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Spatial Analysis of the Relationship between Vegetation Index and Land Surface Temperature in Ternate Island, Indonesia

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Abstract. This research focuses on the spatial analysis of the relationship between vegetation index and land surface temperature in Ternate Island, Indonesia, which is becoming increasingly relevant amidst the phenomenon of rapid urbanization. The background of the research shows that land use change has the potential to reduce green open space, contributing to an increase in surface temperature that can trigger the Urban Heat Island (UHI) phenomenon. The methods used include utilizing Landsat 8 OLI/TRIS satellite image data to calculate NDVI and LST values and statistical analysis using Pearson's correlation test and Spearman's rho to identify the relationship between the two. The results showed a significant negative relationship between NDVI and LST, with a Pearson correlation coefficient of -0.613, indicating that areas with better vegetation cover tend to have lower surface temperatures, and non-vegetated areas influence the increase of land surface temperature. The discussion highlights the importance of vegetation in regulating surface temperature through evapotranspiration and shading processes and suggests the need for afforestation strategies to mitigate climate change on Ternate Island

Keywords: NDVI; LST; Vegetation Index

INTRODUCTION

One of the challenges of sustainable development is the high rate of urbanization in a city. The rapidly developing city will attract rural residents who desire a better life (Liaqat et al., 2021). The increasing phenomenon of urbanization is evidenced by the development of existing data, showing that the number of people living in urban areas reached 50% in the 21st century and continues to rise to 70% by 2050 (Bokaie et al., 2016). The growth of cities has caused a change in the use of green open spaces, converting them into built-up areas. According to (Richards & Belcher, 2019), green open spaces can take the form of city parks, forests, and so on. The lack of green open spaces causes direct sunlight to reflect off the surface of objects (Cheval et al., 2024). The surface of objects that come into direct contact with solar radiation will become surface hot, resulting in an increase in the temperature of the object's surface (Yang et al., 2024). The city center is vulnerable to high temperatures because the area rarely has vegetation and is more dominated by concrete buildings (Latue & Rakuasa, 2023). The lower the concentration of vegetation, the higher the proportion of net radiation that is converted into sensible heat, which impacts the urban heat island phenomenon (Richards & Belcher, 2019; Salakory & Rakuasa, 2022). Land cover changes that result in rising temperatures in urban areas trigger the phenomenon of Urban Heat Island (Xu et al., 2024). Urban Heat Island is a phenomenon characterized by a temperature difference between urban areas and their surrounding rural areas. Therefore, the continuous increase in built-up land and the growing human activities lead to a rise in land surface temperature and air surface temperature, resulting in the emergence of the UHI phenomenon (Fu et al., 2024).

Vegetation density generally refers to how densely plants grow in an area. In remote sensing, vegetation density is often measured by the vegetation index (NDVI), which combines information from visible and infrared light to determine plant health and density (Richards & Belcher, 2019). NDVI values range from -1 to 1, with positive values indicating dense vegetation (Ahmad et al., 2024). The higher the NDVI value, the denser the vegetation in the area; for example, rainforests have high NDVI values due to dense vegetation, while desert areas have low NDVI values due to sparse vegetation (Rakuasa & Sihasale, 2023). LST and NDVI have an inverse relationship, which means that if the vegetation density is low, the land surface temperature will rise and vice versa (Ahmad et al., 2024). LST is defined as the temperature condition of the outermost part of an object on the ground (Rakuasa, 2022). In general, the highest LST value will be found in the city center and decreases gradually towards the edge of the city to the village (Diksha et al., 2023).

The land surface temperature in Ternate Island, specifically in the Central Ternate District, has increased from 2013 to 2023, one of the contributing factors being the continuous development of built-up areas each year. The results of the research conducted by Rakuasa & Pertuack, (2023) show that the highest land surface temperature in 2013 was 24.41°C and increased in 2023 to 28.63°C. This is influenced by the decrease in vegetation index in this area. This is supported by research conducted by (Latue, 2023), which shows that built-up land on Ternate Island has increased in area during the period 2013-2023. In 2013, the percentage of built-up land on Ternate Island was 15.19% and continued to increase to 19.69% by 2023, accounting for the total area of Ternate Island. According to (Rakuasa, 2025), the rapid population growth and increased human activity have caused significant land cover changes in this area, with built-up land reaching 2,242.60 hectares or 22.07% of the total area of Ternate Island. The rapid urban growth on Ternate Island has a negative impact on urban vegetation, which in turn contributes to the increase in land surface temperature. The increase in land surface temperature is primarily caused by urban land management activities, especially in areas with minimal vegetation (Zhang et al., 2022). As a result, the area of Green Open Space on Ternate Island has significantly decreased, induced by ongoing sustainable development efforts in the city (Rakuasa & Pakniany, 2022)

The development of advanced technology has helped in dealing with problems, one of which is the problem of increasing land surface temperature in urban areas (Cetin et al., 2024). Research on the increase in land surface temperature due to land use change is also increasing with remote sensing technology and Geographic Information Systems. The method is done through processing and analyzing Landsat 8 OLI/TRIS images so that changes in land surface temperature can occur. This research was conducted using remote sensing methods to determine the relationship between vegetation index and land surface temperature on Ternate Island, Indonesia. Remote sensing was used to obtain information as well as the spatial distribution of the vegetation index using the Normalized Difference Vegetation Index (NDVI) formula and land surface temperature in 2025. In addition, this study was conducted to determine the correlation between vegetation index and land surface temperature. Based on the above background, this research aims to determine the relationship between vegetation index and land surface temperature on Ternate Island, Indonesia.

MATERIALS AND METHODS

Data Collection

This research was conducted on Ternate Island, Maluku Utara Province, Indonesia. The research location can be seen in Figure 1. The data used is Landsat 8 OLI/TRIS satellite image data downloaded from the U.S. Geological Survey (USGS) website: https://earthexplorer.usgs.gov/ recorded on March 12, 2025. This image data is used to generate LST and vegetation index values. This research also uses data on sub-district administrative boundaries on Ternate Island obtained from the Indonesian Geospatial Information Agency. QGIS software is used to process image data to produce LST and NDVI, and Microsoft Excel and SPSS software are used to analyze the relationship between NDVI and LST.

Data processing and analysis

In the initial stage of data processing, the image must pass the correction stage first. The correction performed is radiometric correction only. Because Landsat 8 OLI already has a Standard Terrain Correction (level IT precision and terrain correction), where this standard is only owned by Landsat 8, which has been free from errors due to sensors, there is no need for geometric correction. The next step after the image is radiometrically corrected is to sharpen the image in order to clarify the appearance of the image to facilitate analysis by changing the luminance and contrast of the image. Then, after the image has been cleaned from existing errors, image cropping is carried out according to the area to be studied and can be processed to determine the value of land surface temperature and vegetation density.

The next stage after the image is radiometrically corrected is image sharpening to clarify the appearance of the image to make it easier to analyze by changing the lighting and contrast of the image. Then, after the image has been cleaned of existing errors, image cropping is carried out according to the area to be studied and can be processed to determine the value of land surface temperature and vegetation density.

In identifying the land surface temperature value, the wave used is a thermal wave. In Landsat 8 OLI/TIRS, band 10 is used in processing land surface temperature. In the process of processing temperature data using Landsat 8 OLI/TIRS images, the stage that must be passed is to convert the pixel value in the image (DN) into spectral radians so that each pixel in the image can describe the radiation value of objects on the ground. The equation for converting DN values into spectral radians is as follows (Ghanbari et al., 2023):

$$L\lambda = \frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\ x\ (QCAL\ -\ QCALMIN)\ +\ LMIN\lambda$$

Information:
Lλ = is a quantity that describes the intensity of spectral radiation at a particular wavelength. The units used are watts per square meter per steradian per micrometer ($W\text{-}m^{-2}\text{-}sr^{-1}\text{-}\mu m^{-1}$).
LMAXλ = the maximum value of spectral radiation that can be measured by the sensor in the thermal band. The units used are the same as Lλ, i.e. $W\text{-}m^{-2}\text{-}sr^{-1}\text{-}\mu m^{-1}$.
LMINλ = the minimum value of spectral radiation that can be measured by the sensor in the thermal band. The units used are the same as Lλ
QCALMIN = the lowest pixel value that can be output by the sensor, usually represented as DN = 1. This value corresponds to LMINλ.
QCALMAX = the highest pixel value that can be output by the sensor, usually represented as DN = 255 (or 225 in some cases). This value corresponds to LMAXλ.

After the spectral radiation value is obtained, it is then converted into a temperature value with the formula (Ghanbari et al., 2023)

$$T = \frac{k_2}{In\left(\frac{k_1}{l\lambda}+1\right)}$$

Information:
T = temperature obtained from satellite sensors, measured in Kelvin (K). This temperature is calculated based on the thermal radiation received by the sensor.
K1 = the first calibration constant used in the calculation of temperature from Landsat OLI satellite data. Its value is 774.853 K.
K2 = the second calibration constant used in the calculation of temperature from Landsat OLI satellite data. Its value is 1321.0789 K.
Lλ = spectral radiation measured by the sensor in the thermal band (in this case, Band 10 on Landsat OLI). The units used are watts per square meter per steradian per micrometer ($W\text{-}m^{-2}\text{-}sr^{-1}\text{-}\mu m^{-1}$).

Convert the Kelvin temperature value to Celsius with the following formula:

$$Temp - CELCIUS\ =\ Temp - KELVIN - 272.15\ =\ T - 272.15$$

After the results of the land surface temperature are obtained, then reclassify the surface temperature based on the surface temperature value at each sample point with the minimum, maximum, and average values of all sample points. Surface temperature is classified into 5 classes consisting of <20°C, 20-25°C, 25-30°C, 30-35°C, and >35°C.

This research uses the NDVI (Normalized Difference Vegetation Index) algorithm to analyze the vegetation index on Ternate Island. NDVI is the result of a mathematical approach based on the reflectance (albedo) of the vegetation canopy, which can be a ratio value or a combination of visible and near-infrared radiation. Basically, NDVI is used to determine the level of greenness in leaves with infrared wavelengths that are very good as the beginning of the division of vegetation areas. Because the optical properties of chlorophyll are very distinctive, namely chlorophyll absorbs the red spectrum and reflects strongly in the infrared spectrum. In Landsat 8 OLI/TIRS to determine the NDVI value, band 4 (red) and band 5 (near infrared) are used. The NDVI formula can be seen in equations 4 and 5 (Rahimi et al., 2025):

$$NDVI\ =\ \frac{NIR - RED}{NIR + RED}$$

In Landsat 8 OL/TIRS, the algorithm is as follows:

$$NDVI\ =\ \frac{Band\ 5 - Band\ 4}{Band\ 5\ +\ Band\ 4}$$

Description:

NDVI = An index used to assess the condition of vegetation in an area. Its value ranges from -1 to 1, where high positive values indicate healthy and dense vegetation, while low or negative values indicate areas without vegetation (such as water, soil, or urban areas).
NIR = NIR is near-infrared light reflected by surfaces, especially vegetation. Healthy plants tend to reflect more near-infrared light due to the cellular structure of their leaves.
RED = red light reflected by surfaces. Plant leaves absorb most of the red light for photosynthesis, so healthy vegetation tends to reflect less red light.

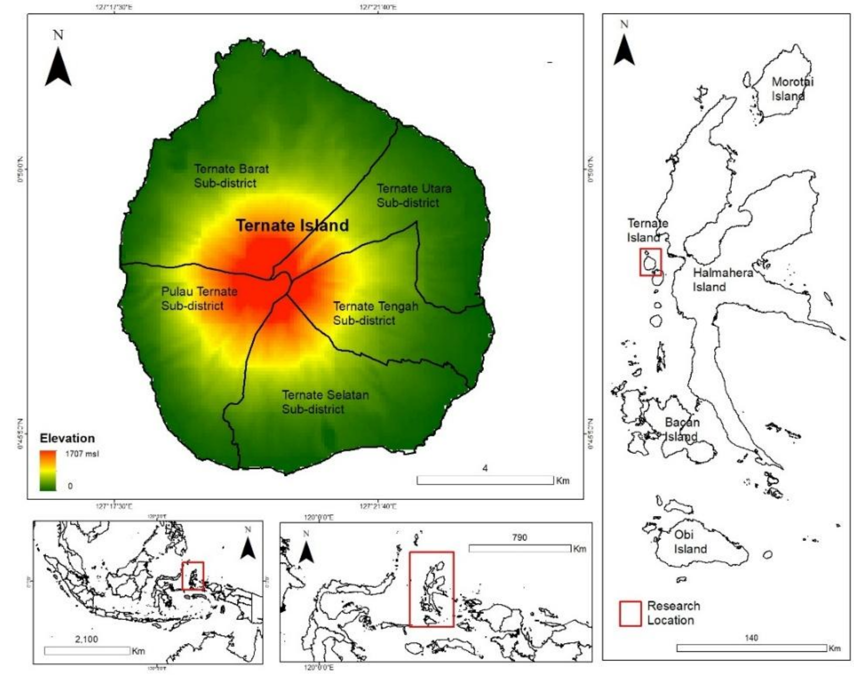

Figure 1. Research Location, Ternate Island, Indonesia

NDVI has values between -1.0 and +1.0. Values greater than 0.1 indicate an increased degree of greenness and intensity of vegetation (Anand et al., 2025). Values lying between 0 and 0.1 are generally characteristic of rocks and bare land, while values less than 0 indicate clouds, ice, and snow (Anand et al., 2025). Vegetated surfaces range from NDVI values of 0.1 for grasslands and shrubs to 0.8 for tropical rainforest areas. Non-vegetated land, including settlements, water areas, open wastelands, and areas with damaged vegetation, will not show a high ratio (minimum), while in very dense vegetation areas, the ratio between the brightness of the red light channel and the near-infrared light channel will be very high. The vegetation index values are then classified into 5 classes: water, no vegetation, low vegetation, medium vegetation, and high vegetation.

The results of the analysis of the vegetation index and land surface temperature of Ternate Island were then analyzed descriptively comparatively through a spatial approach. Analysis of the relationship between land surface temperature and vegetation index. The relationship between land surface temperature and vegetation index is analyzed using the overlay technique so that later it will be seen how the relationship between land surface temperature and vegetation greenness. Then, to see the relationship between surface temperature with altitude and vegetation density, statistical tests were carried out using the Pearson Correlation equation (equation 6) and Spearman's rho in equation 7 (Rahimi et al., 2025). To determine the relationship between NDVI and LST, this statistical test was conducted.

$$r = \frac{\sum_{i=1}^{n}(xi-\bar{x})(yi-\bar{\bar{y}})}{\sqrt{\sum_{i=1}^{n}(xi-\bar{x})^2} \cdot \sqrt{\sum_{i=1}^{n}(yi-\bar{\bar{y}})^2}}$$

Information:
xi and yi are the data values.
$\bar{x}$ and $\bar{\bar{y}}$ are the averages of each variable.
n is the amount of data

$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$

Description:

d_i is the rank difference between two variables.

n is the number of data pairs.

Both of these correlation coefficients have values between -1 and 1, where:

Values close to 1 indicate a strong positive relationship.

Values close to -1 indicate a strong negative relationship.

Values close to 0 indicate no significant relationship.

RESULTS AND DISCUSSION

Land Surface Temperature in Ternate Island

The land surface temperature value on Ternate Island is obtained from the processing of Landsat 8 OLI/TIRS images, which show a varied distribution of temperature values. Land surface temperature processing is obtained by using band 10 algorithm processing. The land surface temperature value on Ternate Island in 2025 is 13.94°C - 28.73°C. The highest LST value is spread in the coastal area of Tenate City and the crater area of Mount Gamalama, and the lowest is spread in areas with high vegetation. The LST value is then classified into 5 classes. Spatially, land surface temperature in Ternate Island can be seen in Figure 2, and the LST area per sub-district in Ternate Island can be seen in Table 1.

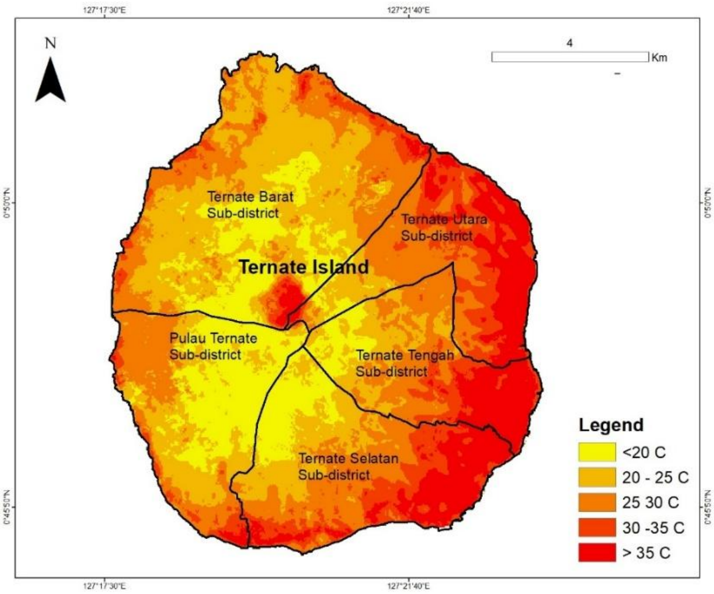

Figure 2. Land Surface Temperature in Ternate Island

Table 1. Land Surface Temperature Area in Ternate Island

Sub-district	Land Surface Temperature Area in Ternate Island (Ha)				
	<20 °C	20 - 25 °C	25 30 °C	30 -35 °C	> 35 °C
Ternate Barat	296,63	423,17	546,23	365,80	417,37
Pulau Ternate	647,07	1.581,42	881,94	203,95	64,18
Ternate Selatan	296,63	423,17	546,23	365,80	417,37
Ternate Tengah	148,35	324,83	457,37	163,92	309,67
Ternate Utara	43,26	148,88	483,98	447,79	451,91
Total area	1.431,96	2.901,46	2.915,75	1.547,25	1.660,49

Table 1 shows the area distribution of Land Surface Temperature (LST) in Ternate Island, Indonesia, classified into five temperature classes: <20°C, 20-25°C, 25-30°C, 30-35°C, and >35°C. This analysis was conducted per sub-district to understand the variation of land surface temperature in the region. West Ternate sub-district has a fairly varied distribution of LST. The area with a temperature <20°C covers 296.63 ha, while the area with a temperature of 20-25°C covers 423.17 ha. The area with 25-30°C dominates with an area of 546.23 ha, followed by the area of 30-35°C (365.80 ha) and >35°C (417.37 ha). This indicates that most areas of West Ternate experience moderate to high temperatures, which may be influenced by uneven vegetation cover and anthropogenic activities. Ternate Island sub-district shows a unique LST pattern. The area with a temperature <20°C covers 647.07 ha, which is the highest value compared to other sub-districts. The area with a temperature of 20-25°C is also very large (1,581.42 ha), while the area with a temperature >35°C is only 64.18 ha. This indicates that Ternate Island has a relatively lower surface temperature, possibly due to the influence of the sea and better vegetation cover.

The distribution of LST in South Ternate is similar to West Ternate, with areas of 25-30°C dominating (546.23 ha). The area with a temperature >35°C is also quite significant (417.37 ha), indicating the presence of areas with high temperatures that may be related to urban activities or open land. Ternate Tengah sub-district has an area of 25-30°C covering 457.37 ha, which is the highest value in this sub-district. The area with a temperature >35°C is also quite large (309.67 ha), indicating the presence of high-temperature hotspots that may be influenced by building density or lack of vegetation cover. North Ternate sub-district has an area with a temperature of 25-30°C covering 483.98 Ha and an area with a temperature >35°C covering 451.91 Ha. This indicates that this area tends to be hotter, possibly due to the influence of topography or intensive human activities. Overall, the distribution of LST in Ternate Island shows significant variation between sub-districts. Areas with temperatures of 25-30°C dominate in all sub-districts, except Ternate Island, which is dominated by temperatures of 20-25°C. Areas with temperatures >35°C are also quite significant, especially in West, South, Central, and North Ternate, indicating the existence of high-temperature areas that need special attention in spatial planning and climate change mitigation.

Vegetation Index in Ternate Island

The value of the vegetation index in Ternate Island was obtained from the processing of Landsat 8 OLI/TIRS images, which showed a varied distribution of temperature values. Vegetation index processing is obtained using NDVI algorithm processing. The vegetation index value on Ternate Island in 2025 is -0.67 - 0.80. The highest vegetation index value is spread in mountainous areas, and areas with low vegetation index are spread in urban areas. The vegetation index value is then classified into 5 classes, namely water, not vegetation, lace vegetation, medium vegetation, and high vegetation. The spatial Vegetation Index in Ternate Island can be seen in Figure 3, and the LST area per sub-district in Ternate Island can be seen in Table 2.

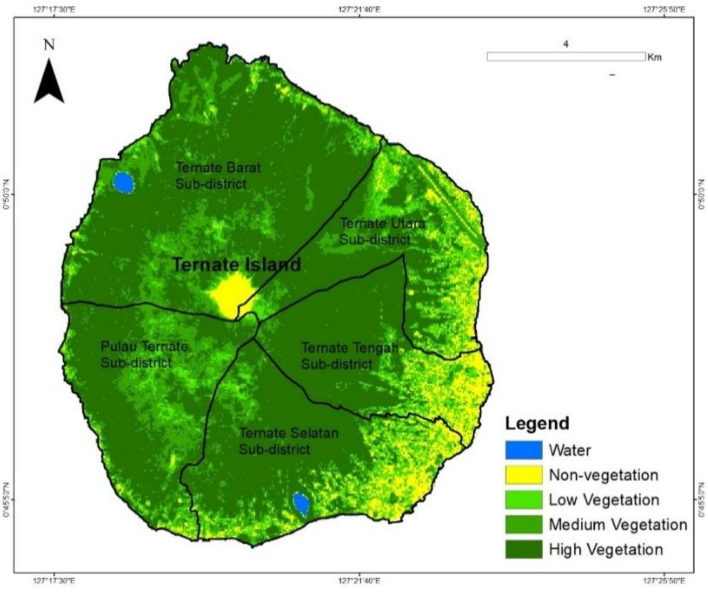

Figure 3. Vegetation Index in Ternate Island

Table 2 shows the distribution of area based on the Vegetation Index on Ternate Island, Indonesia, classified into five categories: Water, Non-Vegetation, Low Vegetation, Medium Vegetation, and High Vegetation. The Ternate Barat District has a very dominant area of high vegetation, which is 2,463.91 ha. This indicates that most of this area still has good vegetation cover, which may contribute to regulating the surface soil temperature. The Medium Vegetation Area is also quite significant (652.81 Ha), while the Non-Vegetation and Low Vegetation Areas are relatively small (103.36 Ha and 132.91 Ha, respectively). The presence of a water area covering 25.00 ha indicates the existence of a water source that may influence the microclimate in this region. The Pulau Ternate District has a high vegetation area of 989.31 ha, which is lower compared to Ternate Barat. The Medium Vegetation Area is also quite large (575.72 Ha), while the Non-Vegetation and Low Vegetation Areas are 23.29 Ha and 140.83 Ha, respectively. The area of water is very small (0.06 ha), indicating that this region may be drier or have limited water sources. The Ternate Selatan District has a large area of high vegetation covering 1,171.01 ha, indicating good vegetation cover. The medium vegetation area is relatively small (316.59 Ha), while the non-vegetation and low vegetation areas are 242.63 Ha and 302.98 Ha, respectively. The presence of a water area covering 15.75 ha indicates the existence of a water source that may influence the distribution of vegetation. The Ternate Tengah District has an area of high vegetation covering 934.86 ha, which is quite significant. The medium vegetation area is relatively small (116.99 Ha), while the non-vegetation and low vegetation areas are 184.42 Ha and 167.61 Ha, respectively. The absence of water areas indicates that this region may be drier or have very limited water sources.

Table 2. Vegetation Index Area in Ternate Island

Sub-district	**Vegetation Index Area (Ha)**				
	Water	**Non-vegetation**	**Low Vegetation**	**Medium Vegetation**	**High Vegetation**
West Ternate	25,00	103,36	132,91	652,81	2.463.91
Ternate Island	0,06	23,29	140,83	575,72	989,31
South Ternate	15,75	242,63	302,98	316,59	1.171,01
Central Ternate	-	184,42	167,61	116,99	934,86
North Ternate	-	178,56	324,25	373,97	698,66
Total area	40,81	732,25	1.068.57	2.036,09	6.257,75

North Ternate sub-district has a high vegetation area of 698.66 ha, which is lower than other sub-districts. The medium vegetation area is quite large (373.97 Ha), while the non-vegetation and low vegetation areas are 178.56 Ha and 324.25 Ha, respectively. The absence of water areas suggests that this area may be drier or have very limited water sources. Overall, the distribution of vegetation index on Ternate Island shows significant variation between sub-districts. West Ternate sub-district has the most extensive high vegetation cover, while North Ternate sub-district has relatively lower high vegetation cover. Non-vegetation and low vegetation areas tend to be smaller than high and medium vegetation areas, indicating that most areas of Ternate Island still have good vegetation cover. However, the significant areas of non-vegetation and low vegetation in some sub-districts, such as South Ternate and North Ternate, indicate the need for conservation and reforestation efforts to maintain ecosystem balance.

Relationship between NDVI and LST in Ternate Island

Statistical analysis conducted using two correlation methods, namely Pearson Correlation and Spearman's rho, showed a significant relationship between the Vegetation Index (NDVI) and Land Surface Temperature (LST) on Ternate Island. Based on Table 3, the Pearson correlation value between NDVI and LST is -0.613 with a significance level (p-value) <0.001. This negative correlation value indicates an inverse relationship between NDVI and LST. That is, the higher the NDVI value (better vegetation cover), the lower the land surface temperature (LST), and vice versa. This is in line with previous research findings that vegetation plays an important role in reducing surface temperature through the process of evapotranspiration and shading provided by the vegetation canopy (Bhartendu et al., 2023). The strength of the relationship between NDVI and LST falls into the moderate to strong category (based on the correlation coefficient criteria), indicating that vegetation cover is one of the dominant factors influencing the variation of land surface temperature on Ternate Island.

Table 3. Pearson Correlation Test Results.

Correlations			
		NDVI	LST
NDVI	Pearson Correlation	1	-.613**
	Sig. (2-tailed)		<,001
	N	655	655
LST	Pearson Correlation	-.613**	1
	Sig. (2-tailed)	<,001	-
	N	655	655

**. Correlation is significant at the 0.01 level (2-tailed).

The Spearman's rho correlation test results (Table 3) also showed a negative relationship between NDVI and LST with a correlation value of -0.430 and a significance level (p-value) of <0.001. Although the Spearman's rho correlation value is lower than that of Pearson, this result still confirms a significant inverse relationship between the two variables. The difference in correlation values between the two methods may be due to the nature of the data that did not fully meet the assumption of normality, so the non-parametric Spearman's rho method provides more conservative results.

Table 4. Spearman's rho Correlation Test Results

Correlations				
			NDVI	LST
Spearman's rho	NDVI	Correlation Coefficient	1.000	-.430**
		Sig. (2-tailed)	-	<,001
		N	655	655
	LST	Correlation Coefficient	-.430**	1.000
		Sig. (2-tailed)	<,001	-
		N	655	655

**. Correlation is significant at the 0.01 level (2-tailed).

Significance Level (α) = 0.05 or Test Level = 95%. The results of hypothesis testing (T test) in Tables 4 and 5 above show that the significance value of the relationship test between NDVI and LST variables is <.001, which is smaller than 0.05. This indicates that the NDVI variable has an influence on LST. The number of test samples was 655. Test results with Pearson Correlation method: -.613**. Test results with Spearman's rho method: -.430**. The results of the hypothesis test (T-test) show that the significance value (p-value) is <0.001, which is much smaller than the set significance level (α = 0.05). This indicates that NDVI has a significant influence on LST on Ternate Island. With 655 test samples, this result has a high level of confidence and can be generalized to the study area. Based on statistical analysis, it can be concluded that there is a significant negative relationship between NDVI and LST on Ternate Island. The Pearson correlation value of -0.613 and Spearman's rho of -0.430 indicate that an increase in vegetation cover contributes to a decrease in land surface temperature. These findings support the importance of afforestation and vegetation conservation policies as part of climate change adaptation and mitigation strategies in the islands.

CONCLUSION

This study shows that there is a significant relationship between vegetation index (NDVI) and land surface temperature (LST) in Ternate Island, Indonesia, which is influenced by the level of urbanization. Rapid urbanization leads to a decrease in green open space, which in turn increases land surface temperature. Analysis using Landsat 8 OLI/TRIS satellite image data revealed that areas with low vegetation density tend to have higher surface temperatures, supporting the Urban Heat Island (UHI) phenomenon. Therefore, the management and maintenance of vegetation in urban areas is essential to mitigate temperature increases and to support environmental sustainability on Ternate Island.

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