mitigating the UHI is strategic planting of vegetation in urban areas and designing green technology approach (Ng, Chen, Wang, & Yuan, 2012; Saffuan, Ariffin, & Amin, 2013).

The Landsat 5 TM and 7 ETM+ are widely used to derive the land use changes monitoring and land surface temperature retrieval. Additionally, the thermal infrared band of the Landsat imagery is capable of deriving the surface temperature. Previous studies have been developed LST using Landsat 5TM or 7ETM+ to estimate radiation budgets in heat balance studies and as a control for climate models (Buyadi, Mohd, & Misni, 2013). The knowledge of radiant surface temperature is important to a range of issues and themes in earth sciences central to urban climatology, global environmental change, and human-environment interactions (Kumar, Bhaskar, & Padmakumari, 2012; Liu & Zhang, 2011). Previous researchers are using the remotely sensed image such as Landsat image and GIS technique to develop the land use map, to monitor the land use changes and as well as their surface temperature map (Mohd, Hashim, & Noor, 2004; Takeuchi, Hashim, & Thet, 2010). In Malaysia, among the most significant change in land conversion was the residential land use, especially in Klang Valley area. Thus, monitoring the land use changes is important to sustain urban planning and development.

Previous studies clearly demonstrated that the implications of rapid urban growth are decreased vegetated areas, increased the surface temperature and modified the urban microclimate. However, temperatures in the vegetated area and its surrounding keep the temperature lower than developed area. Additionally, maturity of the trees and vegetation will be considered as a vital parameter to ensure the temperature keep lower in urban area through its shadow and transpiration. Furthermore, trees and vegetation also act as natural agent in against air pollution which is exposed to unhealthy living environment to urban residents. Temporal spatial evaluation and climate estimation using satellite imagery, GIS and ERDAS software and statistical method are acceptable as technical methodology in analyzing environmental behaviour especially in combating UHI for past, present and future. Thus, this study will investigate the land use changes using remote sensing Landsat image and to identify the green spaces growth impact on the urban microclimate.

2. Study area

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 and heterogeneous land use/ land cover with a complex business centre, vegetated, open space, residential areas, industrial area and other mix-residential-commercial areas. The extent of the small study area is shown in Fig. 1. The climate of the cities is categorized as a hot and humid tropical climate which is warm and sunny, along with abundant rainfall, especially during the Northeast Monsoon seasons from October to March. Temperatures tend to remain constant with maximum values of between 31°C and 33°C, while the minimum between 22°C and 23.5°C. Relative humidity is around 72–78%. The geographical location of the study area is shown in Fig. 1. The spatial extent of the study area is at Ymax 347407.00, Xmax 388761.00 and Ymin 335587.00, Xmin 402951.00. In addition, meteorological data obtained from the permanent local weather station of Subang, Shah Alam was provided by Malaysia Meteorological Department (MMD). The data obtained coincide with the time and date of the Landsat TM satellite pass.

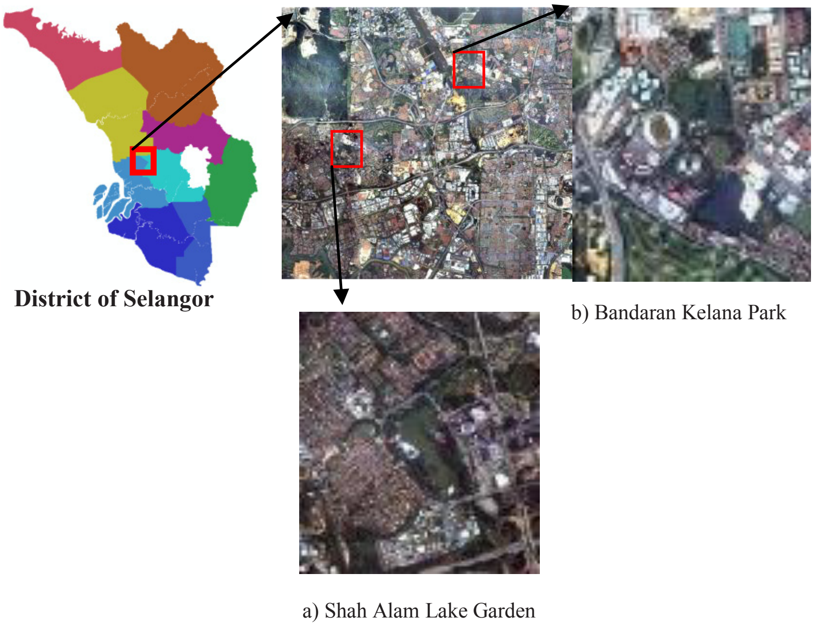


Fig. 1. Map of detailed study area

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, normalize different vegetation index (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 detail of satellite image data (Landsat 5 TM) used in this study dated on 21st February 1991 and 21st January 2009 is acquired from the Malaysian Remote Sensing Agency (ACRS). 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 process based on first-order polynomials and root means square errors (RMSE) obtained less than half of pixel values. The percentages of land use/land cover changes are later calculated. These values of land use/land cover can use to estimate the land use/land cover types individually.

3.2. Land surface temperature (LST) retrieval

The thermal infrared band (Landsat 5 TM Band 6) records the radiation in the spectral range between 10.4 and 12.5μm from the surface of the earth. Land surface temperature plays an important role in many environmental processes. It can provide primary information on the surface physical properties and climate. The mono-window algorithm method is adopted in this study to generate the LST (Sobrino, Jiménez-Muñoz, Paolini, & Jime, 2004). The mono-window algorithm requires three parameters; emissivity, transmittance and effective mean atmospheric temperature. The atmospheric water vapour content and the near surface air temperature simultaneously obtained from local weather stations when the satellite passes (Liu & Zhang, 2011). These two parameters are then converted to air transmittance and effective mean atmospheric temperature. The third required parameter is the emissivity, which can be calculated from the NDVI. The processes involved in this study are as follows:

3.2.1. Conversion of digital number (DN) to spectral radiance

The information on the thermal infrared band for Landsat TM is stored in a digital number (DN) with a range between 0 and 255. The linear equation model is used to convert the DN into radiance temperatures as shown hereunder:

$$R = C_1(DN) + C_2 \tag{1}$$

Where;
R = radiance value
DN = the thermal infrared band pixel value
C_1 = constant value for TM6 (0.0056321) and ETM (0.003705882)
C_2 = offset value for TM6 (0.1238) and ETM (0.3200)

3.2.2. Conversion from radiance to brightness temperature

Thus, the thermal band radiance values were converted to a brightness temperature value using the Planck's function Equation as;

$$T_i = \frac{K2}{\ln\left(\frac{K1}{R} + 1\right)} \tag{2}$$

Where; T_i is the temperature in degree Kelvin.
R - radiance values
K1 - calibration constant 1 for TM (607.76) and ETM (666.09)
K2 - calibration constant 2 for TM (1260.56) and ETM (1282.71)

3.2.3. Estimation of land surface emissivity

The NDVI is one of the most widely applied for vegetation indices. In order to calculate NDVI, Equation 3 can be used as;

$$NDVI = (NIR-R)/(NIR+R) \tag{3}$$

The emissivity can be estimated by utilizing NDVI. The final expression of land surface emissivity is given by;

$$\mathcal{E}i = 0.004\ Pv + 0.986 \tag{4}$$

Where, Pv is the vegetation proportion obtained from Equation 4:

$$Pv = \left[\frac{(NDVI-NDVI_{min})}{(NDVImax- NDVI_{min})}\right]^2 \tag{5}$$

3.2.4. Calculation of atmospheric transmittance and mean atmospheric temperature

The atmospheric transmittance (Equation 6) can be estimated using water vapour (W6). The water vapour estimation is referred from the distribution of water vapour content graph (Qin, Karnieli, & Berliner, 2001). The atmospheric transmittance of Landsat TM6 is shown hereunder. Where T6 is the atmospheric transmittance of Landsat TM6 and W6 represents the water vapour content. The mean atmospheric temperature equation for tropical region is shown in Equation 7. Where To is the near-surface air temperature (K) which can be obtained from the permanent local weather station of Subang.

$$T_6 = 1.031412-0.11536 \times W_6 \quad (6)$$

$$T_a = 17.9769+0.91715 \times T_o \quad (7)$$

3.2.5. Mono-window algorithm LST retrieval

The mono-window algorithm is written as Equation 8. The variables (i.e; emissivity, transmittance and effective mean atmospheric temperature) are required as below;

$$T_s = \{a(1-C-D) + [b(1-C-D) + C + D]T_i - DTa\} / C \quad (8)$$

Where:- Ts is LST in Kelvin; a = -67.355351; b = 0.458606; (C = ε_i x T_a ;where ε_i=emissivity 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 the surface temperature distribution. Equation 2 is used to calculate the NDVI of the study area. The proposed emissivity values from the 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.

$$NDVI = (NIR - R) / (NIR + R) \quad (9)$$

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 discussion

Results and analysis of this study are divided into three phases of outputs. The first output is the land use/land cover change for both 1991 and 2009. The second output is a LST map of study area in 1991 and 2009. The third output is NDVI assessment and evaluation based on the vegetation growth in two different urban areas. The fourth output is correlation plotted onto vegetation indices with respect to LST.

4.1. Land use/ land cover changes

The land cover changes for the two dates of part of the Shah Alam City are significantly detected and presented in the land cover maps in Fig. 2. The total acreage of the study area is 16,904.547 hectares. The detail acreage of the individual land cover of the study area is listed in Table 1. Over the period of 18 years, there is a 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.

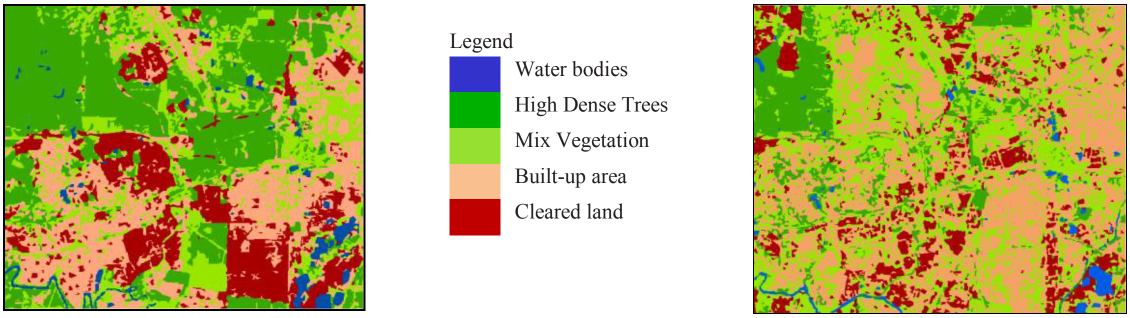


Fig. 2. (a) Land use/ Land cover maps of 1991; (b) Land use/ Land cover maps of 2009

Table 1. Land use/land cover coverage

Land Use/Land Cover Class	Area in Hectare				Changes (%)
	1991	Percentage (%)	2009	Percentage (%)	
(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	

4.2. Land surface temperature (LST)

The LST distributions of 1991 and 2009 are shown in Fig. 3. The mean temperature for individual land use/land cover is summarized in Table 2. Based on Fig. 3 and Table 2, the lowest and highest radiant temperature for 1991 are 25.8°C (in the 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 Fig. 3 (b)). This could be due to the vegetation growth within the study area. On average, over eighteen years of development, regular matured trees, green parks, and other vegetation in urban area potentially can reduce urban temperature and its surrounding.

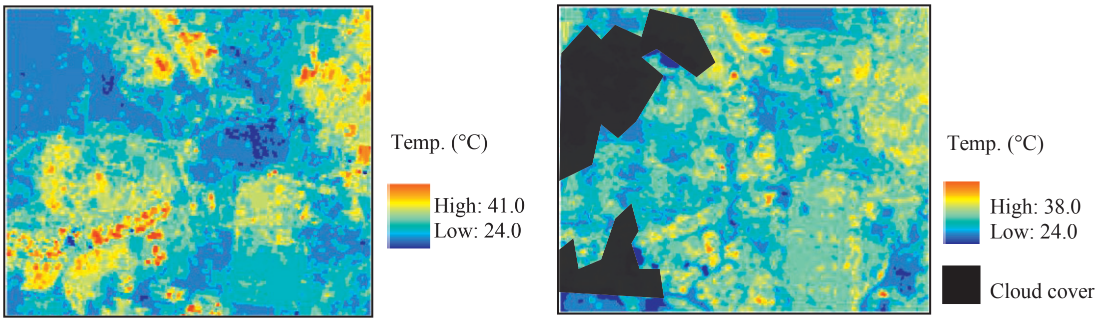


Fig. 3. (a) Land surface temperature for 1991; (b) Land surface temperature for 2009

4.3. Analysis of normalized difference vegetation index (NDVI)

Fig. 4 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 Fig. 4).

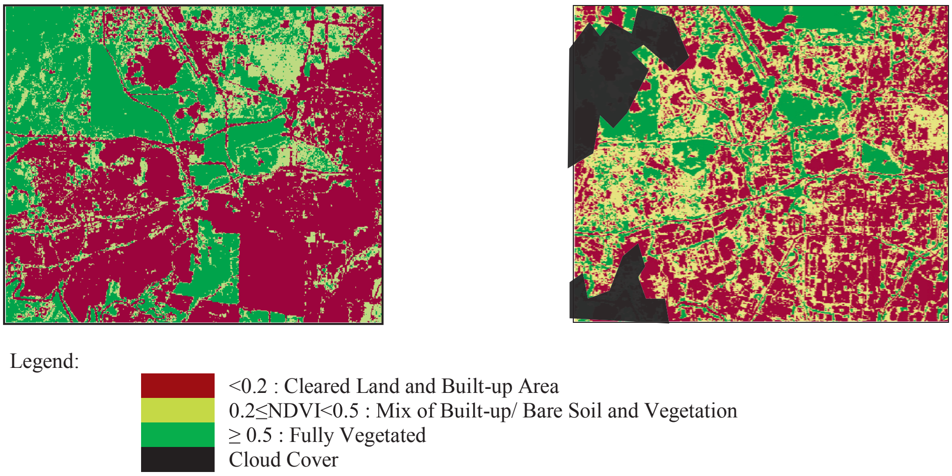
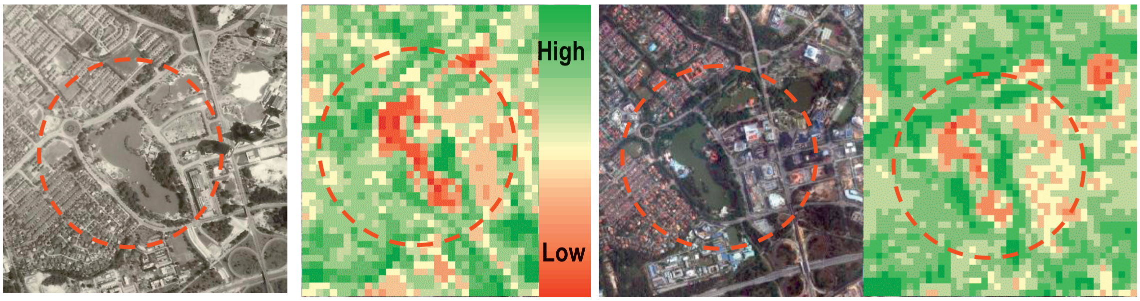


Fig. 4. (a) Vegetation growth in 1991; (b) Vegetation growth in 2009

Scanned aerial photo of 1992 (Fig. 5(a) and digital orthophoto of 2009 (Fig. 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. Fig. 5(b) and d) show the NDVI maps of two different dates. Referring to Fig. 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. Fig. 5(d) 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 in a detailed study area of Shah Alam Lake Garden.

As shown in scanned aerial photo of 1992 (Fig. 6(a)), the Kelana Jaya detailed study area (Bandaran Kelana Park) is not well developed and exhibit the natural green landscapes. However, due to urban development, the area has been transformed to the new urban area and the developed area surrounded with industrial area, high rise building, facilities building (i.e.; stadium and sport centre), road and commercial building which is shown digital orthophoto of 2009 (Fig. 6(c)). Fig. 6(b) and Fig. 6(d) visualized the vegetation decreasing value in year 1991 and 2009. Hence, the graph plotted in Fig. 6(e) shows the significant of non-vegetation value in 2009 where the ground surfaces are converted to cleared-land and built-up surfaces. Vegetation plays vital roles to alleviate the heat island effect by means of transpiration, shading and heat absorption to reduce the emissivity of the hard surface reflectivity by covering the built-up area by its shadow. High trapped solar radiation in the building may cause high energy usage and disturbing human internal thermal comfort.

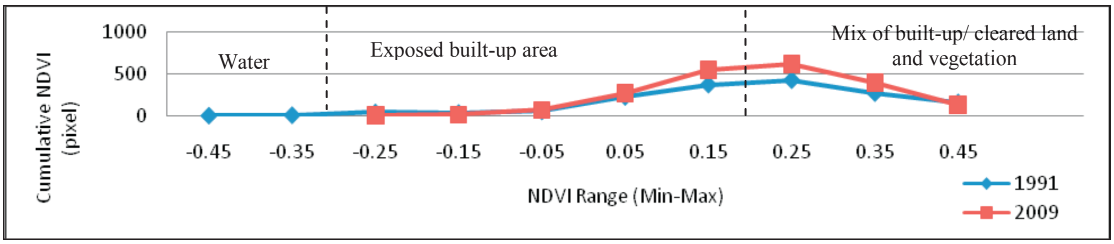


(a) Scanned aerial photo of Shah Alam Lake Garden in 1992

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

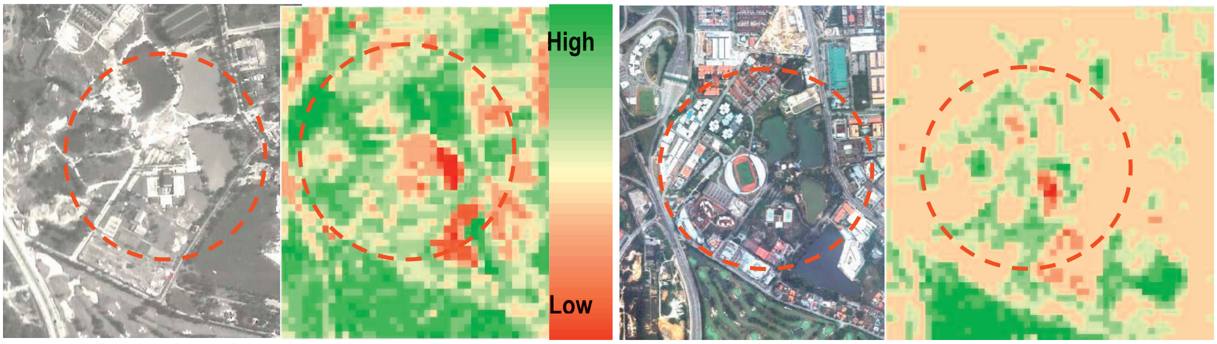
(c) Digital Orthophoto of Shah Alam Lake Garden in 2009

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



(e) Comparison of NDVI pattern in the Shah Alam Lake Gardens

Fig. 5. Aerial images, NDVI maps and NDVI pixel count of the detailed study area

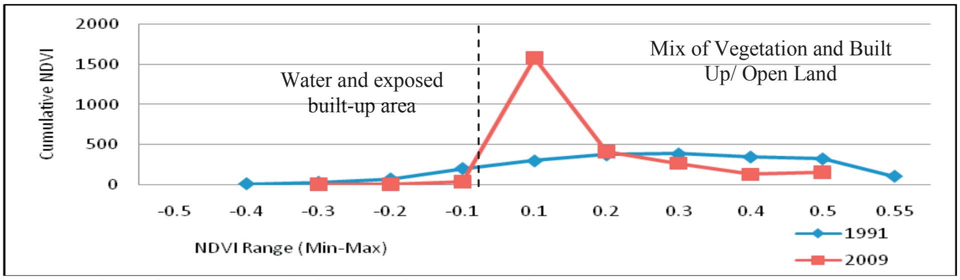


(a) Scanned aerial photo of Bandaran Kelana Park in 1992

(b) NDVI Image1991 (High:0.523; Low: -0.493)

(c) Digital Orthophoto of Bandaran Kelana Park in 2009

(d) NDVI Image 2009 (High:0.504; Low: -0.224)



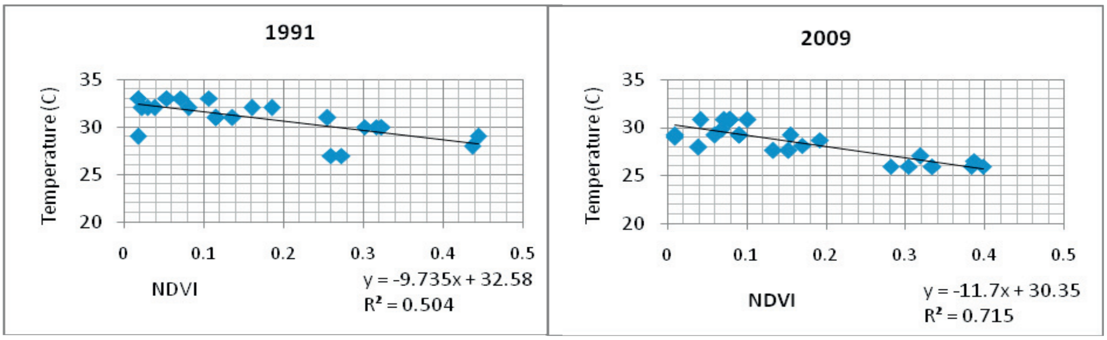
(e) Comparison of NDVI pattern in the Shah Alam Lake Gardens

Fig. 6. Aerial images, NDVI maps and NDVI pixel count of the detailed study area

4.4. Correlation between NDVI and LST

Land surface temperature (LST) is sensitive to vegetation and soil moisture; hence it can be used to detect land use/land cover changes, e.g. tendencies towards urbanization. Various studies have been carried out to investigate LST using the vegetation. Fig. 7 shows the correlation of LST and NDVI in both clipped study areas in 1991 and 2009.

a)



b)

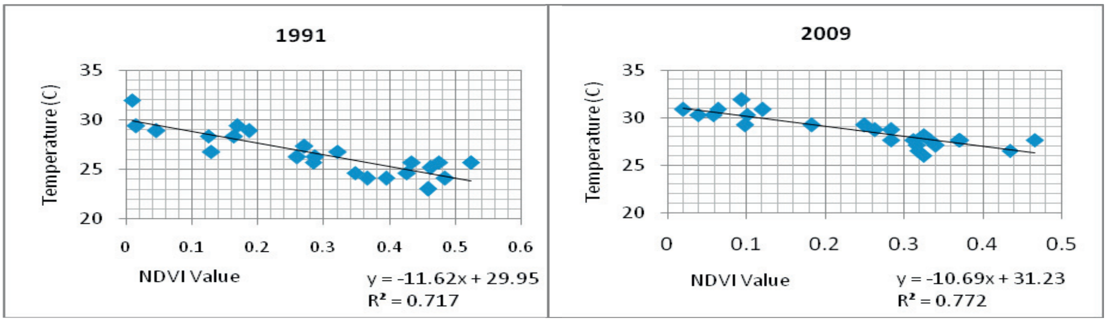


Fig. 7. Relationship of NDVI and LST of the study areas in 1991 and 2009; (a) Correlation of LST and NDVI in Shah Alam Lake Garden surrounding area; (b) Correlation of LST and NDVI in Bandaran Kelana Park and surrounding area

Strong correlation between surface temperature and NDVI values are found in Shah Alam area are 0.504 and 0.715 in 1991 and 2009. The Kelana Jaya area exhibit strong correlations between surface temperatures and NDVI values are 0.717 and 0.772 in 1991 and 2009 respectively. Thus, the surface temperature can be estimated with reasonable accuracy using NDVI values. Precisely, replacing vegetation and greening landscaping in the new urban area can help to reduce the radiant temperature of the built-up area. This study proves the positive impact of vegetation in built-up area especially in urban centres and significantly important to help mitigate the phenomena of UHI.

5. Conclusion

The potential of Landsat 5 TM to monitor the land cover changes and to analyse the spatial distribution of land surface temperature are widely used. The results indicate five major classes of land covers; water bodies, high dense trees, vegetations, built-up area, and cleared land. Due to urban growth, the dramatic changes in land use between 1991 and 2009 are relatively different, where high dense trees land cover areas have relatively decreased about 17.48%. This area is transformed to built-up land cover and cleared land where the dramatic changes happened in 1991 and 2009. The results show that LST and thermal signal of built-up and cleared land have distributed to rise average radiant temperature. While vegetated area (high dense tree and other vegetation) and water body experiencing lower temperature. Although this study is not conclusive, initial findings have shown that there are significant increases 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. Comprehensive ground observations are needed to validate the results obtained from satellite images. As resulting, urbanization significantly increases the LST. However, the initiative taken by the Shah Alam City Council and Kelana Jaya City Council to plant more trees helps to mitigate the UHI effects within a developed urban area. A climatic factor must be considered as criteria to perform sustainable development as well as to mitigate UHI effects in the city centre and to provide better quality of live among urban population. In addition, landscaping vegetation in urban area will help to beautify the urban surroundings tend to modify hot and humid tropical microclimates cities in Malaysian and beneficial to urban resident as well.

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