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UTILIZING LANDSAT IMAGERIES TO MONITOR URBAN HEAT ISLANDS IN HANOI, VIETNAM FROM 2009 TO 2021

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Abstract

This study found out the patterns of urban heat islands in Hanoi: the heat islands are concentrated as large zones in the high construction density urbans, which are also developed of economy and urbanization; Line forms in suburban areas with medium construction density - where planning is in progress and scatters in the low construction density areas - the slower economic development and urbanization. Duration of 12 years, the total urban heat island area in Hanoi has tripled (from 3.1 % to 9.4 %) and the difference of land surface temperature between the lowest value and highest value also increased significantly from 16.9 °C (2009) to 18.7 °C (2021). The increase of urban heat islands is corresponding with the progress of Hanoi urban planning implementation. The results probably contribute to the decision-making of sustainable urban planning and development in the contemporary context of climate change and rapid urbanization.

Keywords: Urban Heat Island; Hanoi; Landsat.

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1. Introduction

Urban Heat Islands (UHI) are urbanized areas that experience higher temperatures than suburban areas. Structures such as buildings, roads and other infrastructure absorb and reemit the sun's heat more than natural landscapes such as forests and water bodies. Urban areas, where these structures are highly concentrated and greenery is limited, become "islands" of higher temperatures relative to outlying areas. Daytime temperatures in urban areas are normally about 1 - 7 °F higher than temperatures in outlying areas and nighttime temperatures are about 2 - 5 °F higher. In the context of climate change and rapid urbanization, urban heat islands are happening more strongly; consequences of urban heat islands are increased energy consumption demand for cooling, increased greenhouse gas emissions and air pollutants, deterioration of water quality and hazards to citizens [15].

Hanoi city where the population increased rapidly in the second half of the 20th century. At the time of 1954, the city had 53,000 inhabitants on an area of 152 km^2; After the boundary expansion in August 2008, Hanoi city has 6,233 million inhabitants; As of February 2022, Hanoi's population reaches more than 8.5 million people [18].

As the capital, Hanoi becomes the political, economic and cultural center

of Vietnam and is also one of the first destinations of domestic and foreign tourists. Hanoi is a hotbed of urbanization leading to rapid decline of vegetation and significant increase of impervious surfaces such as buildings, parking lots, roads and sidewalks, public parks and other constructions. As the percentage of impervious surface increases relative to vegetation cover, urban heat islands appear and become more intense, posing many challenges to environmental issues, climate change and Greenhouse gas emissions,....

The application of remote sensing technology to study urban heat islands shows many outstanding advantages compared to the conventionally direct measurement method at meteorological stations, environmental monitoring stations, car - mounted devices, or handheld devices; namely dense data density, data availability on large - scale and time - series, timesaving, cost reduction and easy updating.

Urban heat island has attracted the attention of governments as well as environmental protection organizations such as the European Environment Agency (EEA), the US Environment Protection Agency (EPA), Japan Meteorological Agency (JMA) [14, 16],... In Vietnam, there were several studies by Tran Thi Van et al., (2009, 2017) [9, 10], Nguyen Duc Thuan and Pham Van Van (2016) [7], Le Van Anh and Tran Anh Tuan (2014) [1], Trinh Le Hung (2014) [4], Pham Van Cu and Hiroshi Watanabe (2004) [2], Huynh The Thu Huong et al., (2012) [3],... However, producing higher resolution land surface temperature maps still faces many challenges; On the other hand, the evolution of urban heat island in recent years has become more and more complicated and needs to be further researched and updated.

Landsat satellite images are freely accessed with continuous data for many years and a resolution of 100 m thermal channels and 30 m multispectral bands, which is suitable for the spatial scale of Hanoi city.

Therefore, this study was conducted with the aim of (i) Determining pattern of the urban heat island in 2009, 2011, 2016 and 2021; (ii) Monitoring urban heat island expansion and trend from 2009 to 2021.

2. Material and methods

2.1. Material

This study uses Landsat - 5 TM and Landsat - 8 OLI/TIRS satellite images downloads from the website https:// earthexplorer.usgs.gov/ [13], with spatial resolution of 30 m in multiespectral and 120 m/100 m in thermal infrared channels. The imageries were acquired on July 18th 2009, July 6th 2011, June 1st 2016 and June 24th 2021 which are sunny days, in the same season (Summer) and less affected by clouds. Hanoi city is covered by two scenes, path/row of 127/45 and 127/46; The multi - spectral bands used are the 7 - 4 - 3 of Landsat - 5 TM and the 7 - 5 - 4 of Landsat - 8 OLI/TIRS; The thermal bands used are 6 of Landsat - 5 TM and 10 of Landsat - 8 OLI/TIRS.

After atmospheric calibrating, the image is cropped according to the administrative boundaries of Hanoi city. The entire procedure of image processing and data analysis was carried out by Envi 5.3 and ArcGIS 10.3 software.

2.2. Methods

The whole processing and analyzing data from radiation correction, vegetation

index calculation, surface emissivity calculation to temperature calculation and UHI thresholding is summarized in the diagram as shown in Fig. 1.

2.2.1. Conversion the pixel values from digital number to radiance values

In the first step, the digital numbers necessitate to be converted to the physical value of the electromagnetic radiation. The conversion of the LANDSAT 5 TM image is done as follows:

$$L_\lambda = G_{rescale}.DN + B_{rescale} \quad (1)$$

Where L_λ - is the cell value as radiance; Grescale, Brescale - are the gain value for a specific band and the bias value for a specific band as constants which are provided in metadata file of LANDSAT TM imageries.

Unlike the LANDSAT TM image, the radiation of LANDSAT 8 is determined as the following formula:

$$L_\lambda = M_L.Q_{Cal} + A_L \quad (2)$$

Where: Qcal - numeric value of the image band; L_λ - is the cell value as radiation.

ML, AL - coefficients for each band (the RADIANCE_MULT_BAND_x and RADIANCE_ADD_BAND_x mentioned in the LANDSAT 8 image metadata file, where x is the band).

2.2.2. Calculating the top of the atmosphere reflectance

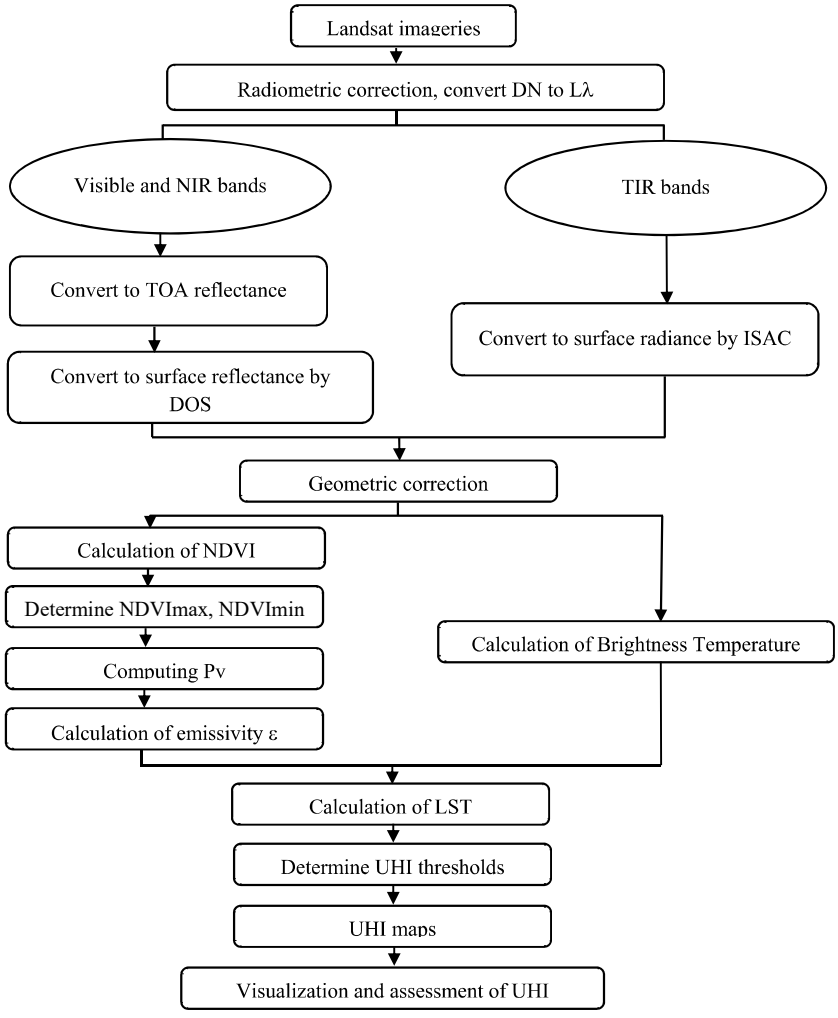

Figure 1: The flowchart on an Urban heat island research

The spectral reflectance value at the top of the atmosphere is corrected due to the influence of the sun angle according to the following formula (3) [8]:

$$R_{TOA} = (M_p.Q_{Cal} + A_p)/sin\theta_{SE} \quad (3)$$

Where: Qcal: Digital number (DNs); $R_{TOA:}$ Top of atmosphere reflectance.

Mp; Ap: Reflectance_Mult_Band_x and Reflectance_Add_Band x provided in metadata file of Landsat images (x-bands).

θse: Local sun elevation angle.

2.2.3. Calculation of surface reflectance

Dark Object Subtraction (DOS) algorithm aims to eliminate errors in the transmission of electromagnetic radiation in the atmosphere. In this method, dark objects are considered as pixels with the lowest grayscale value in the image. Dark objects are identified on the basis of histogram analysis of the image [8]. It can be said that DOS is the most commonly used method in correcting errors caused by the atmosphere in the transmission of electromagnetic radiation. The DOS method is integrated in most popular image processing software such as ENVI, ERDAS Imagine, PCI,...

2.2.4. Calculation of NDVI

The Normalized Difference Vegetation Index (NDVI) is widely used in the calculation of emissivity due to its advantages such as a higher resolution of the obtained emission map than the method calculated from the thermal band; can be used for any sensor regardless of the thermal channel; simple calculation and atmospheric correction.

NDVI_is determined as the following formula (4):

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (4)$$

Where: NIR: Reflectance of Near Infrared band.

RED: Reflectance of Red band.

2.2.5. Computation of emissivity

Surface emissivity is also a necessary parameter to calculate the LST from satellite images. In this study, the surface emissivity was determined based on the NDVI [11] - a suitable method that can be applied on heterogeneous areas as Hanoi:

$$\varepsilon = \varepsilon_v.P_v + \varepsilon_s(1 - P_v) \quad (5)$$

Where: ε: Emissivity of the targets;

ε_v, ε_s: Vegetation emissivity and bare soil emissivity respectively, this study inherits the experimental data ε_v, ε_s of Sobrino (2000) [6] ($\varepsilon_v = 0.971$, $\varepsilon_s = 0.977$).

P_v - Percentage of vegetation in 1 pixel which is calculated by the following formula:

$$P_v = \left(\frac{NDVI-NDVI_{min}}{NDVI_{max}+NDVI_{min}}\right)^2 \quad (6)$$

$NDVI_{max}$ and $NDVI_{min}$ - Minimum and maximum vegetation index values on an image.

2.2.6. Calculation of brightness temperature T

Brightness temperature is the temperature at satellite altitude acquired and is measured by sensors mounted on the satellite. The brightness temperature in this study is calculated using a single-channel algorithm according to Planck's law [8]:

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (7)$$

Where: T_B: Brightness temperature (K);

K_1, K_2: Correction constants are provided in the metadata file that accompanies each scene;

L_λ: Radiance of thermal band at the top of the atmosphere (Watts/(m^2.srad.μm)).

2.2.7. Calculation of land surface temperature LST

Surface temperature is the thermal energy of an object and can be measured by thermometers or sensors mounted on remote sensing satellites. Surface temperature is mainly influenced by solar radiation. The accuracy of surface temperature estimation from remote sensing data depends on many factors such as the interaction between the surface and atmosphere, the emissivity of the object, the resolution of the image, etc., the surface temperature is computed according to the formula (8):

$$LST = \frac{T_B}{1+\left(\frac{\lambda.T_B}{\rho}\right)*ln\varepsilon} \quad (8)$$

Where: T - Brightness temperature (K); λ - Wavelength of band 10; ε - Emissivity of the features:

$$\rho = \frac{h.c}{\sigma} \quad (9)$$

h - Plank's constant ($6{,}626.10^{-34}$ J.sec),

c - Speed of light ($2{,}998.10^8$ m/sec),

σ - Stefan Boltzmann's coefficient ($5{,}67.10^{-8}$ Wm^{-2} K^{-4}).

2.2.8. Determination of Urban heat island UHI

In order to identify areas where urban heat islands appear, it is necessary to first make statistics of the surface temperature value, then threshold LST to determine the UHI urban heat island area - the area with LST>μ+σ/2 [12].

Where: μ: Mean of Land surface temperature; Ϭ: Standard deviation (StdDev).

3. Result and discussion

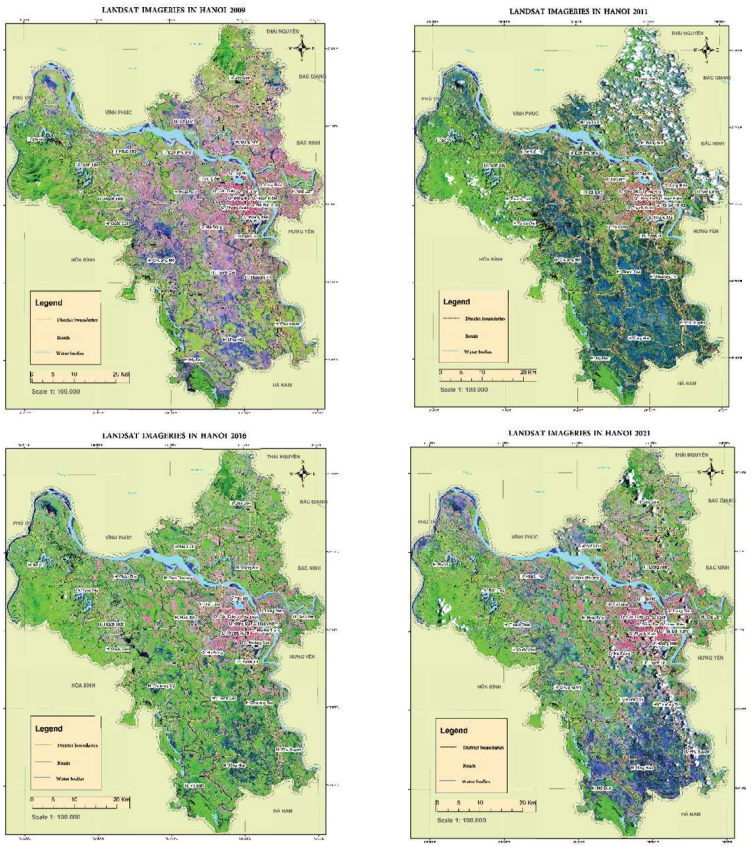

Figure 2: Landsat imageries of Hanoi

3.1. Land surface temperature

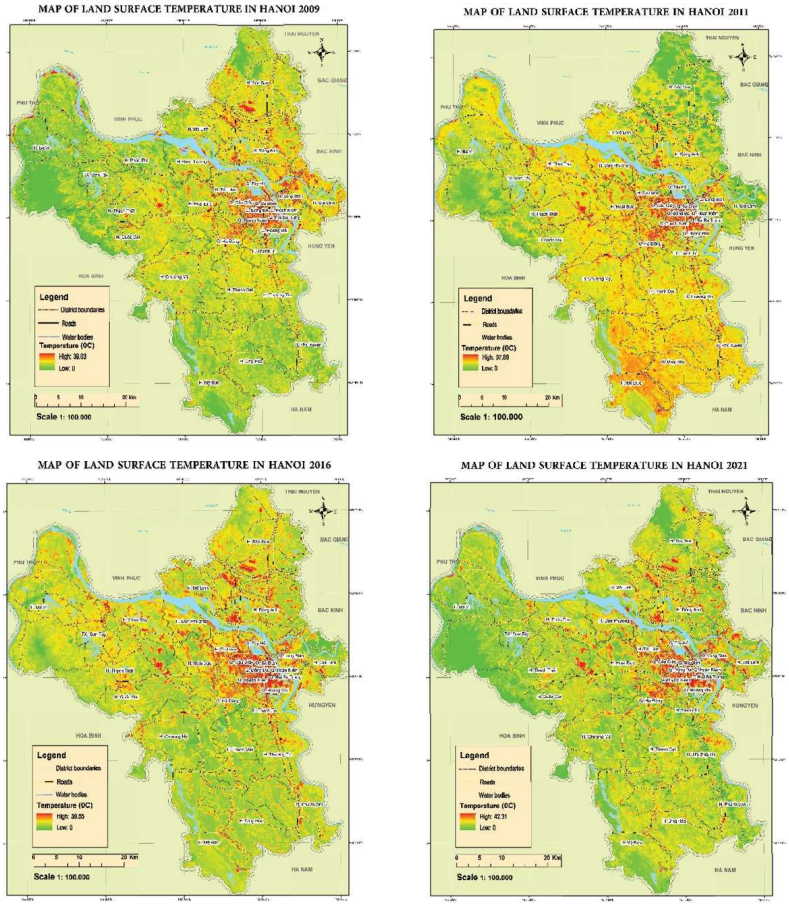

Figure 3: Maps of LST distribution in Hanoi

The results of visualization of the land surface temperature distribution maps (Fig. 3) and the image maps (Fig. 2) of Hanoi in 2009, 2011, 2016 and 2021 showed that the surface temperature has different values corresponding to each land cover type:

- The red color represents the temperature range from 37 ^{o}C to 43 ^{o}C, corresponding to high - density urban areas, high - rise buildings and asphalt road system are the factors that make the surface temperature in this area higher than in the surrounding areas. Additionally, a significant amount of heat is generated by human activities such as vehicle engines, industrial plants and other energy - consuming equipment.

- The orange is the high - temperature threshold between 30 ^{o}C and 37 ^{o}C, corresponding to urban areas with many trees. This is a residential area interspersed with green trees, the construction density is also less.

- The yellow is the average temperature zone, from 26 ^{o}C to 29 ^{o}C, corresponding to vegetation (rice, crops, perennials). The vegetation cover causes the dissipation of solar energy and the evaporation of water that cools the air.

- The blue color is the low - temperature range, from 24 ^{o}C to 27 ^{o}C, corresponding to the water bodies; The temperature - regulating effect of the water makes these areas cooler.

Visualizing and comparing the LST maps over the periods of time, it is found that the area of high - temperature areas tends to increase gradually from 2009 to 2021, the area of lower temperature zones is conspicuously narrowed. The reason is the rapid urbanization process, the numerous immigrants from the suburbs to the city center, requiring a significant land fund to build infrastructure such as houses, roads, schools and hospitals,... Land use changes will lead to land cover conversions, construction works replace green space. Consequently, the heat islands expand more and more - a big challenge to the life, activities and health of Hanoi residents.

3.2. The patterns of urban heat islands

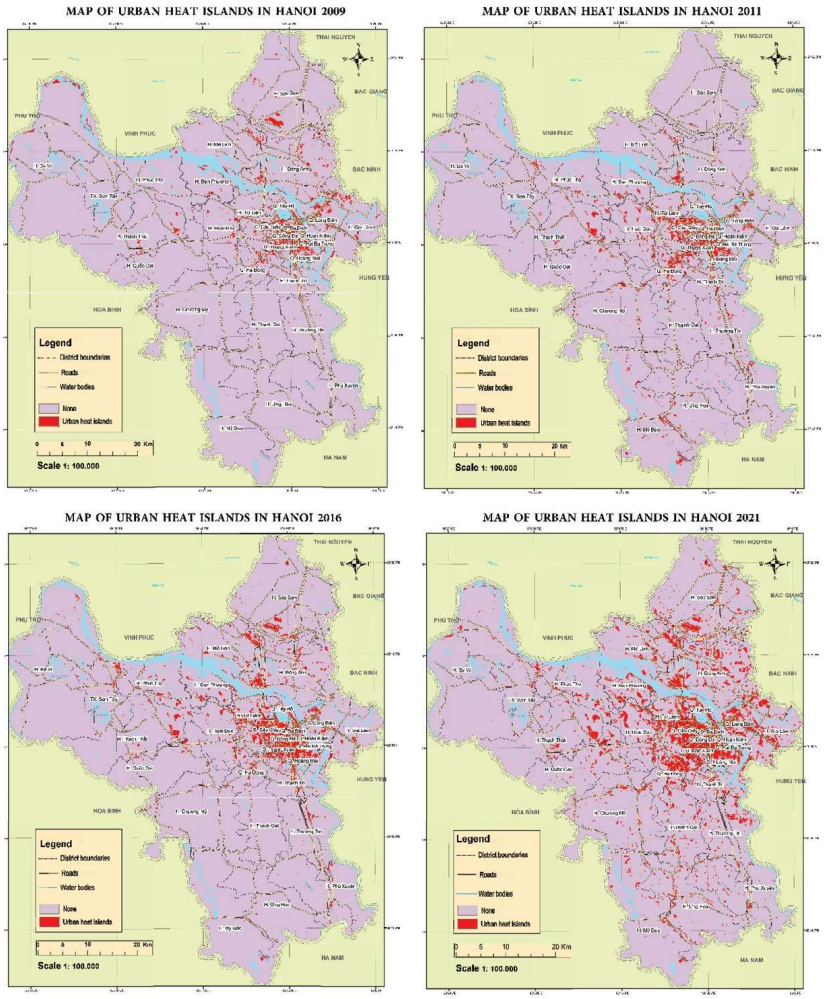

Figure 4: Maps of UHI in Hanoi

Table 1. Area of UHI in Hanoi from 2009 to 2021

No	Dates	Area of UHI (m^2)	Percentage (%)
1	18/7/2009	105.629.400	3,1
2	06/7/2011	112.616.100	3,3
3	01/6/2016	152.282.700	4,5
4	24/6/2021	316.544.400	9,4

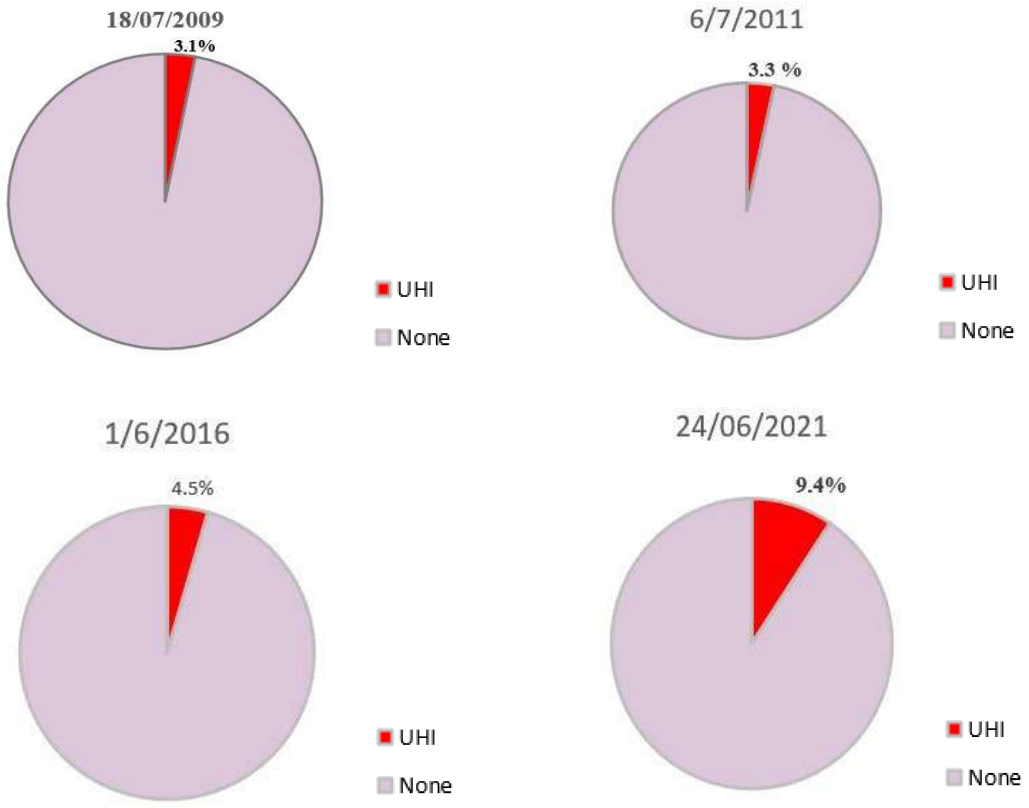

Figure 5: Percentage of heat island area in Hanoi through the years

Distribution of Ha Noi urban heat island at different dates

July 18th, 2009: UHI mainly concentrated in inner city districts such as Cau Giay, Ba Dinh, Dong Da, Hai Ba Trung, Thanh Xuan,…; Spotted UHI areas appeared insignificantly in Thach That, Me Linh and Dong Anh areas.

At this time, Hanoi mainly has developed urban areas in the central city and has not yet implemented the new phase planning for the suburb.

July 6th, 2011: UHI appeared as large areas in the central districts of the city such as Cau Giay, Ba Dinh, Dong Da, Hai Ba Trung, Thanh Xuan,…; dotted pattern spreading to the west of the city like Hoai Duc and Thach That districts and scattered dots in the southern part of the city for example Ung Hoa, My Duc.

This is the time when the Prime Minister signed the Decision No.1259/ QD-TTg dated July 26th, 2011 approving the planning of Hanoi capital area to 2030 and vision to 2050 [5]. The scope of planning includes the entire area according to the administrative boundaries of the city. Hanoi capital expanded by 3,344.6 km^2. In the planning, the urban space of Hanoi will be organized according to the urban cluster model, including the central urban area, 5 satellite towns and towns connected by a ring road system; A combination of radial axes, linked with regional and national traffic networks.

The novel urbans are developed and expanded from the inner city to the West and South to the 4th ring road; To the North

with Me Linh and Dong Anh areas; To the East to Gia Lam and Long Bien districts. This is the political, administrative, economic, cultural, historical, service, medical and educational center of the country.

The plan clearly approved that the central urban includes the inner city; The Southern extension of the Red River; The northern extension of the Red River and the South of Ca Lo river; The areas on both sides of the Red River and 5 satellite towns.

June 1st, 2016: Heat island distributed in the central districts of Cau Giay, Ba Dinh, Dong Da, Hai Ba Trung, Thanh Xuan,... spread to Long Bien, expanded to Dong Anh, Me Linh and Soc Son; and scattered in most districts.

The distribution of the heat island at this time has a close relationship with the implementation of the urban planning in Hanoi: Satellite towns approved: Soc Son (2015), Son Tay (2015), Xuan Mai (2015), Phu Xuyen (2015); The town planning in Ung Hoa and My Duc areas was approved in 2014 and construction has been accelerated in 2016.

June 24th, 2021: The heat island appeared as large regions, expanding in most of the central and northern districts of Hanoi, scattered linear heat islands formed in the south. This type of distribution appeared after Hoa Lac urban was approved by the Prime Minister in regional development planning (May 28, 2020).

Soc Son satellite urban is still in the process of implementing the planning project, but the conservation of the forest environment and natural vegetation due to the influence of the urbanization process did not concern adequately.

Son Tay satellite urban has entered the process of the planning appraisal and urban subdivision planning. Meanwhile, Xuan Mai and Phu Xuyen areas are slow to implement the planning.

Assessment of the changes of urban heat island in Hanoi

In the period from 2009 to 2021, the pattern of urban heat island, in the beginning, is only a few small areas and scattered dots, later increasingly expands into types of large regions and lines.

The heat islands are concentrated as large areas in the central districts including: Cau Giay, Ba Dinh, Dong Da and Hoan Kiem districts. These are areas in the inner city with high population density, low rate of trees and the largest construction density. The number of trees in 9 districts of central Hanoi is low. Impervious surface in new urbans increases the risk of absorbing heat of the ground, causing the air layer near the ground to become hotter and heating the ground longer. Population grows rapidly leading to no more land to plant more trees.

In satellite urbans according to the general planning of Hanoi from 2030 to 2050, the heat islands appear corresponding to the speed of planning implementation, typically in large satellite towns such as Hoa Lac, Son Tay, Soc Son.

Appearing heat islands concentrated in small and medium areas distributed in some industrial zones (Hanel industrial park in Long Bien district), mills and factories (Garment 10 Corporation in Long Bien district), the main traffic roads where the dense vehicles (Nguyen Trai Street in Nam Tu Liem district),...

Suburbs, where the urbanization process has rapidly occurred, have

appeared a number of dotted and scattered heat islands with a tendency to gradually expand.

The area has few heat islands, only a few dotted heat islands scattered in places with a high percentage of trees, a large system of rivers and lakes and concentrated in areas far from the city center are Bac Tu Liem, Nam Tu Liem, Long Bien, Hoang Mai, Ha Dong and Tay Ho districts.

The results of this study showed that the heat island area has also increased significantly, from 105.6 km^2 in 2009 to 112.6 km^2 in 2011, 152.3 km^2 in 2016 and 316.5 km^2 in 2021.

Urban heat islands often occur in impervious surfaces (concrete, asphalt) and bare soils. This is completely consistent with previous research results. The trend of expanding the UHI in the central city in the period from 2009 to 2021 is due to the change in land use during urbanization, leading to an increase of the impervious surface area and a decrease of vegetation and water body area.

UHI versus land use/land cover

The change in land use and the increase in urban heat island area are closely related, typically the forest land area in 2011 was 24,000 hectares, decreasing to 22.3 thousand hectares in 2016 and 22.2 thousand hectares in 2018. Besides, the residential land area increased rapidly, 37.0 thousand hectares in 2011 to 40.2 thousand hectares in 2016 and 40.9 thousand hectares in 2018 [17].

Analysis of the results shows that in the period 2009 - 2021, the area of heat island in Hanoi has increased more than 3 times. The trend of urban heat island expansion is also relatively synchronized with the implementation of the urban planning in Hanoi. That shows the negative side of socio - economic development to the environment and life of Hanoi inhabitants.

Solutions to minimize negative influence of UHI

Based on the research results, we make some recommendations as follows:

- Planning to increase the green space covered. Beside build the construction of high - rise buildings, it is possible to design green roofs of high - rise buildings, intercrop trees, flower gardens, lakes or fountains,... increasing beauty of the landscape as well as cooling in the summer.

- Use of surface materials with strong light reflectivity. Design urban works in locations where good wind is received and heat is easily released; In addition, increasing the use of natural ventilation systems in buildings to reduce the demand of electricity consumption for cooling devices.

- Policies should be implemented to encourage and focus on the development of public transport, thereby reducing the use of private means of transport.

4. Conclusion

The results have detected urban heat island patterns in 2009, 2011, 2016 and 2021 and urban heat island changes in the period from 2009 to 2021; Furthermore analyzing quality the relationship between urban heat island and land use/land cover as well as socio - economic development planning in Hanoi city.

In terms of area, the urban heat island is concentrated mainly in the central districts of Hanoi. During 12 years (from 2009 to 2021), the area of heat island in Hanoi area has more than tripled (from

3.1 % to 9.4 %), the difference in surface temperature between the hottest and the lowest zones also increased significantly from 16.9 °C (in 2009) to 18.7 °C (in 2021).

Regarding the patterns, the heat island appeared in large areas in the inner city - where the density of construction is high, socio - economy and urbanization develops rapidly; The line type in new urban areas with medium construction density, also where planning is in progress; And dotted form in areas with low construction density - with the slower socio - economic and urban development.

In terms of evolution, urban heat island has the type of small areas at the beginning (2009) in some urban districts, then spreads to larger areas and develops more linear forms in new urban areas (2011, 2016) and more dots appeared in suburban districts in 2021. This result corresponds with the progress of Hanoi urban planning implementation and is suitable with the trend of increasing urban heat islands in most developed cities in the world.

Uses of Landsat images to detect the changes of urban heat island are considered as an advanced technology due to the effectiveness i, e simple and fast, the detail of the results is shown on the whole of the interested region, while conventional method using measured data from meteorological stations only gave limited results at a few measurement points.

The results - Hanoi urban heat island map is a useful resource to support decision making in planning sustainable urban development, in the context of climate change and rapid urbanization as nowadays.

The limitation of this study is that it inherits the values of plant and bare soil emissivity of existing experimental studies without measurement in Hanoi; Besides, the surface temperature extracted from the remote sensing image has not been compared to the temperature directly measured.

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