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Land Surface Temperature and Biophysical Factors in Urban Planning

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Abstract**—**Land surface temperature (LST) is an important parameter to study in urban climate. The understanding of the influence of biophysical factors could improve the establishment of modeling urban thermal landscape. It is well established that climate hold a great influence on the urban landscape. However, it has been recognize that climate has a low priority in urban planning process, due to the complex nature of its influence. This study will focus on the relatively cloud free Landsat Thematic Mapper image of the study area, acquired on the 2nd March 2006. Correlation analyses were conducted to identify the relationship of LST to the biophysical factors; vegetation indices, impervious surface, and albedo to investigate the variation of LST. We suggest that the results can be considered by the stackholders during decision-making process to create a cooler and comfortable environment in the urban landscape for city dwellers.

Keywords**—**Biophysical factors, land surface temperature, urban planning.

I. Introduction

LAND surface temperature is an important indicators of the energy balance in an urban climate. It modulates the air temperature which is located at the lowest layers of the atmosphere [1]. As the change of LST can affect the local weather and climate [2], it could also affect the net radiation, heat and water balance due to the change of biophysical factors such as vegetation, impervious surface and albedo. Urbanization changed the natural landscape of the earth surface from vegetated areas to impervious surfaces. By covering the earth surfaces with concretes and asphalts, for example buildings and paved roads, the areas have a higher solar radiation absorption and greater thermal conductivity and capacity for releasing heat stored during the day and night [3]. This process has led to a modified climate that is warmer than the surrounding areas and is referred to as an urban heat island [1]. An advantage of remote sensing is due to its availability of multitemporal and providing uniform planetary coverage which is proving to be a powerful tool in many applications such as geomorphology [4] and marine fisheries [5]. The use of remote sensing started to emerged in environmental policy development, such as forest monitoring [6] but it has started to emerged as a tool to assess the climate impact on the planning policy [7].

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Planners have focused on smart growth and sustainability but unfortunately due to a lack of climate knowledge, planners rarely see these growths as directly connected to climate change [8], although there is awareness from the local authority in the importance of local climate issues. This may be due to the difficulty of translating climatic indicators to urban planning processes.

However, several countries have adopted climate impact to their planning policy. Germany has provide a policy guidelines on climate to maintain sustainable development in the inner cities [9]. To date, Hong Kong has started to proposed a framework on the climatic map to the planning policy. The major challenge is how to integrate indicators of many types across various sectors to give an overall evaluation of sus tainability [10]. Several studies has mentioned the importance of urban weather environment in urban planning [11], but only a few has further discussed on how to integrate them. A work done by [12] is a good example on integrating the local climate regulation to be integrated with spatial planning by using evapotranspiration and land surface emissivity as indicator. Another integration of climate and urban planning by [13] has highlighted specific areas; activities centres and growth areas where planning intervention would be useful to improve local climates. A study on ventilation and building density map are also produced [14]. The information of spatial pattern and temporal dynamics of land cover and land use is critical to address existing problem relating to urban sustainability and planning policy. This study will be concerned with the biophysical indicators; namely impervious surface percentage, Normalized Difference Vegetation Index (NDVI) and albedo. Impervious surfaces such as paved area, tar roads and parking lots have a higher thermal conductivity compare to vegetated areas. Detection of impervious surface is crucial for monitoring and investigating the urban environment and how it is connected and related to the urban heat island phenomenon. NDVI is the vegetation index to show the concentration of vegetated areas. Albedo, is measured as the reflection coefficient i.e the incident radiation that is reflected from the surface. Albedo is one of the major indicators in the energy balance of the earth surface. Albedo measures the total reflectance of the surface and provides information about the soil structure. One limitation of albedo is that different wavelengths of solar radiation are reflected differently for the same surface, resulting in different values of reflectance due to differences in physical or chemical characteristics of the soil surface [15].

The objective of this study is to quantify the LST with the biophysical factors by using quantitative pixel-based remote sensing. In the context of this study, the anthropogenic parameter that was used is NDVI representing the vegetation index, impervious surface and albedo. The relation of these factors and LST to the land use is also evaluated.

II. Study area

A rapid development and urbanization growth in the Klang Valley has caused serious environmental problems such as urban heat island, traffic congestion, air pollution from industrial and vehicular emissions and flash floods in area. Kuala Lumpur the city center of the Klang Valley is located in 3°8′00″N 101°42′00″E. Fig. 1 shows the boundaries of districts in the Klang Valley area that is considered in this research.

Klang Valley has an expanding urban population due to the increasing number of migrants searching for better working opportunities. According to the Statistical Department (2010), it had an estimated population of 1.722 million in 2010. The size of the city will increase as it tries to accommodate the increasing population.

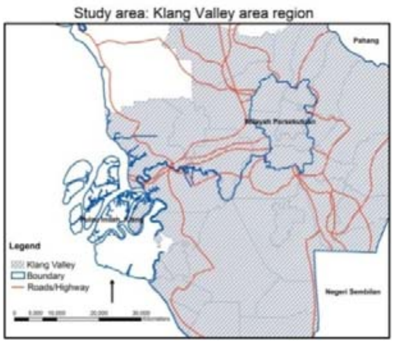

Fig. 1 Klang Valley area

III. Methodology

A. Land Surface Temperature Algorithm

Landsat TM image of 3rd March 2006 taken on 3:19pm was preprocessed by the USGS Center for Earth Resources Observation and Science (EROS) to correct the radiometric and geometric corrections. The rectified image by USGS to Universal Transverse Mercator (UTM) coordinate then was converted to Rectified Skewed Orthomorphic (RSO) coordinate system.

Atmospheric correction need to be applied to the image to remove the effect of the atmosphere. To apply this correction, the algorithm of Dark Object Subtraction by using COST method was applied using the Spatial Models in the Erdas Imagine software.

The next steps that need to be performed is to compute the land surface temperature; (1) by converting the spectral radiance to at-sensor brightness temperature, (2) by computing the transmittance equation, (3) correcting the spectral emissivity and (5) land surface temperature calculation by using the method developed by Qin et al (2001).

1) Converting the spectral radiance to at-sensor brightness temperature

The digital numbers were transformed into absolute radiance [18]

$$L(\lambda) = Gain\lambda * DN\lambda + Bias\lambda \tag{1}$$

where Lλ is the spectral radiance, $Lmin$ and $Lmax$ are spectral radiances for each band at digital numbers 0 and 255 respectively. In the case of the new sensors in Landsat ETM+, different values need to be referred;

Low Gain: $Lmin$ = 0.0, $Lmax$ = 17.04

High Gain: $Lmin$ = 3.2, $Lmax$ = 12.65

The spectral radiances (Lλ) were converted into the temperature brightness (T_b)

$$T_b = K2/(\ln(\frac{K1*0.95}{L\lambda} + 1)) \tag{2}$$

Where $K1$ and $K2$ is a constant at 666.09 and 1287.71 for Landsat ETM+, while 607.09 and 1260.56 for Landsat TM respectively. 0.95 indicated as the emissivity of the vegetated surfaces.

2) Computing the transmittance equation

As the water vapour cannot be obtained from local meteorological data, the estimation of water vapor can be gathered from the calculation can be used as;

$$w^i = 0.0981 \times \left\{10 \times 0.6108 \times \exp\left[\frac{17.27\times(\mathrm{T_0}-273.15)}{237.3+(\mathrm{T_0}-273.15)}\right] \times \mathrm{RH}\right\} + 0.1697 \tag{3}$$

According to [19], the total atmospheric water vapour will be derived as;

$$\tau 6 = 1.031412 - 0.11536 w^i \tag{4}$$

3) Correcting emissivity

Before carrying out an emissivity calculation, the percentage of vegetation within a pixel, need to be calculated [20]. According to [21], the NDVImin is 0.15 and the NDVImax is 0.9.

$$\mathrm{pv} = (\mathrm{NDVI} - \mathrm{NDVImin})/(\mathrm{NDVImax} - \mathrm{NDVImin})^2 \tag{5}$$

The emissivity can be calculated by referring to the equation produced by [21];

$$\varepsilon^6 = 0.004pv + 0.986 \tag{6}$$

4) Land Surface Temperature retrieval

The brightness temperature needs to be corrected based on the radiance transfer equation, which states that the sensor-observed radiance is impacted by the atmosphere and the emitted ground [22].

$$\mathrm{T_s} = [\mathrm{a}^6 + (\mathrm{b}^6 (1 - \mathrm{C}^6 - \mathrm{D}^6) + \mathrm{C}^6 + \mathrm{D}^6)\mathrm{T_6} - \mathrm{D}^6\mathrm{T_a}]/\mathrm{C}^6 \tag{7}$$

$$\mathrm{C}^6 = \tau^6\varepsilon^6 \tag{8}$$

$$\mathrm{D}^6 = (1 - \tau^6)[1 + \tau^6(1 - \varepsilon^6)] \tag{9}$$

where T_6 is the at-sensor brightness temperature derived from the Plank function. According to [22], the coefficient of parameter T_6 in according to the temperature ranges which is between 20° - 50°, $a6$ = -67.9542, $b6$ = +0.45987

B. Preparation of Biophysical Factors Image

The images need to be prepared for this task. Therefore, the algorithms on retrieving the biophysical factors need to be refined. Areas of associated haze and scattered clouds that mostly located at the coastal and upper areas are not included in the analysis.

1) NDVI

The algorithm of NDVI derivation can be used as below;

$$NDVI = (\rho^2 - \rho^1)/(\rho^2 + \rho^1) \tag{10}$$

Where, ρ^2 is reflectance of the near infrared band (band 4) and ρ^1 is the reflectance of the red band of the image (band 3).

2) Impervious Surface

Impervious surface was generated by using the method developed by Bauer[23]. Instead of using Landsat TM (30-meter per pixel), this method needs another high resolution image, IKONOS (4-meter per pixel) to be matched with. Polygons were drawn in the same sizes (AOI sample) to represent the impervious surface percentages and the size of the polygon must match with a pixel of Landsat. Area of the impervious surface are devided with the total of polygon area and multiplied by hundred. It was then compared to NDVI values and the regression of these parameters can be used as the percentage of impervious surface. An accuracy assessment was applied before adopting the algorithm to the image.

3) Albedo

It was formulated from the albedo retrieval using Landsat TM [23].

$$\alpha_{short} = 0.356_{\alpha 1} + 0.130_{\alpha 3} + 0.374_{\alpha 4} + 0.085_{\alpha 5} + 0.072_{\alpha 7} - 0.0018 \tag{11}$$

Where, α is the shortwave for each band.

A better way to validate the albedo values was to compare the retrieved albedo by using Landsat image to ground measurement. The other way is to assume that the surface is homogenous. This is however difficult to undertake due to the heterogeneity of the surface area. The ground measurements need to be carried out for this purpose but with a same sun and viewing geometry and atmospheric conditions [24]. In this case, a ground measurement and the Landsat retrieval need to be simultaneously taken.

In order to correlate these biophysical indicators with LST, those areas with availability of water features, clouds and haze are removed to maintain the accurateness of the result.

IV. RESULTS AND DISCUSSION

1) LST Retrieval for 2nd March 2006

Fig. 2 shows the distribution of land surface temperature in the study area. The range of temperature was 26 to 47 °C that shows obvious temperature differences with the urban temperature being higher than that of suburban and rural areas. The upper region is surrounded with mountainous areas and that to the right of the image is also a forested area that helps in lowering the temperature. The region of the darkest red is the higher temperature while the darkest green is the lowest temperature.

In general, it was found that the high temperatures corresponded with the pattern of highways distribution at the centre of the districts. The high temperature region can be seen stretching from Ampang to Sg. Buloh.

It was extraordinary to find some hot spot (higher temperature) and cool spot (lower temperature) areas in Kuala Lumpur itself. In this case, the cool spots of were associated with recreational areas (30.4°C) while the higher temperature hot spots were associated with industrial and residential areas (41°C). This shows an unbalance development between these areas whereby the planners and the decision makers could contribute to mitigating this problem.

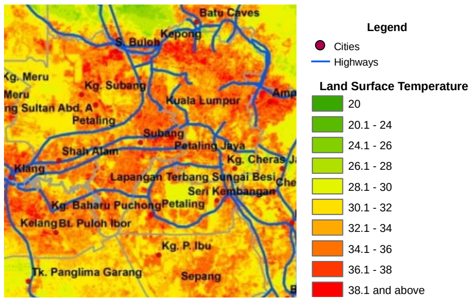

Fig. 2 Land Surface Temperature in the Klang Valley area

2) Impervious Surface (Percentage)

Impervious surface is the reflection of the build-up areas. The impervious surface model are described as percentages, 0 to 100%, 0 indicate that it would be a dense vegetation or forest area and while the 100% is the concrete jungle with the impervious surface. In this study area, it was found that the percentage of ISA in the study area can be represented as (12) below;

$$ISA\ (\%) = -63.236(NDVI^2) - 50.958(NDVI) + 105.35 \tag{12}$$

Accuracy assessment was performed between the inversed calibration and the accuracy of the algorithm is acceptable (R^2 = .856) to be applied in the image.

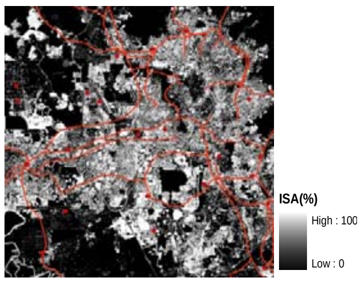

Fig. 3 Impervious Surface Percentage

The percentage of the impervious surface is shown in Fig. 3. The lightest area and the darkest are represent a high and low percentage of impervious surface, respectively. For all district across the area, the impervious surface decreases from the urban core with has an average value of about 71%, while the average value in the rural areas, which is mostly cropland has about 5% of impervious surface.

It can be seen that there are areas of very low value is located in the urban areas, represented as a forest/recreational park with very low impervious surface.

3) NDVI Extraction

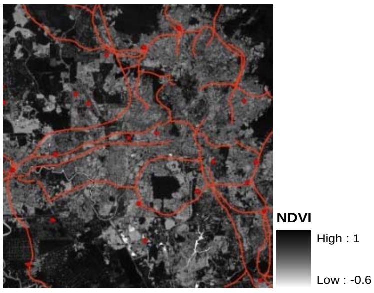

Fig. 4 NDVI extraction

Fig. 4 shows the NDVI extraction in the study area. The darkest show the lowest value of NDVI and the lightest is the highest value. The range of NDVI fraction is between -1 to 1. The ranges from 0.4 - 0.8 are the built-up areas while the vegetation and forest ranges from 0.90 - 0.99. The result show that NDVI value gradually increases in the suburban and rural areas except in the urban park areas.

4) Albedo Extraction

Albedo ranges from 0 to 1. The highest fraction (1.0) is seldom found in the tropical areas since this is usually associated with snow. The water bodies have a small albedo (0.03) indicating an efficient radiance absorption. Albedo image are presented as Fig. 5 which show the range of albedo in the urban is between 0.11 - 0.17 and that in the city-core the albedo was higher than the surrounding areas. It refers to dark-colored and rough soil surfaces, which also indicated that it contain a low albedo value, compared to the paved and concrete areas which contain higher albedo, in ranged between 0.2 - 0.3, which represent smooth, light-colored soil surfaces. The results of the albedo values in the forested areas ranges from 0.11 – 0.14 while the vegetation areas ranges 0.14 – 0.19.

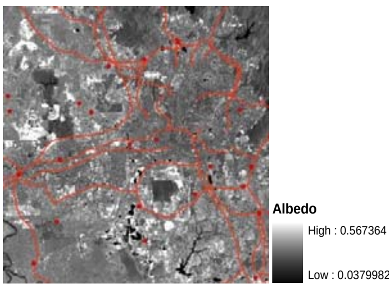

Fig. 5 Albedo extraction

Forest has a lower albedo compared to vegetation because the radiation can penetrate deeply and only reradiate in a small portion as most of it are trapped in the canopy. Vegetation such as grass, shrub and crop has a higher albedo ranges in comparison to forest. Therefore, these differences of albedo range are due to the type and structure of the surface features.

5) Correlation of LST and biophysical indicators

A sample of 6000 generated points was used to investigate the relationship of LST and impervious surface, NDVI and albedo. In this analysis, the areas with the haze, clouds and waterbodies are excluded. This analysis indicated a linear positively moderate correlation (R2 = .526) was found between the LST and impervious surface. The scatterplot of NDVI and LST resulted in an oval shape, negatively moderate correlation of pixels (R2 = .516). Lower LST found in the areas with a high NDVI, explaining 52% of the variation. In addition, there negatively small correlation that was found between LST and albedo (R^2 = .022) indicating that LST is not sensitive to albedo variations in the study area. Instead of the understanding of high albedo would provide low temperature and vice versa, it is also relate to the surface material of the ground. This is due to the other factor of albedo such as its surface material, for example the newly construction areas are having high albedo but high temperature. This shows that the use of remote sensing can help to evaluate the environmental influences.

TABLE I
CORRELATION OF LST AND BIOPHYSICAL DESCRIPTORS

	Intercept	Slope	R^2
ISA	.004	34.529	.526
NDVI	-5.783	39.439	.516
Albedo	-1.653	36.870	.020

V. Application of Biophysical Factors to Urban Planning

Since this paper proposed that climatic factors need to be considered in policy planning the digital data of land use that was produced by City Hall Kuala Lumpur (CHKL) was used to correlate LST to the biophysical factors and its policy and planning implications.

A. Identification of Policy

National Urbanization Policy (NUP) was formulated to create a visionary city with a peaceful community and living environment through sustainable urban development. For this study, NUP26 was reviewed and the target is ‘a sustainable and environmentally friendly development shall form the basis of environmental conservation and improve the urban livability. Therefore the need of incorporating the urban climate need to the urban planning policy becomes vital. Measure (iii) has emphasized that it was to encourage development that reduces the impact of urban heat islands. For this study, the climatic element (LST) and climatic factors (biophysical) were introduced as the indicator for urban heat island mitigation. The landuse map of 2006 that was prepared by the authority was overlaid to these biophysical indicators. In order to maintain the accurateness, the polygon was converted to point and intersect to the points of biophysical indicators.

Table II show the mean values of LST and biophysical descriptors with landuse types.

TABLE II
MEAN VALUES OF LST AND BIOPHYSICAL DESCRIPTORS OVERLAID TO LANDUSE

*LU	Temperature	Albedo	ISA	NDVI
Inst	33.6	0.146	38.7	0.623
road	35	0.147	56.7	0.520
nodev	36	0.138	60.3	0.489
recr	32.6	0.148	35.0	0.656
resid	34.7	0.146	51.6	0.550
pave	35.6	0.139	55.5	0.521
comme	35.4	0.142	65.1	0.471
indus	36.1	0.151	69.2	0.443

Abbreviations: LU = land use, inst = institutional area, road = roads area, no dev =no development, recr = recreational, resid = residential areas, pave = pavement, comme = commercial areas, indus = industrial areas.

It shows that industrial areas contained the highest mean temperature, with the highest albedo and ISA but inversed to NDVI. The high albedo could be related to the reflective capacity proportional to the diurnal solar radiative variation [26]. However, the no development areas and pavement areas has almost the same temperature, with almost the same low albedo and among the other land use types. It was concerned of the mean NDVI value is low in no development areas and highly ISA, and this predicted that it is having a low vegetation. This assumed of these land uses run the same activities as car park areas, due to limited parking spaces in the Kuala Lumpur areas. Commercial areas, residential areas and roads are also having almost the same temperatures and albedo, but higher impervious surface in commercial areas. In contrast, the recretional areas show relatively low mean temperature and albedo values. This may be attributed to the high absorption capacity of incoming radiation due to the development of the green nature of vegetation, whereby the absorption of canopy layer has trap the radiation. It was monitored that the NDVI value and ISA of institutional areas and recreational areas are almost the same mean values, whereby this reflect to the institutional areas that protect the vegetation landscape. It was also establish that a high variation of the land use types is because the different land use/cover types have quite significantly different NDVI values. A surprised finding was found in the Titiwangsa Lake Garden whereby it was not able to reduce the high temperature from its surrounding areas. From the close examination of high temperature of Titiwangsa Lake Garden, forests and parks are examined in term of its coverage areas and NDVI values, and were found that a moderate regression was found between the variables (coverage areas and NDVI values) and LST. It was also found that Titiwangsa Lake Garden has low NDVI value (mean 0.485), and therefore this study shown that this garden needs trees with high NDVI values to help in mitigating urban heat island.

In order to confirm on the correlation of forests and parks with the NDVI area, each of them (forests and parks) are delineated and the area and NDVI values are calculated. A linear pattern show that the NDVI values is having moderate correlation with area; NDVI = 0.0132area + 0.4296 ($R^2 = 0.4$). This result show that the bigger coverage of forest and parks are indicated to have a higher NDVI values. A stern action need to be overlooked at the land uses such as no development and industrial areas due to the high mean temperature.

Even though the relative albedo of the industrial sites having higher values among the other land uses, it is demonstrated that it is a needs to take action on the roof material.

The findings of this study should be referred to the urban planning for roof design. It was proposed that using high albedo material reduces the amount if solar radiation absorbed through building envelopes and urban structure and keeps their surfaces cooler [27], especially to the specific land uses, such as commercial and industrial. This can be done for those buildings that had reflected a low albedo. Most of the paved areas have using black asphalt that estimated it has .04 at the time of paving and increases to about .12 as it ages over time [28] that allow absorb heat to the surface and this activity would contributes to the UHI effect.

Analysis of albedo integrated to a land use plan would help to pursue sustainability and the reduction of heat. Overlaid of impervious surface to the spatial planning plan can signal how much heat would be produced. In addition, influence of NDVI would help to mitigate on the percentage of areas would be appropriately used to reduce heat.

VI. Conclusion

Satellite remote sensing was beneficial in estimation of surface temperature and biophysical descriptors to the land use types. Study in climatic approach integrated to urban planning would be valuable for the planning guidelines whereby new contribution of the climatic indicators can be applied. Future study will goes to the biophysical and climatic variables and the policy planning proposed study as would be important in the study area. It is learnt that the type of trees with high NDVI values for mitigating urban heat island will also studied.

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