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Effects of Soil Moisture on Urban Heat Island Occurrences: Case of Selangor, Malaysia

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Abstract: The state of Selangor experienced the most rapid development and urbanisation growth in Malaysia. In Selangor, urban encroachment was significantly found in urbanised mukims such as Kajang, Cheras and Dengkil. This article investigates the application of remote sensing thermal infra red band for detecting land surface temperature and the effect of soil moisture content on urban heat island occurrences. A subset of Landsat TM acquired on April 17th, 1988 and February 11th, 1999 that covers Kajang-Cheras-Dengkil area (with less than 5 percent cloud cover on the image) were used in this study. The 1999 image was used in this study due to substantial changes in land use and land cover within the new administrative centre, i.e. Putrajaya. The image interpretation result showed the increase of urban cover within the period, from 69330 ha in 1988 to 91420 ha in 1999. Even though the urban cover increased within the period, the heat island phenomenon was less occurred in 1999. A further analysis showed the antecedent precipitation index prior to the scene acquisition for February 11th 1999 was comparatively very high and produced high value of soil moisture content. It is believed that the high moisture content due to antecedent precipitation in 1999 image has a removal effect on the urban heat island intensity.

Key words: Urban heat island . urban cover . soil wetness . antecedent precipitation index

INTRODUCTION

Increment of impervious areas cause warmer environment in urban areas than its surrounding rural areas. In tropical country like Malaysia, the temperature difference between urban and its surrounding sometime can reach up to 10 degrees Celcius [1, 2]. The replacement of the previous pervious surfaces by built up surfaces significantly reduces the cooling effect of the green vegetation through its natural evapotranspiration processes [3].

Urban sprawl is a phenomenon associated with the early stage of urbanisation and has a considerable impact on the resultant urban landscapes. As the result, more impervious surfaces were developed and modified the urban microclimate characteristics [4], thus increased the occurrences of the urban heat island (UHI) phenomenon [5]. Besides, UHI alters the thermal and hydrological components of the energy fluxes and their interaction with the land surface [6]. It also reduced the human comfortability by increasing the effective temperature above its acceptable value [7]. The higher UHI intensities and occurrences could significantly control the surface-atmosphere interaction, especially the water exchange within urban atmosphere [8].

Although the vegetation covers could reduced the UHI intensity [9], studies elsewhere has confirmed that soil moisture condition could also gave same result as the green natural surfaces. For example, due to prolonged wet spell the land surface temperature has abruptly reduced and inhibit the occurrence of UHI [10]. Previous studies carried out by urban hydrologists and meteorologists either from the western region [11-13] or from eastern region [1, 14, 15] have revealed a strong correlation between land surface temperature and the soil moisture condition. The change of land surface temperature is sensitive to the soil moisture characteristics of the

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land cover. In relation to this, regions of high soil wetness exhibit cooler surface temperature as compared to dry soil which is lack of soil moisture [16].

This article attempt to investigate the effects of soil moisture content on the occurrences of UHI in the state of Selangor, Malaysia which is known as the most urbanized state in the country [17]. The objective of this research is to quantify the removal effect of soil moisture on UHI due to prolonged wet spell in the state of Selangor by using the thermal infrared band (10.40-12.50 µm) of the 1988 and 1999 Landsat TM imageries.

STUDY AREA

The study area is located in the central part of the state of Selangor, the most urbanized state in Malaysia (Fig. 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 selected area covers the area of Kajang, Cheras and Dengkil districts in Selangor with the total area of 44927 ha.

The study area is located downstream of Langat river basin, whereby Sungai Langat forms major drainage flows towards the Straits of Malacca. The general topography varies considerably. The study area experienced hot and wet tropical climate with an average annual temperature is 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 [17]. The months from October to December are considered as wet season, whereas January, June and August are months of the driest period in the study area.

A subset of Landsat TM acquired on April 17, 1988 and February 11th, 1999 (path 127/row58) that covers an urbanised districts (Kajang-Cheras-Dengkil) used in this study. Both scenes have been selected due to several factors, i.e., the UHI study should take into consideration the antecedent soil moisture conditions (Table 1). In our study, the recent image (1999-Path 127/Row58) have a prolonged wet spell and produced a high soil moisture content relatively. The latest images of the study area (e.g. 2001 and 2003) are impossible to apply in this study as the significant effect of high cloud coverage.

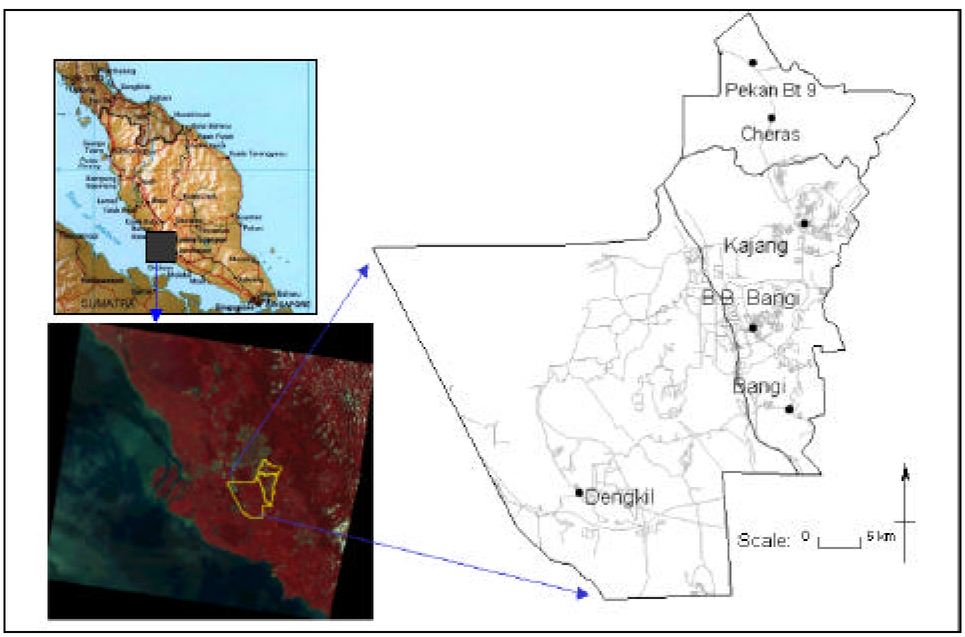

Fig. 1: A subset of Landsat TM covers three main urban districts, i.e. Dengkil, Kajang and Cheras

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

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 17th, 1988 (dry period)	12.0	0	7.2
February 11th, 1999 (wet period)	111.5	72	21.4

The February 11th, 1999 scene has also recorded drastic changes of land cover within the state of Selangor. Based on landuse maps (1988-1999), it was recorded a significant increment of urban land cover especially in Cheras, Kajang and Dengkil districts [18]. This was due to the development of newly township areas within Kajang-Bandar Baru Bangi corridor in the late 1980s.

APPROACH AND METHOD

Basically, there are three major methods involved in this study, i.e. estimation of urban land cover change (between 1988 and 1999), the land surface temperature (LST) retrieval and the estimation of soil moisture based on antecedent precipitation index (API). The urban land cover change is based on published land cover map of the state for 1988 and 1999. The hardcopies of the land cover maps were converted into digital form and the demarcation of urban land covers were made possible through on-screen digitizing method using GIS ArcView software.

LST retrieval was carried out through three phases, i.e. i) Conversion from Digital Number to Radiance, ii) Conversion from Radiance to Brightness Temperature and iii) Land Surface Temperature Retrieval:

Conversion from Digital Number(DN) to Radiance: All TM bands are stored in DN with their ranges between 0 to 255 [21]. The data were then converted to radiance using a linear equation as proposed by Sobrino [19]:

$$CV_R = G(CV_{DN}) + B$$

Where:

CV_R = The cell value as radiance
CV_{DN} = The cell value digital number
G = The gain (0.005632156 for TM6)
B = The offset (0.1238 for TM6)

Conversion from radiance to brightness temperature: By applying the inverse of the Planck function, thermal bands radiance values were then converted to brightness temperature value [20].

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

Where:
T = Degrees Kelvin
CV_R = The cell value as radiance
K_1 = Calibration constant 1 (607.76 for TM)
K_2 = Calibration constant 2 (1260.56 for TM)

Land surface temperature retrieval: Land surface temperature was derived based on the brightness temperature data. The conversion were carried out through the following equation [21]:

$$Y = 0.457X - 37.96, \quad R^2 = 0.90$$

Where,
Y = Land surface temperature (in degree Celcius)
X = Brightness temperature (in degree Celcius)

In order to compare the result of land surface temperature with soil moisture content, three local main meteorological stations namely, Subang International Airport station, Petaling Jaya (PJ) meteorological station and the University of Malaya (UM) meteorological station were used in this study. These selected meteorological stations were within 30 to 45 km radius from the study area. Due to high correlation between soil moisture and API, the 5-day antecedent precipitation value will be utilised to estimate soil moisture content. The calculation of API was made possible by using formula derived by Gregory & Walling [22], i.e.

$$API_d = (API_{d-1})\,K + P$$

Where,
API_d = Antecedent Precipitation Index (API) for d day
API_{d-1} = API for preceding day
K = API constant (K =< 1.0 and usually 0.85-0.98)
P = Rainfall in preceding 24 hours

Note: The value of K in this study has been determined as 0.9 as for tropical region [22, 23].

RESULT AND DISCUSSION

Figure 2 displays the urban land cover for the study area in 1988 and 1999. The result showed that the expansion of urban surfaces between the years were about 9320 ha or approximately 135 % increment. In

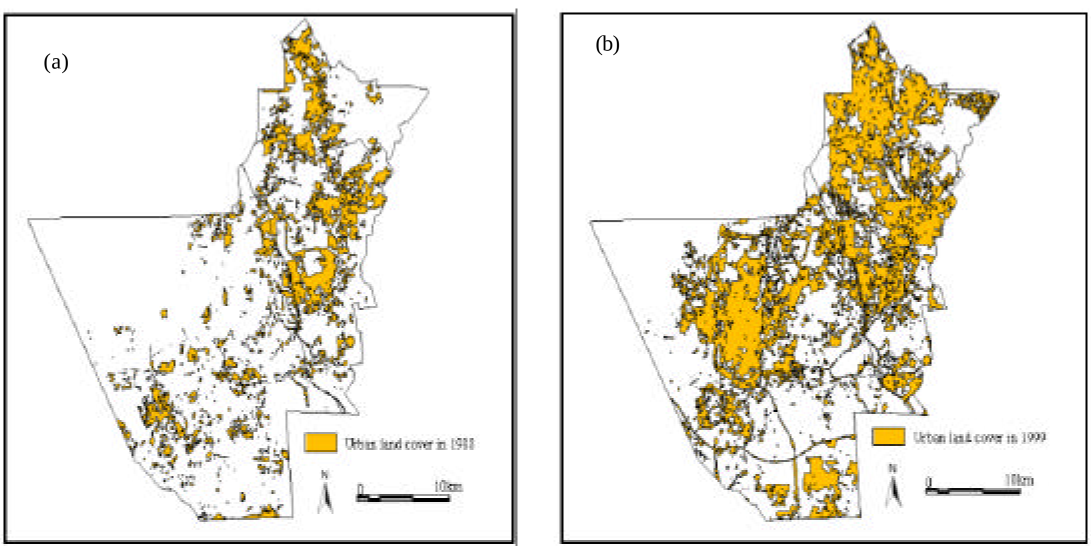

Fig. 2: Urban land cover for the study area (a) 1988 and (b) 1999

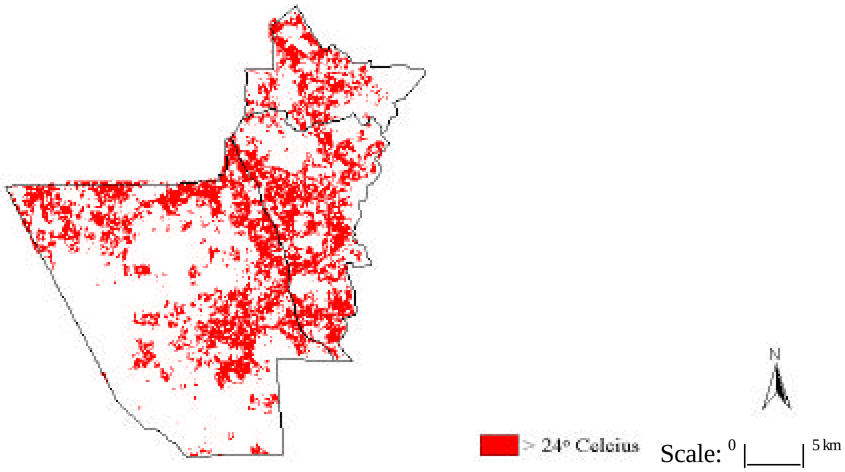

Fig. 3: The 1988 temperature image-red region indicates areas with temperature of greater than 24° C

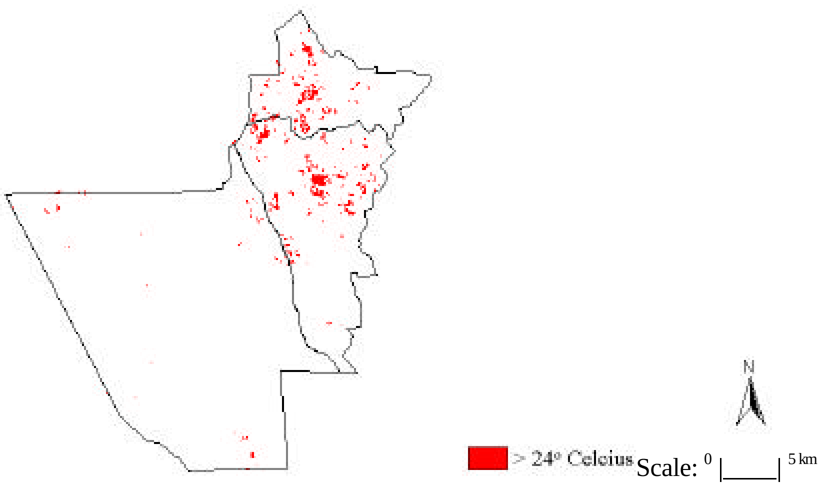

Fig. 4: The 1999 temperature image-red region indicates areas with temperature of greater than 24° C

1988, there was only 6831 ha of urban area exist in the urbanized districts. However in 1999, the area involved in urbanization was 16151 ha. Among the areas involved in the urban expansion were Cheras and Kajang townships, the newly developed area, i.e. Putrajaya in Dengkil and also patches of highly developed area in Bandar Baru Bangi (Bangi New Town).

Further study showed that, there were significant changes in the urban imperviousness in the study area. It was within the period approximately about 4234 ha area of increment in the urban imperviousness has been estimated in 1999 based on equation proposed by Asmala and Noorazuan [20]. The high increment of imperviousness could be related to the development of new highways and residential estates within newly developed areas. High percentage of vegetation land uses gave away to urban development could be another reason the increases of imperviousness in the study area.

In terms of Land Surface Temperature (LST), the result showed that most of the heated areas (greater than 24°C) were associated with the urban land cover (Fig. 3 and 4). The total amount of hot pixels was

Table 2: 5-day API values based on different period (wet and dry)

Scene (date)	5-day API at UM station (mm)	5-day API at PJ station (mm)	5-day API at Subang station (mm)	Average 5-day API (mm)
April 17th, 1988 (dry period)	10.8	0.0	6.5	5.7
February 11th, 1999 (wet period)	100.3	64.8	19.3	61.4

approximately 146,236 pixels in 1988 whereas only 9274 hot pixels were detected in 1999. Although there was a higher urban built up areas in 1999, the occurrences of the heat islands were less compared to 1988 scenario. A further investigation was carried out to determine the land surface moisture in order to validate the LST result. Based on the three meteorological stations, effort has been made to estimate the API value for each station (Table 2).

Based on 5-day API values, the wet period has nearly ten-fold of API value compared to the dry period (Table 2). The higher antecedent moisture content could be the major cause of heat surface reduction within the urban corridors. In wet period (1999), urban region with high soil moisture content has access to a source of moisture to exhibit cooler surface temperature than the dry soil in 1988. Thus, there was only 9274 hot pixels shown in wet period or approximately 5 percent from the total hot pixels in 1988.

CONCLUSION

The urban conurbation within urbanised mukims in Selangor has a remarkable heat island-related area in 1988, i.e. 146,236 pixels if compared to the latest urban cover in 1999. Even though a significant positive changes of urban cover between 1988 and 1999 in the study area, the occurrences of heat island were less recorded due to the effect of soil moisture content. In general, the urban land cover can be associated with buildings, road pavement, highways, green parks and also bare soil due to earthworks activities [21]. Therefore, in rainy season the permeable cover in urban area can reacted as retention area to retain rainwater and permit infiltration processes. In relation to this, the reduction of the heat island was substanstial, i.e. about 90 percent of the heat pixels disappeared due to the 'coldness effect' from the sky. The result shows that the remote sensing techniques is useful and effective method in analysing urban-land surface temperature relationships in the tropical region like Malaysia. This study has also proved that the thermal band of Landsat TM data can be utilised to demarcate heat island occurrences in urban land cover.

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