Quantifying Green Space Cooling Effects on the Urban Microclimate using Remote Sensing and GIS Techniques

Siti Nor Afzan BUYADI, Wan Mohd Naim WAN MOHD and Alamah MISNI, Malaysia

Key words: Urban Heat Island, urban green space, mono-window algorithm and cooling effects

SUMMARY

Urban heat island (UHI) is a phenomenon where temperature distribution in the urban area is significantly warmer than its surrounding suburban areas. One of the main causes of UHI is the replacement of natural surfaces by built surfaces through urbanization. Trees and vegetation play vital role to mitigate the UHI effects especially by regulating high temperature in saturated urban areas and their surrounding. This study attempts to evaluate the urban green spaces (UGS) cooling effects on the microclimate of the surrounding areas especially in a hot and humid tropical climate like Malaysia. Shah Alam Lake Garden (Shah Alam), Bandaran Kelana Park (Kelana Jaya) and Subang Ria Recreational Park (Subang Jaya) which are located in the Petaling District, Selangor, Malaysia are selected as the study areas. UGS land cover profile and surface temperature distribution are derived from Landsat 5 Thematic Mapper (TM) image of 2009. Mono-window algorithm is used to generate temperature distribution map of the study areas. Land cover classification and land cover profile of the selected study areas are generated in the digital image processing software. Geographical Information System (GIS) is used to generate the land surface temperature (LST) map, measure the LST of selected points within specified buffer zones, perform overlay and buffer operations. The green space cooling effects intensity and the relationship between intensity and proximity from green space boundary are later determined. Results obtained have indicated that the cooling effects intensity of the surrounding urban areas largely depends on the green space profile and the distance from the park boundary. The introduction of green areas or parks in urban areas can be considered as a good initiative to replace the loss of natural greenery and can potentially reduce the effects of UHI.

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1. INTRODUCTION

Increased replacement of the natural greenery area to urbanised areas has led to significant changes in the local climate conditions. Due to the economic demands, urban populations are rapidly increasing in size and complexity because more and more people are leaving rural areas and migrate to urban areas. Earlier studies by Akbari (2011), Elsayed (2009), Giannaros and Melas (2012), Senanayake et al. (2013) and Wan Mohd et al. (2004) have indicated that the temperature distribution in the urban areas is significantly warmer than its surrounding suburban areas. The anthropogenic heat released from vehicles, power plants, air conditioners and other heat sources, dramatic removal the vegetation cover and increasing of hard surfaces are major contributor for the formation of UHI (Memon et al., 2008 and Senanayake et al., 2013).

The UHI phenomenon can be found in many major cities throughout the world. UHI occurs when air and surface temperatures are hotter than their rural surrounding (Gartland, 2008). Rapid urbanisation causes reduction of vegetated areas and increases the built-up surfaces. The large amount of heat generated from the built-up surfaces trap the incoming solar radiation during the day and re-radiate it at night (Memon et al., 2008 and Solecki et al., 2004). Several studies have been carried out to investigate the UHI impacts and the mitigation strategies to minimise the UHI adverse impact (Choi et al., 2012; Gago et al., 2013; Omar, 2009; Mallick & Rahman, 2012; Shahmohamadi et al., 2009 and Yan et al., 2012). Among the strategies to minimise the UHI effects are urban greening, the use of high-albedo building material, the use of suitable pavement material and proper distribution of urban buildings and structure.

Landsat and ASTER satellite imagery are widely used to monitor the land use changes and derive land surface temperature of an area. Examples on the use of these satellite images in UHI studies in Malaysia can be found in Wan Mohd et al. (2004); Takeuchi et al. (2010) and Asmat et al. (2003). Previous studies clearly demonstrated that the implication of rapid urban growth is the decreased in the vegetated areas, increased the surface temperature and hence modified the urban microclimate. However, vegetation helps to keep the temperature of the surrounding lower than the non-vegetated developed area (Choi et al., 2012b and Buyadi et al., 2013). Additionally, maturity of trees is considered as a vital parameter to ensure lower temperature in urban areas through shadow and evapotranspiration (Georgi & Zafiriadis, 2006 and Qiu et al., 2013)

According to Cao et al. (2010), the temperature of urban parks is found to be 1–2°C, and sometimes even 5–7°C cooler than their urban surroundings. According to Vidrih and Medved (2013), an irregular pattern of cooler areas within generally warmer urban areas is known as Park Cool Island (PCI). Other studies by Edward et al. (2012) and Oliveira et al. (2011) also proved that PCI has strong cooling effects on the local surrounding. The shadows of high density trees and the water element in the urban green spaces contribute to cooling effect factors (Armson et al., 2012 and Mackey et al., 2012). Trees are found to be more effective than grass surfaces in cooling the surrounding areas. The green areas can create a cooling effect that extends few hundred metres to the surrounding areas especially in summer time and during the day (Oliveira et al., 2011). Besides reducing the thermal effects, trees and vegetation can help to reduce the adverse effects of air quality and noise level in areas surrounding the park. The cooling effect intensity is mainly due to the compactness of green spaces not the size of the park (Gago et al., 2013). The objectives of this paper are to highlight findings from a research carried out to determine the effects of vegetation growth on the land surface temperature (LST) distribution and to quantify the cooling effects intensity of parks on the surrounding area within the Petaling District, Malaysia.

2. STUDY AREA AND DATA ACQUISITION

The study areas are located within the District of Petaling (i.e. City of Shah Alam, Petaling Jaya and Subang Jaya). These cities are selected due to rapid urban development activities and the existance of urban parks. The climate of the cities is categorized as 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 temperature is between 22°C and 23.5°C. Relative humidity is around 72 to 78%, and the annual rainfall is about 3300 mm. The geographical location of the study areas is shown in Figure 1.

The temperature and water vapor content data of nearby weather station (i.e. Subang Meteorological Station) are obtained from the Malaysian Meteorological Department (MMD). The data obtained coincide with the time and date of the Landsat 5 TM satellite pass. Landsat 5 TM image dated the 21st January 2009 is used. For a more detailed study on the effects of green spaces on the temperature of the surrounding areas, three (3) parks are selected i.e. Shah Alam Lake Garden (located in Shah Alam), Bandaran Kelana Park (located in Kelana Jaya) and Subang Ria Recreational Park (located in Subang Jaya). These study areas are selected due to existance of heterogeneous land use/land cover such as commercial areas, vegetated areas, open spaces, residential areas, industrial areas and mixed residential-commercial areas.

3. METHODOLOGY

The methodology adopted for this study is organized into four (4) main stages i.e. i) generation of land use/land cover profile map, ii) generation of normalized differences vegetation index map iii) generation of temperature distribution of urban green spaces, iv) determination of park cooling effect intensity and its relationship with distance from park boundary.

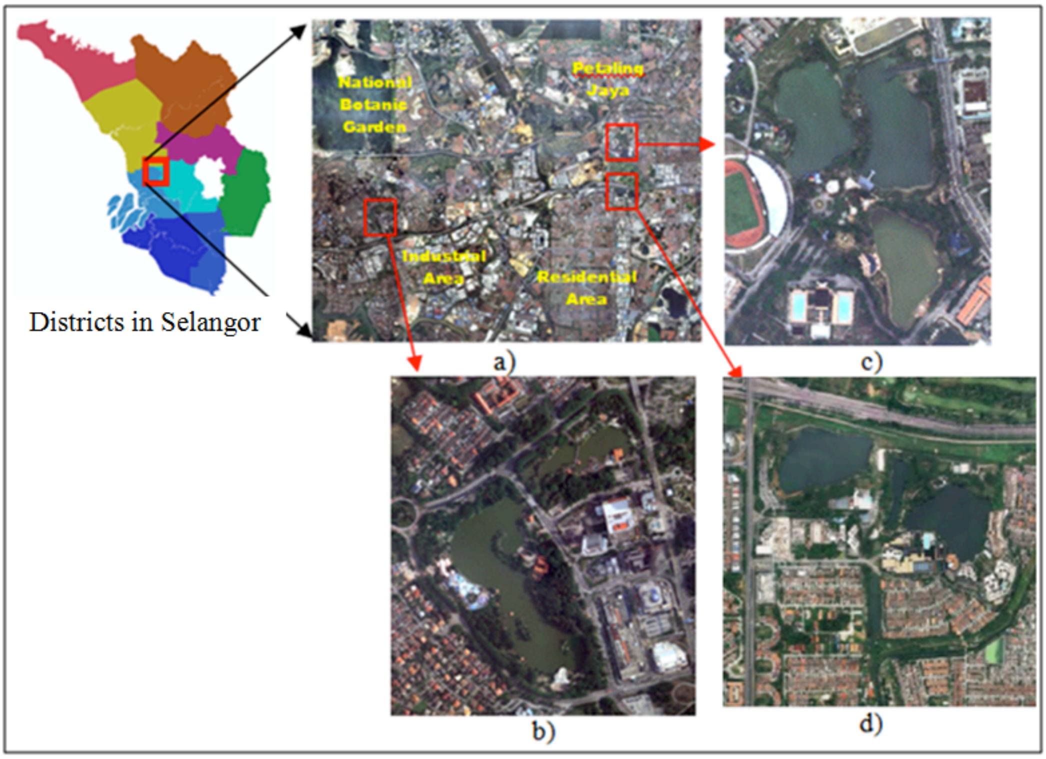


Figure 1: Location of the study areas a) part of Petaling District b) Shah Alam Lake Garden, c) Kelana Jaya Recreational Park and c) Subang Ria Recreational Park (Source : Google Map, 2013)

3.1 Generation of Land Use/Land Cover Profile Map

Landsat 5 TM image acquired from the Malaysia Remote Sensing Agency is used to generate the land use/land cover maps of the Petaling District. The process of generating land use map is carried out in the ERDAS Imagine digital image processing software. The unsupervised classification method is used to generate land use/land cover maps. For a more detailed study, image subset of all the selected study areas is performed. Based on the land use/land cover map and field verification, the land use/land cover profile and characteristics of the study areas are identified.

3.2 Generation of Normalized Differences Vegetation Index (NDVI) Map

GIS spatial analysis and zonal statistical analysis technique are used to visualize the vegetation fragmentation and surface temperature distribution. Equation 1 is used to calculate the NDVI of the study area. The emissivity values used for different NDVI range are 0.99 for

NDVI<0.2 (bare soil), 0.98 for NDVI between 0.2 and 0.5 (mixture of bare soil, vegetation and hard surfaces) and 0.98 for NDVI> 0.5 (fully vegetated area) (Jenerette et al., 2008).

$$NDVI = (NIR - R) / (NIR + R) \quad (1)$$

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

3.3 Land Surface Temperature (LST) retrieval

The mono-window algorithm as utilized by Qin et al. (2001) is used to generate the LST map. The mono-window algorithm requires three parameters; emissivity, transmittance and effective mean atmospheric temperature (Sobrino et al., 2004). The atmospheric water vapour content and the near surface air temperature are used to calculate the air transmittance and effective mean atmospheric temperature (Liu and Zhang, 2011). The third parameter is emissivity, which is calculated from NDVI. The mono-window algorithm is given as:-

$$T_s = \{a(1-C-D) + [b(1-C-D) + C + D]T_i - DTa\} / C \quad (2)$$

where:- Ts is LST in Kelvin; a = -67.355351; b = 0.458606; ($C = \mathcal{E}_i \times T_a$;where $\mathcal{E}_i$=emissivity can be computed from NDVI); $D = (1- T_a) [1+(1- \mathcal{E}_i) \times T_a]$; T_i is the brightness temperature (K) and T_a is the effective mean atmospheric temperature.

3.4 Determination of Park Cooling Effect Intensity and its Relationship with Distance from Park Boundary

The intensity of park cooling is usually measured from air temperature observations along transects or at stations in a park and the surrounding urban areas. In this study the park cooling intensity (in unit °C) is defined as the difference in temperature between the inside and outside of a park. Park cooling intensity as mentioned by Cao et al. (2010) can be represented by Equation 3:

$$\text{Park cooling intensity } (\Delta T) = T_u - T_p \quad (3)$$

where, T_p is the average LST inside the park
T_u is the average LST outside the park

Based on the LST maps of the study areas, average temperature within the built-up areas at every 50 m buffer from the park boundary are obtained. The 50 m buffer interval is considered as suitable choice as it is almost twice the size of the resampled pixel of the LST layer (i.e. 30 m). The maximum buffer distance from the park boundary is 1000 m. The effective cooling intensity buffer zones of different parks are later computed. Park cooling intensity is correlated with the buffer distance to determine the relationship between these two parameters.

4. RESULTS AND DISCUSSION

4.1 Land use/land cover, NDVI and LST Maps

Figures 2, 3 and 4 show the land use/land cover, NDVI and LST maps of part the Petaling District respectively. NDVI and LST maps of the detailed study areas extracted from NDVI and LST maps of a larger area are shown in figures 5, 6 and 7. The total acreage of part of the Petaling District is 16,904.547 hectares. The detail acreage of individual land use/land cover is listed in Table 1. Water bodies, high density trees, mixed vegetation (i.e. crops, parks and bushes), built-up areas (i.e. commercial, residential and administrative building), built–up areas and cleared land constitute 1.88%, 16.61%, 31.97%, 39.09% and 10.45% respectively.

The mean temperature for individual land use/land cover is summarized in Table 2. Based on Figure 3 and Table 2, the radiant temperature for 2009 range between 24.0°C and 38.0°C. The highest mean temperature is within the built-up area (i.e. 30.8°C) while the lowest is within water bodies (i.e. 30.8°C) 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. Image subset for the NDVI and LST of the detailed study areas are shown in figures 5, 6 and 7.

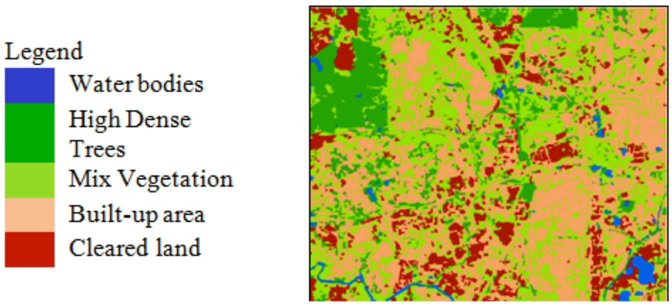


Figure 2: Land use/land cover map of part of the Petaling District

Table 1: Land use/land cover coverage

Land Use/Land Cover Class	Area in Hectares	Percentage (%)
1) Water bodies	317.827	1.88
2) High Density Trees	2807.432	16.61
3) Mixed Vegetation	5403.899	31.97
4) Built-up area	6608.361	39.09
5) Cleared Land	1767.028	10.45
Total	16,904.547	100

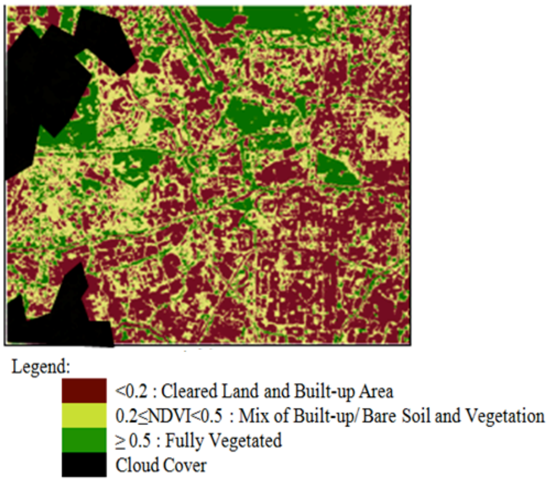


Figure 3: NDVI map of part of the Petaling District

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

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

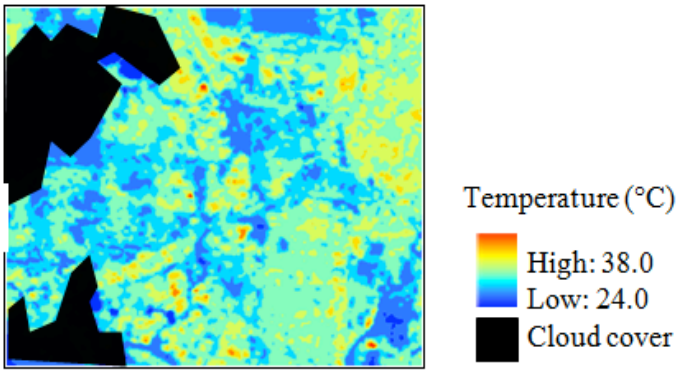


Figure 4: LST map of part of the Petaling District

Figures 5 a), b) and c) show the orthoimage, NDVI and LST maps of Shah Alam Lake. The NDVI and LST cross section profiles passing through residential area (Section 2), urban park (i.e.; water body, high density trees and vegetation) and administrative building is shown in figures 5 d) and e) respectively. Figure 6 d) and e) show the NDVI value range from -0.2 to 0.28 and the surface temperature range from 25.5ºC (in park area) to 29.9ºC (max) in commercial area. The difference in the surface temperature between built-up areas and high density tree areas is more than 4°C. As the profile line cross over the grass area the temperature remain unchanged. It is clear that grass does not significantly reduce the surface temperature within the built-up area. Different tree type and density of vegetation could have different effects in reducing surface temperature in urban areas. The cross section profiles at Subang Ria Recreational Park are shown in figures 7 d) and e). The transect profile cross different types of land use (i.e. residential, vegetation , built-up, urban park-water body and trees). The highest and lowest LST are within residential areas and water bodies respectively. It is clear that water body contribute to lowering the surface radiant temperature of the surrounding area.

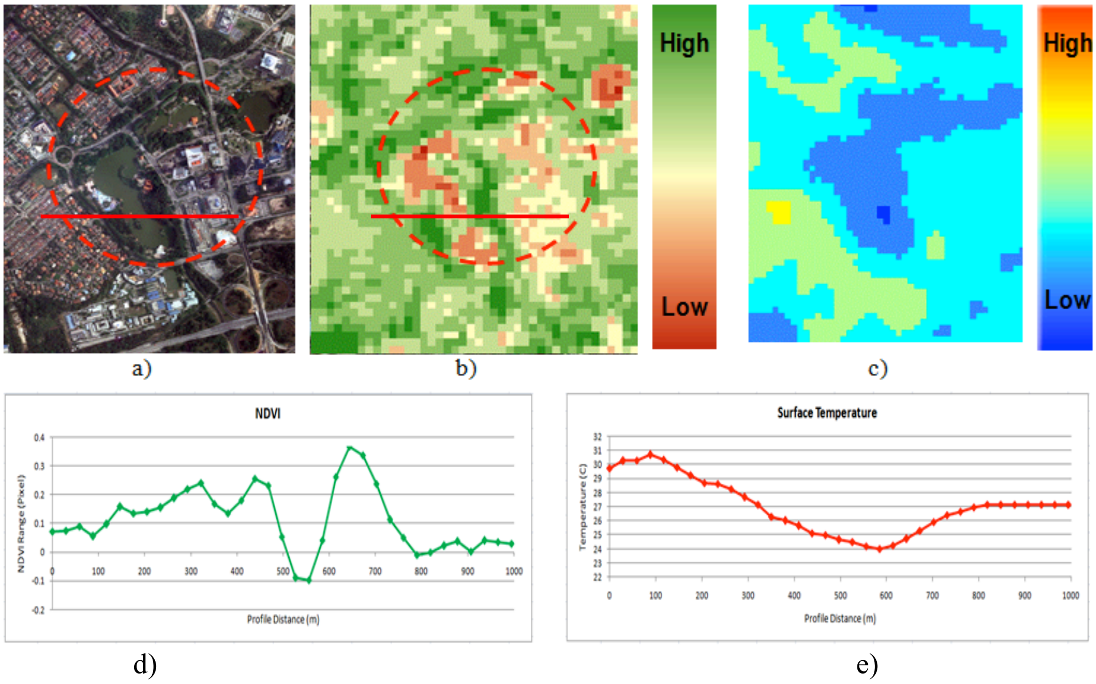


Figure 5: a) Orthophoto image, b) NDVI map, c) surface temperature map, d) NDVI transect profile and e) LST transect profile of the detailed study area in Shah Alam

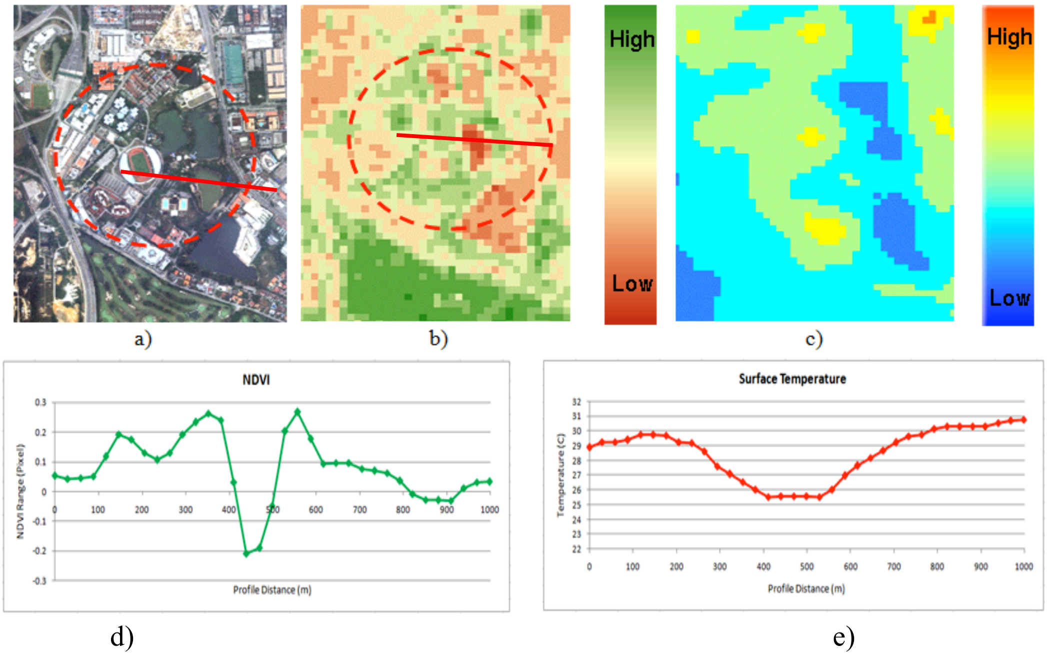


Figure 6: a) Orthophoto image, b) NDVI map, c) surface temperature map, d) NDVI transect profile and e) LST transect profile of Bandaran Kelana Park

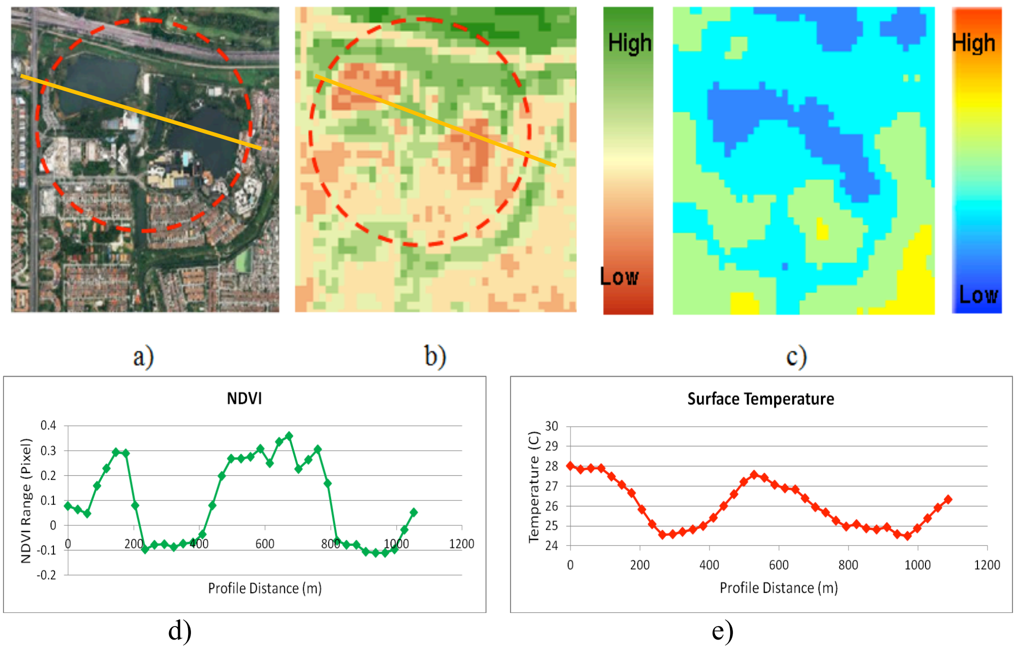


Figure 7: a) Orthophoto image, b) NDVI map, c) surface temperature map, d) NDVI transect profile and e) LST transect profile of Subang Ria Park

4.2 Land Use/Land Cover Profile and Surface Temperature Distribution

The detail acreage of land use/land cover profile and surface temperature distribution of the three study areas are shown in Figure 8. The major land use/land cover for the detailed study areas are water bodies (lake), high-density trees (matured trees and wide canopy trees), mix vegetation (shrubs and bushes), built-up (shelter) and open area (paved area). The total acreage of the study areas for the Shah Alam Lake Garden, Bandaran Kelana Park and Subang Ria Recreational Park are 32.67, 15.57 and 12.06 hectares respectively. Based on the detailed profile of the study areas given in Figure 8, Shah Alam Lake Garden gives the lowest mean temperature (25.48 ºC) followed by Subang Ria Park (25.78 ºC) and Bandaran Kelana Park (26.4 ºC).

For the Shah Alam Lake Garden the highest and lowest land use/land cover types are high-density trees (53.72 %) and built-up areas (3.86%) respectively. For the Bandaran Kelana Park, 47% of the area is covered by water bodies while high-density trees, mixed vegetation and built–up area covers 29.48%, 4.62% and 18.50% percent respectively. The Subang Ria Recreational Park consist of four major types of land use/land cover (i.e. water bodies, high-density trees, mixed vegetation and open area). Due to different land use/land cover profile composition, slight variation in the mean temperature distribution is expected. The Shah Alam Lake Garden which comprise of more than 50% high-density tree gives the lowest mean temperature as compared to urban park which comprise of water bodies as the major land use/land cover. The vegetation growth especially areas with high-density trees within the study area clearly contribute to the lowering of temperature within the park.

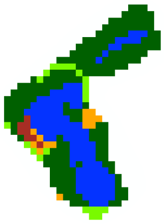
4.3 Green Spaces Cooling Effect

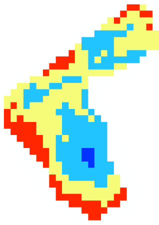
Figures 9 a), b) and c) show the 50 m multiple ring buffer (with maximum buffer distance of 1000 m) generated from the green space/park boundary. The mean temperature inside the urban green space (i.e. Shah Alam Lake Garden, Bandaran Kelana Park and Subang Ria Recreational Park) are 25.5 ºC, 26.4 ºC and 25.8ºC respectively. The green space cooling effect intensity (ΔT) for the study areas are summarised in Table 2.

The urban green space intensity of the the study areas have shown difference intensity values in each buffer range. The intensity value increases as distance from the outer boundary increases. In the 50 m buffer zone the intensity range from 1ºC – 1.7ºC. As the buffer distance reaches the 500 m buffer zone, the intensity value increases by more than 3ºC. At the Bandaran Kelana Park, the intensity value at the 400 m buffer zone is 3.9ºC at the buffer distance of 400 m. Beyond this buffer distance the value start to decrease. The land use/land cover types within the 400m buffer zone are mainly commercial and built-up areas. The mean temperature in this region is approximately 29.8ºC.

Land cover profile	LST Distribution	Green Space Profile

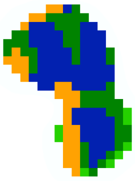
a)

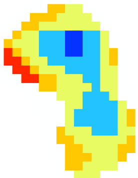




Class Name	Area (Hectare)	%	LST (ºC)
Water	10.26	31.40	24.6
High-density Trees	17.55	53.72	25.3
Mixed-vegetation	1.98	6.06	25.8
Built-up	1.26	3.86	25.6
Open_area	1.62	4.96	26.0
Total Acreage	32.67	100	Mean = 25.5

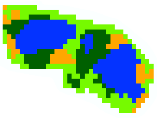
b)

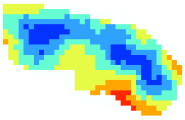




Class Name	Area (Hectare)	%	LST (ºC)
Water	7.38	47.40	25.3
High_density Trees	4.59	29.48	26.3
Mix_vegetation	0.72	4.62	26.8
Built_up	2.88	18.50	27.3
Open_area	-	-	-
Total Acreage	15.57	100	Mean = 26.4

c)





Class Name	Area (Hectare)	%	LST (ºC)
Water	6.66	55.23	24.50
High_density Trees	2.79	23.13	25.50
Mix_vegetation	1.98	16.42	26.32
Built_up	-	-	-
Open_area	0.63	5.22	26.80
Total Acreage	12.06	100	Mean = 25.8

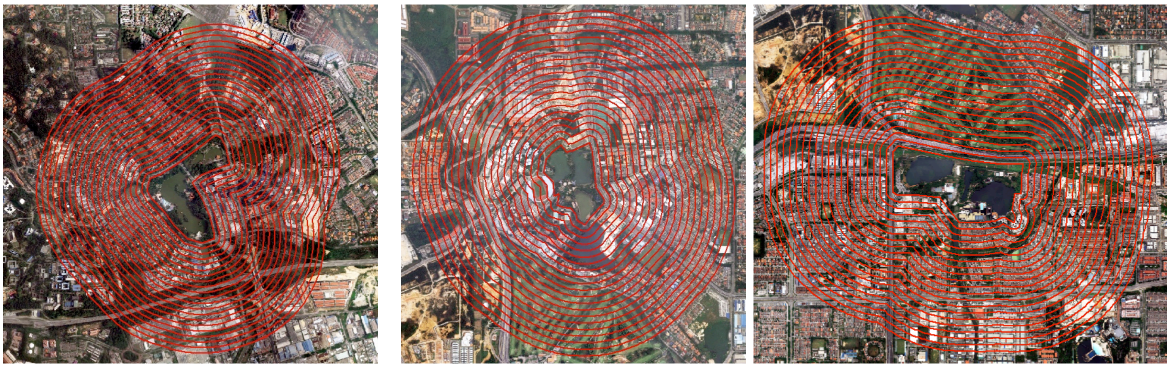
Legend: UGS Profile
- Water
- High Density Trees
- Mix Vegetation
- Built-up
- Open land

Legend: LST distribution

Temperature (°C)

High: 38.0
Low: 24.0

Figure 8: Land use/cover profile and LST distribution within the boundary of a) Shah Alam Lake Garden, b) Bandaran Kelana Park and c) Subang Ria Recreational Park



a) b) c)

Figure 9: 50 m multiple buffer ring generated from a) Shah Alam Lake Garden, b) Bandaran Kelana Park and c) Subang Ria Recreational Park

Table 2: Urban green space cooling effects intensity of the study areas

Park	Buffer Range (m)/ PCI Intensity (ΔTºC)										
	T_p(ºC)	50	100	150	200	250	300	350	400	450	500
Shah Alam	25.5	1	1.33	1.39	1.5	2	2.8	2.8	2.9	3	3
Kelana Jaya	26.4	1.7	2.2	3.3	3	3.3	3.3	3.6	3.9	3.7	3.2
Subang Jaya	25.8	1	1.1	1.4	2.03	2.5	2.3	2.5	2.56	2.8	3.3
	Tp(ºC)	550	600	650	700	750	800	850	900	950	1000
Shah Alam	25.5	3.6	2.2	1.9	1.9	1.9	1.6	2.3	1.6	2.6	3.3
Kelana Jaya	26.4	4.4	3.1	2.8	3.8	3.4	3.1	3.1	3.8	4.4	4.4
Subang Jaya	25.8	2.9	3.3	4.0	3.4	2.7	2.7	4.9	4.9	4.9	4.9

4.4 Correlation between cooling effect intensity and buffer distance

Figures 10 a), b) and c) show the correlation of cooling effect intensity and buffer range from park boundary of the three study areas. Although cooling effect intensity for different buffer zones are measured up to 1000 m distance from the park boundary, strong positive correlation between cooling effect intensity and proximity from the park boundary are clearly evident only until 500 m. Beyond this 500 m buffer, the effects are not consistence and this could be due to other factors such as the existance of matured trees or building density within the residential/commercial areas. The R^2 coefficients for the Shah Alam Lake Garden, Bandaran Kelana Park and Subang Ria Recreational Park are 0.908, 0.816 and 0.917 respectively. The results obtained clearly shows that urban green spaces are capable of reducing the high radiant temperature of the surrounding developed areas.

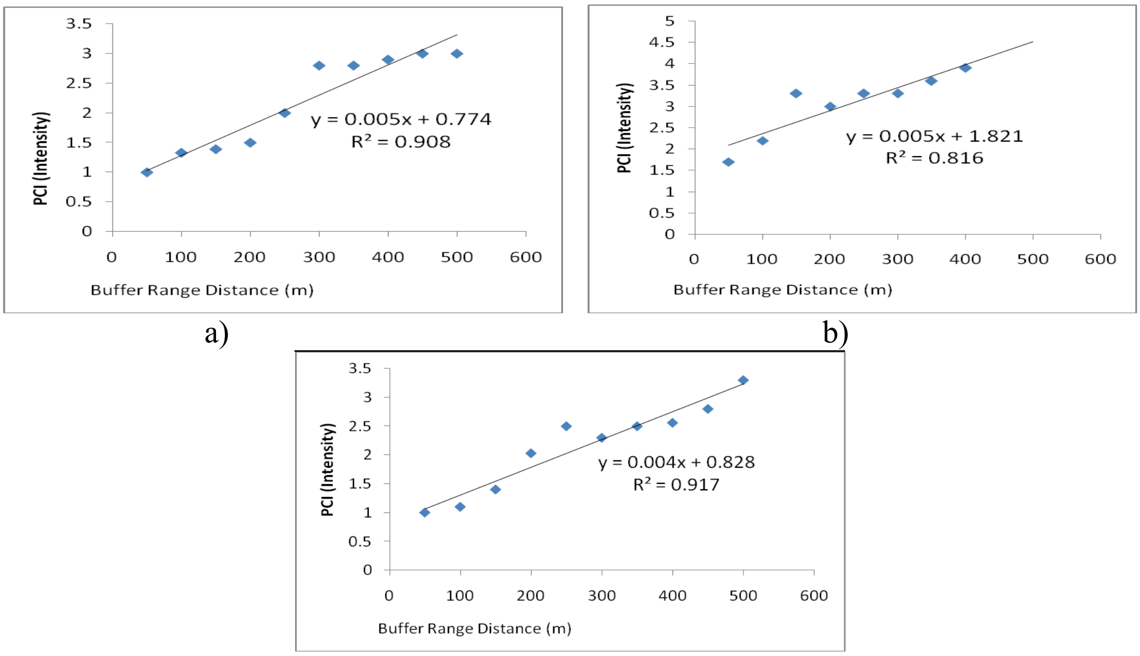


Figure 10: Relationship between cooling effects intensity and buffer range in a) Shah Alam Lake Garden, b) Bandaran Kelana Park and c) Subang Ria Recreational Park

5. CONCLUSIONS

The results of this study suggest that the cooling effects of parks depend on the composition park land use/land cover profile (water body, high density trees, mix vegetation, built-up area and open spaces) and also the distance from the park boundary. The cooling effect intensity increases as distance from the park boundary increases. The temperature difference between the interior of the park and the zones 500 m from the park boundary is more than 3ºC. Further research should include detailed studies on the urban green spaces cooling effect based on various park design, park size and park orientation. Findings from this study will help urban planners or urban designers to understand the interaction between urban parks and UHI effects especially in a hot and humid tropical climate region like Malaysia.

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BIOGRAPHICAL NOTES

Siti Nor Afzan BUYADI

Education
MSc (Edu) in Technical and Vocational Education (Universiti Tun Hussien Onn, 2006)
BSc in Surveying Science and Geomatics (Hons) (Universiti Teknologi MARA, 2005)
Diploma in Geomatics (GIS) (Universiti Teknologi MARA, 2003)

Siti Nor Afzan Buyadi has graduated her first degree in UiTM in the field Surveying Science and Geomatics and her master in Vocational and Technical Education. She has served as a lecturer in the Department of Civil Engineering (Land Survey Unit), Politeknik Merlimau, Melaka since 2006 before being transferred to the Ministry of Higher Education (MOHE), Putrajaya in 2009. Her research interest is in the field of Geographical Information Science, Land Surveying and Remote Sensing. Currently she is completing her PhD studies in Built Environment at Universiti Teknologi MARA, Malaysia.

CONTACTS

Siti Nor Afzan BUYADI
Centre of Studies for Surveying Science and Geomatics
Faculty of Architecture, Planning and Surveying
Universiti Teknologi MARA
40450 Shah Alam
Selangor Darul Ehsan
MALAYSIA
Tel. +6019-3577147
Fax + +603-55444545
Email:afzanphd@gmail.com
Web site:

Dr Wan Mohd Naim WAN MOHD
Associate Professor
Centre of Studies for Surveying Science and Geomatics
Faculty of Architecture, Planning and Surveying
Universiti Teknologi MARA
40450 Shah Alam
Selangor Darul Ehsan
MALAYSIA
Tel. +6019-3577147
Fax + +603-55444545
Email: wmn@salam.uitm.edu.my