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Spatio-Temporal Analysis of Vegetation Index Change on Land Surface Temperature in Yogyakarta Special Region Using MODIS Imagery (2000-2023)

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ABSTRACT

Yogyakarta has become a province renowned for its abundance of tourist destinations and learning opportunities for students from all over Indonesia. Temperature and vegetation density are key factors contributing to comfort in both academic pursuits and recreational activities. This study utilizes NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) to determine these crucial parameters. MODIS imagery serves as a vital data source for analyzing NDVI and LST. The aim of this research is to comprehend the environmental dynamics of DIY (Yogyakarta Special Region) by exploring the relationship between NDVI and LST. Through the Pearson correlation method, the relationship between these variables is deeply evaluated. The analysis reveals a significant correlation between changes in NDVI and LST, indicating a complex interaction between vegetation and land surface temperature. However, these significant findings have minimal impact on Yogyakarta City and Sleman, which serve as the focal points of community activities in Yogyakarta. These changes can be attributed to various factors, including changes in land use, urbanization, and climate variability, which show weak correlation values when associated with vegetation. Another finding is that Yogyakarta City exhibits the most distinct response in vegetation density and surface temperature compared to the surrounding four cities. This is attributed to Yogyakarta City being the administrative center and economic hub of DIY. These findings provide a deeper understanding of the environment's response to these factors in DIY. By employing spatial and temporal analysis, this study offers valuable insights for climate change mitigation efforts and adaptation to the evolving environmental dynamics.

1. Introduction

The Special Region of Yogyakarta (DIY) is one of the provinces in Indonesia that has experienced rapid urbanization in recent years. This phenomenon has resulted in a decrease in greenery levels and an increase in surface temperatures. One of the areas of focus is the city of Yogyakarta. According to UU No. 26 of 2007 concerning Spatial Planning, the city of Yogyakarta, with an area of 3,250 hectares, must have a minimum of 975 hectares of green open space (RTH) [1]. Previous research has been carried out using satellite image interpretation to assess the area of green open space in the city of Yogyakarta to be 584.45 hectares, indicating a deficiency of 390.55 hectares of green open space [2]. The loss of vegetation cover, particularly in urban areas, has been associated with various negative impacts, including: (1) Increase in surface temperatures: Vegetation plays a crucial role in regulating microclimate temperatures. Trees and plants help cool the environment by absorbing solar radiation, providing shade, and releasing water vapor through transpiration. Loss of vegetation can lead to significant increases in surface temperatures, especially in densely populated urban areas with limited green open spaces [3];

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(2) Decline in air quality: Vegetation assists in purifying the air by absorbing pollutants such as nitrogen dioxide and sulphur dioxide. Loss of vegetation can result in a decline in air quality, which may pose health risks to the public [4]; (3) Increase in flood risks: Vegetation aids in absorbing rainwater and reducing surface water runoff. Loss of vegetation can heighten the risk of floods, particularly in urban areas with inadequate drainage systems [5].

The objectives of this study are manifold: firstly, to characterize the temporal trends and spatial patterns of vegetation index changes within Yogyakarta Special Region from 2000 to 2023; secondly, to investigate the corresponding variations in land surface temperature over the same period; and thirdly, to assess the relationship between vegetation index dynamics and land surface temperature fluctuations, identifying areas of significant impact and potential hotspots.

By conducting a comprehensive spatio-temporal analysis, this research endeavors to contribute valuable insights into the complex interactions between vegetation dynamics and land surface temperature variations in the context of Yogyakarta Special Region. The findings of this study have the potential to inform evidence-based land management strategies, facilitate climate change adaptation measures, and foster sustainable development practices in the region and beyond.

2. Data and Method

The location of the research to be carried out is on the island of Java. Astronomically, according to the Badan Informasi Geospasial, Special Region of Yogyakarta is located between 110.002937°- 110.834633° East Longitude and -7.541897° - -8.204329° South Latitude, with an estimated area of 3233,253 km^2, see Figure 1 [6].

The research was conducted over a span of 24 years from 2000 to 2023. Analysis will be performed monthly throughout these 24 years. MODIS satellite data is utilized for analyzing greenness indices and land surface temperature. Specifically, the greenness index data employs MOD13A1.061 Terra Vegetation Indices 16-Day Global, while the temperature data utilizes MOD11A2.061 Terra Land Surface Temperature and Emissivity.

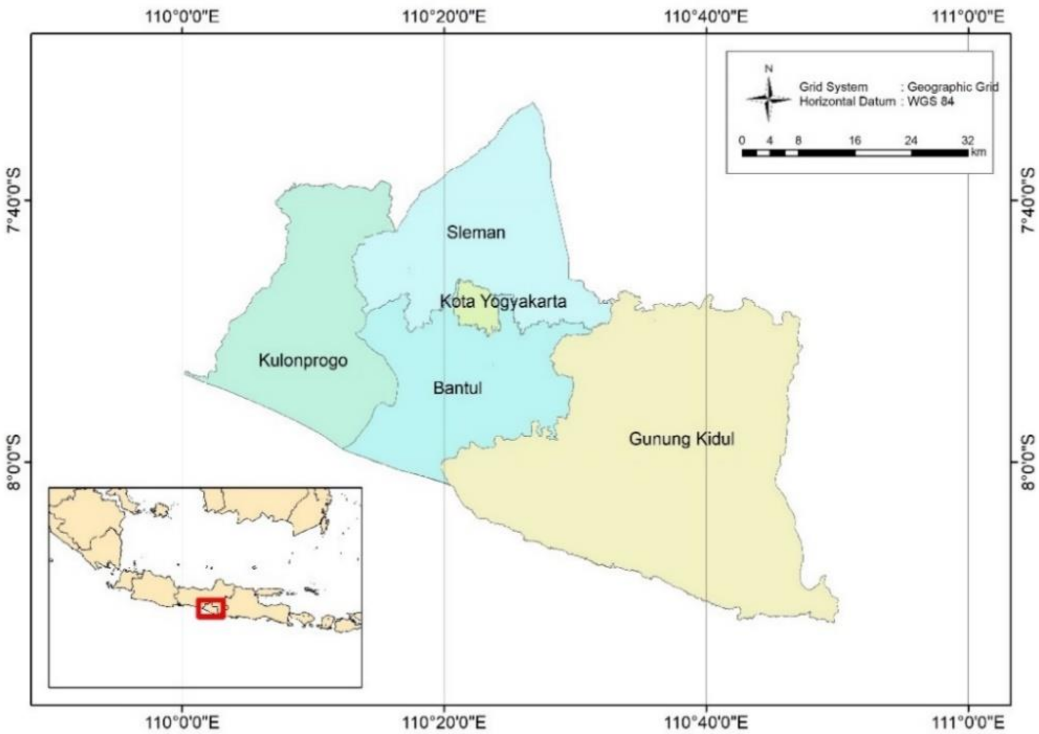

Figure 1. Area of Study (Yogyakarta Region)

This research used statistical methods to analyze the relationships we found between different sets of data. The specific technique used is called Pearson correlation. This method gives us a value between -1 and +1, where a higher value (positive or negative) indicates a stronger connection between the data. To understand how strong these connections are in our study, we'll refer to a classification system in Table 1 [7]. The strength of the correlation between the two data is classified into several classes as in Table 1.

Table 1. Strength of Correlation Coefficient [8]

Correlation Coefficient Value (R)	Correlation Strength
0.00 – 0.10	Neglected correlation
0.10 – 0.39	Weak correlation
0.40 – 0.69	Medium correlation
0.70 – 0.89	Strong correlation
0.90 – 1.00	Very strong correlation

The specific mathematical formula used to calculate R is as Equation 1.

$$R = r_{xy} = \frac{\sum(x_i - \bar{x_i})(y_i - \bar{y_i})}{\sqrt{\sum(x_i - \bar{x_i})^2}\sqrt{\sum(y_i - \bar{y_i})^2}} \quad (1)$$

This formula computes the correlation coefficient R, which ranges from -1 to 1 and indicates the strength and direction of the linear relationship between variable x and y. A value of R close to 1 suggests a strong positive linear relationship, R close to -1 indicates a strong negative linear relationship, and R close to 0 suggests little to no linear relationship between x and y [7].

2.1 Datasets

The Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator that can be used to analyze remote sensing measurements from remote platforms and assess whether the observed target or object contains green vegetation or not. NDVI can be modeled with a mathematical equation using the near-infrared (NIR) and red (R) channels as Equation 2 [9].

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (2)$$

Where red represents the reflectance from the visible red channel (R), and NIR is the reflectance in the near-infrared. The wavelength range for NIR is (750-1300 nm), and for red, it is (600-700 nm).

The NDVI values range from -1 to +1. High positive NDVI values indicate dense vegetation, while water has negative NDVI values. NDVI values of 0.1 and below represent barren rocks, snow, or sand. Moderate values (0.2 to 0.3) represent shrubs and grasslands, while high values represent tropical and subtropical areas [10].

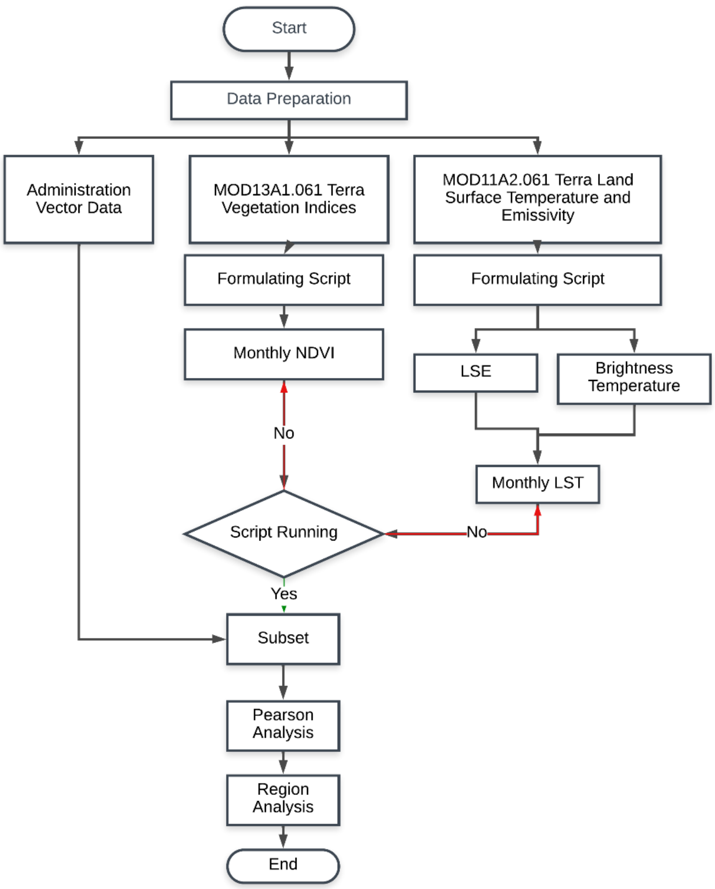

Figure 2. Flow Chart of The Research

Land Surface Temperature (LST) is the temperature measured or estimated from the ground surface or the entire surface of the Earth in a particular area at a specific time. LST is a critical parameter in environmental science and remote sensing as it influences physical, chemical, and biological processes on the Earth's surface.

LST is often measured using remote sensing techniques, primarily with satellites equipped with thermal sensors. Thermal sensors measure the infrared radiation emitted by the Earth's surface, which is then converted into temperature using appropriate algorithms.

The SC algorithm is a method for estimating Land Surface Temperature (LST) using data from a single thermal infrared band captured by a satellite sensor [11].

$$T_s = \gamma[1/\varepsilon(\psi_1 L_{sen} + \psi_2) + \psi_3] + \delta \qquad (3)$$

Where ε is the surface emissivity and (δ, γ) are two other parameters given as Equation 4.

$$\gamma \approx T_{sen}^2/b_\gamma L_{sen}; \quad \gamma \approx T_{sen} - T_{sen}^2/b_\gamma \qquad (4)$$

Where T_{sen} is the brightness temperature and ψ_1, ψ_2, ψ_3 are atmospheric functions, given as Equation 5.

$$\psi_1 = \frac{1}{\tau}; \quad \psi_2 = -L_d - \frac{L_u}{\tau}; \quad \psi_2 = L_d \qquad (5)$$

2.2 Methods

The workflow of this research is explained in Figure 2. The process is carried out by starting with data preparation, including:

1. Shapefile data of administrative boundaries of districts/cities (Geospatial Information Agency)
2. MOD13A1.061 Terra Vegetation Indices 16-Day Global (2000-2023)
3. MOD11A2.061 Terra Land Surface Temperature and Emissivity (2000-2023)

The data is then processed using a script in Google Earth Engine with a monthly temporal resolution from 2000 to 2023. NDVI is a green index that will be used to identify green space parameters in Yogyakarta. LST (Land Surface Temperature) is obtained by calculating the thermal emissivity and brightness temperature in MODIS imagery. The data will then be subsisted according to the administrative boundaries of the districts/cities in the Special Region of Yogyakarta. The analyses performed are Pearson correlation analysis and analysis for each region.

3. Results and Discussion

3.1. NDVI

The Normalized Difference Vegetation Index (NDVI) is calculated using Terra MODIS data. Annual data is used to analyze changes in vegetation patterns from 2000 to 2023. The annual NDVI patterns, as shown in Figure 3, indicate that vegetation in all districts except Yogyakarta city has experienced a stable trend, with vegetation index even tending to rise in Kulon Progo.

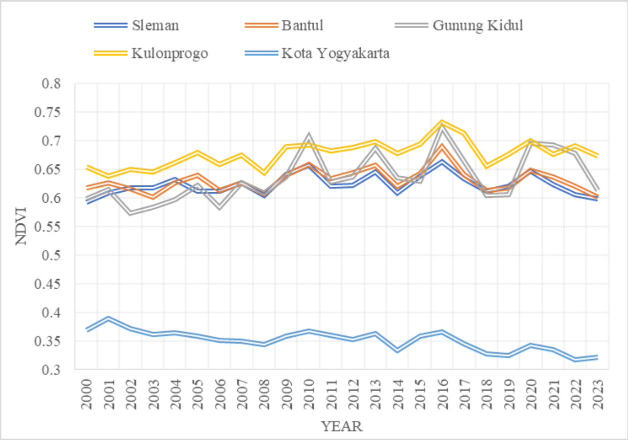

Figure 3. Annual NDVI in Yogyakarta

Spatial analysis highlights the spatial variation of vegetation index in the Yogyakarta Special Region. It was found that there are significant differences in vegetation density between urban and rural areas. Rural areas, especially Gunungkidul, tend to have thicker vegetation compared to urban areas such as Yogyakarta City and Sleman.

Things to note in this annual analysis are that Yogyakarta City has a much lower vegetation index compared to the other four cities. This should certainly be a cause for concern because the population of Yogyakarta is concentrated in the city area. It's also found from the results that the NDVI value in Yogyakarta City is decreasing. Therefore, with these results, the local government needs to conduct an evaluation regarding the decreasing trend observed from year to year.

The NDVI values are then visualized using a map in Figure 4. The NDVI values obtained range from 0 to 1, indicating that the darker green the area, the denser the vegetation in that area.

Table 2. Average Value of NDVI in Yogyakarta

City	NDVI Value
Sleman	0.623
Bantul	0.631
Gunungkidul	0.635
Kulon Progo	0.677
Kota Yogyakarta	0.351

Table 3. Vegetation Index in Yogyakarta Subdistricts

City	NDVI
Danurejan	0.33
Gedongtengen	0.32
Gondokusuman	0.35
Gondomanan	0.29
Jetis	0.63
Kotagede	0.43
Kraton	0.35
Mantrijeron	0.38
Mergangsan	0.36
Ngampilan	0.32
Pakualaman	0.33
Tegalrejo	0.41
Umbulharjo	0.40
Wirobrajan	0.35

The highest vegetation index is in the Kulon Progo area, which is consistent with the results obtained in Figure 3, where Kulon Progo has the highest average NDVI compared to other cities in Yogyakarta.

Yogyakarta City is filled with orange color, indicating minimal vegetation in that area and it is far behind other areas that are still dominated by vegetated areas. The average vegetation values in Yogyakarta can be observed in Table 2.

The very low vegetation density see in Figure 4 prompts the author to conduct an analysis using the zonal statistics method, particularly focusing on the districts (kecamatan) within the city of Yogyakarta. This analysis will entail examining the average density over a span of 24 years from 2000 to 2003. Table 3 represents various vegetation density values for the regions within Yogyakarta City.

Based on Table 3, Jetis emerges as the district with the highest vegetation index among the other 13 districts, with a commendable value of 0.63. Meanwhile, several locations that may require attention for the addition of vegetation or green spaces are Gondomanan, Gedongtengen, and Ngampilan.

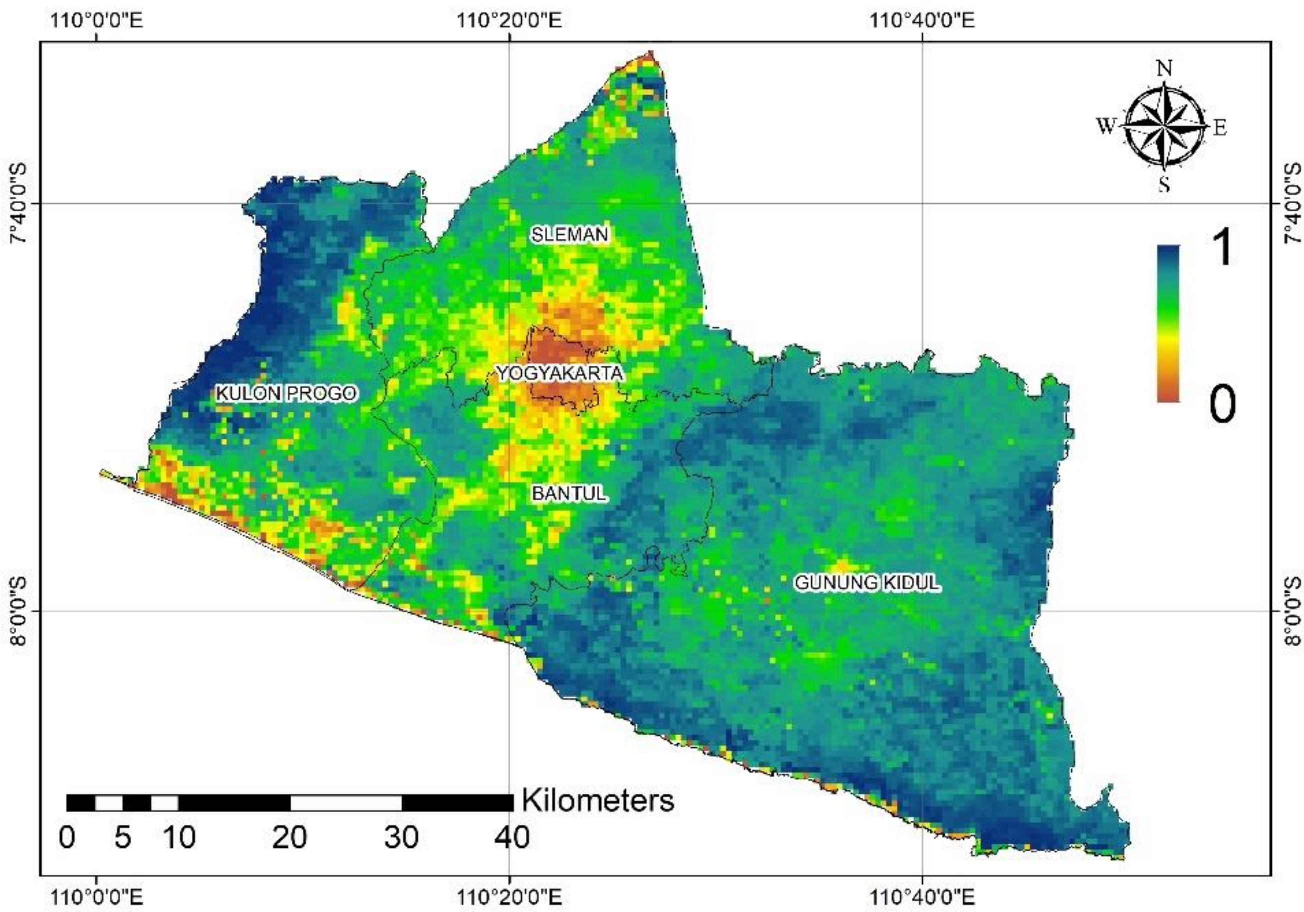

Figure 4. NDVI of Yogyakarta Province

3.2. LST

Land Surface Temperature (LST) is calculated based on brightness temperature and thermal emissivity values. The results of LST can be seen per city in Figure 5. The data is acquired from 2000 to 2023 using the MOD11A2.061 Terra Land Surface Temperature and Emissivity dataset. The data represents the annual mean from all monthly data per year.

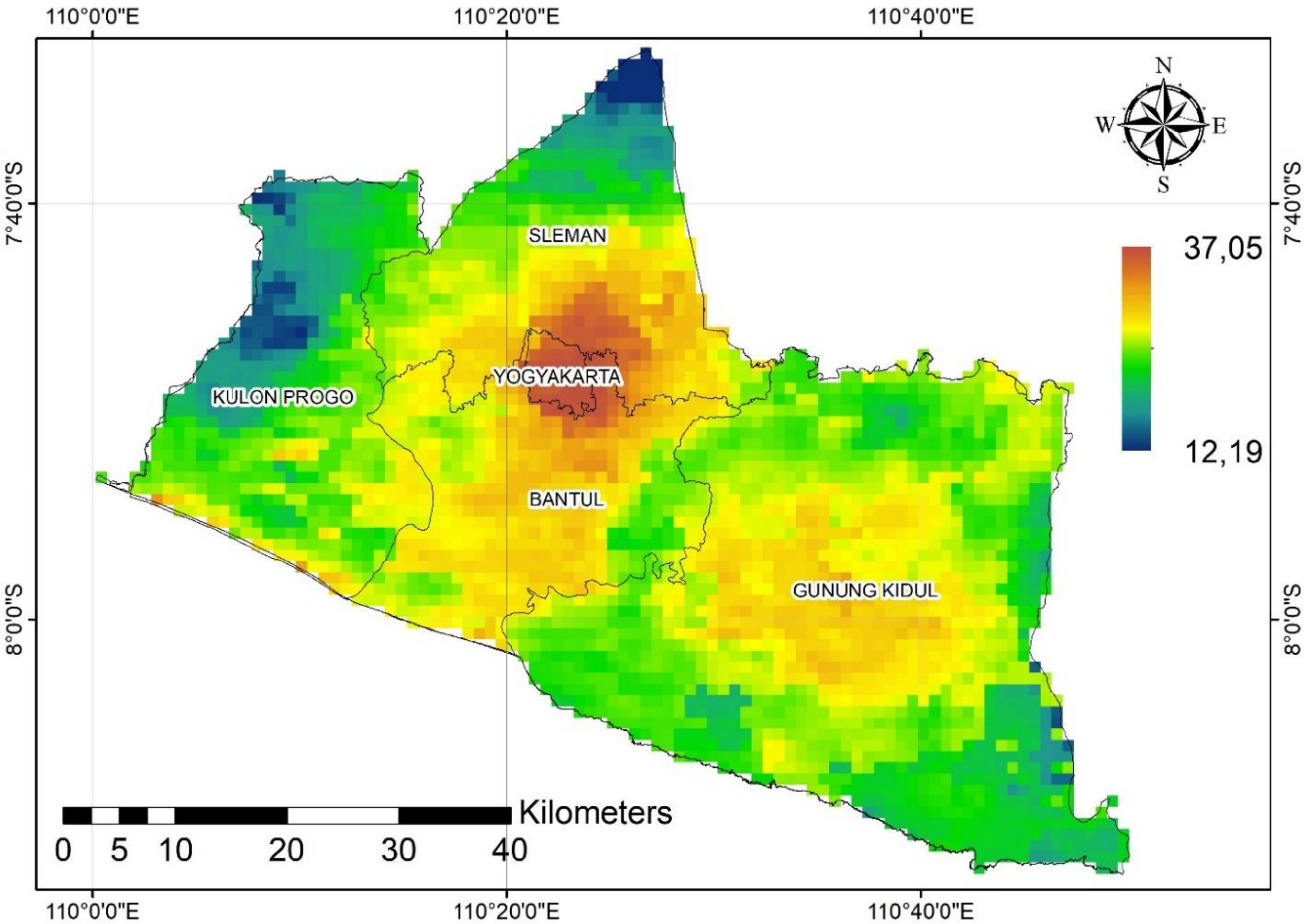

Figure 5. LST of Yogyakarta Province

The spatial pattern of land surface temperature was identified using MODIS imagery data. Areas with thicker vegetation tend to exhibit lower land surface temperatures, whereas areas with lower vegetation density or more built-up land tend to have higher temperatures.

The temperature values from Figure 5 show that Yogyakarta City has the highest average temperature in the Yogyakarta Province compared to other cities, with an average temperature of 37.23°C. Kulon Progo still holds the title of the city with the lowest average temperature among all cities, with a value of 29.45°C. Figure 5 indicates that Yogyakarta City requires more attention regarding air temperature.

The analysis then focused on the city of Yogyakarta to observe which areas have the highest temperatures. Here are the results of LST (Land Surface Temperature) for each district in the city of Yogyakarta.

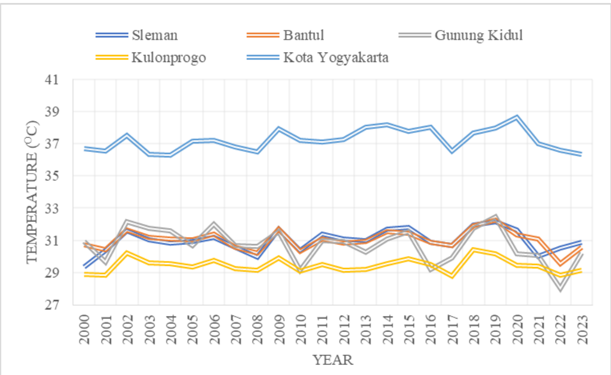

Figure 6. Annual LST (2000-2023) of Yogyakarta Province

Table 4. Average LST over 24 years (2000-2023) in Yogyakarta Subdistricts

City	LST (ºC)
Danurejan	36.81
Gedongtengen	35.61
Gondokusuman	35.96
Gondomanan	35.66
Jetis	31.24
Kotagede	36.54
Kraton	36.80
Mantrijeron	35.71
Mergangsan	35.61
Ngampilan	36.17
Pakualaman	36.81
Tegalrejo	32.23
Umbulharjo	36.65
Wirobrajan	34.27

Based on the average temperature over 24 years in Table 4, the Pakualaman and Danurejan subdistricts have the highest average temperature at 36.81°C. Meanwhile, Jetis has the lowest average temperature at 31.24°C.

The statements above both indicate that Jetis is the most suitable district in terms of both vegetation density and temperature in the city of Yogyakarta compared to other districts. Meanwhile, Danurejan is a district that requires more attention regarding both temperature and vegetation.

3.3. Pearson's Correlation Analysis

Spatial analysis reveals a complex spatial pattern in the relationship between changes in vegetation index and land surface temperature over the observed period. There is spatial variation in the degree of influence of vegetation on land surface temperature, influenced by local environmental factors such as land use patterns, topography, and human activities.

Overall, spatial analysis provides a deeper understanding of the spatial distribution patterns of changes in vegetation index and land surface temperature in the Yogyakarta Special Region. This information is crucial for the development of climate change mitigation strategies and environmental management in the region.

In this study, an analysis was conducted based on the greenness index of an area (vegetation density) and air temperature. The results from subsection 3.1 and subsection 3.2 suggest that there is a relationship between the greenness of an area and air temperature, as depicted in Figure 4 and Figure 5. In brief, it can be concluded that the smaller the green index value of an area, the hotter the area tends to be.

Subsequently, Pearson correlation analysis was performed to determine the extent to which the greenness value of an area influences the temperature in that area. Two types of analyses were conducted: firstly, using spatial analysis with a fishnet method per 1000x1000 meters; secondly, employing temporal analysis using temperature data and greenness index data for each month.

Thus, through Pearson correlation analysis, it will be possible to ascertain the extent of the relationship between area greenness and air temperature, both spatially and temporally, as well as the significance of their impact on the phenomenon.

3.3.1. Temporal Analysis

The temporal analysis was conducted by examining the greenness index and temperature for each month. Figure 7 to Figure 11 depict scatter plots illustrating the relationship between each district/city.

Yogyakarta stands out as the city with the highest attention due to having the smallest vegetation index value and the highest temperature value. However, the results of the Pearson correlation analysis suggest a different assumption because the correlation coefficient value is not as high as expected. A value of R = 0.285 was obtained, indicating a weak relationship between vegetation index and temperature in Yogyakarta City. Conversely, in the other four cities in the vicinity with minimal built-up land, a higher correlation is observed as presented in Figure 7 to Figure 11.

Table 5. Correlation Coeficient Summary

City	R value	Strenght
Sleman	0.339	Weak
Bantul	0.495	Moderate
Gunungkidul	0.792	Strong
Kulon Progo	0.556	Moderate
Kota Yogyakarta	0.285	Weak

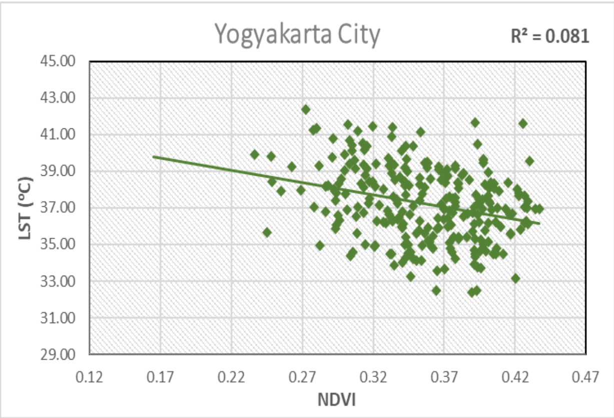

Figure 7. Scatter Plot NDVI and LST in Yogyakarta City

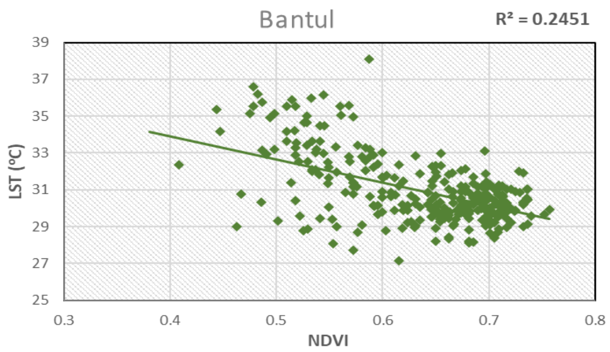

Figure 8. Scatter Plot NDVI and LST in Bantul

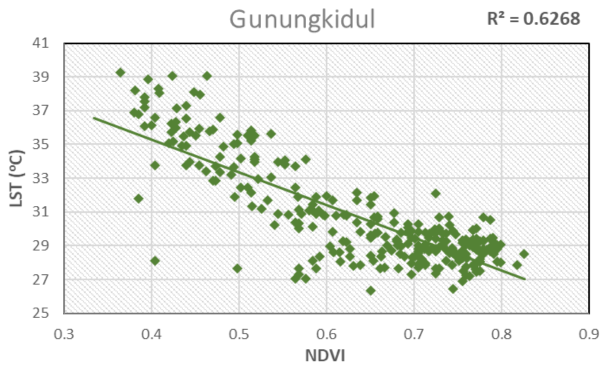

Figure 9. Scatter Plot NDVI and LST in Gunungkidul

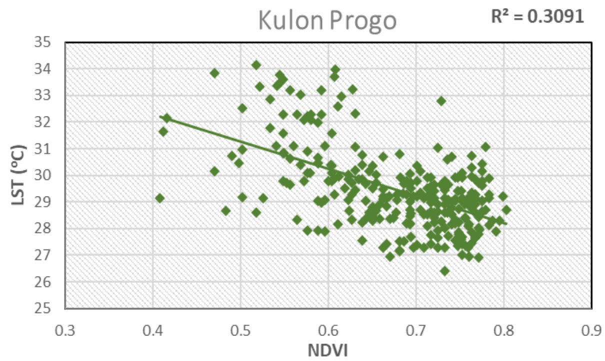

Figure 10. Scatter Plot NDVI and LST in Kulon Progo

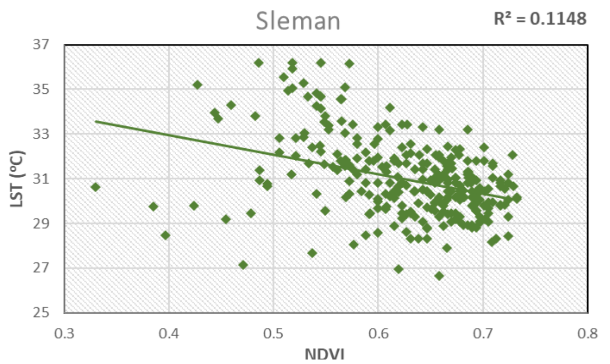

Figure 11. Scatter Plot NDVI and LST in Sleman

Based on the temporal analysis results (Table 5), an interesting finding emerged where cities with a higher amount of built-up land have lower correlation values compared to other cities. Gunungkidul is the city with the highest correlation value among others, indicating a strong correlation (0.792), which means that the temperature in Gunungkidul is heavily influenced by the density of vegetation. Meanwhile, weak correlation values were obtained when the location has high population activities, namely in Yogyakarta City and Sleman. These activities can be identified through the road performance index provided by the Transportation Agency of the Special Region of Yogyakarta Province, summarized in the "Transportation Statistics 2021" as Table 6.

Table 6. Road Performance in Yogyakarta [12]

City	Road Performance
Sleman	0.70
Bantul	0.59
Gunungkidul	0.36
Kulon Progo	0.36
Kota Yogyakarta	0,765

In this analysis, it can be concluded that temperature is not only influenced by vegetation density, especially in the areas of Yogyakarta City and Sleman. Air pollution, the number of vehicles, and built-up land area also need to be considered in the analysis when conducted in urban areas.

3.3.2. Spatial Analysis

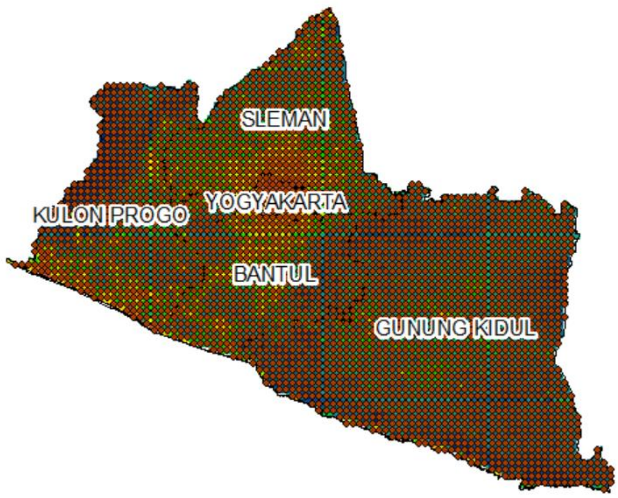

Figure 12. Fishnet Analysis 1 km^2

Spatial analysis using the Fishnet technique is a method used to divide an area into grids or uniform cells (Figure 12). The purpose of this analysis is to investigate the spatial distribution of specific phenomena or objects within the study area. Spatial analysis is conducted by sampling every 1 km². The results of the sampling can be observed in Figure 13.

The scatter plot generated based on the results of the spatial fishnet analysis obtained lower residual results. The analysis states that the correlation between vegetation density and surface temperature is quite high, with a value of R (correlation coefficient) = 0.57, which is a moderate influence when we use samples with a resolution of 1 km^2.

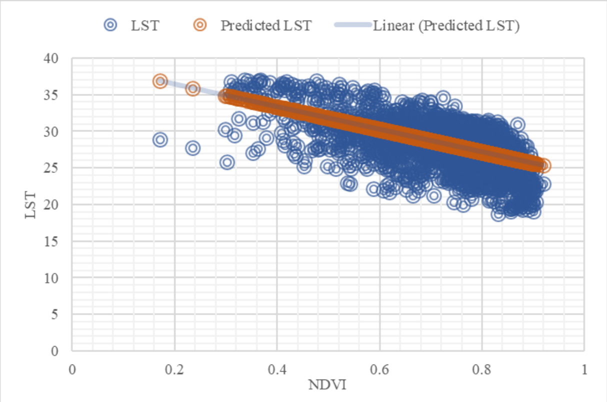

Figure 13. Scatter Plot Sampel 1 km of Yogyakarta

Conclusions

The Impact of Vegetation Index Change on Land Surface Temperature: Findings from the analysis indicate a relationship between changes in vegetation index and land surface temperature in the Yogyakarta Special Region. Two analyses were conducted: temporal analysis indicates that Gunungkidul Regency had the highest influence of vegetation density change on affecting surface temperature, while Yogyakarta City had the lowest influence. This is because variables in temperature change are not solely dependent on green spaces but also on air pollution, built-up land area, industrial activities, population density, and other variables that could be further investigated. Furthermore, spatial analysis using the fishnet method with 1 km² grid shows a moderate correlation, meaning vegetation change is not the sole factor influencing land surface temperature changes throughout the period of 2000-2023.

The Spatio-Temporal Trends: Spatio-temporal analysis reveals complex patterns of change in the relationship between vegetation index and land surface temperature in the Yogyakarta Special Region. These patterns include seasonal variations as well as long-term changes in this relationship.

The Urbanization Impact: Urbanization and urban growth in Yogyakarta have the potential to influence the relationship between vegetation and land surface temperature. Findings highlight the importance of considering urbanization impacts in understanding urban environmental dynamics.

Utilization of MODIS Imagery: The use of MODIS imagery contributes significantly to understanding the environmental dynamics of the Yogyakarta Special Region. These images enable comprehensive spatio-temporal analysis of vegetation and land surface temperature changes.

Policy Implications: These findings have important implications for environmental planning and management in the Yogyakarta Special Region. The information obtained can be used to design policies aimed at maintaining ecosystem balance and reducing the negative impacts of environmental changes.

Research Expansion: These conclusions underscore the need for further research to better understand the factors influencing vegetation and land surface temperature changes in Yogyakarta. Further studies can integrate additional factors such as land use, rainfall patterns, human activities, and the extent of built-up land to gain a more holistic understanding.

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