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ASSESSING THE RELATIONSHIP BETWEEN URBAN GREEN SPACE AND URBAN HEAT ISLAND IN HANOI CITY

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Abstract: Uncontrolled urbanization with the encroachment of constructions has caused negative impacts on the environment, promoting a significant increase in temperature in the cities. The urban heat island (UHI) effect is making the climate in cities more extreme, increasing energy consumption and seriously affecting people's health. Green space development is considered a strategic solution to limit the negative impacts of the urban heat island effect. The main purpose of this study is to assess the relationship between urban green space and urban heat island effect in Hanoi city. The normalized vegetation difference index (NDVI) and land surface temperature (LST) extracted from the 2015 and 2020 Landsat satellite data of Hanoi city were used for analysis, comparison, and analysis to determine the role of green space in keeping the temperature down in summer temperature. Research results showed that green space plays an important role in cooling in the summer period. At the same time, the surface temperature in the non-vegetated areas is always higher than that in the vegetated areas at high levels of 2 to 3°C. The research results provide a significant source of reference material that makes an important contribution to an effective and sustainable urban planning strategy.

***Keywords*:** green space, urban heat island, surface temperature, Hanoi city.

1. Introduction

The process of urbanization has been taking place rapidly in many countries around the world, it is expected that nearly 70% of the world's population will live in urban areas by 2050 [1]. Rapid population growth along with housing demand makes the area of construction land increase rapidly, while the area of green space is gradually shrinking. The consequence of this problem is a serious decline in air quality and a significant increase in the urban heat island effect. At the same time, climate change in the past decades has deepened the urban heat island effect. Urban heat island (UHI) is a phenomenon in which, at the same time, the average temperature in an urban development area with many man-made structures is higher than in the surrounding area [2]. UHI is mainly triggered by the densely built environment as well as anthropogenic heat in cities. It causes negative effects on the health of urban residents [3]. The local climate of an urban area can be fundamentally influenced by landscape factors as well as by geometrical features, human activities, and existing heat sources in the area [4]. UHI is the dark side of urbanization and will be exacerbated by the effects of climate change. Development of regional urban green space is considered as one of the main strategies contributing to reducing UHI effect, air conditioning. From there, it contributes to improving the health and life quality of the people.

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Urban Green Space (UGS) is defined as urban land partially or completely covered with grass, trees, bushes, or other vegetation. It also includes blue zones such as ditches, canals, canals, inland waterways, rivers, and riverbanks [5]. In the current legal regulations, Circular 06/2013/TT-BXD of the Ministry of Construction of Vietnam guiding the urban design content has defined green space including "green corridors, green belts, green wedges, parks or natural and man-made forests in urban areas".

The relationship between green space and the intensity of the UHI effect has been mentioned recently. In which, green space is considered a nature based-solution to reduce the impact of UHI [6-7]. Studies show that urban green space has a positive effect on the adaptation of the thermal environment in cities through evapotranspiration and shading provided by green vegetation [8]. The compositional characteristics of the landscape and the structure forming the green space (eg, the size, the shape of the structure) also influence the cooling effect of the urban heat island [9]. Large urban parks can extend positive impacts on the surrounding built environment. The air temperature increases gradually with increasing distance to the park boundary [10].

Hanoi is the capital and the largest economic, political and cultural center in the country. It is the second-highest population density in the country. In the past 50 years, Hanoi has continuously experienced record-breaking heat waves in the summer, and UHI makes the air environment in Hanoi more severe. The characteristics of UGS, as well as UHI, have been mentioned in a few reports and studies in recent years, but in-depth studies on the relationship between the role of UGS and UHI are very limited. The purpose of this study is (1) to assess the status of urban green space and temperature surface distribution of Hanoi city; (2) to determine the quantitative relationship between UHI and UGS in Hanoi city; and (3) to propose solutions to plan UGS in a reasonable way, ensuring the sustainable development of Hanoi city in the future.

2. Content

2.1. Research Methods

2.1.1 Data used

Satellite images taken in the years 2015 and 2020 were freely downloaded from the website of United States Geological Survey (https://earthexplorer.usgs.gov). They were taken on extremely hot days in the summer in Hanoi. The purpose of this work is to recognize the sharp difference in temperature between areas with high vegetation cover and those without vegetation cover or low vegetation cover. At the same time, these images were selected in close time (June 28th and July 1st) to avoid the influence of seasonal factors in agricultural production in some parts of Hanoi city on the results of image interpretation (Table 1).

Table 1. Research data

Satellite data	Acquisition Date	Path/Row	Resolution (m)
Landsat 8- OLI	July 1st, 2015	127/045	30
Landsat 8- OLI	July 1st, 2015	127/046	30
Landsat 8- OLI	June 28th, 2020	127/045	30
Landsat 8- OLI	June 28th, 2020	127/046	30

2.1.2 Methodology

a) Pre-processing

The purpose of this process is to eliminate errors caused by camera tilt angle and atmosphere. The pre-processing for satellite data includes the following steps.

- Atmospheric correction: This process helps to eliminate the negative effects from the atmosphere, causing interpretation errors. It consists of converting digital numbers (NDs) into radiance values and standardizing the effect of the atmosphere.

- Stacking and clipping the layers: The image is clipped according to the boundary of the study area, which will increase the speed of information processing on the image.

These processes are performed using ENVI 5.2 software and ArcGIS 10.4 software.

b) Calculate the index

- Urban green space index

The heat reduction efficiency of urban vegetation is influenced by many factors including cover area, plant growth status, and green space structure, in which cover area is considered the most important factor [9]. In this study, the current status of urban green space was determined based on the standardized vegetation difference index NDVI. This index is calculated based on the difference in reflectance values of the red band and the infrared band, as the following equation (1):

$$NDVI = (NIR - Red) / (NIR + Red) \quad (1)$$

Where, NIR: Near Infrared band; Red: Red band

NDVI is a standardized index to measure healthy vegetation. The values of NDVI range from -1 to +1. A high NDVI value corresponds to an area with a high vegetation cover, and conversely, a low NDVI value is usually an area of bare land or sparse vegetation. Based on the threshold of NDVI value of Afirah T et al. (2007) [11], the status of green space is classified into four levels including None green, low green, moderate green, and dense green with NDVI values below 0, from 0 to 0.3, from 0.3 to 0.5 and from 0.5, respectively

Table 2. Classification based on NDVI values

Values of NDVI	Description
NDVI < 0	None green
0 ≤ NDVI < 0.3	Low green
0.3 ≤ NDVI < 0.5	Moderate green
NDVI ≥ 0.5	Dense green

- Land surface temperature index

To determine the land surface temperature of Hanoi on 1st July 2015 and 28 June 2020 from satellite image data, the thermal bands, namely band 10 and band 11 of Landsat 8 data were used to calculate, the procedure follow these steps.

- Convert the Digital number on the image to the value of the Top of Atmosphere (TOA) spectral radiation at the sensor:

$$L_{\lambda} = M_L * Q_{cal} + A \quad (2)$$

Where:

L_λ : TOA spectral radiance (Watts/(m^2 * srad * μm))

M_L : Band-specific multiplicative rescaling factor from the metadata

A_L : Band-specific additive rescaling factor from the metadata

Q_{cal}: Quantized and calibrated standard product pixel values (DN)

- Convert spectral irradiance value to TOA Brightness Temperature (Celsius)

$$T = [K_2/Ln\{(K_1/L_\lambda) + 1\}] - 273{,}15 \quad (3)$$

Where:

***T*:** Top of atmosphere brightness temperature

L_λ**:** TOA spectral radiance (Watts/(m2 * srad * μm))

K_1: Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K_2**:** Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

In this case, band 10 (K2 =1321.0789; K1= 774,8853), Band 11 (K2 =1201.1442; K1 = 480.8883)

- Calculating the Proportion of Vegetation (Pv):

$$Pv = [(NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})]^2 \quad (4)$$

- Calculate the Land Surface Emission (e):

$$e = 0.004*Pv + 0.986 \quad (5)$$

Where:

0.004 is the weighted average of the different surface types [12]

Pv: Proportion of Vegetation

- Calculate the LST (Land Surface Temperature) value:

$$LST = T/\{1+ W*(T/p)\}* Ln(e) \quad (6)$$

Where:

T: Top of Atmosphere Brightness Temperature

W: wavelength of emitted radiance

p = 14380

e: Land Surface Emission

- To evaluate the relationship between UGS and UHI, 100 samples are randomly taken in the study area. From values of NDVI and LST of 100 different positions. The regression analysis is used to evaluate the above relationship.

2.2. Discussion

2.2.1. Characteristics of the study area

Hanoi stretches from 20°53' to 21°23' North latitude and 105°44' to 106°02' East longitude. It shares borders with Thai Nguyen and Vinh Phuc to the north; Ha Nam and Hoa Binh to the south; Bac Giang, Bac Ninh, Hung Yen to the east; and Hoa Binh, Phu Tho to the west. Hanoi has a natural area of 335.9 thousand hectares. Currently, Hanoi is divided into 30 district-level administrative units, including 12 urban districts, 17 districts, and one town [13] (Fig 1.).

Hanoi is located in the humid tropical monsoon region. There are four different seasons in the year. Summer often starts from May to the end of August, the climate is hot, humid, and rainy. The weather is cool and dry in September and October. Winter lasts about 3-4 months, starting from the end of November to the end of March next year. In which, the weather is cold and dry from the end of November to early February, and it becomes cold and drizzly in February and March. In recent years, the temperature in the summer of Hanoi tends to increase. Hanoi has experienced many intense heat waves with temperatures up to 42.5°C. In addition, due to urban effects and high humidity climate, during a heat wave, the actual perceived temperature is always higher than measured, possibly up to 50°C. It has a negative impact on people's health.

Hanoi is the second biggest in the country in terms of population and population density. In 2020, Hanoi's population reach 8,246.6 thousand people, accounting for 8.45% of the country's population. The population density of Hanoi city is 2,455 people/km², 8.3 times higher than the

national density. There is a significant difference in population between the inner district and the suburban. The population in inner districts is usually much higher than that in the suburbs, typically Dong Da (37,347 people/km²), Thanh Xuan (32,291 people/km²), Hai Ba Trung (29,589 people/km²), Hoan Kiem (25,637 people/km²), Ba Dinh (24,093 people/km²) and Cau Giay (23,745 people/km²) [13].

Rapid population growth and high population density lead to a huge demand for housing while the natural land area is limited. Therefore, the area of green space is increasingly shrinking, converting it into residential land. The evidence is that the green space in the inner area is very low (from 1 to 2 m²/person). It is much lower than the standard of Vietnam Ministry of Construction for urban planning (from 12 to 15 m²/person). This has caused significant impacts on air quality, it makes the summer become more uncomfortable.

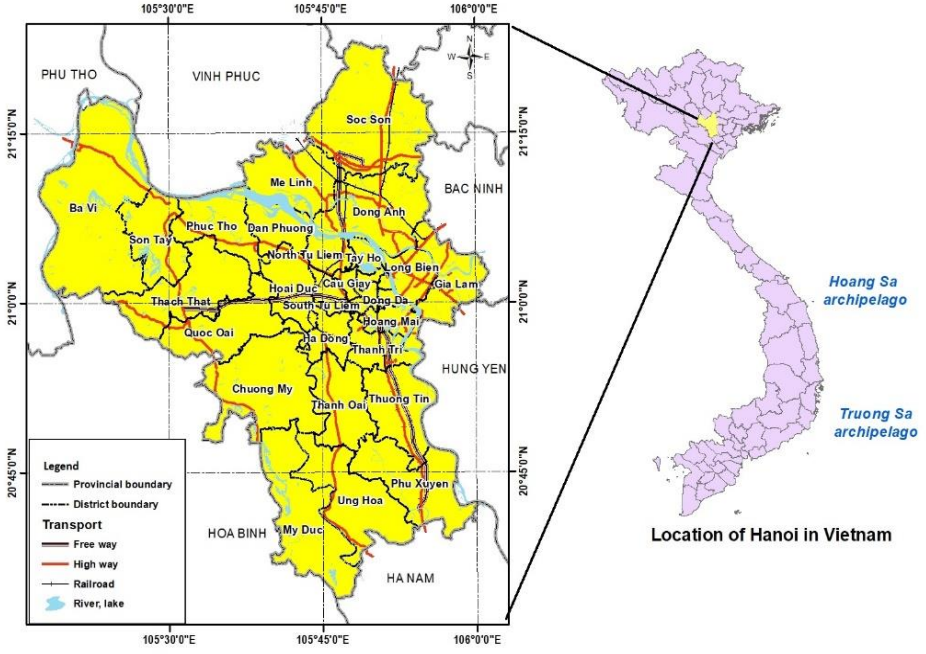

Figure 1. Location of the study area

2.2.2. Urban green space index

Figure 2 describes the NDVI of Hanoi city in 2015 and 2020. As the result, the magnitude of NDVI is directly proportional to the green space quality. In areas with dense green space quality, the NDVI value is high and opposite. The results show that the value range of NDVI changed markedly, and its upper limit trended down. Accordingly, the NDVI values for the years 2015 and 2020 are from (-0.335634) to 0.658465, and from (-0.264734) to 0.664452 respectively. Based on the thresholds in Table 2, the NDVI values are classified into four levels, namely none-green, low-green, moderate-green, and dense-green. The non-green area corresponds to the water body areas or entirely constructed areas. Areas with low green are assigned to areas of residential land, grasslands, shrubs, and pitch. Areas with moderate green are usually associated with agricultural land, flower gardens, and urban green corridors. Areas with dense green are forests, conservation areas, and green parks.

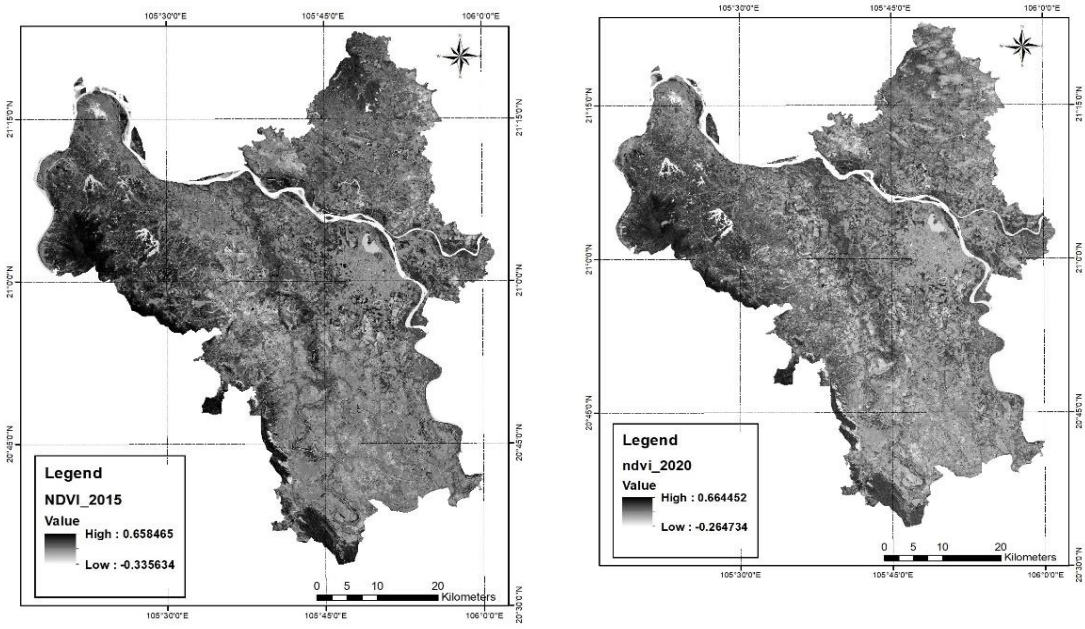

Figure 2. NDVI value of Hanoi city

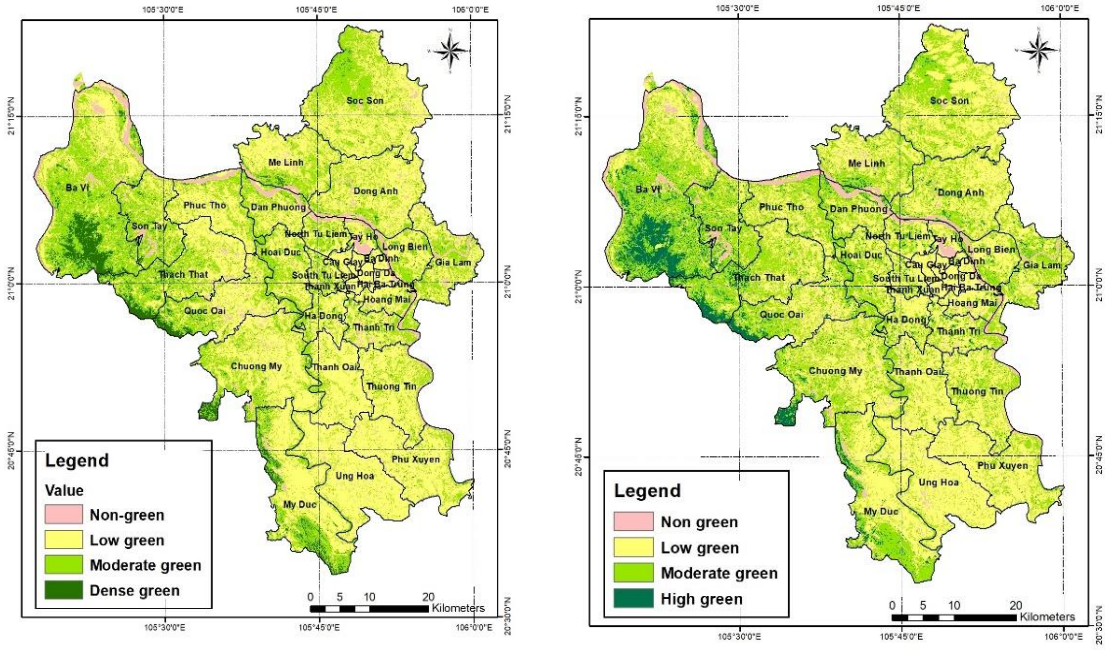

Figure 3. Green space quality

The research results show that the coverage rate of Hanoi city tends to increase in the period 2015 - 2020. In which the area with low green area decreases from 57.8% to 52.3%. Moderate green and dense green areas tend to increase in the above period, with values from 32.5% to 36.9% and from 4.5% to 5.9%, respectively. This shows that the city's green space restoration and development solutions have been effective, which is considered a positive signal contributing to improving the environmental quality of the capital.

Table 3. Area and percentage of green spaces

Type	2015		2020	
	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)
None green	17538.4	5.2	16543	4.9
Low green	194283.3	57.8	176048.1	52.3
Moderate green	109467.3	32.5	123978.8	36.9
Dense green	15126.8	4.5	19845.9	5.9

2.2.3. Land surface temperature index

To evaluate the surface temperature of Hanoi city, the study used two thermal bands, namely band 10 and band 11 of Landsat-8 image. Land surface temperatures are calculated on June 28, 2015, and February 1, 2020. According to report results from the Hydrometeorological National Center, these are two of the hottest days in Hanoi. The results of interpretation from satellite images show that the temperature levels on two days 28th June 2015, and 1st July 2020 scaled from 30.5^{0}C to 41.5^{0}C, from 28.3^{0}C to 39.3^{0}C, respectively (Table 4).

Figure 4 shows quite clearly the difference in temperature between the inner city and the suburbs of Hanoi, whereby the inner city has a significantly higher temperature than the suburban area. Areas with high temperatures above 35^{0}C are mainly distributed in concrete works, residential land, bare land, and riverside sandy beaches. In general, the suburban area has a lower temperature of 2-3^{0}C than the inner city. Especially in areas with forests and agricultural land, the temperature is lower significantly.

Table 4. Land surface temperature in Hanoi city

Temperature value (^{0}C)	2015	2020
Maximum	41.5	39.3
Minimum	24.4	21.9
Average	30.5	28.3
Standard deviation	1.5	1.5

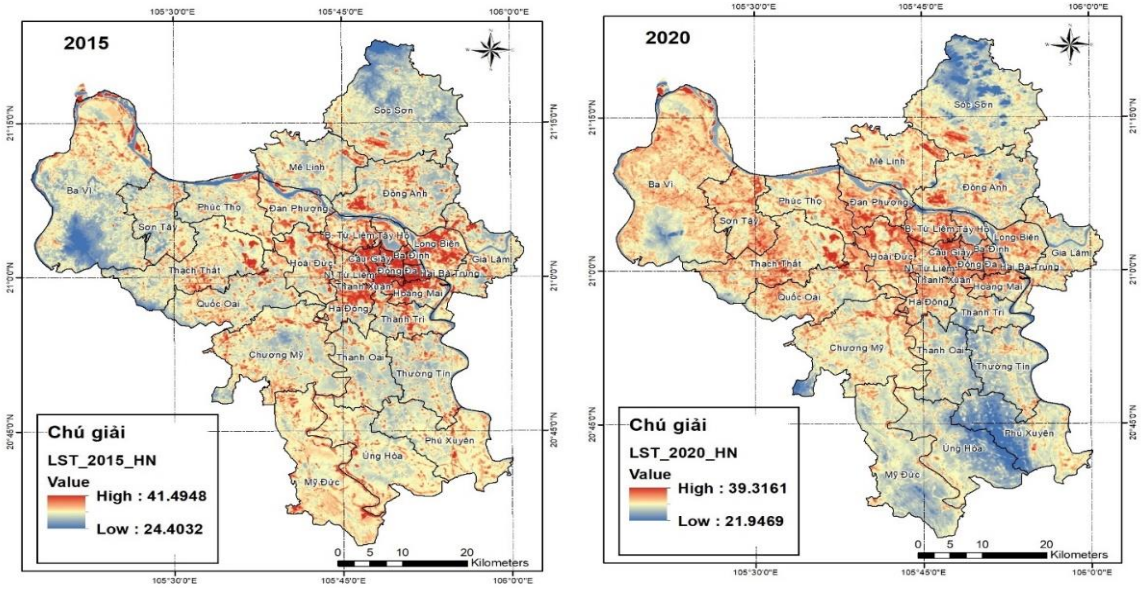

Figure 4. Land surface temperature on 28th June, 2015 and 1st July, 2020

2.2.4. Relationship between urban green space and urban heat island

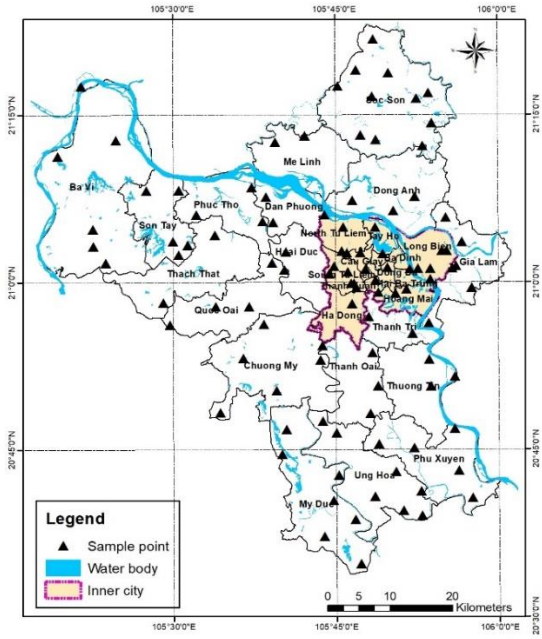

Figure 5. Location of sample points

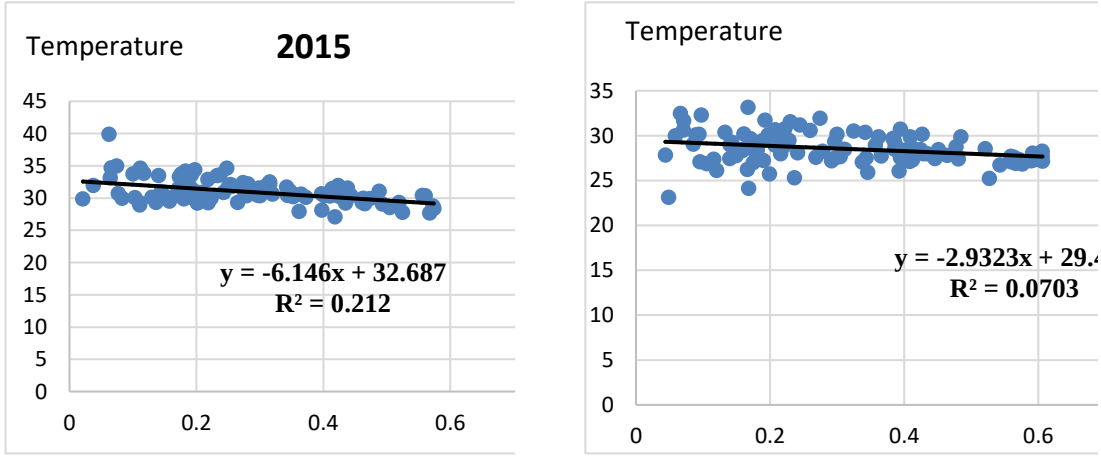

Figure 6. Regression analysis of the surface temperature difference and NDVI in summer

To evaluate the role of green space in balancing temperature and reducing heat in summer, the study randomly selected 100 samples for overlay subjects (excluding the water body) (Figure 5). Regression analysis of the area of the green space with the cooling ability of vegetation is shown in Figure 6. The linear graph between the surface temperature value and NDVI shows that this is an inverse relationship, the linear line tends to go down. The higher the green space area is, the lower the temperature is, and vice versa. The correlation coefficient for the regression equation R^2 for the years 2015 and 2020 is 0.2 and 0.1, respectively. The results show a close relationship between surface temperature and green space coverage. It could be found that UGS is basically negatively correlated to UHI in summer, which is consistent with

previous works. Moreover, the results also show that the quality of green space in the study area is low. Therefore, it is very necessary to increase the area and quality of green space in Hanoi city to limit the urban heat island situation.

2.2.5. Suggestions for implementation

Research results showed that UGS has a positive impact on the urban environment, cooling the air. Proposing possible solutions to limit the negative impacts of the UHI effect, and providing a healthy living environment for urban people is an important objective of this study. It includes the below solutions.

- Expand the area of UGS in the whole city. Greenspace infrastructures should be proposed and implemented in densely built-up areas. Developing the UGS is considered an effective Nature based-solution to reduce the polluted environment in the city.

- Developing modern green architecture is an effective method. This type of architecture has been applied in many cities around the world because it not only brings a beautiful space but also makes the most of the available space for green. It is especially suitable for densely populated cities and limited land funds.

- Relocation of the building structure to reduce the high population density in the inner city. Ensuring a sustainable balance between the area ratio of construction land and green land.

- Strengthen cooperation between urban management agencies and government levels in the use and management of urban green space sustainability.

- Raising people's awareness of protecting the environment and living space. Encouraging people to participate in environmental activities such as planting trees, and limiting waste in the environment.

3. Conclusion

The cooling role of UGS in the summer period to help limit the UHI phenomenon in Hanoi city is studied and evaluated through the correlation relationship between green space and urban surface temperature. Accordingly, in areas with dense vegetation, the temperature tends to decrease significantly in the summer and vice versa, and the urban heat island phenomenon becomes more pronounced in the areas without vegetation or low vegetation. Water surface also plays an important role in air conditioning in urban areas. Research results also show that around the area of large lakes, the temperature is also lower than that of the adjacent area.

The green space quality is inversely proportional to the UHI effect, which can be considered as a reliable basis to develop suitable solutions to control the UHI effect and bring a pleasant atmosphere in the summer. Solutions to enhance UGS are essential to ensure sustainable urban development. This research, however, is subject to several limitations. Firstly, this study only assesses the role of UGS in reducing UHI effect through the vegetation index, namely NDVI. In fact, other factors such as the perimeter and shape of green space also significantly affect the ability to reduce urban heat. Secondly, the study only evaluated the relationship between UGS and UHI during the summer period, and the winter period was not mentioned. This point will be added in future studies.

In recent years, facing the alarming situation of environmental pollution in big cities, management agencies have had many positive solutions to improve green space in cities. However, this is still a big challenge, because the land fund in cities, especially the inner city of Hanoi, has been thoroughly used for residential and construction land. Converting the structure of land use, and increasing green space areas such as parks, flower gardens, ecological gardens, green belts, etc. is a necessary solution in the sustainable urban development strategy.

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