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THE RELATIONSHIP BETWEEN LST, NDVI AND NDBI INDICATORS, AN INVESTIGATION USING LANDSAT IMAGES IN HOA BINH, VIETNAM

Bui Thi Thuy Dao*, Ninh Thi Kim Anh
Hanoi University of Natural Resources and Environment, Vietnam

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Abstract

The study uses Landsat 8 OLI-TIRS satellite images to extract indices and Pearson correlation analysis techniques to evaluate the correlation in the distribution between land surface temperature LST), vegetation index (NDVI), normalized difference built-up index (NDBI) in Hoa Binh province. The results indicate that areas with expansion and increased density of impermeable surfaces are characteristic causes contributing to increased temperatures in urban areas compared to surrounding areas and tend to be 5 - 7 °C higher than the average temperature of the entire study area. The correlation coefficient values reached r = - 0.96791, r = 0.9628, and r = -0.9352 for the relationship between LST-NDVI, LST-NDBI, and NDVI-NDBI respectively. The study results show inter-relationships and transformations of the three indicators in the research context, where urban land temperature and Urban Heat Island (UHI) are raised by built-up areas and in contrast, reduced by vegetated areas. As a result, urban green space would be a driver to mitigate the harmful impact of the "heat island" effect in urban areas. Aim to strengthen concentrated green areas and vegetation in land areas that are less favorable for construction.

Keywords: Land Surface Temperature; NDBI; NDVI; Remote sensing.

***Corresponding author. Email:** bttdao@hunre.edu.vn

1. Introduction

Urbanization is an inevitable trend in every country in the world, including Vietnam. Besides the positive aspects it brings to the economy and society, the rapid process of urbanization and a lack of scientific planning bring negative impacts on resources and the environment, including an increase in temperature in urban areas, which is one of the clearest proofs. The higher the urban density, the greater the urban heat island intensity. High temperatures in urban areas are caused by various factors: Urban areas have reduced cooling capacity (due to reduced vegetation, increased runoff due to increased impermeable surfaces); Increased heat absorption in urban areas (due to reduced reflection, increased heat radiated from heat-absorbing surfaces).

Multi-time and multi-resolution remote sensing images can provide basic data to analyze urban spatial information and thermal environments effectively.

Currently, the remote sensing satellite system is equipped with thermal infrared sensors, recording the radiant temperature information of matter. Thermal infrared remote sensing data include Landsat, Aster, and MODIS.

Land surface temperature (LST) can be determined using thermal infrared data of satellites such as MODIS, NOAA/AHVRR, and Landsat [1, 2]. Typical algorithms to determine LST from satellite images include Monowindow [3], Single-channel [4, 5], The on-line Atmospheric Correction Parameters Calculator (ACPC) [6, 7] and Multi-channel [8]. The LST index proves valuable in monitoring temperatures of different types of soil/land use surfaces. Therefore, LST can be used to support research related to land use changes such as urbanization, desertification, and deforestation.

The vegetation index (VI) is determined based on the ratio of near-infrared and red wavelength values. The NDVI value is closely associated with the state of vegetation, reflecting aspects like vegetation cover density. The Normalized Difference Built-up Index (NDBI) is derived from the principle that constructed or built-up soil reflects more in the mid-infrared (MIR) range compared to the near-infrared (NIR) range [26]. The value of NDBI indicates the built-up area density. Thus, different objects on the land surface have different reflectivity for each spectral channel of the satellite image and this is a property that helps classify the cover layers for each area.

Therefore, studies on LST and assessment of correlations between LST-NDVI, LST-NDBI, and NDVI-NDBI play an important role, especially in the context that green tree resources tend to decrease rapidly, while tree density is increasing. population and the rate of urbanization is increasing. Many studies in the world and Vietnam have used thermal infrared remote sensing data, mainly Landsat thermal infrared images, to evaluate the relationship between land cover/use and surface temperature distribution face [9, 10]

Research indicates a negative correlation between LST and NDVI [11, 12]. NDVI is often used to investigate the relationship between LST and vegetation [13]. LST varies according to the different land use and land cover (LULC) types, influenced by factors like surface reflectance and roughness [14, 15]. Besides, studies also show that many factors affect the relationship between LST and NDVI such as urbanization rate, land use change, and land cover types [16]. On the other hand, the correlation between the NDBI construction difference index and LST is also of interest to consider. Accordingly, the expansion of impermeable surface areas during the urbanization process such as traffic systems, buildings, parking lots, etc., leads to the absorption of more shortwave radiation and the emission of more long-wave radiation [17, 19]. Urban surfaces are mostly covered with impermeable materials with high heat absorption, which has led to increased surface and air temperatures in these areas causing an "urban heat island" effect. So, it can be seen that the NDBI index is very useful to provide information about the level of urbanization as well as land cover change in an area. At the same time, a good correlation was found between NDBI and LST [17, 18].

This study aims to (i) Calculate the NDVI and NDBI spectral indices; (ii) Determine LST using Landsat thermal bands and single channel algorithm; (iii)

Examine the correlation between LST, NDVI, and NDBI.

2. Materials and methods

2.1. Study area

Hoa Binh is a mountainous province located at the gateway of the Northwest mountainous region of Vietnam, connecting the plains and mountains. The province's geographical coordinates are from 20°19' to 21°08' North latitude; and 104°48' to 105°40' East longitude. To the North, it borders the Phu Tho province; To the South, it adjoins Ha Nam and Ninh Binh provinces. To the east, it shares a boundary with the capital, Hanoi, while to the west, it borders Son La and Thanh Hoa. The provincial capital is Hoa Binh city, situated 73 km from Hanoi. The province covers a natural area of 4,662.5 km², accounting for 44.8 % area of the entire region, accounting for 1.41 % of the total natural area of the country. In recent years, Hoa Binh has prioritized investment in key projects to cater to development needs, expand its space, and enhance its urbanization rate and urban landscape.

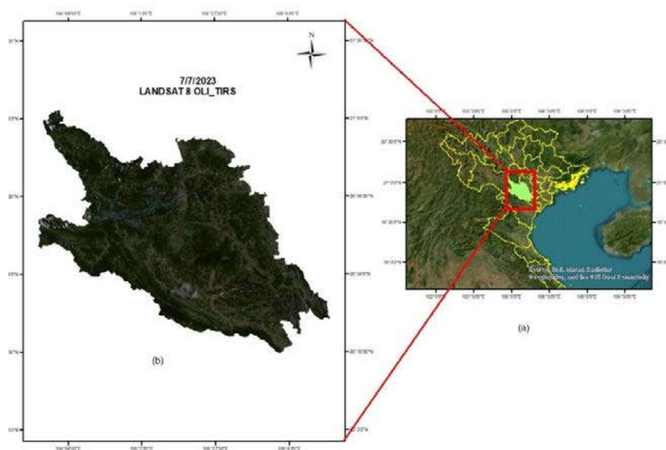

Figure 1: Location of the study area: (a) The red rectangle indicates the study area in Viet Nam; and (b) a Landsat-8 true-color image (RGB: 432) of the study area obtained 07/7/2023

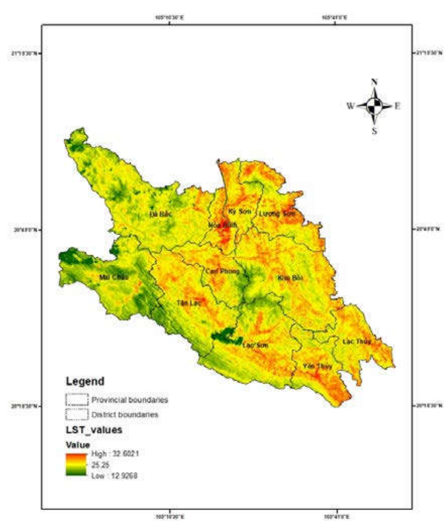

Figure 2: Land surface temperature (LST) in the study area determined from Landsat 8 images on 07/7/2023

2.2. Research data

Within the scope of research, the data used is Landsat 8-OLI and TIRS optical satellite images downloaded from the website https://earthexplorer.usgs.gov/ of the United States Geological Survey (USGS). The spatial resolutions of the visible-near infrared-shortwave infrared bands (0.43 - 2.3 µm wavelength) and thermal infrared bands (10.6 - 12.5 µm wavelength) are 30 m and 100 m, respectively. Photo scene of Hoa Binh area taken on July 7, 2023. The image was calibrated to the L1TP level and calibrated with the WGS 1984 UTM, Zone 48 North reference system. Channels 4 and 5 (30 m resolution) of Landsat 8 images are used to calculate the NDVI index, channels 6 and 5 (30 m resolution) is used to calculate the NDBI index, and channel 10 (resolution 100 m) is used to determine the LST surface temperature.

2.3. Extract indicators

This study uses spectral channels, including channel 4, channel 5, channel 6, and channel 10 of the collected Landsat8-OLI satellite image data to build products on brightness temperature and emissivity, NDVI, and NDBI index.

2.3.1. Calculation of NDVI

NDVI (Normalized Difference Vegetation Index) quantifies the vegetation density on the earth's surface by leveraging differential reflectance between near-infrared wavelengths and the red wavelength [20, 21]. NDVI has a value in the range from -1 to +1 corresponding to different coverage density values of plants on the surface. NDVI usually falls between 0.2 and 0.8 for areas with lush green vegetation. NDVI index is determined according to the following formula [22]

$$\text{NDVI} = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED})} \quad (1)$$

Where ρ_NIR and ρ_RED are the reflection values of near-infrared and red wavelengths, respectively.

2.3.2. Calculation of NDBI

The NDBI (Normalized Difference Built-up Index) is based on the basis that construction soil has a reflectance coefficient in the first short-wave infrared band (ρ_SWIR1) that is much higher than that in the near-infrared band (ρ_NIR). The NDBI index is calculated according to the formula [23]:

$$NDBI = \frac{(\rho_{SWIR1} - \rho_{NIR})}{(\rho_{SWIR1} + \rho_{NIR})} \quad (2)$$

Similar to the principle of constructing the NDVI index, the NDBI values range from -1 to 1. The NDBI index was established and used to analyze areas with built-up areas [23]. Built-up areas typically exhibit high NDBI values, vegetated regions show low NDBI values and water surfaces tend to have negative NDBI values.

2.3.3. Estimating Land Surface Temperature

Land surface temperature (LST) represents the temperature of the interface between the land surface and the atmosphere. Land surface temperature is mainly affected by solar radiation. When the Sun radiates to the Earth's surface, most of the radiation is absorbed. Then, the Earth's surface radiates back into the atmosphere and space. The balance of the amount of solar radiation absorbed depends on two factors: the transmission capacity of the air and the absorption of surface materials. Therefore, LST is a good indicator of energy balance at the Earth's surface.

In research, the single channel method SC (Single channel method) was used to calculate surface temperature. Accordingly, 01 Landsat 8 thermal infrared channel (channel 10) is used. Implementation steps include:

- *Convert integer values to electromagnetic radiation values:*

To calculate the surface temperature, the first step is to convert the integer value of the image (DN - Digital number) to the actual value of the radiation ($Wm^{-2}\mu m^{-1}$). For Landsat 8 thermal infrared images, radiance correction is performed as follows [24]:

$$L_\lambda = M_L.Q_{cal} + A_L \quad (3)$$

where: Lλ- value of electromagnetic radiation

M_L, A_L are conversion factors, provided in the Landsat 8 satellite image metadata file

Q_{cal} is the numerical value of the image channel.

- Determine radiation temperature

After converting the numerical value to the radiation value, the thermal infrared image will be used to calculate the temperature. This temperature is also known as radiation temperature or luminance temperature. For Landsat 8 images, Brightness Temperature is calculated according to the following formula:

$$T_B = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (4)$$

where: Tb is the spectral radiation value

K1 and K2 are constants provided in the Landsat image metadata file [24].

- Determine surface emissivity

In this step, the value of the NDVI vegetation index is according to formula (1). The NDVI vegetation index continues to be used to calculate the proportion of vegetation in a Pv image pixel. Pv can be determined according to the following formula:

$$P_v = \left(\frac{NDVI-NDVI_{min}}{NDVI_{max.}-NDVI_{min}}\right)^2 \quad (5)$$

P_v takes a value of 0 for bare soil and 1 for soil covered with plants. Then, the Pv value is used to determine the surface emissivity in terms of work awake:

$$\varepsilon = \varepsilon_v.P_v + \varepsilon_s(1 - P_v) \quad (6)$$

where: εv, εs - emissivity typical for homogeneous soil and plants.

- Determine surface temperature

After determining the surface emissivity, the luminance temperature Tb is corrected to obtain the surface temperature value LST. Therefore, the land surface temperature is determined according to the formula:

$$LST = \frac{T_B}{1+\frac{\lambda.T_B}{\rho}ln\varepsilon} \quad (7)$$

where: Tb - radiation temperature or luminance temperature.

λ - central wavelength value of the thermal infrared wave band. For channel 10 and channel 11 of Landsat 8 images, the central wavelength value of the thermal infrared wave band is taken to be 11μm and 12μm, respectively.

ε - surface emissivity.

ρ - *Stefan-Boltzmann constant* (= 1,438.10-2 m.K)

3. Results and discussion

3.1. Spatial distribution of LST

The spatial distribution and frequency distribution of LST surface temperature values in Hoa Binh province on July 7th, 2023, are shown in Figure 2. In particular, the central area of Hoa Binh city and scattered in the district centers of Luong Son, Ky Son, Cao Phong, Tan Lac, Lac Son, Kim Boi, Yen Thuy, and Lac Thuy exhibit higher average surface temperatures than the remaining areas and 2 districts: Da Bac and Mai Chau. In addition, the surface temperature value in Hoa Binh province at the time of the study had the lowest temperature of 12.93 °C and the highest temperature of 32.6 °C (Table 1). Most temperature values appear to fluctuate between 24 - 26 °C (Figure 2). Based on Figure 2, areas with high surface temperatures are concentrated in areas with high construction density and large populations such as wards: Thinh Lang, Huu Nghi, Dong Tien, Tan Thinh, Phuong Lam, and 1 the Western-Southern part of Dan Chu ward (in Hoa Binh city); Hang Tram town, Ngoc Luong commune (Yen Thuy district); Chi Ne town, Dong Tam commune (Lac Thuy district), Luong Son town (Luong Son district), Muong Khen town (Tan Lac district) while the remaining areas have lower temperatures. Most of these central areas had surface temperatures at the time of the study above 30 - 32 °C, which is notably 5 - 7 °C higher than the estimated average temperature of 25.25 °C for the entire province. This represents a substantial temperature differential.

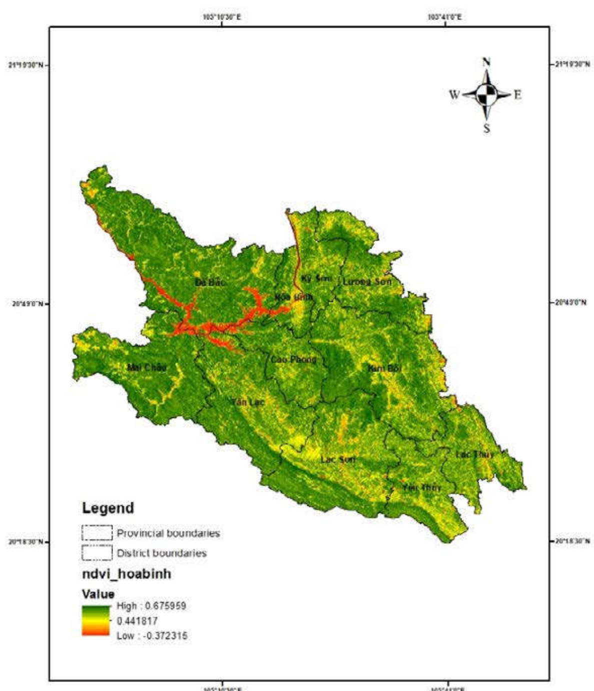

Figure 3: Normalized Difference Vegetation Index (NDVI) in the study area determined from Landsat 8 images on 07/7/2023

Table1. Statistical description of LST, NDVI, and NDBI in Hoa Binh province on July 7, 2023

	Min	**Max**	**Mean**	**Standard Deviation**
LST	12.93	32.60	25.25	1.27
NDVI	-0.37	0.68	0.45	0.14
NDBI	-0.49	0.42	-0.24	0.08

3.2. Spatial distribution of NDVI, NDBI

Based on Figure 3 and Figure 4, it's evident that the NDVI index exhibits lower values (< 0.26) inwards and towns, while the NDBI index shows higher values (0.4). Conversely, the remaining areas follow the opposite trend. These values are specific to each type of surface coating. In general, it can be seen that the spatial distribution of LST values has a positive relationship with the NDBI index and an inverse relationship with NDVI. The threshold value of NDVI in the entire Hoa Binh province ranges from -0.37 to 0.68, the average value is 0.45 and the values are mainly concentrated in the threshold from 0.40 to 0.68, showing that the overall study area is 0.45. The study had high vegetation cover [25]. The NDBI index ranges from -0.49 (low built-up area density) to 0.42 (high built-up area density), the average value is -0.24 with values mainly distributed within the -0.48 threshold. to -0.17. In general, such NDBI index shows that the density of construction area in Hoa Binh province is low (Statistics on NDVI and NDBI are given in Table 1).

3.3. Evaluate the correlation between surface temperature and NDVI and NDBI values

3.3.1. Relationship between LST (°C) and NDVI

Normalized difference vegetation index (NDVI) is an important index in studies on the growth, development, and variation of vegetation cover. In addition, this index is also a measure of the quantity and vitality of plants on the surface. Low NDVI values represent areas with low vegetation coverage. High NDVI values represent areas with high vegetation cover, while negative NDVI values represent areas with moist soil and water surfaces (Table 1, Figures 4 [25]). Correlation analysis was performed to find the relationship between LST and NDVI, which showed that the coefficient of determination R2 was 0.9403, indicating a strong relationship between NDVI and LST. On the other hand, the correlation coefficient $r < 0$ ($r = -0.96791$) means that the values of the two indices NDVI and LST have an inverse correlation. When the NDVI value decreases, the LST value increases, and vice versa.

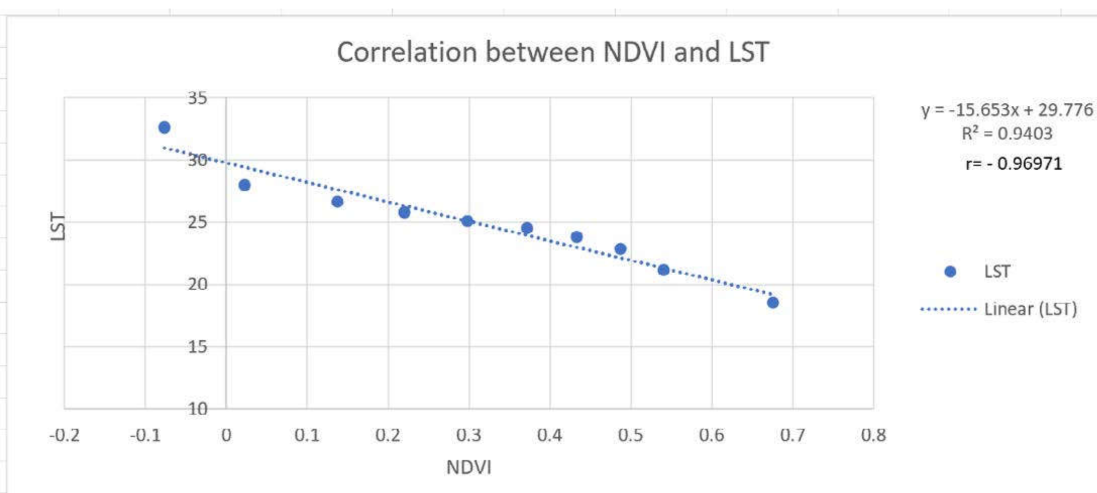

Figure 4: Relationship between NDVI and LST

3.3.2. Relationship between LST (°C) and NDBI

Based on the above relationship charts, it becomes evident that in most surface areas, an increase in built-up areas tends to elevate surface temperatures. Conversely, areas with moderate vegetation cover tend to experience lower temperatures due to the cooling effect of vegetation density. Therefore, it is predicted that the pace of urbanization with the emergence of more and more urban areas, areas with many construction works are mostly covered by waterproof materials with good absorption properties. High heat has led to increased surface and air temperatures. On the other hand, the correlation chart shows that there is a positive relationship between NDBI and LST with the coefficient of determination R2 = 0.9271 and the positive correlation coefficient (r = 0.9628) meaning a value of 2 values. NDBI and LST depend on each other. If the NDBI value increases, LST also increases, and vice versa, when the LST value increases, NDBI also increases. Thus, the positive relationship between NDBI and LST indicates that built-up area is the cause of much surface temperature variation and is the main factor causing the urban heat island phenomenon. In contrast, areas with healthy vegetation will play an important role in reducing the "urban heat island effect", reducing radiation, and reducing air temperature and land surface temperature.

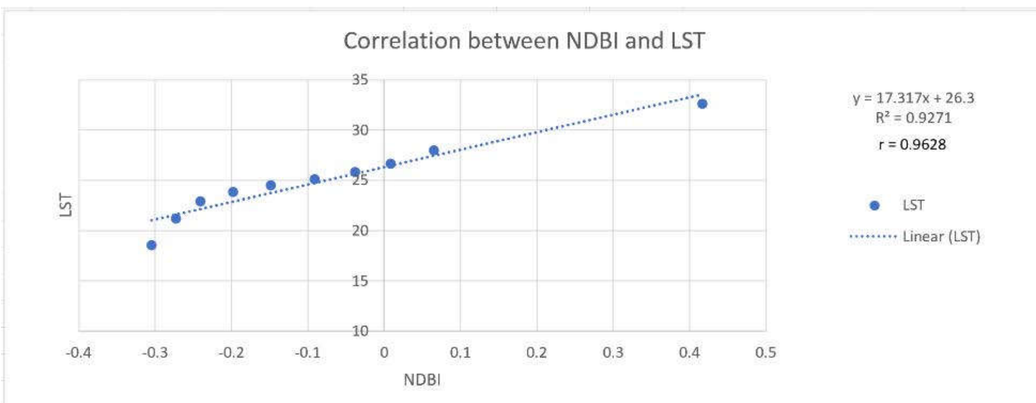

Figure 5: Relationship between NDBI and LST

3.3.3. Relationship Between NDVI and NBDI

The correlation between NDVI-NDBI is depicted in (Figure 7) which shows that NDVI is negatively correlated with NDBI. Accordingly, the chart shows that there is a quite close relationship between the NDVI index and the NDBI index (R2 = 0.8746) and accordingly there is a negative correlation between the vegetation index and the construction index (r = -0.9352). Therefore, it is clear that NDBI can be used to illustrate the assessment and expansion of the construction index. Thus, based on the above relationship charts, it can be seen that on most of the covered surfaces, increased construction area will increase the surface temperature while areas with average vegetation cover will increase the surface temperature. On average, higher vegetation density results in reduced surface temperatures.

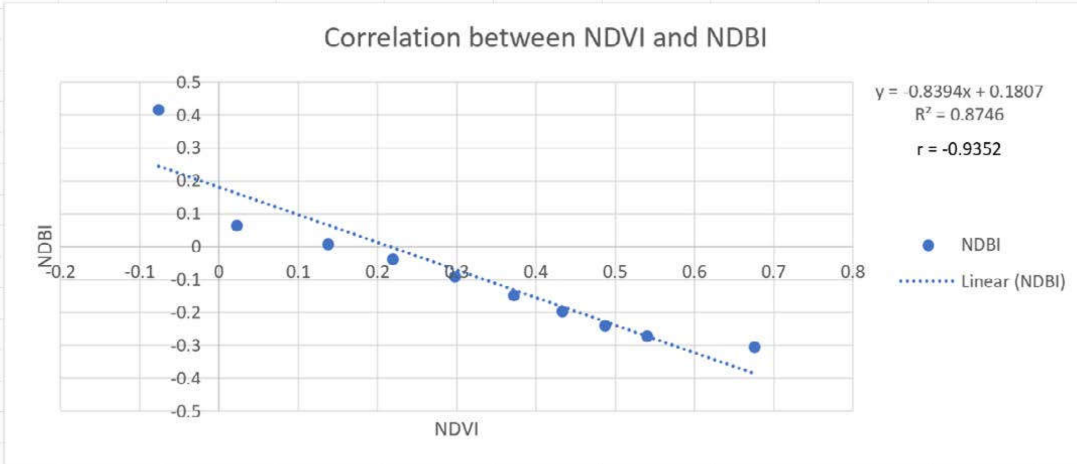

Figure 6: Relationship between NDVI and NDBI

4. Conclusion

The study used Landsat 8 OLI-TIRS satellite images to build spatial distribution maps and evaluate the relationship between LST, NDVI, and NDBI indices in the study area. The analysis results of the determination index R2 and correlation index r show that the spatial distribution of LST tends to vary with the NDBI index and inversely with the NDVI. The strong positive correlation (r = 0.9628) found between LST and NDBI means that surface temperatures will be higher in areas with high construction density. The strong negative correlation (r = - 0.96791) of NDVI with LST shows that areas with healthy green vegetation will reduce surface temperatures. Therefore, it can be suggested that NDBI can not only be used to analyze and predict LST but can also be used to consider the urban heat island effect in any area and provide a reliable basis for urban development planning and construction.

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