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INVESTIGATING LAND SURFACE TEMPERATURE CHANGES IN THANH HOA CITY FROM 2000 TO 2023 USING GOOGLE EARTH ENGINE

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Abstract

In recent years, rapid urbanization has significantly increased surface temperatures in major urban areas. Surface temperature is one of the key factors in studying the impacts of urbanization on the environment and society. This study focused on identifying changes in surface temperature values in Thanh Hoa city, located in Thanh Hoa province, from 2000 to 2023 using satellite imagery on the Google Earth Engine platform. The results indicated that land surface temperature values fluctuated over different periods in the study area. The average surface temperature reached its highest value in 2023, followed by 2015, 2019, 2001, and 2022, and the lowest in 2007. The results obtained in this paper can provide useful information to assist managers and policymakers in making decisions regarding land use planning and urban development.

Keywords: Land Surface Temperature; Google Earth Engine; Satellite imagery.

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1. Introduction

Thanh Hoa city is the Northern gateway to the North Central economic region and serves as the economic, cultural, and political center of Thanh Hoa province. After 30 years after its establishment, Thanh Hoa city has rapidly urbanized, growing from 30 urban areas in 2016 to 70 urban areas in 2020, and Thanh Hoa city has become an urban Type I in August 2024 [15]. Urbanization has significantly increased the impervious surface area and raised environmental temperatures in Thanh Hoa city, causing ecological imbalances and urban landscape issues.

Traditional methods for determining data on temperature, rainfall, and humidity involve using monitoring stations, which can be costly and only reflect localized values, leading to errors when interpolating for larger areas [20].

Recently, remote sensing technology, with its multi-spectral and multi-temporal data, has offered significant advantages such as shorter update times and broader surface monitoring. The surface temperature value can also be monitored through thermal infrared bands. This issue has garnered considerable attention from scientists worldwide, including in Vietnam. Studies [1, 2, 6, 9, 11, 13] have investigated methods to calculate the Land Surface Temperature (LST) index to monitor temperature changes using optical images. The LST is an index used to determine surface temperature based on the energy emitted from objects captured in the thermal bands of optical images [20]. Research has evaluated urban heat islands using LST on Landsat 7 images [3], identified an inverse correlation between urban heat islands and urban green spaces on Landsat 8 images [10], and assessed the impact of human activities on thermal environments [12].

In most provinces and cities across Vietnam, significant impacts from climate change can be observed. Notably, studies indicate the expansion of thermal environments into suburban areas in Ho Chi Minh city, determining urban heat island phenomena from thermal infrared bands on Landsat images [18, 19, 8, 16, 14], or using ArcGIS to interpret Landsat satellite images to monitor urbanization processes in Ho Chi Minh city from 1989 to 2019 through impervious surfaces and Kappa coefficients [5].

Calculating the Land Surface Temperature (LST) index on the Google Earth Engine platform shows that the increase in the built-up area also contributes to rising thermal environments [17]. Another study [4] in Thanh Hoa City also identified the changes in land surface temperature in the region from 2000 to 2017 using thermal infrared Landsat remote sensing data.

The above studies demonstrate the suitability of using the LST index for monitoring thermal environmental changes with remote sensing images. Moreover, the development of remote sensing and artificial intelligence technology has led to the emergence of numerous free tools available to users. Google Earth Engine (GEE) developed by Google, with its satellite database of Earth's surface, is recognized as a cloud-based platform for processing and analyzing spatial data, allowing convenient and efficient monitoring of basin surface changes (such as surface temperature, land cover, land use situations, etc.). GEE stores vast amounts of geographical data collected from various satellite imagery sources, with regularly updated images to better serve research needs, enabling remote sensing image processing, machine learning algorithms, and spatial analysis tools to yield reliable results. GEE is built on a cloud computing platform that handles large data volumes, overcoming the limitations of data storage or image processing speed, and computational volume compared to traditional image processing methods. It can be regarded as a supportive tool for researchers to access and utilize available data in using satellite imagery for managing and monitoring natural resources and the environment [7]. This is also the approach that the paper employed to use the GEE platform for calculating the land surface temperature index through a period of 2000 to 2023. Additionally, the paper also developed the Earth Engine Apps for sharing results conveniently with users for querying information.

2. Data and research methods

This study employed the near-infrared bands, the thermal infrared bands, and the red bands from optical imagery of Landsat 5, Landsat 8, and Landsat 9, at the raw scene level, with a spatial resolution of 30 meters, the time step of acquisition is day. The images were collected during the dry season (March, April, May) over Thanh Hoa city in the years 2001, 2007, 2010, 2015, 2019, 2020, 2022, and 2023, with less than 5 % of cloud cover, provided by the United States Geological Survey (USGS). The image source information is shown in Table 1, and the workflow of the key steps in the study is illustrated in Figure 1.

Table 1. Landsat image source information

Date	Image ID	Satellite type
21/4/2001	LANDSAT/LT05/C02/T1/LT05_125052_20010421	Landsat 5
08/5/2007	LANDSAT/LT05/C02/T1/LT05_125052_20070508	Landsat 5
25/2/2010	LANDSAT/LT05/C02/T1/LT05_125052_20100225	Landsat 5
30/5/2015	LANDSAT/LC08/C02/T1/LC08_125052_20150530	Landsat 8
18/5/2019	LANDSAT/LC08/C02/T1/LC08_125052_20190518	Landsat 8
08/3/2020	LANDSAT/LC08/C02/T1/LC08_125052_20200308	Landsat 8
08/4/2022	LANDSAT/LC08/C02/T1/LC08_125052_20220408	Landsat 8
05/5/2023	LANDSAT/LC09/C02/T1/LC09_125052_20230505	Landsat 9

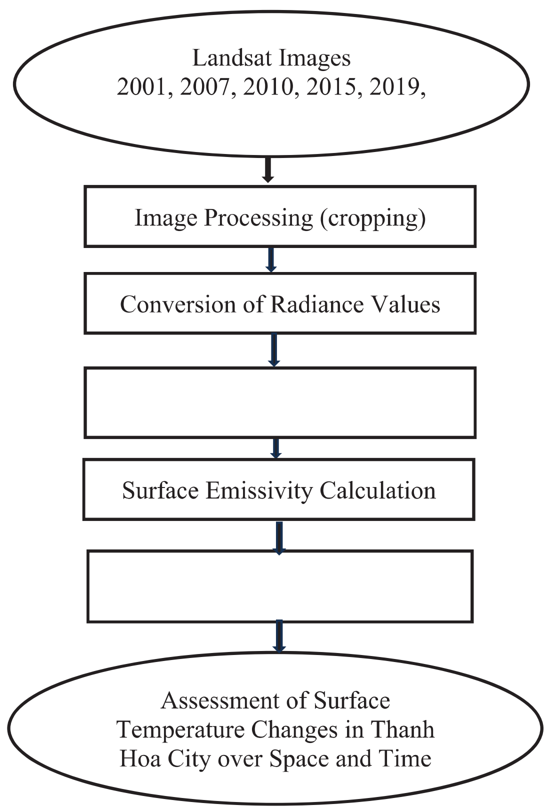


Figure 1: Workflow for evaluating the surface temperature changes in Thanh Hoa city

Surface temperature on satellite images is determined based on the energy reflected from objects on the Earth's surface, captured by sensors in the thermal infrared range [20]. According to the workflow in Figure 1, the steps for calculating surface temperature index in this paper are as follows:

Step 1: Convert Digital Number (DN) to radiance value.

For Landsat 5 images, the radiance conversion is calculated using Equation (1):

$$L_\lambda = ((L_{max} - L_{min})/(Q_{cal,max} - Q_{cal,min})) * (Q_{cal} - Q_{Cal,min}) + L_{min} \quad (1)$$

where: L_λ: Radiance value

L_{max}: Maximum spectral radiance (RADIANCE_MAXIMUM-BAND_6_VCID_1)

L_{min}: Minimum spectral radiance (RADIANCE_MINIMUM-BAND_6_VCID_1)

Q_{cal}: Pixel value of the thermal band (Band 6)

$Q_{cal,max}$, $Q_{cal,min}$: Maximum and minimum radiance values calibrated as integers.

For Landsat 8 and 9, the radiance value is determined using Equation (2):

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

where: L_λ: Radiance value

M_L: Radiance scaling factor (RADIANCE_MULT_BAND_10)

A_L: Conversion factor in metadata (RADIANCE_ADD_BAND_10)

Q_{cal}: Pixel value of the thermal band (Band 10)

Step 2: Convert radiance to brightness temperature using Equation (3):

$$T_B = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (3)$$

where: K_1; K_2: Calibration constants for the thermal infrared band of the satellite image

T_B: Brightness temperature (°K)

L_λ: Radiance value

Step 3: Calculate surface emissivity using Equation (4), emissivity of natural surfaces may vary based on soil and vegetation characteristics, so it depends on the land cover type:

$$\varepsilon = f_v * \varepsilon_{vegetation} + (1 - f_v) * \varepsilon_{bare\ soil} \quad (4)$$

where: $\varepsilon_{vegetation}$ Emissivity of vegetation = 0.97

$\varepsilon_{bare\ soil}$: Emissivity of bare soil = 0.96

f_v: The fractional vegetation or the proportion of vegetation within a pixel. The value of f_v is calculated using Equation (5)

$$f_v = ((NDVI - NDVI_{soil})/(NDVI_{vegetation} - NDVI_{soil}))^2 \quad (5)$$

The value of f_v will be 0 for bare soil and 1 for areas fully covered by vegetation.

Step 4: Calculate the land surface temperature using Equation (6):

$$LST = \frac{T_B}{1+\frac{\lambda * T_B}{\rho} * ln\varepsilon} - 273.15 \quad (6)$$

LST: Surface temperature (°C)

T_B: Brightness temperature (°K)

λ : Head Channel center wavelength (Band 10)

ε: Surface emissivity

$$\rho = \frac{h*c}{K} = 1{,}438 * 10^{-2} \text{ mK}$$

h = 6,626.10^{-34} J.sec: Planck Constant;

C = 2,998.10^{8} m/sec: Speed of light;

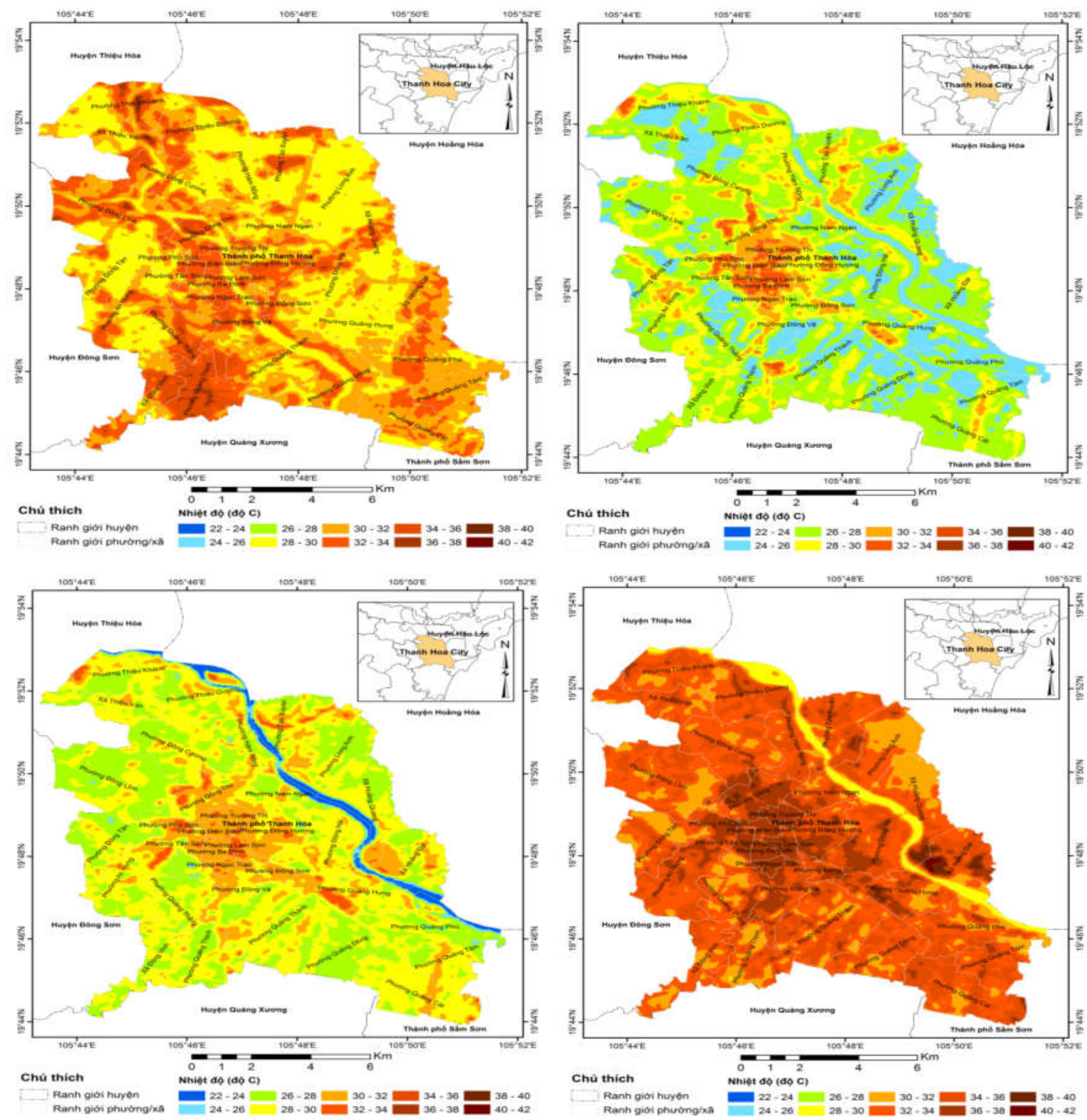
K = 1,38.10^{-23} J/K or 5,67.10^{-8} $Wm^{-2}K^{-4}$: Stefan Bolzmann Constant)

The calculations are performed on the Google Earth Engine platform, which enables quick processing and analysis of satellite imagery, helping to effectively determine surface temperatures in the study area.

3. Research results

3.1. Land surface temperature values in Thanh Hoa city from 2000 to 2023

From the land surface temperature values calculated for the area of Thanh Hoa city, the study used QGIS tools to construct thermal maps for the years 2001, 2007, 2010, 2015, 2019, 2022, and 2023. The results indicated that land surface temperature values fluctuated over different periods, as shown in Figure 2.



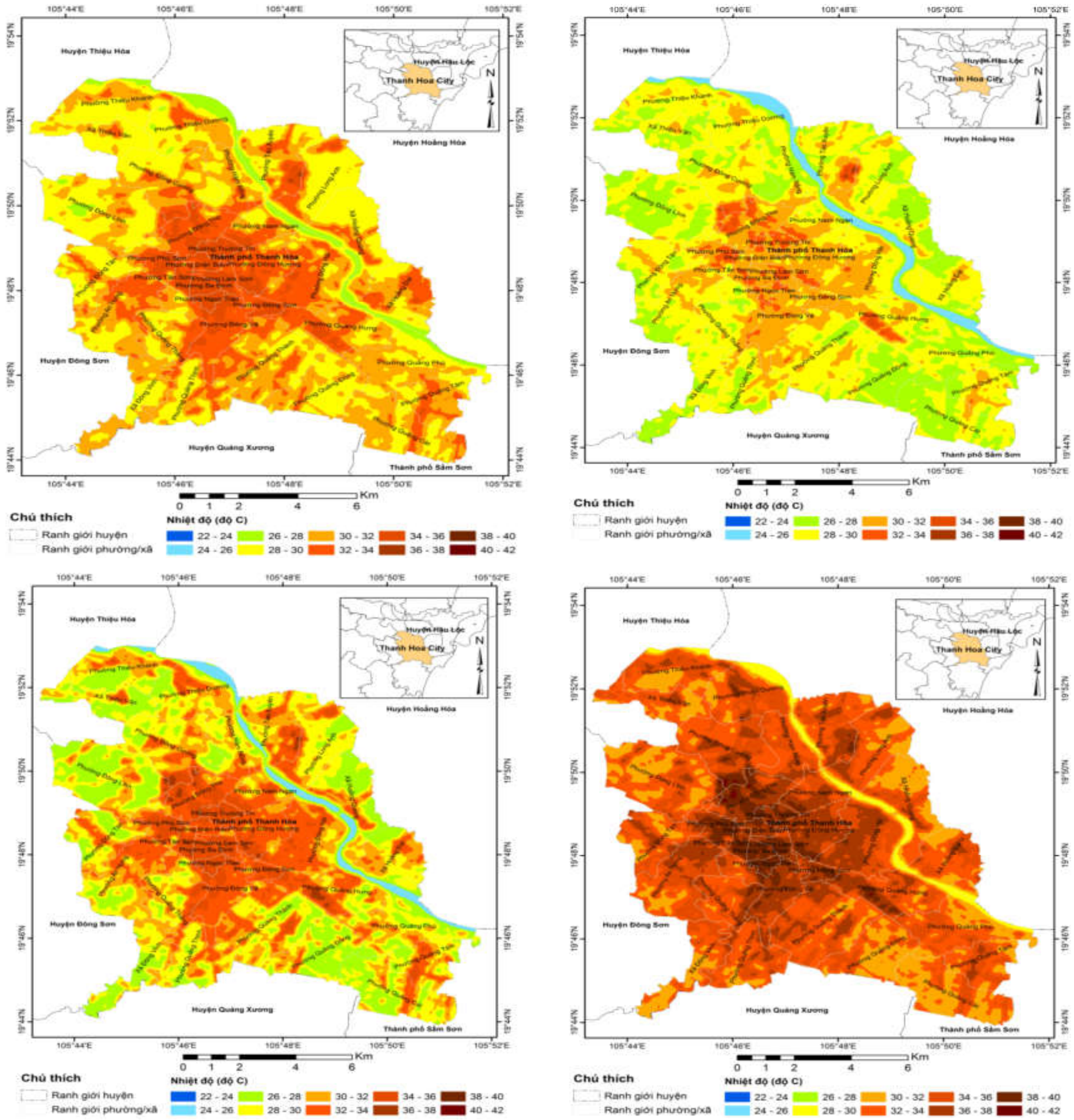


Figure 2: Surface temperature maps of Thanh Hoa city for the period 2000 - 2023

The spatial distribution of surface temperature in Thanh Hoa city, Thanh Hoa province, from 2000 to 2023, at various time points: 2001, 2007, 2010, 2015, 2019, 2020, 2022, and 2023, is shown in Figure 2. The area statistics for surface temperature in Thanh Hoa city according to different temperature groups (Table 2, Figure 3) indicate that temperatures exhibit varying trends over time and space.

Over time, it is evident that the average surface temperature reached its highest value in 2023, followed by 2015, 2019, 2001, 2022, and the lowest in 2007. From 2000 to 2023, temperatures fluctuated between 22 °C and 42 °C. The years 2015, 2019, and 2023 are considered record hot years for Thanh Hoa in general and Thanh Hoa city in particular, with observed temperatures recorded at the Thanh Hoa Meteorological Station in May being 39.8 °C (May 29, 2015), 41.0 °C (May 19, 2019), and 39.9 °C (May 17, 2023).

In 2015, areas with temperatures exceeding 32 °C were primarily concentrated in the central districts of Thanh Hoa city (in the wards of Dien Bien, Dong Tho, Truong Thi, Ba Dinh, etc.), and industrial zones located in the areas of Tay Bac Ga, Hac Thanh, and Hoang Long Bridge, with a total area of 118.07 km², accounting for 80.6 % of the total surface area of Thanh Hoa city. There were 18.81 km² of areas with temperatures exceeding 38 °C, accounting for 12.8 % of the city's total area.

From 2015 to 2023, there has been a remarkable change in surface temperature variability. In the industrial zones and inner Thanh Hoa city, high temperatures fluctuated between 38 °C and 42 °C.

Table 2. Statistics of areas corresponding to temperature groups in Thanh Hoa city from 2000 to 2023

Temperature range (°C)	Corresponding area for each year (km²)							
	2001	2007	2010	2015	2019	2020	2022	2023
22 - 24	0.00	0.00	3.51	0.00	0.00	0.00	0.00	0.00
24 - 26	0.00	31.49	2.34	0.00	0.00	4.66	3.29	0.00
26 - 28	0.00	65.66	45.50	0.00	4.90	36.93	29.36	3.45
28 - 30	50.44	34.17	69.51	4.60	52.20	69.48	40.09	28.80
30 - 32	55.22	11.80	22.63	23.79	49.98	29.77	32.70	44.21
32 - 34	29.82	3.28	2.94	56.45	30.14	5.07	29.11	36.87
34 - 36	10.00	0.09	0.04	42.81	9.18	0.46	11.10	25.36
36 - 38	0.90	0.00	0.00	17.26	0.04	0.05	0.79	7.55
38 - 40	0.08	0.00	0.00	1.39	0.00	0.00	0.01	0.20
40 - 42	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00

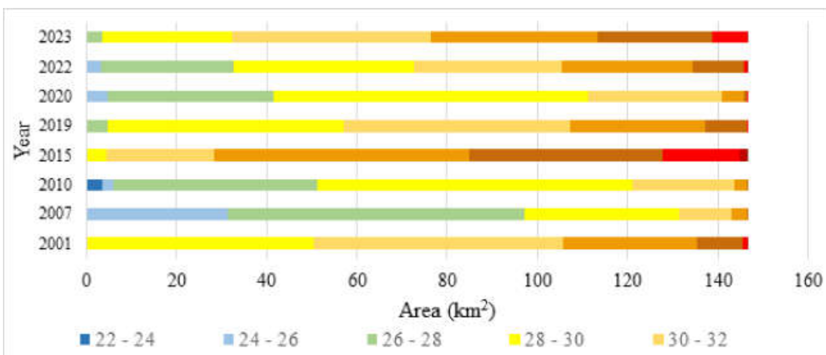


Figure 3: Statistics of areas corresponding to temperature groups in Thanh Hoa city for the period 2000 - 2023

Additionally, based on the study results calculating surface temperature values from satellite images using Google Earth Engine, the study developed a basic Earth Engine App for users to access and query surface temperature values at any location within the study area. The Earth Engine App can be accessed via the following link: https://ee-ntrnhan2022.projects.earthengine.app/view/nhietdobemat-tp-thanh-hoa.

3.2. Evaluating results of Landsat-derived surface temperature

To evaluate the accuracy of surface temperature values, the study compared the results of temperature values derived from satellite images and temperature values observed at the Thanh Hoa meteorological station. The study used temperature data observed at 3:00 p.m. each day for the 8 study years. These are the times that coincide with the time of satellite image acquisition for the study area, to compare and check the calculated values of surface temperature from satellite images through the Google Earth Engine platform, details as in Table 3.

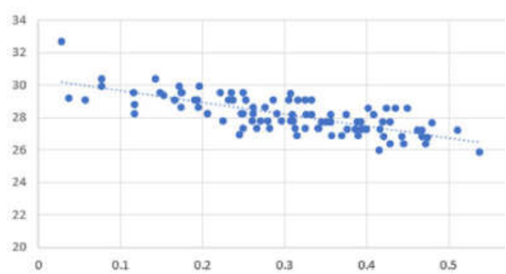
Table 3. Measured and satellite-derived surface temperature

Date	Measured temperature (°C)	Satellite-derived temperature (°C)	Difference (°C)	Relative error (%)
21/04/2001	36.3	36.9	0.6	1.65
08/05/2007	27.5	28.5	1.0	3.49
25/02/2010	30.5	29.9	0.6	1.96
30/05/2015	36.2	37.1	0.9	2.48
18/05/2019	34.8	35.3	0.5	1.43
08/03/2020	26.4	27.3	0.9	3.40
08/04/2022	29.1	30.5	1.4	4.81
05/05/2023	34.8	35.6	0.8	2.29

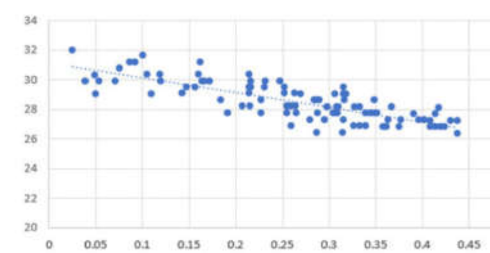
From the results shown in Table 3, it can be observed that the difference is insignificant, ranging from 0.5 °C to 1.4 °C. The difference in temperature values in 2022 is the highest at 1.4 °C and the corresponding relative error is 4.81 %. It shows that the error is within the acceptable range. Therefore, the calculated results of the surface index values from satellite images in this study are acceptable.

3.3. Correlation analysis of surface temperature and normalized difference vegetation

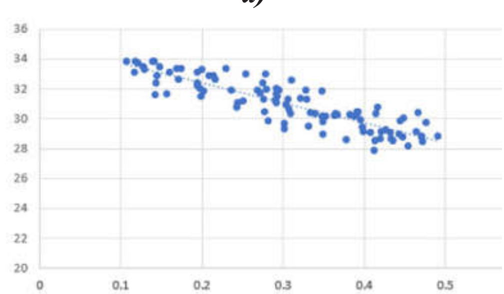
The Normalized Difference Vegetation Index (NDVI) and surface temperature index were calculated on Google Earth Engine, afterwards a correlation relationship was built based on the Pearson correlation coefficient (ρ). The results indicated that there was a negative correlation between the surface temperature and the NDVI and a high Pearson correlation coefficient: in 2007, the correlation coefficient (ρ_xy) was -0.762 (Figure 4a); in 2015, ρ_xy was -0.822 (Figure 4b); in 2019, ρ_xy was -0.865 (Figure 4c), and in 2023, ρ_xy was -0.893 (Figure 4d).



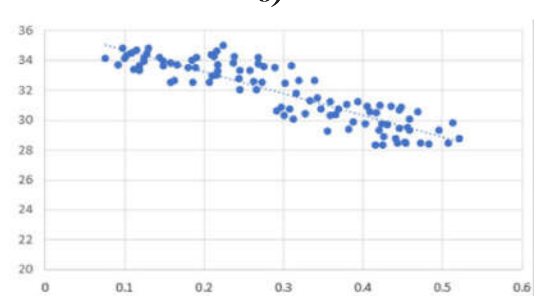
a)



b)



c)



d)

Figure 4: Correlation between surface temperature index (LST - vertical axis) and Normalized Difference Vegetation Index (NDVI - horizontal axis) of Thanh Hoa city in the period 2000 - 2023

3.4. Investigating land surface temperature in Thanh Hoa city from 2000 to 2023

It can be observed that the increase in the thermal environment in Thanh Hoa city from 2000 to 2023 can be attributed to several indirect factors, including urbanization and the structural transition of the economy, with a shift in land use from agricultural land to urban and industrial land.

From 2015 to 2023, Thanh Hoa expanded its urban units from 30 in 2016 to 70 in 2020, including the renovation and expansion of 24 urban units and the establishment of 40 new ones. In 2020, changes in land use resulted in a decrease in agricultural land, while non-agricultural land increased, especially for commercial services.

With rapid urbanization, Thanh Hoa city is expected to meet the criteria for type I urban areas by 2024. This, combined with current climate change conditions, has significantly raised surface temperatures by 2023. Areas with high surface temperatures correspond to regions with high building density, such as residential areas, urban centers, and industrial zones.

In addition, according to the resolution on the approval of the 1/2000 scale construction zoning plan for the Western Industrial Park of Thanh Hoa city in July 2024, the total planning area is about 645.2 hectares and the structure and planning criteria for land use include 447.94 hectares for factories, accounting for 69.43 % with a maximum building density of 70 %, a maximum building height of 5 floors, and a maximum land use coefficient of 3.5 times; 36.39 hectares for administrative and public-service land, accounting for 5.64 % and 8.12 hectares for infrastructure covering 1.26 %. Additionally, green space accounts for 10.14 %; Water surface for 3.04 %, and transportation for 10.49 %. Regarding spatial organization, the industrial zone, spanning approximately 645.2 ha, is divided into two sub-zones: Zone A, about 375 hectares located south of the route from Thanh Hoa city to Tho Xuan Airport, and Zone B, about 270.2 hectares located North of the same route. These favorable socio-economic development factors in Thanh Hoa province have contributed to a gradual increase in the thermal environment amidst current climate change.

Using the land surface temperature index allows for close monitoring of the trends in the thermal environment rapidly through the construction of tools to calculate temperature values from satellite images on Google Earth Engine. This shows that this tool is highly effective in extracting thermal values from satellite images, supporting thermal environmental monitoring in general and environmental resource management in particular in the context of climate change. However, the study still has data limitations due to the inability to collect satellite image data coinciding with the highest measured temperatures at monitoring stations. Furthermore, to evaluate the reasons for the transformation of land use structure and its impact on the thermal environment comprehensively, continuous monitoring of surface cover changes or mapping of the current land use status annually should be conducted using high-resolution remote sensing imagery combined with field surveys. This would contribute to the development of measures to address the existing issues in urban planning.

4. Conclusion

With the advantages of Google Earth Engine in calculating and processing satellite images to derive surface temperature values for Thanh Hoa city, the results indicated that surface temperature values in the study area have varied over the period from 2000 to 2023. Particularly, the years 2015 and 2023 recorded high surface temperatures in densely populated areas, commercial centers, and industrial zones such as Tay Bac Ga and Hac Thanh. This study demonstrated that Google Earth Engine can quickly and effectively monitor changes in the thermal environment through satellite imagery. Furthermore, the study has developed a basic Earth Engine App to allow users to easily and quickly query surface temperature values at their desired locations. However, further research is needed on surface cover changes that closely impact surface temperature trends during urbanization in major cities.

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