

MAPPING VEGETATION DENSITY (NDVI) AND LAND SURFACE TEMPERATURE (LST) TO SUPPORT URBAN PLANNING ADAPTATION TO CLIMATE CHANGE IN SEMARANG CITY

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ABSTRAK

Climate change is a global issue with significant implications for urban planning. This study examines Vegetation Density (NDVI) and Land Surface Temperature (LST) in Semarang City to support climate-adaptive urban planning. Using Landsat 8 imagery data from 2015 and 2023, analyzed through a Geographic Information System (GIS) approach, the findings reveal a substantial decline in vegetated areas. The moderately dense vegetation category decreased by 1,085.13 hectares (10.82%), while non-vegetated areas expanded by 1,988.64 hectares (30.05%). Additionally, there was a significant rise in surface temperature, from a maximum of 28.445°C in 2015 to 35.730°C in 2023. A strong negative correlation between NDVI and LST indicates that vegetation loss contributes to increased temperatures. To mitigate these effects, this study recommends adaptation strategies such as enhancing urban vegetation, expanding green open spaces, and implementing sustainable water management. These measures are expected to assist policymakers in developing strategies to enhance urban resilience to climate change.

Keywords : NDVI, LST, Climate Change, Urban Planning, Semarang City

A. INTRODUCTION

Climate change is a pressing global issue that affects societies worldwide. Semarang City, like many other urban areas in Indonesia, is experiencing significant climate change impacts, including frequent tidal flooding, rising surface temperatures, and shifting rainfall patterns. One of the most critical consequences of climate change is the increase in global temperatures, which contributes to ecosystem disruptions and extreme weather events (IPCC, 2023).

Semarang faces multiple climate-related challenges, particularly rising temperatures that can negatively affect public health and overall quality of life. Higher surface temperatures exacerbate environmental conditions and heighten the risks of natural disasters such as flooding and landslides. Additionally, rapid urbanization has led to a reduction in green open spaces, limiting the city's ability to absorb rainwater and regulate temperature. Previous studies indicate that urban areas are particularly vulnerable to heat due to the Urban Heat Island (UHI) effect, which significantly elevates city temperatures (Oke, 1982). Understanding surface temperature dynamics through NDVI and LST mapping is therefore crucial for climate-adaptive urban planning in Semarang.

Several studies on NDVI and LST have been conducted in various Indonesian cities. Research by Hatipah Yasmine et al., (2022) demonstrates that NDVI analysis can effectively identify low-vegetation areas with potential temperature increases. Building on this foundation, the present study explores how NDVI and LST can serve as analytical tools to support urban planning. This research not only contributes to the academic literature but also provides valuable insights for local policymakers.

This study aims to map and analyze the relationship between NDVI and LST, as well as their implications for urban planning in Semarang in response to climate change. Integrating climate information into spatial planning is essential for mitigating climate change impacts (Boer et al., 2013). Additionally, this study seeks to provide data-driven policy recommendations to enhance urban resilience. The research addresses key questions: What are the current conditions of vegetation density and surface temperature in Semarang? How does NDVI correlate with LST? What adaptation strategies can be implemented to address climate change? The findings are expected to contribute to the development of sustainable and climate-adaptive urban planning strategies.

B. METHODOLOGY

This study focuses on mapping Vegetation Density (NDVI) and Land Surface Temperature (LST) to support urban planning adaptation to climate change in Semarang City. Astronomically, Semarang is located between 6°56'–7°07' S and 110°16'–110°31' E, with a diverse topography ranging from flatlands and gentle slopes to mountainous areas.

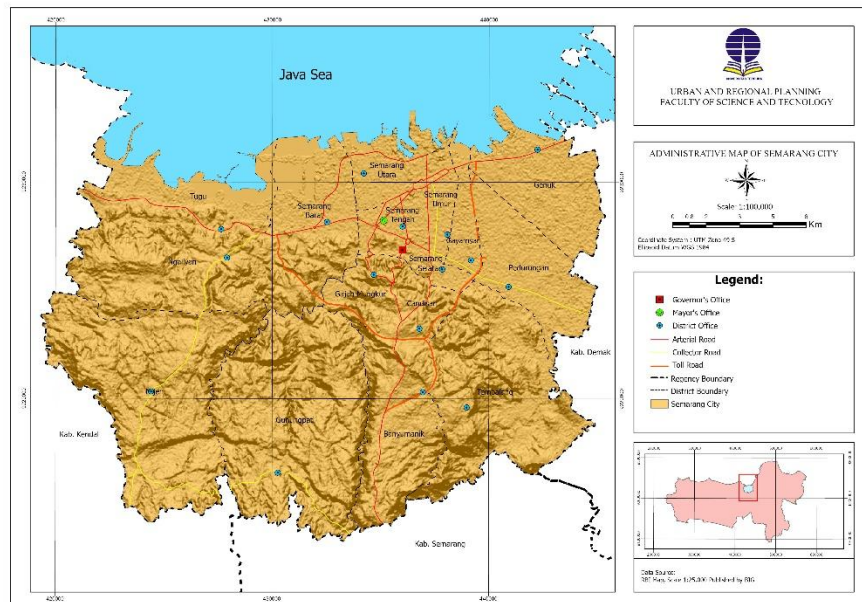


Figure 1. Administrative Map of Semarang City
Source: Proccesed Data Using ArcGIS Pro From RBI Map

This study utilizes secondary data, specifically Landsat 8 satellite imagery, a remote sensing dataset with a spatial resolution of 30 meters, obtained from the United States Geological Survey (USGS). Data from the years 2015 and 2023 were used to analyze changes in vegetation and surface temperature. The band combinations applied in this study are presented in Table 1.

Table 1. Landsat 8 Band Classification

Data Source	Band	Resolution	Description
Landsat 8	TIR-1 (B10)	100 m	Cloud Cover < 5%
	TIR-2 (B11)	100 m	
	RED (B4)	30 m	
	NIR (B5)	30m	

Source: NASA, 2013

The analysis was conducted using the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST), processed with Geographic Information System (GIS) software, **ArcGIS Pro**. ArcGIS Pro is a spatial analysis tool used for data visualization, analysis, and processing (Esri Indonesia, 2022). The flowchart below illustrates the Landsat 8 image processing steps for NDVI and LST analysis in ArcGIS Pro.

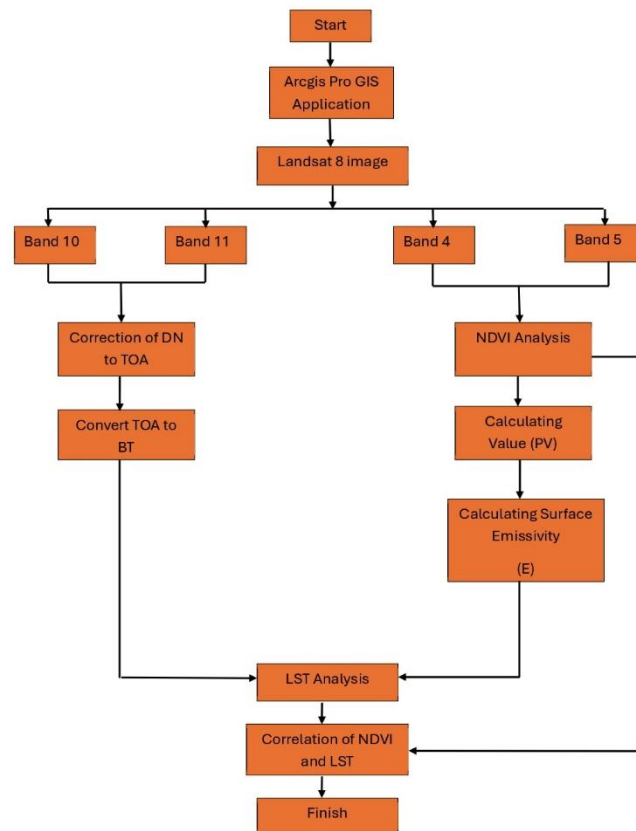


Figure 2. Process Flow Diagram

1. Digital Number (DN) Correction to Top of Atmosphere (TOA) Radiance

Digital Number (DN) represents raw satellite imagery values that require correction to obtain actual radiation information. TOA Radiance provides standardized and consistent radiation values across different data sources and observation periods (Hatipah Yasmine et al., 2022). The formula used is as follows:

$$L\lambda = ML * Qcal + AL$$

Where:

Lλ = TOA Spectral Radiance

ML = Radiance Scale Factor (RADIANCE_MULT_BAND) from metadata

Qcal = Digital Number (DN) of the respective band

AL = Radiance Additive Factor (RADIANCE_ADD_BAND) from metadata

2. Conversion from TOA Radiance to TOA Brightness Temperature (BT) in °C

TOA Brightness Temperature (BT) is a measure of land surface temperature in Kelvin, derived from satellite infrared radiation data. Converting TOA Radiance to BT allows temperature estimation in Celsius for better interpretability. The conversion formula is:

$$BT = K2 / (\ln(K1 / L\lambda + 1)) - 273,15$$

Where:

BT = Brightness Temperature (°C)

K2 = Calibration constant for absolute temperature (K2_CONSTANT_BAND) from metadata

K1 = Calibration constant for spectral radiance (K1_CONSTANT_BAND) from metadata

3. NDVI Calculation

NDVI is used to enhance the accuracy of surface temperature estimation by considering vegetation cover effects. Studies suggest that incorporating NDVI into LST models improves temperature estimations compared to models that exclude vegetation factors (Wang et al., 2015). NDVI is calculated using the following equation:

$$NDVI = ((NIR - RED)) / ((NIR + RED))$$

Where:

NDVI = Vegetation index

NIR = Near Infrared reflectance (Band 5)

RED = Red reflectance (Band 4)

4. Proportional Vegetation (PV) Calculation

Proportional Vegetation (PV) measures the fraction of an area covered by vegetation. In LST analysis, PV is used to assess and correct vegetation effects on surface temperature. PV is calculated using NDVI values (Yang et al., 2017):

$$PV = ((NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}))^2$$

Where:

NDVI_{min} = Minimum NDVI value

NDVI_{max} = Maximum NDVI value

5. Land Surface Emissivity (E) Calculation

Emissivity (E) represents a surface's ability to emit thermal radiation. In LST calculations, emissivity correction is necessary to enhance surface temperature accuracy. The formula used is:

$$E = 0.004 * PV + 0.986$$

Where:

0.004 = Average emissivity value for dense vegetation

0.986 = Standard emissivity for open land

6. Land Surface Temperature (LST) Calculation

LST represents land surface temperature as measured from satellite imagery. It is widely used for environmental and climate change studies. LST calculations are based on thermal infrared sensor (TIRS) data from Landsat 8 (Ode Alwi et al., 2022). The formula is as follows:

$$LST = BT / (1 + ((\lambda * BT) / c2) \ln E)$$

Where:

BT = Brightness Temperature (°C)

λ = Central Wavelength of emitted radiance (for Landsat 8: Band 10 = 10.80, Band 11 = 12)

$c2 = h * c / s = 1.4388 \times 10^{-2} \text{ mK} = 14388 \text{ } \mu\text{mK}$

The methodological framework applied in this study integrates remote sensing techniques with GIS-based spatial analysis to assess the relationship between vegetation density and land surface temperature in Semarang City. The findings are expected to provide a data-driven foundation for climate adaptation strategies in urban planning, particularly in mitigating urban heat effects and enhancing environmental resilience.

C. RESULTS AND DISCUSSION

1. NDVI (Normalized Difference Vegetation Index) Analysis

Vegetation density serves as an essential indicator of a region's ecological productivity and environmental health. Areas with higher vegetation density contribute significantly to carbon sequestration, water cycle regulation, and soil erosion prevention. Understanding vegetation cover provides a comprehensive insight into the environmental conditions of a region.

The NDVI analysis for Semarang City in 2015 and 2023 classified vegetation density into four categories: dense vegetation, moderately dense vegetation, sparse vegetation, and non-vegetated areas. The NDVI classification for Semarang City in 2015 is presented in Figure 3.

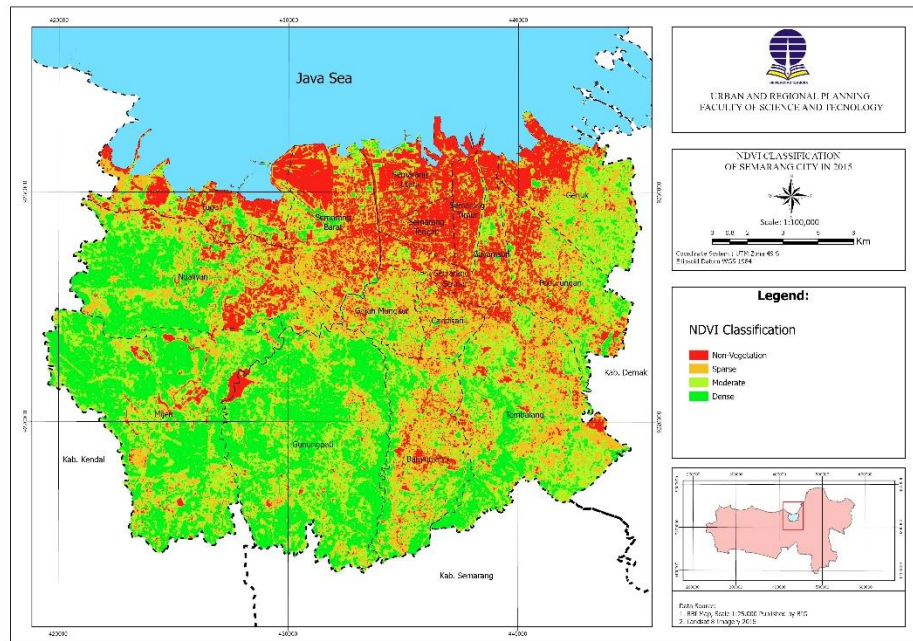


Figure 3. NDVI Classification of Semarang City in 2015
Source: Analysis of Landsat 8 Imagery (2015) using ArcGIS Pro

The NDVI values for 2015 ranged from -0.171 to 0.543, with classifications represented as follows: dark green for dense vegetation, light green for moderately dense vegetation, yellow for sparse vegetation, and red for non-vegetated areas. The classification and distribution of NDVI values in 2015 are summarized in Table 2

Table 2. NDVI Classification and Values for Semarang City (2015)

Classification	NDVI Value 2015	NDVI Area, 2015 (Ha)	Percentage
Non-Vegetation	-0.171 - 0.120	6617.7	17.9%
Sparse	0.121 - 0.229	9652.32	26.1%
Moderate	0.230 - 0.341	10025.55	27.1%
Dense	0.342 - 0.543	10678.59	28.9%
Total		36974.16	100.0%

Source: GIS Analysis (2024) from Landsat 8 Imagery (2015)

Similarly, the NDVI analysis for 2023 (Figure 4) revealed a value range of -0.184 to 0.573, with classifications following the same color coding.

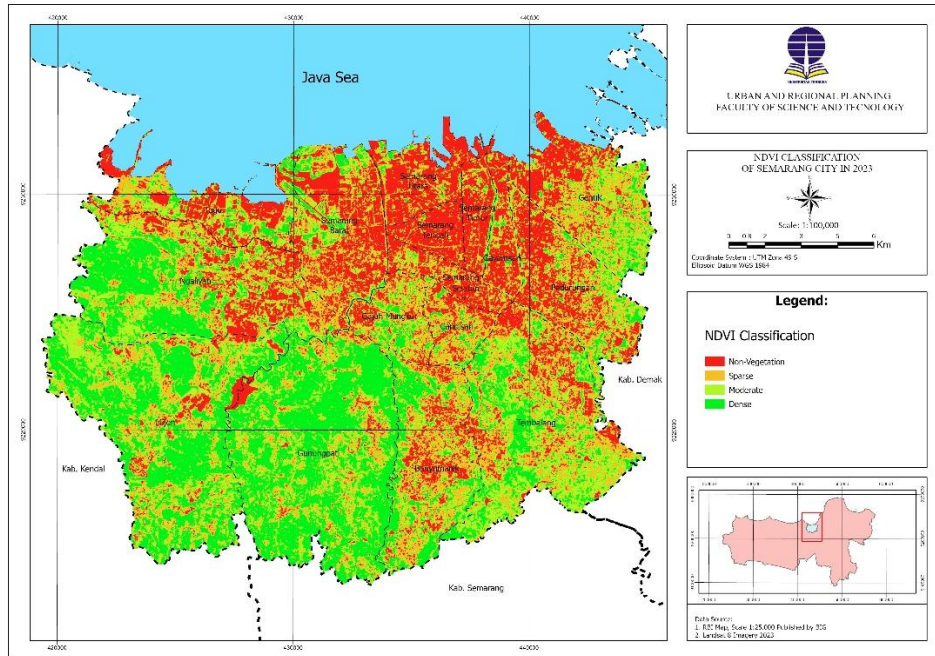


Figure 4. NDVI Classification of Semarang City in 2023

Source: GIS Analysis (2024) from Landsat 8 Imagery (2023) using ArcGIS Pro

The results of the 2023 NDVI analysis indicate values ranging from -0.184 to 0.573, with green representing dense vegetation, light green indicating moderately dense vegetation, yellow signifying sparse vegetation, and red denoting non-vegetated areas. The area distribution and classification of NDVI in Semarang City are presented in the following table.

Table 3. NDVI Classification and Values for Semarang City (2023)

Classification	NDVI Value 2023	NDVI Area, 2023 (Ha)	Percentage
Non-Vegetation	-0.184 - 0.130	8606.34	23.3%
Sparse	0.131 - 0.240	9039.15	24.4%
Moderate	0.241 - 0.353	8940.42	24.2%
Dense	0.354 - 0.573	10388.34	28.1%
Total		36974.25	100.0%

Source: GIS Analysis (2024) from Landsat 8 Imagery (2023)

Comparative analysis of the two years indicates significant changes in vegetation density. Between 2015 and 2023, the area classified as moderately dense vegetation decreased by 1,085.13 hectares (10.82%), while non-vegetated areas increased by 1,988.64 hectares (30.05%). These changes have implications for air quality, water absorption capacity, flood risks, and surface temperature increases. Figure 5 illustrates these variations.

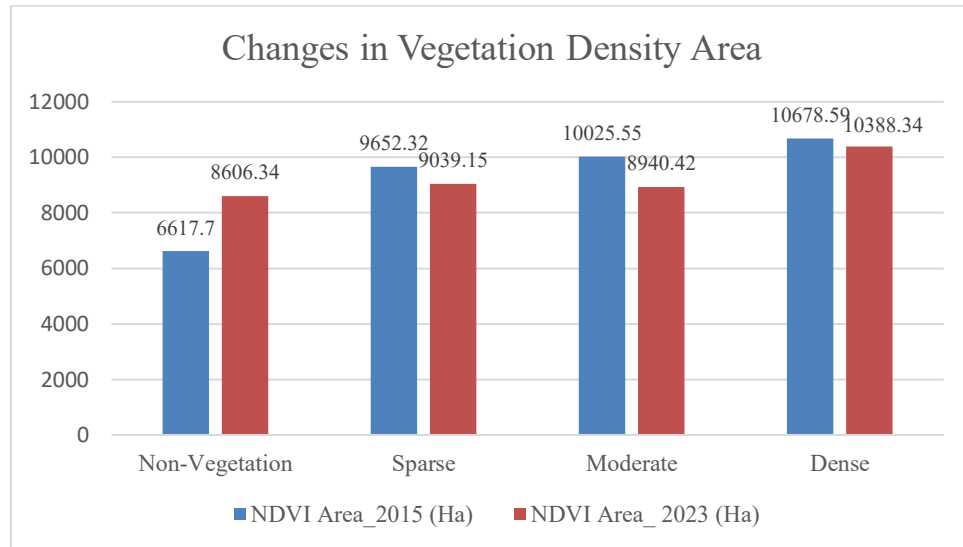


Figure 5. Changes in Vegetation Density in Semarang City
Source: GIS Analysis (2024) from Landsat 8 Imagery (2015 and 2023)

2. Land Surface Temperature (LST) Analysis

Land Surface Temperature (LST) analysis provides insights into urban thermal patterns and their environmental impacts. Using remote sensing data, LST enables comprehensive temperature assessments across a region.

In 2015, the minimum recorded surface temperature in Semarang City was 17.307°C, while the maximum was 28.445°C. The LST classification for 2015 is detailed in Table 4, and its spatial distribution is illustrated in Figure 6.

Table 4. Land Surface Temperature in Semarang City (2015)

No	LST Range (°C)	Area (Ha)	Percentage %
1	17.307 - 20.713	22.950	0.062
2	20.714 - 22.111	1268.100	3.430
3	22.112 - 22.679	2350.710	6.358
4	22.680 - 23.247	3822.480	10.338
5	23.248 - 23.815	4386.600	11.864
6	23.816 - 24.426	5273.910	14.264
7	24.427 - 25.082	5668.110	15.330
8	25.083 - 25.737	5619.780	15.199
9	25.738 - 26.392	5597.730	15.140
10	26.393 - 28.445	2963.880	8.016
Total		36974.250	100

Source: GIS Analysis (2024) from Landsat 8 Imagery (2015)

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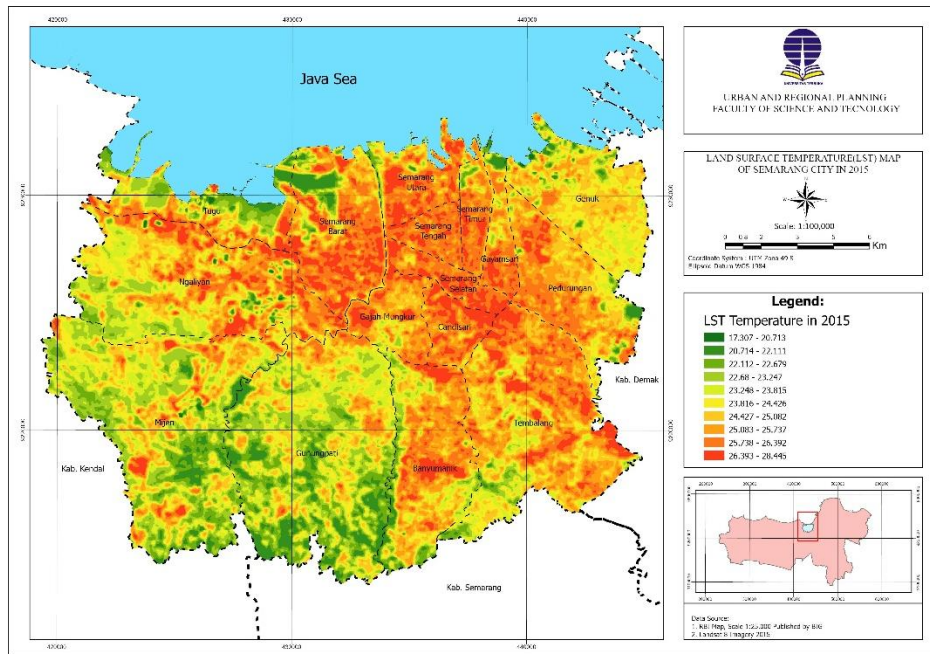


Figure 6. Land Surface Temperature Map of Semarang City (2015)

Source: GIS Analysis (2024) from Landsat 8 Imagery (2015) using ArcGIS Pro

For 2023, LST analysis indicated a minimum temperature of 17.863°C and a maximum of 35.730°C. The temperature distribution is presented in Table 5, with the spatial representation in Figure 7.

Tabel 5. Land Surface Temperature in Semarang City (2023)

No	LST Range (°C)	Area (Ha)	Percentage %
1	17.863 - 22.417	38.070	0.103
2	22.418 - 24.098	1871.820	5.062
3	24.099 - 24.869	4703.490	12.721
4	24.870 - 25.640	5375.700	14.539
5	25.641 - 26.341	5332.410	14.422
6	26.342 - 27.041	5946.030	16.082
7	27.042 - 27.742	5755.140	15.565
8	27.743 - 28.443	4907.430	13.273
9	28.444 - 29.353	2696.670	7.293
10	29.354 - 35.730	347.490	0.940
Total (Ha)		36974.250	100

Source: GIS Analysis (2024) from Landsat 8 Imagery (2023)

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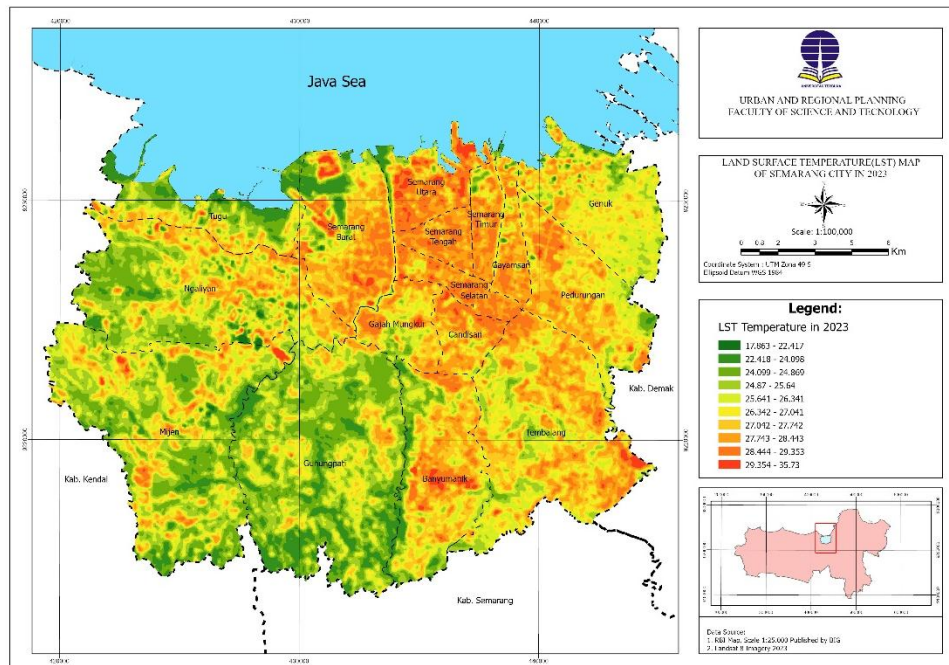


Figure 7. Land Surface Temperature Map of Semarang City (2023)
Source: GIS Analysis (2024) from Landsat 8 Imagery (2023) using ArcGIS Pro

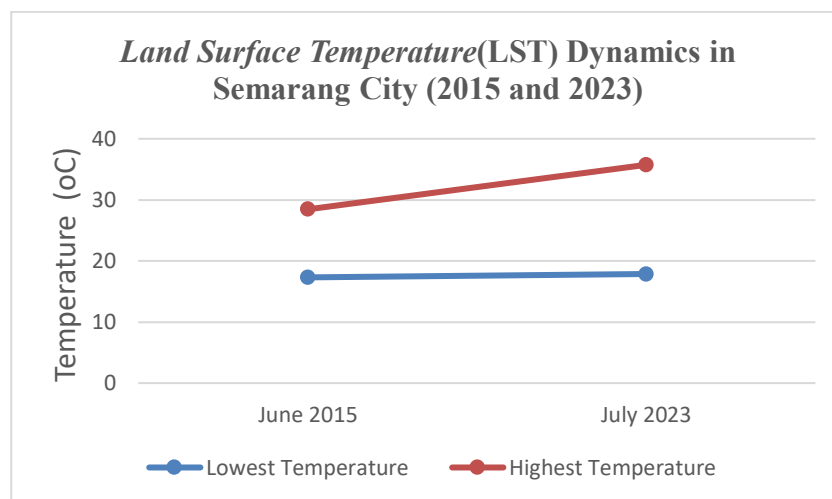


Figure 8. LST Dynamics in Semarang City (2015–2023)
Source: GIS Analysis (2024) from Landsat 8 Imagery (2015 and 2023)

The data reveal a significant temperature increase over the eight-year period, highlighting the need for interventions to expand green spaces, including tree planting and the development of urban parks to mitigate rising surface temperatures. Figure 8 illustrates LST changes between 2015 and 2023.

3. Correlation Between Vegetation Density and Surface Temperature

Understanding the relationship between vegetation density (NDVI) and surface temperature (LST) is essential for assessing vegetation's cooling effect. Pearson correlation analysis showed a negative correlation between NDVI and LST, with

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values of -0.497 in 2015 and -0.560 in 2023. This indicates that lower vegetation density is associated with higher surface temperatures.

Correlations			
		NDVI_2015	LST_2015
NDVI_2015	Pearson Correlation	1	-.497**
	Sig. (2-tailed)		.000
	N	1758	1758
LST_2015	Pearson Correlation	-.497**	1
	Sig. (2-tailed)	.000	
	N	1758	1758
**. Correlation is significant at the 0.01 level (2-tailed).			

Correlations			
		NDVI_2023	LST_2023
NDVI_2023	Pearson Correlation	1	-.560**
	Sig. (2-tailed)		.000
	N	1758	1758
LST_2023	Pearson Correlation	-.560**	1
	Sig. (2-tailed)	.000	
	N	1758	1758
**. Correlation is significant at the 0.01 level (2-tailed).			

Figure 9. Correlation Analysis Between NDVI and LST (2015 & 2023)

Source: Statistical Analysis using SPSS

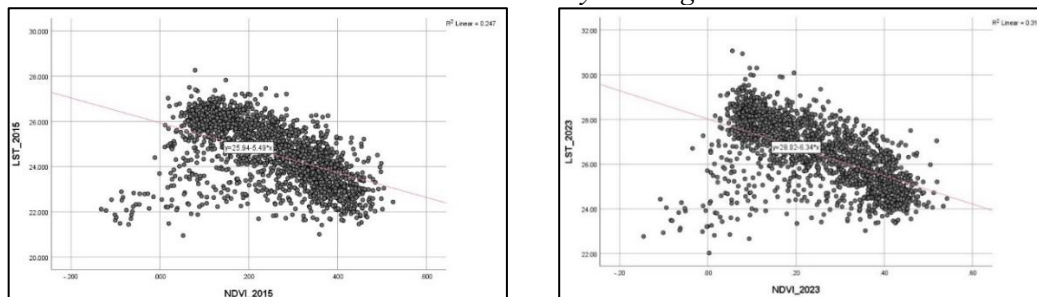


Figure 10. Graph of NDVI-LST Correlation (2015 & 2023)

Source: Statistical Analysis using SPSS

4. Climate Change Adaptation Strategies

Climate change adaptation involves strategies to minimize its adverse impacts. Human activities such as land-use changes and fossil fuel consumption contribute to climate change, resulting in rising urban temperatures, unpredictable seasonal patterns, and increased frequency of extreme weather events. Sustainable urban planning is essential for addressing these challenges.

A key adaptation strategy for Semarang City is increasing urban vegetation, particularly in non-vegetated and high-temperature areas. This can be achieved through tree planting and creating green spaces along urban roads, which not only provide shade but also enhance evapotranspiration, helping to lower surface temperatures.

Expanding green open spaces (RTH) is another crucial adaptation measure. Green spaces help reduce greenhouse gas emissions, particularly CO₂, by facilitating photosynthesis, which converts CO₂ into oxygen. Consequently, green open spaces contribute to urban cooling.

Effective water management is also vital for temperature regulation. The implementation of bioswales, for example, can efficiently manage rainwater runoff. Bioswales function as natural drainage systems, capturing stormwater from roads, parking lots, and rooftops, allowing it to infiltrate into the ground. This method not only mitigates flood risks but also indirectly contributes to surface temperature reduction.

D. CONCLUSION

This study concludes that mapping vegetation density (NDVI) and land surface temperature (LST), along with analyzing their correlation, provides valuable insights into one of the impacts of climate change. Satellite imagery data over the past two years indicate a significant decline in vegetation cover in Semarang, which has consequently led to an increase in surface temperatures. The analysis further reveals a significant negative correlation between vegetation density and land surface temperature.

These findings not only serve as analytical results but also offer a basis for urban planning adaptation strategies. Key adaptation measures that can be implemented include increasing urban vegetation, expanding green open spaces (RTH), and improving water management. These efforts are expected to mitigate the adverse effects of climate change in Semarang.

For future research, it is recommended that high-resolution satellite imagery be utilized to achieve more precise and accurate results. Additionally, employing a broader temporal range would allow for a more detailed analysis of temperature dynamics, enhancing the understanding of temperature fluctuations and their impacts. Furthermore, assessing the effectiveness of existing mitigation strategies is crucial to ensure that the recommendations provided are practical and beneficial for both policymakers and the community.

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