MAPPING URBAN HEAT ISLAND PHENOMENON: REMOTE SENSING APPROACH

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ABSTRACT

This article investigates the application of remote sensing data for mapping urban heat island (UHI) phenomenon in an urbanised area of Selangor. The selected area covers Kajang, Cheras and Dengkil mukims in Selangor with total area of 4950 ha. The urban heat island was determined by using the land surface temperature (LST) information from thermal infrared band (Band 6) of Landsat image with 120 m pixel resolution. A subset of Landsat TM acquired on April 17, 1988 (path 127/row58) covers the urbanised mukims was used in this study. Erdas Imagine 8.5 was the main software for image classification of urban land covers in 1988, while GIS-Grid Calculator functions were used to derive land surface temperature. This study demonstrates the spatial variation of LST within urban blocks with temperature above 27.5^o Celcius. About 3557 pixels (or approximately 32 ha of area) has been identified as UHI pixels in both Cheras and Kajang mukims. Urban impervious area near Pekan Bt 9, Cheras, Kajang town and Bandar Baru Bangi have been recognised areas with highest number of UHI-related pixels. The result revealed the effectiveness of remote sensing data application in analysing urban heat island-land surface temperature relationships in Selangor.

Keywords: *Land Surface Temperature (LST), Thermal Infrared, Urban Heat Island (UHI)*

1. INTRODUCTION

The state of Selangor has experienced rapid development and high growth of urbanisation and industrialisation over the past two decades. These urban transfusions especially in Klang Valley conurbation have altered its physical and natural environment. Urban encroachment was significant especially in urbanised mukims of Kajang, Cheras and Dengkil, transferred rural environment into a new urban landscape. In late 1980s, a large rural area of agricultural land has been converted into urban areas, hence changed the surface profile of the area [1, 2].

The urban surfaces absorb heat and increase the temperature comparatively to the surrounding area. The heat bubble, known as urban heat island (UHI) not only reduced human comfortability but it also could increase energy consumption in buildings [3, 4]. For daytime temperatures, it is observed that large cities such as Kuala Lumpur, Georgetown and Seremban can be 3^{o}C hotter than the suburbs area [5]. Latest research has also showed the effectiveness of urban heat island in changing the urban micro-climate e.g. changes of intensity and frequency of rainfall [6, 7, 8]. Urban areas may create higher frequency and magnitude of rainfall events due to the 'urban heat island' effect and increase the water input into an urban catchment.

2. URBAN HEAT ISLAND STUDIES

The UHI phenomenon is also well known among various agencies in Malaysia. For example, the Malaysian Meteorological Service is concerned on warm nights due to UHI in metropolitan areas that can induced higher frequency of 'heavy' rainfall. A study carried out by the Department of Irrigation and Drainage has revealed a rising trend of 3-hour rainstorms characteristics in Kuala Lumpur compared with rainfall observed in a rural area [6]. The difference of the 3-hour rainstorms has increased at least 6 % in the urban station i.e. Kuala Lumpur due to UHI phenomenon.

The urban heat island effect defines as larger temperatures in urbaniced areas as compared to surrounding areas with relatively larger amount of vegetation [3, 9]. Nowadays, urban heat island is a common phenomenon in major cities in the world, including Malaysia. This is because of large areas of dark surfaces like concrete roofs, pavements and asphalt whereby these surfaces can absorb more heat from the sun all day.

In general, land surface temperature is recorded by using Sling Psychrometer at certain point on the ground. The reading shows ambient temperature variation within a limited space, for example, from 10 m^2 up to 1 km^2 radius, or depend on land cover types as well as local topographical element. However, surface temperature detection using remote sensing method is cost effective and involved large and synoptic view [10, 11].

This article investigates the application of remote sensing data for detecting land surface temperature (LST) and mapping UHI phenomenon. Urban heat island due to rapid growth in urbanisation can be determined by using the surface temperature information from Thermal Infrared band (10.40 – 12.50 μm) of Landsat image. However, works need to be done for LST retrieval from the original raw Digital Number (DN) value of band 6 Thermal Infrared Landsat TM.

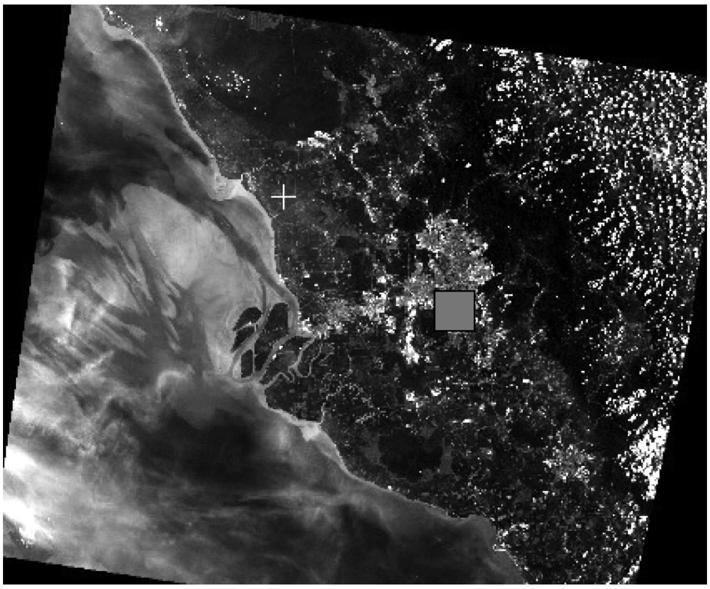

Figure 1: The location of study area in Landsat TM scene

LST is an important parameter in the field of atmospheric sciences as it combines the result of all surface-atmosphere interaction and energy fluxes between the ground and the atmosphere and is, therefore, a good indicator of the energy balance at the Earth's surface [12]. LST controls the surface heat and water exchange with atmosphere. Estimation of LST from satellites infrared radiometers has been proven useful and most studies have focused on the use of Landsat images because of their high spatial resolution [11].

3. STUDY AREA

The study area (Cheras, Kajang and Dengkil mukims) is located in central part of Selangor, the most urbanised state in Malaysia (Figure 1). Geographically, the study area falls within latitudes 3° 26' N and 3° 31'N, and longitudes 101° 18' E and 102° 33'E. The geographic location of the Landsat TM image for this study area is Path 203, Row 23 according to the Worldwide Reference System (WRS).

The study area is located downstream of Langat river basin, which Sungai Langat forms major drainage flows towards Straits of Malacca. The general topography varies considerably. The study area experienced hot and wet tropical climate with an average annual temperature between 21° to 32° Celsius. The annual rainfall is approximately 1900 mm, that is lower than the overall average rainfall for the Peninsular of Malaysia [3]. October to December are considered as wet season, whereas January, June and August are months of the driest period in the study area.

Table 1: Image acquisition date and total rain for 1988, 1999 and 2001

Image Acquisition Date	Total rain 5 days before image acquisition date at UM station (mm)	Total rain 5 days before image acquisition date at PJ station (mm)	Total rain 5 days before image acquisition date at Subang station (mm)
April 17, 1988 (dry)	12	0	7.2
February 11, 1999 (wet)	111.5	72	21.4
May 5, 2001 (wet)	35	32	29.5

The April 17, 1988 scene has been selected due to several factors, i) the UHI study should take consideration on antecedent soil wetness condition (ASW). High value of ASW will produced error in the LST retrieval [13]. In our pilot study, most of recent images (1999 and 2001 for Path 127/Row58) have a very high ASW relatively due to prolonged wet spell within the Langat basin (Table 1).

The April 17, 1988 scene has also recorded drastic changes of land cover within the Langat basin. Based on landuse maps (1984-1999), it was recorded a significant increment of urban land cover especially in Cheras, Kajang and Dengkil mukims [1]. This was due to the development of newly township area within Kajang-Bandar Baru Bangi corridor in the late 1980s.

4. METHODOLOGY

Basically, there are two major methods involved in this study, image classification and land surface temperature retrieval:

i. Image classification

A subset of Landsat TM acquired on April 17, 1988 (path 127/ row58) that covers an urbanised mukims (Kajang-Cheras-Dengkil) was used in this study (Figure 2). 15-class ISODATA unsupervised classification was then performed using ERDAS-IMAGINE on the dataset in order to interprete the land cover information of the study area [1]. Based on visual examination on the 1984 Land Use Map of

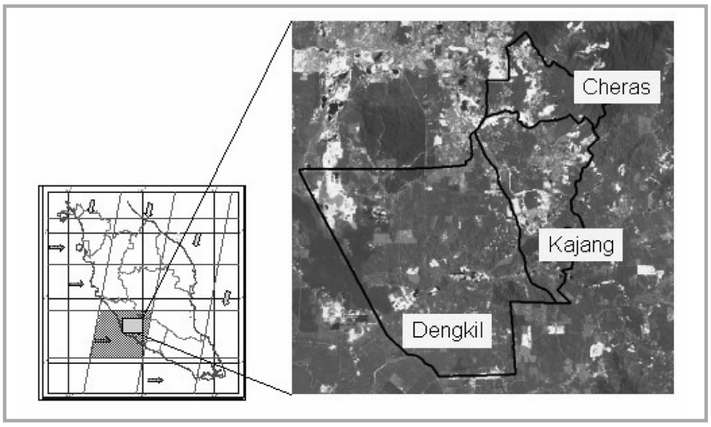

Figure 2: A subset of Landsat TM covers three main urban mukims, i.e. Dengkil, Kajang and Cheras

Figure 3: Image classification for 1988

Selangor, five common land cover types can be detected and well represented in the ISODATA result (Figure 3).

ii) Land Surface Temperature (LST) Retrieval

LST retrieval was carried out through three phases.

i) Conversion from Digital Number to Radiance

All TM bands are quantised as 8 bit data thus, all information is stored in DN with range between 0 to 255. The data was converted to radiance using a linear equation as shown below:

$$CV_R = G\,(CV_{DN}) + B \qquad (2)$$

where:

CV_R = the cell value as radiance

CV_{DN} = the cell value digital number

G = the gain (0.005632156 for TM6 and 0.003705882 for ETM+6)

ii) Conversion from Radiance to Brightness Temperature

By applying the inverse of the Planck function, thermal bands radiance values was converted to brightness temperature value.

$$T = \frac{K_2}{\ln\left(\frac{K_1}{CV_R}\right) + 1} \qquad (3)$$

where:

T = ° Kelvin

CV_R = the cell value as radiance

K_1 = *calibration constant 1 (607.76 for TM) and (666.09 for ETM+)*

K_2 = calibration constant 2 (1260.56 for TM) and (1282.71 for ETM+)

iii) LST Retrieval

LST was derived from TM6 using model developed which use spectral surface emmissivity and Normalised Density Vegetation Index or NDVI values of the particular scene [18]. The equation is as below,

$$S_t = \frac{T}{1 + (\lambda x\, T / \rho) \ln \varepsilon} \qquad (4)$$

where:

St = LST

λ = wavelength of emitted radiance (λ = 11.5 µm)

ρ = $h \times c/\sigma$ (1.438 ×10^{-2} m K)

σ = Boltzman constant (1.38 ×10^{-23} J/K)

h = Planck's constant (6.626×10^{-34} J s)

c = velocity of light (2.998 ×10^{8} m/s)

Emissivity ε *can be estimated through:*

$$\varepsilon = f_v\, \varepsilon_v + (1 - f_v)\, \varepsilon_s \qquad (5)$$

where ε_v and ε_s denote emissivity of vegetation (ε_v = 0.99) and soil (ε_s = 0.973), while f_v can be expressed as [14]:

$$f_v = 1 - \left(\frac{NDVI_{max} - NDVI}{NDVI_{max} - NDVI_{min}}\right)^a \qquad (6)$$

where:

NDVI max = NDVI for complete vegetation cover

NDVI min = NDVI for bare soil

a = function of leaf orientation distribution with the canopy

Table 2: Land cover of the study area year 1988

Land cover type	Area (ha)	Percent (%)
Forest	965.73	19.5
Permanent Crops	2191.81	44.2
Grass	852.66	17.2
Urban	693.30	14.1
Bare soil	248.48	5.0
Total	**4951.98**	**100**

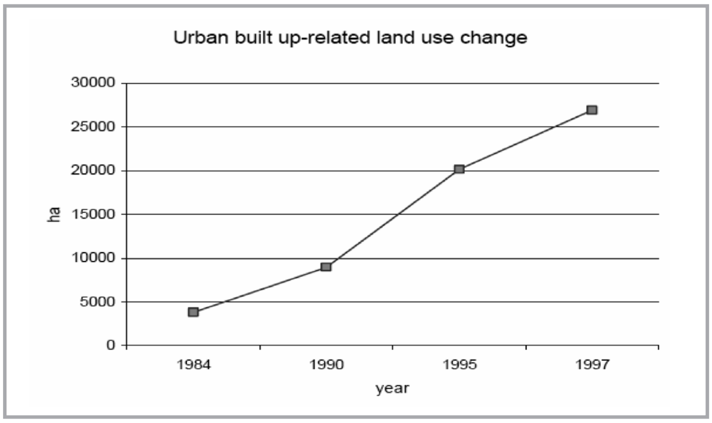

Figure 3: The increment of urban built up area in Langat River Basin [1]

5. RESULT AND DISCUSSION

Table 2 shows the land cover classification result based on the year 1988 in the study area. The result shows the spatial variation of land covers within the mukims in 1988. Cheras and Kajang were the most urbanised area compared to Dengkil. The vegetated or permanent crops area occupied more of the Dengkil than other land cover types. Most of the agricultural area was high-grade farmland that is associated with local alluvium soil.

In 1988, the most extensive urban area is within Cheras-Kajang-Bandar Baru Bangi corridor. Some of the open spaces, especially around Dengkil and Kajang area were bare soils demarcated the newly urban development area. The amount of urban area in 1988 indicates that the area had undergone urbanisation and industrialisation in the the early 80s. The increment of the urban built up area in Langat river basin from 1984 to 1997 (Figure 3) [1]. These urbanised mukims were most affected area of urbanisation in the Langat river basin since late 1980s (Figure 4).

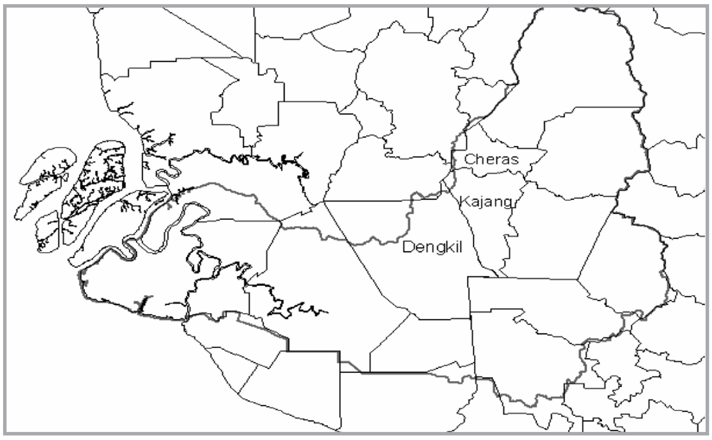

Figure 4: The study area within Langat river basin

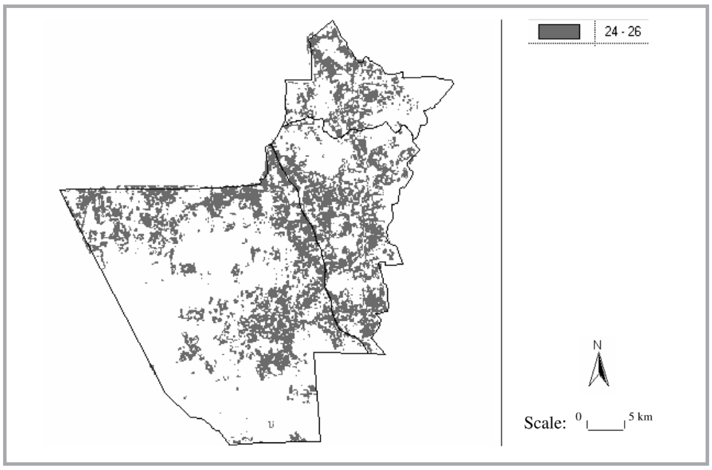

Figure 5: 1988 temperature image – red region indicates area with temperature 24° C – 26° C (146,236 pixels). The white region indicates area mostly from vegetation cover

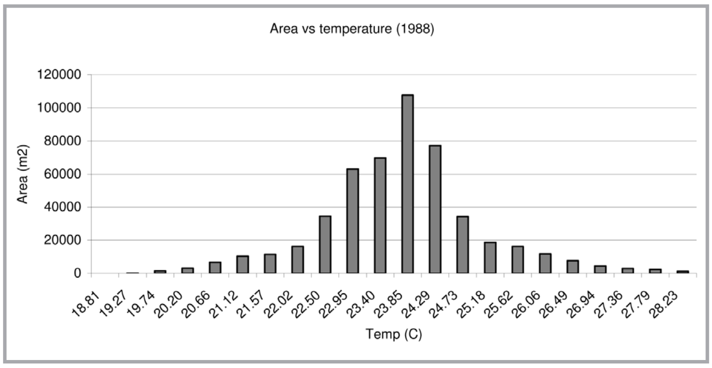

Figure 6: Temperature distribution based on LST analysis for 1988

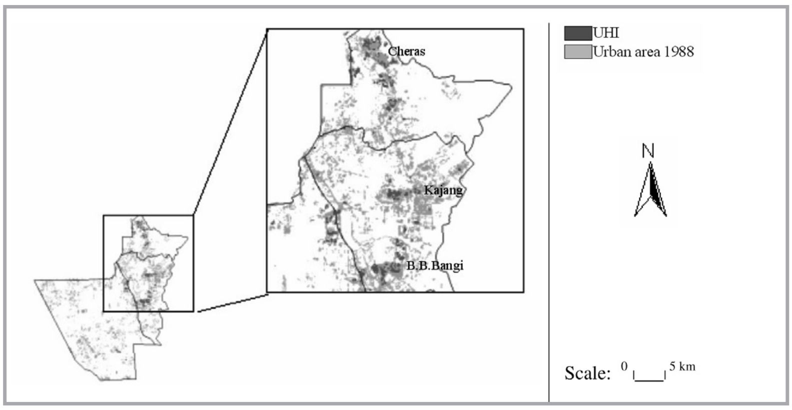

Figure 7: Distribution of UHI (in red) greater than 27.5° C in the year 1988 within the urban blocks (in yellow). 3557 pixels has UHI greater than 27.5° C

In terms of LST spatial variation, Figure 5 shows the temperature values between 24° to 26° Celsius. Most of the areas with these temperature values include urban, grass and bare soil covers (see Figures 5 and 7). These areas cover approximately 146,236 pixels. Agricultural and forest covers exhibit lower temperature value, i.e. less than 24° Celsius and form 'cold island' phenomenon.

Based on Figure 5, the two degree Celcius difference is significant enough to visualise the effective temperature for human comfortability. According to Shaharuddin [15], temperature value above 24° Celcius refers to the 'above acceptable value' for human comfort in the tropical region. He also recommended the optimum effective temperature for Kuala Lumpur i.e. between 20 to 22° Celcius. However, the area (total pixel involved) that can be considered as optimum effective temperature was rather small in 1988 (Figure 6).

Figures 7 to 9 shows the location of urban heat island (UHI) within the urban blocks, especially in Cheras and Kajang mukims. About 3557 UHI-related pixels have been identified, mostly within Pekan Bt. 9, Cheras, Kajang town center and Bandar Baru Bangi area. These areas have the highest LST values (above 27.5° Celsius) as the high intensity of thermal energy responses due to the man-made impervious covers such as asphalt and concrete [3, 9, 15]. This variability of UHI in the study area will likely to increase energy consumption and demand for cooling system in buildings.

Research elsewhere also confirmed the human health risk due to UHI because of heightened levels of secondary pollutants such as ozone in urban conurbation [8]. Given the relationship between surface temperature and the land cover types, the dynamics in urban changes have a profound effect on the UHI. For example, if the deforestation is not practice wisely, this will increase the area related to UHI.

Vegetation or forest patches within urban conurbation are essential in reducing surface temperature as cooling effect due to evapo-transpiration processes [4]. The inverse relationship between forest cover and urban built-up in affecting LST has been significantly proven (Figure 10). Based on 20 ground control points collected randomly for within the LST map, it shows a different group of surface temperature based on land cover characteristics in the study area (Table 3). The differences between both land cover types, i.e. about 8.5° Celsius shows the importance of vegetation coverage in minimising the thermal energy responses in urban areas.

6. CONCLUSION

The urban conurbation of Kajang-Cheras-Dengkil mukims, one of the fast expanding Selangor urban areas, has a remarkable UHI-related area in 1988. It becomes more important to urbanisation as the new central government city, i.e. Putrajaya hasten in-migration processes towards this conurbation area in 1990s. The Landsat TM data with 120 m resolution of band 6 in estimating LST succeed to highlight the UHI-related area in 1988.

This LST result could help especially to urban planners in better understanding urban climate as well as finding solution of managing urban environment. The result also shows remote sensing data has been found to be effective in analysing urban-land surface temperature relationships. Data quality and accuracy assessment of

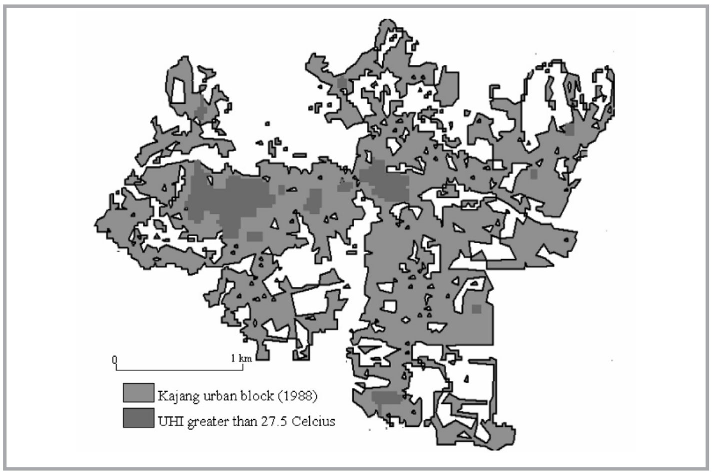

Figure 8: The UHI within Kajang urban block

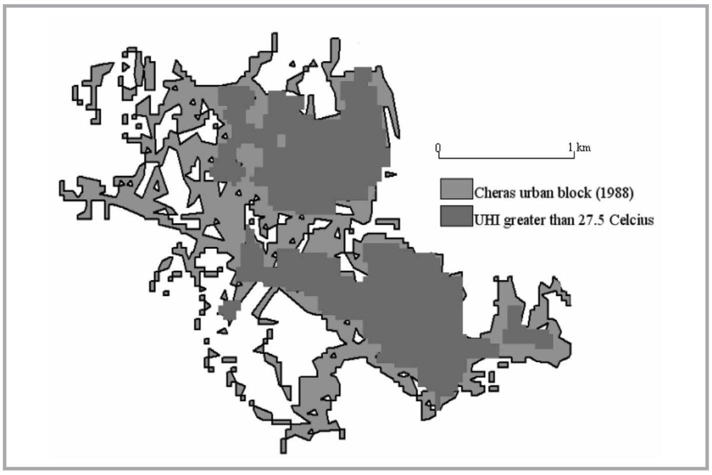

Figure 9: The UHI within Cheras urban block

Table 3: 20 GCP collected for land cover – LST relationships

Forest Cover (x,y Coor)			Urban Cover (x,y Coor)		
X	**Y**	**Temp (Celcius)**	**X**	**Y**	**Temp (Celcius)**
403578	322929	22	419222	325640	28.2
405553	318073	20	416106	328342	28.2
408104	329431	23.4	424322	332548	26.9
426458	337580	22.4	418688	334923	26.9
404372	318508	19.7	419674	336668	27.7
416857	317640	23.4	416852	335250	27.3
415921	318816	23.8	412253	324849	23.4
422194	321346	24.2	423130	330148	22.9
418741	322396	23.4	419627	336915	25.6
322863	322863	23.8	416718	331653	24.2
	Average	22.6		Average	26.1
	Min	19.7		Max	28.2

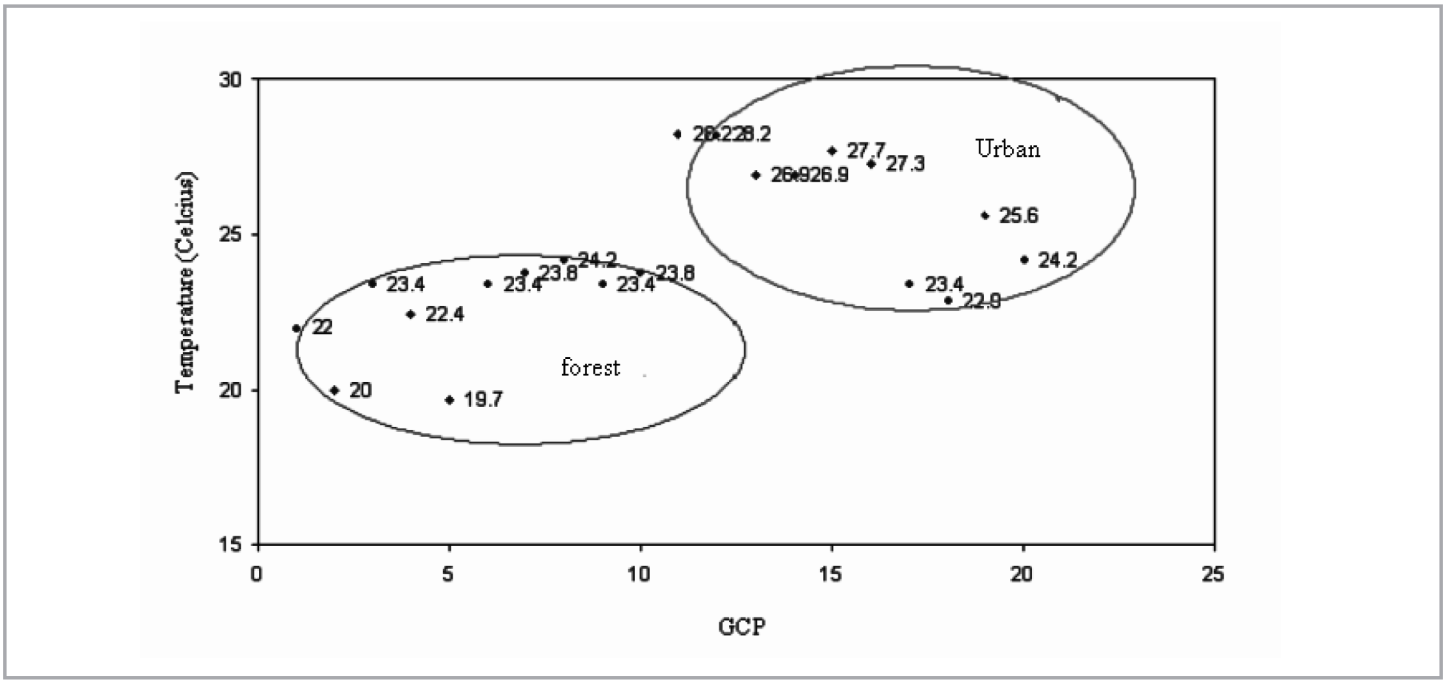

Figure 10: LST differences between forest and urban covers in 1988

the result is an important and rather difficult task in LST analysis. In our study, the assessment of the result was not conducted due to lacking of ground temperature information. However, in order to produce more reliable and meaningful result, future study should incorporate ground weather station information for thermal infrared data calibration. ■

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PROFILES

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