DATA CONCURRENCY FOR URBAN HEAT ISLAND (UHI) MONITORING IN HANOI, VIETNAM

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ABSTRACT: The Urban heat island (UHI) phenomenon is known as having impacts on environment, energy consumption and human life. In most of previous studies, the UHI intensity is estimated based on the outdated map to separate the urban and the surrounding areas, which can lead to the bias in UHI intensity, especially in rapid urbanization regions. In this study, we focus on using remote sensing data for assessment of UHI effect in Hanoi city from 1989 to 2013. Here, to estimate the UHI intensity, two approaches are employed to define the urban – rural boundary: the first approach is based on the changes of administrative boundary; and the second approach traces the real expansion of urban boundary generated from land use maps in the same years. The result demonstrates the changes of UHI phenomena in Hanoi city in the period. It also suggests that for monitoring UHI, the UHI intensity estimation should be based on the real change of the urban area; since the method which is based on the administrative boundary, fails to capture the real magnitude of UHI.

1. INTRODUCTION

Urbanization refers to the growth of the population living in the urban area (Nations, 1997). Currently, more than half of world population resides in the urbanized areas (Nations, 2014). As the consequence, urbanization requires more spaces for expanding houses, commercials, industrial and other land uses for the increasing of urban population. The modification of the land surface leads to the appearance of new materials in urban regions such as: concrete, asphalt, ceramic titles … Theses materials are known for having higher heat capacities than soil and vegetation, and alter the energy and radiation balance. As the result, it leads to Urban Heat Island (UHI) phenomenon, where the temperature in the urban regions is higher than the surrounding areas (Horward, 1833; Oke, 1973). UHI can generate negative impacts on energy demand/energy consumption for cooling (Santamouris *et al.*, 2015) (Radhi *et al.*, 2015) (EPA), degrading air and water quality (Countant, 2013; Luvall *et al.*, 2015), human health and mortality (Lowe, 2016).

For UHI studies, UHI intensity is commonly considered as the spatially-average temperature difference between urban and surrounding areas at the specific time, by calculating air or surface temperature differences (Memon *et al.*, 2009). Therefore, it is necessary to have a well-defined urban – rural boundary from the land use map to estimate the UHI Intensity. However, most of the previous studies are based on the outdated maps to separate urban and surrounding areas. A recent study suggests that it is important that UHI intensity estimation should be based on the concurrent land use/land cover maps; because outdated map can cause biases in estimating UHI intensity, especially cities in Asia, Africa, which are under the rapid urbanization (Zhao *et al.*, 2016).

For urban development, Hanoi city has changed the administrative boundary several times from 1975 to present. In this paper, we focus on investigating the UHI effect in Hanoi city from 1989 to 2013, in combination with the changes of urban – rural boundary. We also propose an approach for UHI intensity estimation in UHI monitoring.

2. DATA AND METHODS

2.1. Study area

In this paper, Hanoi city is chosen as study area to observe the UHI effect. As mentioned in the previous section, the administrative boundary of Hanoi city changed many times from 1975 to present. After the expansion in 2008, Hanoi area increases to 3.344,7 km^2, which is 3.5 times larger than the former city; with 9 urban districts and 19 suburban districts. However, most of expanded areas are suburban districts or rural areas in other words. Majority of urban districts locates within the former administrative boundary. Therefore, Hanoi city in this study will be based on the boundary before the expansion; in addition to Ha Dong district (former Ha Dong city of Ha Tay Province).

Figure 1 Boundary of Hanoi city as study area

2.2. Data acquisition

Number of Landsat scenes is collected from 1989 to 2013 for this study (distributed by USGS http://earthexplorer.usgs.gov/). Only cloud-free scenes are collected for UHI observation and extracting land use information. Landsat scenes in study include Landsat TM, Landsat ETM+ and Landsat 8. For UHI observation, the Landsat scenes are expected in the same season (summer or winter), because the UHI effect is strong in summer or winter (EPA). Therefore the collected scenes must follow this restriction.

Table 1 Detail of Landsat scenes in this study

Year	1989	2000	2003	2010	2013
Image	Landsat 5 TM	Landsat 7 ETM+	Landsat 7 ETM+	Landsat 5 TM	Landsat 8
Data type	L1T	L1T	L1T	L1T	L1T
Acquisition date (yyyy/mm/dd)	1989/11/30	2000/11/04	2003/01/13	2010/11/08	2013/12/18
Acquisition time (24h format)	09h47m	10h13m	10h11m	10h13m	10h13m
Season	Winter	Late Autumn	Winter	Late Autumn	Winter

2.3. Data analysis

2.3.1. Estimating the temperature for UHI observation

Urban heat island effect is measured from the surface temperature maps of Hanoi city, from 1989 to 2013. Landsat 5 TM and Landsat 7 ETM+ only have one thermal band, meanwhile Landsat 8 have two thermal bands (band 10 and band 11). However, due to the technical error, USGS does not recommend band 11 data in science studies, as well as using split-window method to estimate the surface temperature. In this study, only band 10 is used to estimate the surface temperature from Landsat 8 data.

The spectral values are calculated from the digital number of thermal bands using the radiance rescaling factors contained in the meta-data file. Then these spectral values are converted to brightness temperature by the diversion of Planck's law equation:

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_x} + 1\right)} \tag{1}$$

In the equation (1) T_B is brightness temperature in Kelvin; L_x is spectral radiance value; K_1 and K_2 are calibration constant values from the meta-data files. These constant values are according to each Landsat data by the following table:

Table 2 The calibration constant values

Data	Constant 1 – K_1 (watts/meter squared * ster * µm)	Constant 2 – K_2 (Kelvin)
Landsat 5 (Band 6)	607.76	1260.56
Landsat 7 (Band 6)	666.09	1282.71
Landsat 8 (Band 10)	774.89	1321.08

However, the Earth is not an ideal black body; therefore the brightness temperature is different with the real surface temperature. The surface temperature need to be calibrated from brightness temperature for atmospheric transmission and surface emissivity effects for a particular sensor viewing angle (Voogt & Oke, 2003). Surface temperature in this study is computed by the following model (Artis & Carnahan, 1982):

$$T_S = \frac{T_B}{1 + \left(\lambda * \frac{Tb}{\rho}\right) * ln\varepsilon} \tag{2}$$

$$\text{with } \rho = h * c * \sigma = 1.438\text{E-02 (mK)} \tag{3}$$

Where, T_B and T_S are brightness temperature and surface temperature in Kelvin Degree, respectively; λ is the wavelength of emitted radiance, σ and h are Boltzman's constant (1.38E-23 J/K) and Planck's constant (6.626E-34 Js), respectively; c is velocity of light (2.998E08 m/s); ε is surface emissivity, which is computed by its relationship with NDVI (Griend & Owe, 1993):

$$\varepsilon = 1.0094 + 0.047 * \ln(NDVI) \tag{4}$$

The temperature maps are derived from satellite data present the surface temperature of the study area. However, our aim is to generate the spatial distribution of the air temperature from the satellite. Recent studies by (Fu *et al.*, 2011), (Kloog *et al.*, 2012) and (Kloog *et al.*, 2014) suggest that the surface temperature can be used reliably to predict the air temperature at high resolution in large area, if it is modelled properly. In this study, we experiment to estimate the air temperature from the surface temperature and the temperature from the weather stations by linear regression analysis. The regression analysis estimates the air temperature at a height of 2 meters above the ground, because this estimation is based on the temperature from the weather stations. From the experiment, the correlation efficiency is high enough (R^2 = 0.9578), and it may conclude that the air temperature can be estimated from the surface temperature by linear regression analysis. Analysing the UHI intensities of study areas will be based on air temperature data.

2.3.2. Analysing UHI Intensity

To understand the UHI phenomenon and UHI intensity, it is necessary to separate the urban and the surrounding areas by the urban – rural boundary, and this boundary should be concurrent with the temperature map to avoid the bias of UHI intensity. Therefore, we use two approaches for the urban – rural boundary: the first approach is based on the change of the administrative boundary of Hanoi city from 1989 to 2013; and the second is derived from the land use map to define the urban – rural boundary. Base on these boundaries, the UHI intensities are calculated by the average temperature of urban and rural areas

Figure 2 The expanding of urban administrative boundary over time: 1989, 2000, 2003, 2010 and 2013 (follow the order from left to right, top to bottom)

Figure 2 display the change of the urban administrative boundary from 1989 to 2013. Through years, new urban districts are established by promotion from the rural districts. Majority of urban districts in the present time (2016) are established in the period from 1989 to 2013. For 10 years (from 2003 to 2013), the urban districts' boundary has been more stable. Only two more urban districts are promoted in this period.

For the second approach, the urban – rural boundary should be determined by the "physical boundary". In other words, the boundary should be based on the "real" expanding of urban, not the administrative boundary. The "physical boundary" of urban is extracted from the land use/land cover classes to separate the urban and rural zone. We extracted the land use/land cover from the satellite images to determine the boundary for this approach. The following table present the group of several land use/land cover to separate the urban and rural zone.

Table 3 Group of land use/land cover classes to determine urban – rural boundary for the second approach

	Urban zone	**Rural zone**
Land use/land cover class	• Industrial zone • Urban residence • Transportation	• Agricultural land • Rural residence • Recreation land • Other • Water surface

By this approach, the urban and rural zone is determined by grouping several land use/land cover classes which have the similar albedo characteristic. The materials such as concrete, asphalt, ceramic (construct in urban area) have the surface had higher albedo than other surface such as soil, water, vegetation cover. This approach assumes that urban zone is presented by the land use/land cover classes which have high albedo, while the rural zone is presented by low albedo land use/land cover classes. The dynamic change of urban zone's boundary is demonstrated by the following figure, from 1989 to 2013.

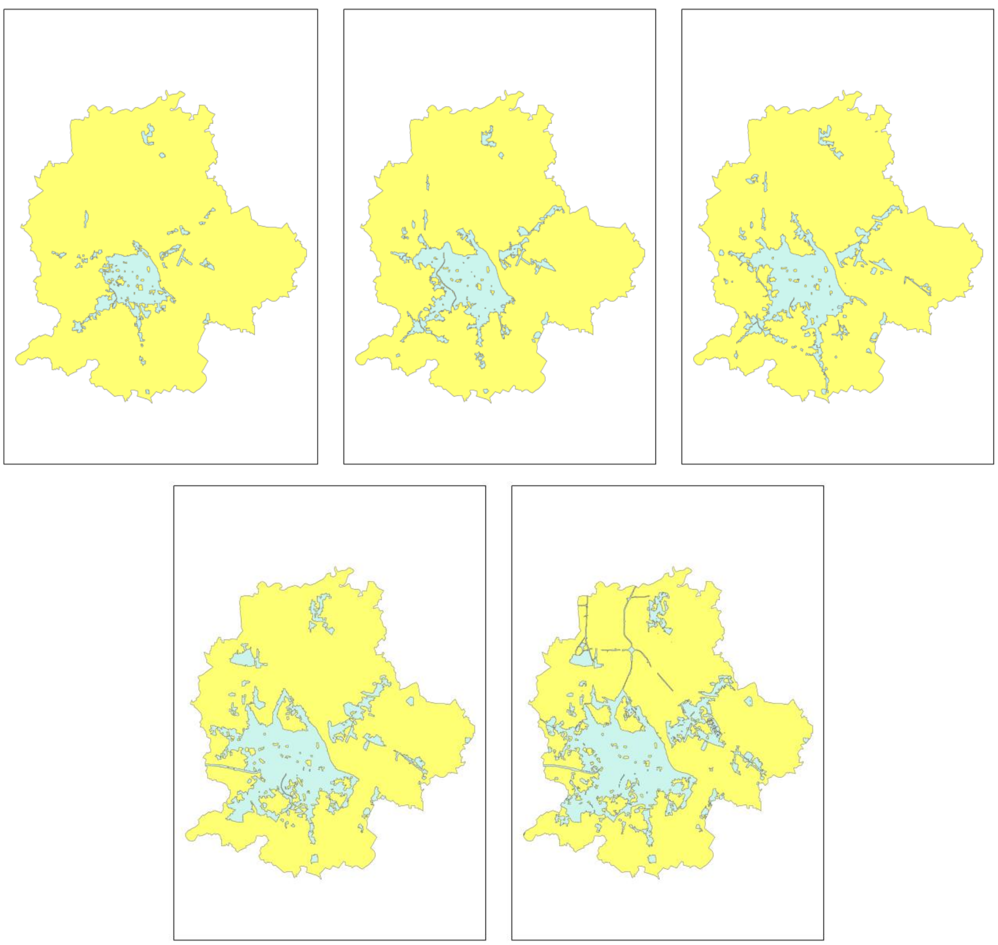


Figure 3 The expanding of "physical" urban boundary from 1989 to 2013 (follow the order from left to right, top to bottom)

3. RESULT AND DISCUSSION

3.1. The extension of heat island effect and its relation to the urbanization

By extracting the land use/land cover information, the result clearly shows the increasing of urban residence from 1989 to 2013, which is the result of urbanization in Hanoi city. The majority of change of urban boundary in figure 3 is the extension of the urban residence class. For monitoring the urban heat island effect, it is necessary to understand the spatial distribution of the heat island, how the heat island changes and how it relates to the urbanization; in addition to quantify the urban heat island intensity (or magnitude of the urban heat island). For analysing the change of the UHI, we overlap the spatial distribution of the air temperature and the extension of the urban area, which is represented by the urban residence class, in the same year. The following figure demonstrates the extension of the urban heat island over 24 years in Hanoi city.

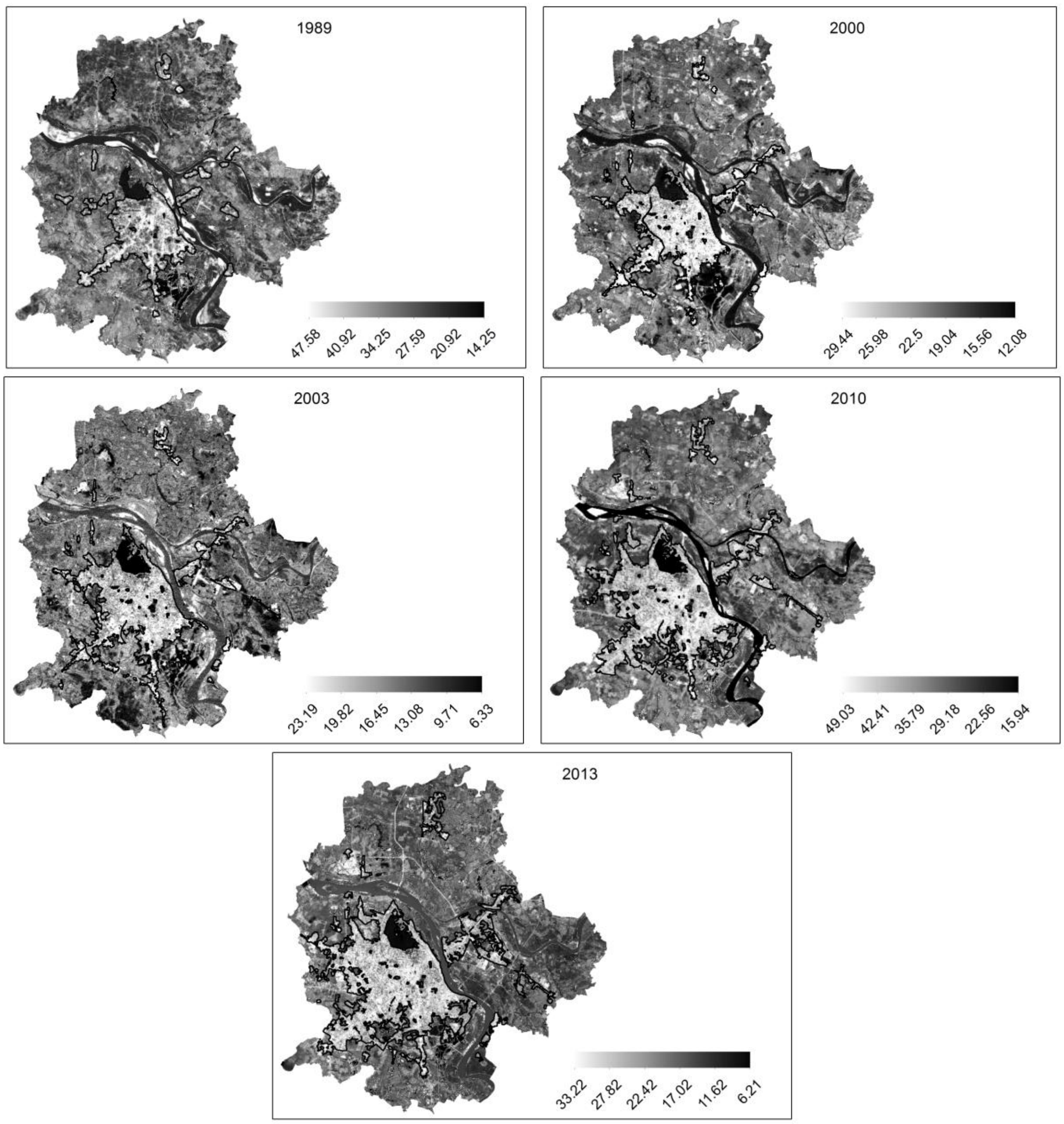


Figure 4 The extension of urban heat island from 1989 to 2013

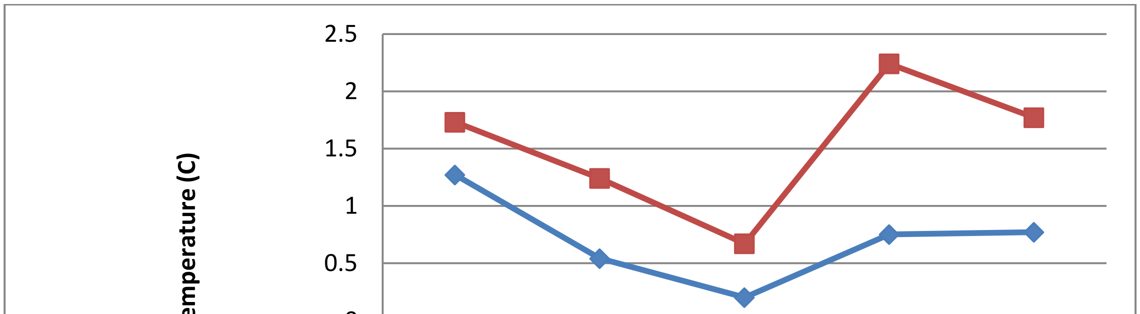
Figure 4 demonstrates clearly the extension and the spatial distribution of the heat island. In general, Hanoi city sees the temperature in the urban area is always higher than the surrounding area. In other words, Hanoi city experiences the "heat island", not the "cool island" or "urban heat sink" phenomenon. The high temperature, which is indicated by the bright color (white) are mainly located within the boundary of urban area (is represented by the urban residence class). For 24 years, the heat island has extended, and is matched to the expansion of the urban area, and it changes significantly.

At the early stage (in 1989), the higher temperature zone was mainly concentrated in the former urban core (four urban districts were established in 1978). Although there are some "hot spots" distributed outside of the boundary, these spots were not the urban residence class, or urban area. In the middle stages (in 2000 and 2003), the higher temperature zone moderately extends mainly toward the west of the urban core. The higher temperature zone still locates within the urban area. However in 2000, the thermal image sees the appearance of several high temperature clusters in Dong Anh district (north of the urban core). Dong Anh is a "rural district"; therefore these new clusters are represented by the rural towns (rural residence class). The appearance of these clusters is just temporary, because they don't grow to become a heat island.

In the latest stages (2010 to 2013), the extension of the high temperature zone becomes considerable compared to the previous stages. Only the Dong Anh district mostly remains unchanged and there is a significant change of the heat island: it extends to the west, and the new heat island is formed in the east side of the city. The high temperature is based on the former urban core, and extends and matches with the growth of urban area. The former urban core has high temperature all the time. In Dong Anh district, the new high temperature zones appear due to the construction of the new highway, and the factories. The west side of the city sees the urban area expands in Tu Liem and Ha Dong district. These areas are heavily developed by the investment in new apartments and factories. Consequently, the temperature in this district becomes higher. Notably, the urban area in Ha Dong district is well-expanded, because of Ha Dong district used to be Ha Dong city, one of the satellite cities of Hanoi. The high temperature zone becomes larger; as a result, it extends the boundary of the heat island.

Overall, by a visual comparison with the figure 14, it shows the extension and the spatial distribution of the high temperature zone, or the urban heat island has a high correlation with the growth of the urban area.

3.2. The urban heat island intensity – the comparison of estimating UHI intensity by two methods



	1989	2000	2003	2010	2013
UHII by the 2nd method	1.73	1.24	0.67	2.24	1.77
UHII by the 1st method	1.27	0.54	0.2	0.75	0.77

Figure 5 The comparison of UHI intensity by two methods

Figure 5 shows the difference of the urban heat island intensity values when using the different definition to determine the urban – rural boundary. It shows that the UHI intensities are varied by years. Due to the lack of the data, there are only 5 scenes of Landsat to estimate the UHI intensities; it does not show clearly how the UHI intensity changes in the period. Although the UHI intensity values are varied, the trend lines of UHI intensity share some similarities: the UHI intensity tends to decrease in the period from 1989 to 2003; but shows the upward trend after 2003, especially the urban heat island intensity by the second method. The first method shows that the UHI intensity in 2010 – 2013 is stronger than the UHI intensity in 2003, but the change is not significant.

UHI intensity estimating by the first method shows no significant temperature difference between urban and rural temperature, while the second method quantifies the intensity better than the first method. It suggests that because being based on the extension of the administrative boundaries, the UHII – 1 fails to capture the true characteristic of the urban heat island. On the other hand, by using the real "physical boundary" of the urban area (from the land use classes that share the same albedo characteristic), the UHI intensity shows the better temperature differences of urban – rural area, as well as demonstrates the real effect of heat island.

Figure 6 Comparison of the extension of administrative boundary and the urban residence

It clearly shows that at the early stages (from 1989 to 2000), the administrative boundary fits fairly well with the urban area; especially in 1989, when four urban district are mostly covered by "urban residence"; despite of failing to cover some urban clusters outside of the boundary, or containing some non urban elements. However, from 2003 to 2013, the boundary of the urban districts extends beyond the real development of urban area. As a result, the boundary of urban districts from 2003 to 2013 not only fails to cover the urban clusters beyond the reach of boundary, but also contains many non urban elements such as: rural town, agricultural land, water surface, vegetation. These elements are known for having lower albedo than the urban surface. As a consequence, the UHI intensity estimation based on administrative boundary or the urban districts may create a bias of UHI intensity, or underestimate the real effect of the UHI intensity.

4. CONCLUSION

In terms of the spatial distribution of the urban heat island, the result shows the boundary of the heat island increasing over the time, and the heat island matches well with the growth of urban area. The high temperature zone is mostly located in the urban districts, and forms the heat island. In Long Bien district (on the east side of the former urban core), it is observed that the clusters of high temperature evolve to the new heat island due to the urbanization in this district.

To quantify the UHI intensity, it is necessary to have a clear definition of the urban – rural boundary. This study uses two methods to define the boundary: the first method is based on the administrative boundary; and the second is based on the real extension of the urban area. The result shows that the UHI intensity estimation by the first method is weak; there are no significant temperature differences between the urban and rural area. The UHI intensity of the first method ranges from 0.2 to 1.27 degrees Celsius. By contrast, the UHI intensity estimated with the second method ranges from 0.67 to 2.24 degrees Celsius and shows stronger magnitude than the first method. Therefore, it can be concluded that for UHI monitoring, especially in Hanoi city which is under rapid urbanization; the UHI intensity should be calculated by the second approach, since the first approach may create bias in the UHI intensity, or underestimate the UHI intensity, as well as the UHI effect.

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