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Exploring the role of green and blue infrastructure in reducing temperature in Iskandar Malaysia using remote sensing approach

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Abstract. Development of cities has led to various environmental problems as a consequence of non sustainable town planning. One of the strategies to make cities a livable place and to achieve low levels of CO₂ emissions (low carbon cities or LCC) is the integration of the blue and green infrastructure into the development and planning of new urban areas. Iskandar Malaysia (IM) located in the southern part of Malaysia is a special economic zone that has major urban centres. The planning of these urban centres will incorporate LCC strategies to achieve a sustainable development. The role of green (plants) and blue bodies (lakes and rivers) in moderating temperature in IM have been investigated in the current study. A remotely sensed satellite imagery was used to calculate the vegetation density and land surface temperature (LST). The effect of lakes in cooling the surrounding temperature was also investigated. Results show that increasing vegetation density by 1% can decrease the LST by 0.09°C. As for the water bodies we found as the distance increased from the lake side the temperature also increased about 1.7°C and the reduction in air humidity is 9% as the distance increased to 100 meter away from the lake.

1. Introduction

The impact of urbanization on local weather and micro climate is well documented [1,2]. One of the notorious effect of urbanization is the urban heat island (UHI), which can be defined as an increase in the mean air and land surface temperature of built up areas compared to the nearby rural areas[3]. Increase in temperature is mainly attributed to the deforestation or replacement of green spaces with concreted and impervious surfaces (i.e. buildings, roads and other concrete surfaces). Additionally, industrial and transportation activities in the urban environment emit green house gases that trap longwave solar radiation and increase the temperature. In order to reduce the effect of UHI and to increase the thermal comfort of people in the cities, various efforts have been undertaken. One of the strategies to achieve a sustainable urban development is to integrate the “low carbon city (LCC)” framework in the process of urban development[4]. LCC aims to achieve a balance between low-carbon economic development and urban construction, population, resources, ecology and the environment[5]. LCC can be part of solutions to the climate change phenomena that occurs in many parts of the world.

Iskandar Malaysia (IM) located in the southern part of Malaysia is a special economic zone that has five flagship zones with each zones has major urban centres. The planning of these urban centres will incorporate LCC strategies to achieve a sustainable development. There are many actions proposed to achieve LCC in Iskandar Malaysia and one of them is the integration of green and blue infrastructure [4]. In this paper, we have explored the role of green and blue infrastructure in reducing temperature in IM. Among others green infrastructure includes agricultural land, grasslands, orchards, community gardens, coastal habitats, institutional grounds, orchards, outdoor sports facilities, parks and public gardens, private domestic gardens, street trees, while, blue infrastructure refers to among others water bodies and courses, wetlands, fountains, etc. [6].

Traditionally, urban heat island has been analysed using temperature data acquired at meteorological stations. Since the 1960s, remote sensing technology has been utilized extensively to

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calculate the land surface temperature and provide primary information for the UHI analysis. Remote sensing could provide temperature information over a large spatial extent and on a continuous manner (i.e. every 26 days) [10]. Land surface temperature (LST) retrieved from Landsat thermal infrared bands have been proved to have the most suitable spatial resolution for urban thermal environment studies [7]. Thus, the objective of this study is to use a Landsat Thematic Mapper satellite image to derive information about the land surface temperature and vegetation and to analyse the effect of vegetation and water bodies on moderating temperature in IM.

2. Materials and methods

2.1 Study area

Iskandar Malaysia (IM) is located in the south of Peninsular Malaysia and covers an area of ~2216km² (figure 1). There are five Flagship zones in IM, including Johor Bahru City Centre, Nusajaya, Senai-Skudai, Western Gate Development, and Eastern Gate Development, covering both the Johor Bahru and Kulaijaya districts and several sub-districts of Pontian [5]. The region has a tropical climate with temperature varies from 21°C to 32°C and the annual rainfall is between 2000 and 2500mm. This region is one of the latest economic passages in Malaysia which is predicted to turn into a metropolis by 2025. It is estimated that the population would increase from 1.4 million in 2008 to 3 million in 2025. The rapid economic development together with population increase are expected to cause lots of land use and land cover changes. If sustainable planning measures such as LCC are not implemented this region might face various environmental problems including increased temperature, air pollution and subsequently climate change.

In this study, we focus on vegetation and temperature analysis in the entire IM. Moreover, we selected four locations (Taman Awam Layang-Layang, Mutiara Rini Urban forest and Universiti Teknologi Malaysia campus) as shown in figure 1 to conduct a pilot study looking at the effect of lakes (water bodies) on temperature.

2.2 Data

The primary data used in this study is the Landsat Thematic Mapper (TM) satellite image. The data was used to estimate the density of vegetation and to calculate the land surface temperature (LST) in IM. Only one image dated 4 May 2005 was selected in this study due to the difficulty in getting a cloud free scene over the study area. The image was downloaded from the USGS Earth Explorer website (<http://earthexplorer.usgs.gov>). TM image has 7 spectral bands, but we utilised 2 bands (red, and near infra red) to calculate vegetation density and one band (thermal infra red) to calculate LST. Due to their different spatial resolutions, we produced vegetation density at 30 meter and LST at 120 meter spatial resolutions.

We also collected temperature data (micro-scale study) at and few meters away from water bodies at several urban parks as shown in figure 1 to find out the effect of water bodies on air temperature. We utilized Davis Weather Station Vantage Pro2 model to record the temperature and relative humidity at 2 meter above the land surface at several points near and away from the lakes. Points were pinned around lake and the distance between each point was constantly set to 20 meters.

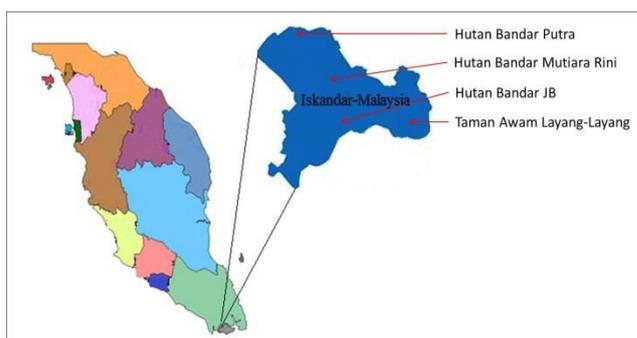


Figure 1. Location of Iskandar Malaysia (IM) in Peninsular Malaysia and several parks within IM.

2.3 Methodology

The Thematic Mapper (TM) image was first radiometrically corrected and atmospheric correction was performed based on the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) module, then the image was geometrically corrected by registering it on a local landuse map, using ENVI 4.8 software. Subsequently, image was processed to derive vegetation density. We calculated vegetation density using the Normalized Difference Vegetation Index (NDVI) as:

$$NDVI = \frac{(Infrared - Red)}{(Infrared + Red)} \quad (1)$$

The value of NDVI ranges between -1 (water bodies, clouds and shadow) and +1 (vegetation). We used the same image to calculate LST. The at-satellite brightness temperature was used to calculate LST. We used the following equation [8] to get LST:

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

Where T_B is effective at-satellite brightness temperature in Kelvin, K_1 and K_2 are calibration constants with values of 607.76 and 1260.56 respectively for Landsat TM, L_λ = Spectral radiance in $W\ m^{-2}\ sr^{-1}\ nm^{-1}$. The emissivity-corrected LST (T_s) were estimated as follows [9] (Equation 3):

$$T_s = \frac{T_B}{1 + \left(\lambda \times \frac{T_B}{\rho}\right) \ln \varepsilon} \quad (3)$$

Where T_s is the LST, λ is wavelength of emitted radiance, ρ is $h \times c / \sigma$ (1.438×10^{-2} m K), σ is Boltzmann constant (1.38×10^{-23} J K⁻¹), h is Planck's constant (6.626×10^{-34} Js), c is velocity of light (2.998×10^8 m sec⁻¹), ε is the surface emissivity. We used equation 4 [10] to retrieve land surface emissivity (ε)

$$\varepsilon = \varepsilon_v F_v + \varepsilon_u (1 - F_v) + d \varepsilon \quad (4)$$

Where ε_v and ε_u are the emissivity of vegetation (0.99) and urban surface (0.92) respectively, and F_v is the vegetation proportion derived as follows [11]:

$$F_v = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right]^2 \quad 0.5 < NDVI > 0.2 \quad (5)$$

$d \varepsilon$ is a term to take into account of of the geometrical distribution of the internal reflections and the natural surface and it is calculated as:

$$d \varepsilon = (1 - \varepsilon_u)(1 - f_v) f \varepsilon \quad (6)$$

Where f is the shape factor = 0.55 according to [12].

3. Results and Discussion

The LST and NDVI calculated for IM are shown in figure 2. The figures depict a clear spatial variation in terms of temperature and vegetation density. LST in IM is found to vary from 19°C to 35°C. Highest temperature is found in major cities or town areas like Johor Bahru, Pasir Gudang, Senai, Masai, etc. (south and south east of IM), while the lowest temperature is recorded in the forested area (i.e Gunung Pulai) in the northwest of IM. Similar trend is also portrayed in the NDVI map of IM where high NDVI values (0.59-0.79) is found in the vegetated areas including forests. Meanwhile, cities/towns and settlement areas have low vegetation density with NDVI values ranging between 0.22 to 0.42.

In order to investigate the link between vegetation density and temperature, we selected 100 collocated NDVI and LST points/pixels distributed throughout IM and correlated them. The result is shown in figure 3. A strong negative correlation is obtained between NDVI and LST ($R^2 = 0.75$ - figure 3). This study reveals that increasing vegetation density (NDVI) by 1% can decrease the LST by 0.09°C. Study in the Manchester city [13] indicates that increasing green cover by 10% in the built up areas could decrease maximum surface temperatures by 2.4°C to 2.5°C. Similar strategies can be

adopted in IM by increasing the tree cover in “hot spots” such as town and city centres, transport hubs, tourist destinations, etc. This can be done via creating new green spaces, increasing street tree planting, and designing of green roofs and walls. According to [14] a 10% increase in vegetation cover (as a general rule) reduces the temperature by about 3°C, hence, cooling the ambient temperatures.

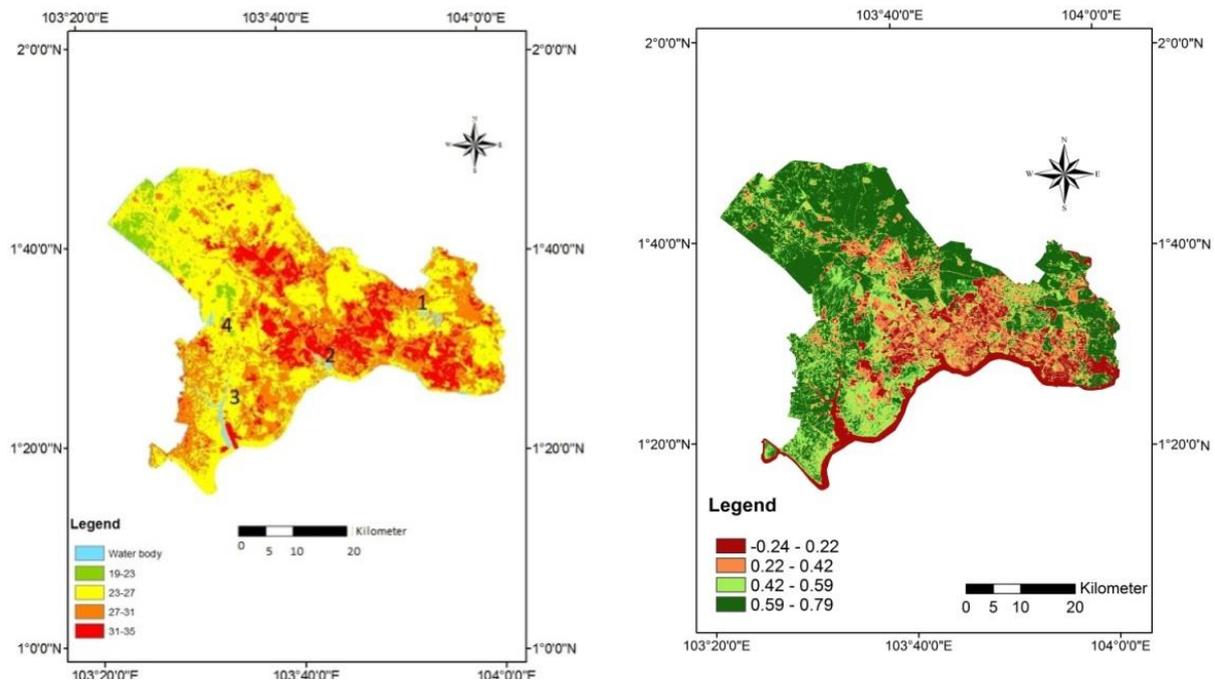


Figure 2. Land surface temperature (left) and Normalized Difference Vegetation Index (right) calculated for Iskandar Malaysia. Numbers shown in figure 2 (left) refers to (1) Sultan Iskandar dam, 2) Skudai river 3) Sungai pulai river 4) Pontian Kolam air Singapura.

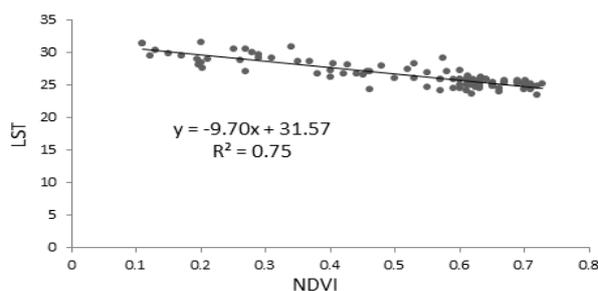


Figure 3. The relationship between Normalised Difference Vegetation Index (NDVI) and land surface temperature (LST) in Iskandar Malaysia. A total of 100 collocated NDVI and LST points were used to plot the graph.

In order to study the effect of water bodies on moderating temperature in IM, first we conducted a micro-scale study at several water bodies (i.e. lakes) in IM. The results of the study conducted at Taman Layang-Layang, Masai, Pasir Gudang district is shown in figure 4. We found that as the distance increased from the lake side the temperature also increased in a linear fashion ($R^2 = 0.62$). The increase in air temperature is about 1.7°C and the reduction in air humidity is 9% respectively as the distance increased to 100 meter away from the lake (figure 4).

We extended the analysis over a large area using LST derived from the satellite image. We selected 2 rivers (Kampung Bakar batu river Sungai pulai river) and 2 lakes (Sultan Iskandar dam and Pontian kechil Kolam Air Singapura) as shown in figure 2. We examined the temperature changes over a few hundreds meters (each TM pixel is 120m) depending on whether the pixel examined is covered by vegetation or not. The analysis will be terminated if we find the pixel has high vegetation density (i.e. NDVI value). According to the results (data not shown) as one moves away from the

water bodies, the temperature was found to decrease between 0.61 to 1.79°C for a distance of up to 480m.

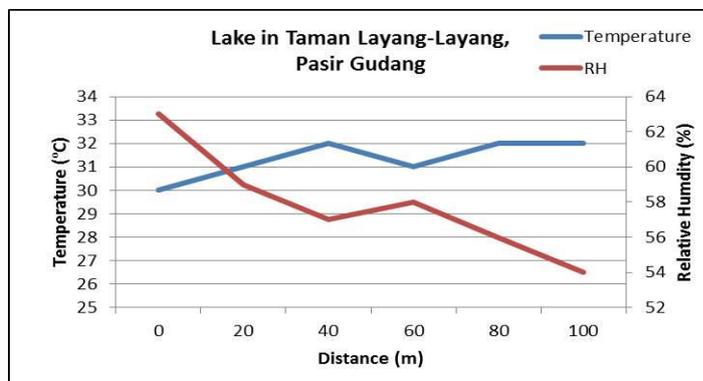


Figure 4. Relationship between distance from water bodies (lake) and temperature and relative humidity in Taman Layang Layang, Pasir Gudang.

4. Conclusion

From the results obtained in this study we conclude that the increase in vegetation density and the presence of water bodies (lakes, dams and rivers) can decrease the temperature in the study area probably due to the increase in the rate of transpiration and/or evapotranspiration. This results show that more green spaces and locations such as along the river and waterways should be developed as new urban parks because vegetation and water bodies can greatly reduce the air temperature and increase relative humidity and thereby could provide thermal comfort to people. This also reduces the need for air conditioning, so helps to mitigate climate change.

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