The Evaluation of Urban Heat Island Effect and New Town Development Based on Remote Sensing

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Abstract. Hong Kong’s urbanization rate is close to 100%, which is one of the highest urbanization rates in the world. The rapid development of cities has produced a large number of urban problems. Urban heat island effect is one of the typical features of the urban climate and the phenomenon, which can extreme weather and air pollution, which threatens human health directly and seriously. This paper uses remote sensing technology to evaluate the urban heat island effect and new town development situation, including land surface temperature retrieval and BUAI (Built up Area Index) analysis. Eventually some practical suggestions are put forward for making a better living environment.

1. Backgrounds
Urban heat island effect is caused by land modification, artificial heat source and high density urban building and so on, which is one of the typical features of the urban climate and the phenomenon that the temperature of the urban space is higher than that of the suburb. It has the possibilities to lead to extreme weather and air pollution, which threatens human health directly and seriously.

Hong Kong’s urbanization and industrialization begins at 1970s. The developing industry and oversea investment stimulated the urban sprawl, then it went through industry incline, economic transformation and optimization. Urban heat island effect is accelerated by industrialization and urbanization. The high density of urban structure and compact city development mode results in the Hong Kong’s city sprawl and changes of urban areas. In order to create a better living and working environment, several policies related to Hong Kong’s new town development have been released, such as traffic oriented, public housing development mode and more attention on mitigating environmental impact.
2. Methodology

![Image](image.png)

**Figure 1. Original Geospatial Data in 2001 and 2009**

2.1. **Urban Heat Island Monitor Method ----Land Surface Temperature Retrieval**

Remote sensing technology is one of the most useful methods to monitor the process of the geographic environment, in which Land Surface Temperature (LST) has become the most important index in weighing urban heat island effect and analysis on geographic environment.

There are many methodologies for LST: atmospheric correction, mono-window algorithm and the single channel method. In this program, we adopt atmospheric correction method to retrieve land surface temperature. Temperature retrieval is through atmospheric correction eliminating the influence of surface radiation. Deduct the natural solar radiation from surface radiation accepted by the satellite observation and make use of the surface emissivity of thermal infrared band (Band 6), to further retrieve the real temperature. Land surface temperature (LST) based on the reference of Landsat handbook, transforming the original DN value of TM/ETM+ Band 6 to the spectra radiation value of sensors.

2.2. **Urban Impermeable Land (Urban land) ------BUAI (Built-up Area Index)**

With the urbanization of cities, people, industries aggregated to the cities, causing the increase of population density, the transformation of the land use types and the expansion of building areas.

The construction of roads, buildings, sewer tunnels making the increase of impermeable land in urban area. This kind of land has significant impact to physical geographic environment of cities. For example, aggravating the Urban Heat Island Effect.

The DN value of urban land and nudation will increase from Band 4 to Band 5 while others decrease.

\[
\text{NDBI (Normalized Difference Built-up Index)} = \frac{(\text{MIR} - \text{NIR})}{(\text{MIR} + \text{NIR})} \tag{1}
\]

MIR represents Band 5. NIR represents Band 4

But purely using NDBI has some disadvantages. The result also contains these two kinds of land which are not belongs to urban built-up area: nudation and low-density vegetation area.

In order to improve the result of urban built-up areas extraction. We use:

\[
\text{BUAI (Built Up Area Index)} = \text{NDBI} - \text{NDVI} \tag{2}
\]

(-NDVI) represents non-vegetation area, like built-up land, nudation and water body.

We think that nudation and water body are easy to distinguish from Google map, so we use BUAI to enhance the information of urban built-up area.

3. Data Processing

3.1. **Land Surface Temperature Retrieval**

Step 1: Normalized Difference Vegetation Index (NDVI)

\[
\text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})};
\]

NIR: DN value in ETM+ band 4; R: DN value in ETM+ band 3.
Results:

**Figure 2.** Normalized Difference Vegetation Index (NDVI)

Step 2: Vegetation Coverage

In this part, we take Pixel Unmixing Models, and classify the land category of whole image as three types: water, vegetable and buildings.

\[ PV = \frac{((NDVI - NDVIS)/ (NDVIV - NDVIS))^2}{\text{NDVIV} = 0.70 & \text{NDVIS} = 0.00;} \]

If NDVI>0.70, PV=1, or NDVI<0.00, PV=0

Put the formula into the band math:

\[ (b1 \text{ gt } 0.7) \times 1+(b1 \text{ lt } 0.) \times 0+(b1 \text{ ge } 0 \text{ and } b1 \text{ le } 0.7) \times ((b1-0.0)/ (0.7-0.0)) \]

b1: Value of NDVI

The images of NDVI and computer statistic are as follows:

**Figure 3.** NDVI and computer statistic

Step 3: Surface emissivity
Based on the former research, we divide the image of remote sensing as three types: water, urban and natural surface. We adopt the following method: value the water emissivity as 0.995, and calculate the natural surface and urban emissivity as following formula respect:

\[
\varepsilon_{\text{surface}} = 0.9625 + 0.0614PV - 0.0461PV^2
\]

(5)

\[
\varepsilon_{\text{building}} = 0.9589 + 0.086PV - 0.0671PV^2
\]

(6)

Put the formula into the band math:

\[
(b_1 \leq 0) \times 0.995 + (b_1 > 0 \text{ and } b_1 < 0.7) \times (0.9589 + 0.086*b_2 - 0.0671*b_2^2) + (b_1 \geq 0.7) \times (0.9625 + 0.0614*b_2 - 0.0461*b_2^2)
\]

(7)

\(b_1\): NDVI value; \(b_2\): Vegetable coverage

Resize the data as 60 m * 60 m. The images are as follows:

![Figure 4. (a)NDVI value, (b)Vegetable coverage](image)

Step 4: Auxiliary parameters obtain

There are three component of thermal infrared radiation brightness value \(L_\lambda\) from satellite sensor: atmospheric upward radiation brightness value \(L^\uparrow\), ground real radiation brightness value which can be accepted as form of energy, and blackbody radiation brightness \(L_T\) which is as the same temperature as real radiation brightness.

Formula:

\[
L_\lambda = (\varepsilon \cdot L_T + (1-\varepsilon) \cdot L_\downarrow) \cdot \tau + L^\uparrow
\]

(8)

\(T\): Land surface real temperature.

\(\tau\): Atmosphere transmittance in thermal infrared band.

\[
L_T = \frac{[L_\lambda - L^\uparrow] \cdot \tau \cdot (1-\varepsilon) \cdot L_\downarrow \cdot \tau}{\varepsilon}
\]

The index comes from the NASA official website (http://atmcorr.gsfc.nasa.gov/)

Put the formula into the band math: 

\[
(b_2-3.39-0.6*(1-b_1) *5.12)/(0.6*b_1)
\]

(9)

\(b_1\): 60m*60m surface emissivity value;

\(b_2\): Radiometric calibration value in the thermal infrared band after atmosphere correction
Step 5: Land surface temperature retrieval
Based on the Planck inverse function, calculate the real temperature:

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

(10)

For TM 5, $K_1 = 666.09 \text{W/(m}^2 \text{·sr} \cdot \mu\text{m)}$, $K_2 = 1282.71 \text{K}$. Put the formula into the band math:

$$ \frac{K_2}{\ln \left( \frac{K_1}{b_1} + 1 \right)} $$

(11)

$b_1$: Thermal infrared radiation brightness value
The results are as follows:
Figure 7. Thermal infrared radiation brightness value

Step 6: Density slicing analysis - Single band colour transform method
Red: above 18 °C; Yellow: 13°C to 17°C;
Green:8°C to 12°C; Blue: Below 11 °C.
The accuracy of LST can be verified by the real temperature in 2001 and 2009, shown as below:

Figure 8. The accuracy of LST can be verified by the real temperature in 2001 and 2009

Figure 9. BUAI (2001) Calculation Process
In general, the built-up areas of Hong Kong only occupied a little portion of the total land of Hong Kong. The built-up areas of Hong Kong had no greatly increase from 2001 to 2009.

Inside the old town district like Kowlong, Central and Causeway Bay, the proportion of urban built up lands has increased interiorly. For the new town like Yuen Long, Tuen Mun, Sha Tin and Tai Po, the built-up land also increased, but it was more likely to expand toward outside.

4. Comparative Analysis
The built-up land from 2001 to 2009 had no greatly change, but the airport had become heater. Because burning fossil fuel will emit large amount of heat. So, besides the urban built-up land area, the fossil fuel burning is also a critical factor contributes to Urban Heat Island Effect.

The situation of Hong Kong International cargo dock is similar to the Hong Kong international airport. From the comparison, we also can find that inside the Kwun Tong Area, the built-up area has no significant increase from 2001 to 2009. But the heat effect is more serious. Even though the Kai Tak Coastal Park will soon become built with large amount of greenery inside. The whole Kwun Tong District is now being transformed from industrial area to business area.

For the Yuen Long New Town, the new town was developed from 2001 to 2009 with the built-up land area increased. So, the projects that construct buildings and increase built-up land also contributes to heat emission, which will increase urban-heat island effect. The comparison shows that in Aberdeen Country Park, there was no built-up land increase from 2001 to 2009. And inside the country park, the temperature was cooler. The mitigation function of park is obvious.

5. Conclusion and Discussion
Although land modification in traffic hub is the main factor of urban heat island effect, the waste heat from the transport cannot be neglect. Thus, improving the situation of the heat island effect around the traffic hub area cannot be easily complemented. It can be proved that the new town development will lead to the increase of impervious area, which can cause the heat island effect intensified.

The reconstruction processes for the urban regeneration will also emits heat in short period. Even though the project finally increases greenery of the region. The country parks have significant function for the Urban Heat Island Effect mitigation. And the mitigation function is long-termed and gradual. So, it is important to protect existing country parks.

Although the urban regeneration and reconstruction processes will increase Heat Island Effect in short-term. More and more small-scale renewal projects should be encouraged especially the projects that increasing greenery rate. The government should continue to protect the country parks because their significant function in Urban Heat Island mitigation. The electric vehicles which is low heat emission should be encouraged to use.
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