Jurnal Ilmu Alam dan Lingkungan 15 (2), (2024). 43 - 52

Jurnal
Ilmu Alam dan Lingkungan

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Characteristics of Urban Heat Island in Pare-Pare City: Insights From Spatial Analysis

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Abstract

This research focuses on understanding the characteristics of the Urban Heat Island (UHI) phenomenon in Parepare City, Indonesia, and its relationship with vegetation density and land surface temperature. The study utilizes satellite imagery data from 2014 and 2021 to analyze the spatial distribution of land surface temperature and vegetation density. The results show a significant negative correlation between vegetation density and land surface temperature, indicating that an increase in vegetation density can contribute to lowering the land surface temperature and mitigating the UHI effect. The findings also emphasize the importance of green open spaces in maintaining a balance of vegetation and preventing a drastic increase in UHI. However, challenges such as land conversion and high population density in the city center pose threats to vegetation preservation. Sustainable land management practices and urban greening initiatives need to be implemented to address these issues. The research concludes that by prioritizing these measures, Parepare City can effectively mitigate the UHI effect and enhance the urban environment's quality and livability.

***Keywords**: Land Surface, NDVI, Pearson correlation, Temperature, Urban Heat Island*

INTRODUCTION

Urban Heat Island (UHI) is an event that describes higher temperatures in urban areas compared to the surrounding regions (Liu *et al*., 2020). Human activities such as transportation, industry, waste, and domestic energy consumption are the sources of pollutant emissions that cause the urban heat island phenomenon (Yang *et al*., 2020). The Urban Heat Island phenomenon refers to the condition where the surface temperature in a certain area is relatively warmer, meaning that the temperature in urban areas

P ISSN: 2086 - 4604
E ISSN: 2549 - 8819

is warmer compared to the surrounding environment (Rehan, 2016; Nur, dkk., 2024; Nuryadin *et al*., 2024). UHI can be likened to a giant dome that traps heat in a specific area. The increasing development and urbanization processes in society have led to the growing relevance of UHI and its negative impacts on the environment, energy consumption, air quality, and future climate change. Some factors causing the Urban Heat Island phenomenon include minimal vegetation in urban areas, surface temperature, and land use changes in urban areas (Maru & Ahmad, 2015a, 2015b). The formation of heat islands is closely related to decreased vegetation in an area. Vegetation plays a role in absorbing CO2 and heat radiation, providing shade that can cool down the surroundings (Sofia *et al*., 2020). The conversion of extensive vegetation land not only reduces the benefits of vegetation for the surrounding temperature but also hampers the atmospheric cooling process, as the presence of vegetation can balance the urban air, also known as the park island effect. Infrastructure such as settlements, factories, and roads contributes to vegetation (Chen & Lin, 2021). The lack of vegetation affects the balance of air composition. This causes an increase in temperature by 10°C to 20°C from the ambient air temperature (Sadeghian & Vardanyan, 2013; Amdah, 2024).

Parepare City is one of the cities in South Sulawesi Province, which, based on the national urban system direction, has been designated as a Regional Activity Center with a focus on being an industrial processing center. This policy can contribute to increased land surface temperature and decreased vegetation areas in Parepare City. Researching the relationship between vegetation density and land surface temperature to identify the Urban Heat Island (UHI) phenomenon in Parepare City is crucial to understanding the correlation between existing vegetation density and the varying land surface temperature. This research can be analyzed using remote sensing methods, utilizing Landsat satellite imagery.

MATERIALS AND METHODS

The research methodology used in this study is a quantitative descriptive method, utilizing primary data from Landsat satellite imagery downloaded from the official USGS website. Secondary data includes land use data for Parepare City in 2014 and 2021.

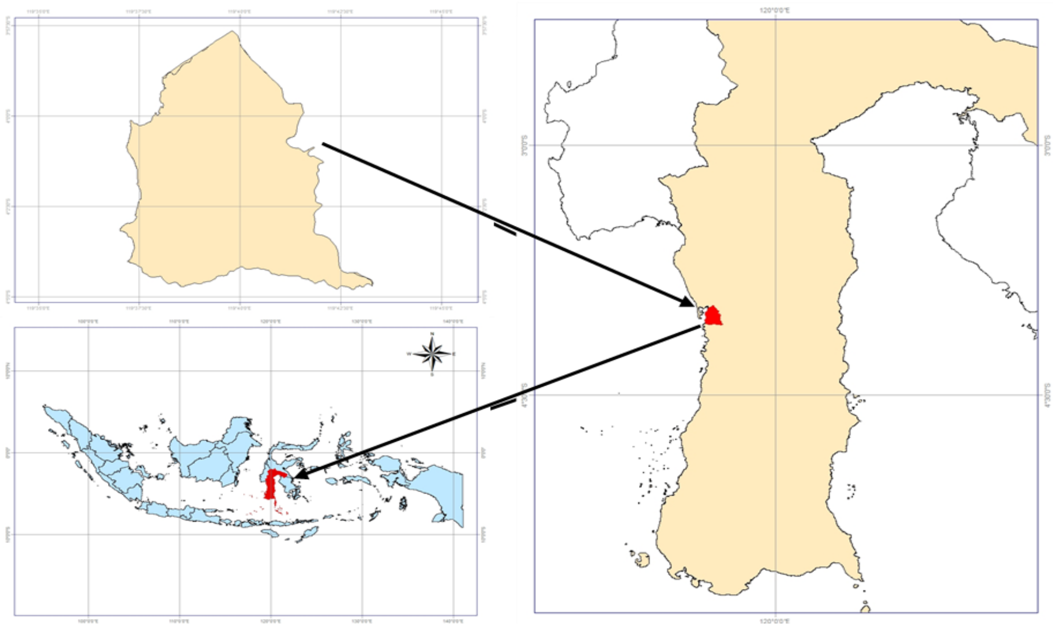

Figure 1. Administration Map of Pare-pare City.

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E ISSN: 2549 - 8819

The study was conducted in Parepare City. The analysis method used to identify the Urban Heat Island phenomenon involved analyzing the transformation of Landsat 8 OLI/TIRS satellite imagery into vegetation density values and land surface temperature in Parepare City for 2014 and 2021. The Pearson correlation analysis method was employed to determine the relationship between vegetation density and land surface temperature in Parepare City, with vegetation density as the X variable and land surface temperature as the Y variable.

1. Vegetation density

Vegetation density refers to the value derived from the changes in the Normalized Difference Vegetation Index (NDVI) of Landsat 8 satellite imagery using remote sensing technology. Vegetation density is analyzed on an index scale of 0-1, where a value approaching 1 indicates a higher density of vegetation, while a value approaching 0 indicates a lower density of vegetation (Sanderman *et al.*, 2018).

2. Land Surface Temperature

Land Surface Temperature (LST) refers to the value obtained from the transformation of Land Surface Temperature using Landsat 8 satellite imagery through remote sensing technology. This process produces a land surface temperature map in degrees Celsius (°C). Land surface temperature is an essential component in the analysis of the Urban Heat Island (UHI) phenomenon

RESULTS AND DISCUSSION

1. The characteristics of Urban Heat Island (UHI) in Parepare City

Based on the distribution map of Urban Heat Island (UHI) in Parepare City in 2014, it can be observed that the hotspots are formed in the southern and northern parts of Bacukiki District, characterized by the land use of dry fields and rice fields. This is due to the data acquisition of Landsat satellite imagery during the dry season, which results in higher temperatures in residential areas. In 2021, the hotspots shifted to Soreang and Ujung Districts, predominantly residential areas. Based on the analysis of the average Land Surface Temperature, it can be concluded that the characteristics of the UHI phenomenon in Parepare City have experienced an increase from 2014 to 2021, with an average surface temperature ranging from 28.41°C to 29.36°C. From 2014 to 2021, Parepare City has undergone a temperature change of 0.95°C in the past 7 years. This is attributed to the land use changes in Parepare City, which have been accompanied by greening efforts in urban areas and the establishment of Green Open Spaces.

Table 1. Distribution of Green Open Spaces in Parepare City in 2019

No.	Sub-District	Large	
		(ha)	(%)
1.	Bacukiki	1,847.50	95.29
2.	Bacukiki Barat	1.89	0.10
3.	Ujung	1.82	0.09
4.	Soreang	87.60	4.52
		1,938.82	100

Source: Analysis results, 2023.

From the above data, it is known that 19.51% of the total area of Parepare City consists of Green Open Spaces. balanced vegetation areas in Parepare City help mitigate the drastic increase of Urban Heat Island (UHI) phenomena from 2014 to 2021. Vegetation within Green Open Spaces plays a crucial role in controlling visual aspects, acting as barriers, regulating climate, preventing erosion, providing habitats for wildlife, and enhancing aesthetics. High-quality Green Open Spaces should optimally fulfill these vegetation functions. The optimal arrangement of Green Open Spaces requires a canopy structure resembling a tropical rainforest or urban forest. Urban forests effectively function as climate controllers,

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including temperature reduction, solar radiation absorption, wind flow breakers, soil and water conservation, and wildlife habitats (Albdour & Baranyai, 2019).

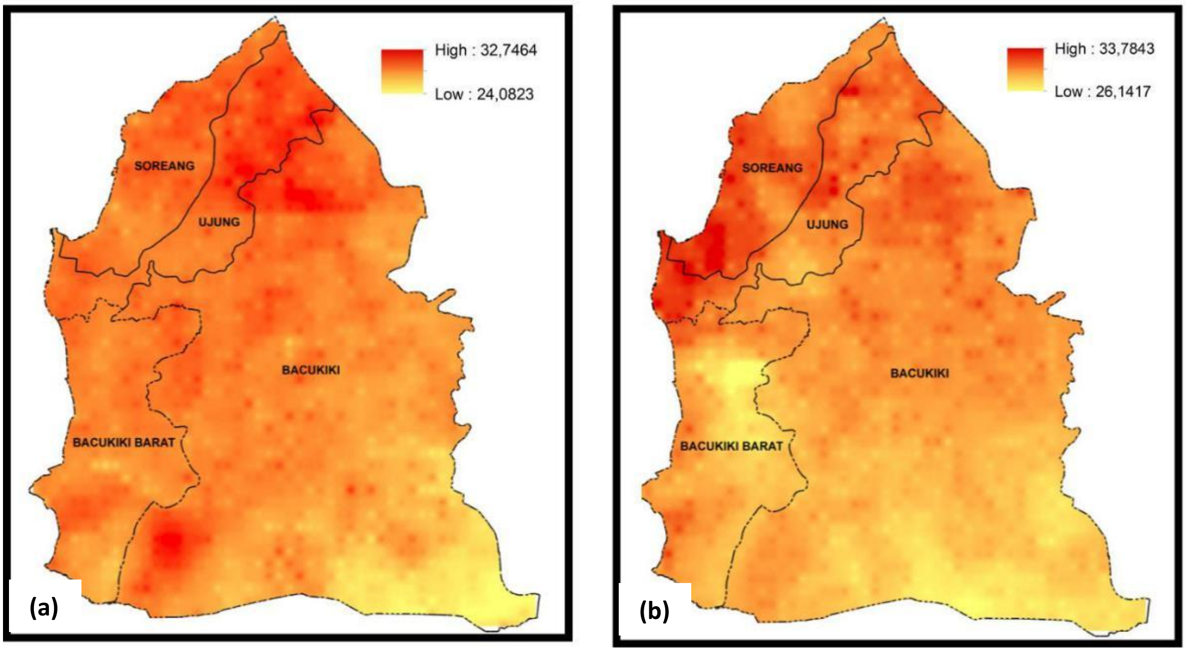

Figure 1. Distribution of Urban Heat Island in Parepare City (a) Urban Heat Island in Parepare City in 2014, (b) Urban Heat Island in Parepare City in 2021.

Based on the Urban Heat Island phenomenon analysis, the highest temperature value in 2014 was 32.45°C, while the lowest was 24.01°C. In 2021, the highest temperature value was 33.94°C, and the lowest was 26.04°C. The UHI phenomena in Parepare City exhibit similar characteristics yearly, with a central hotspot in the city center. This is attributed to several factors, such as land use conversion from vegetation to non-vegetated areas, as observed from the land use change matrix in Parepare City from 2014 to 2021. Another contributing factor is the high population density in the city center, where there is a significant demand for residential land to accommodate urban dwellers, especially those working in the trade and service sectors within the commercial areas of the city center. The availability of complete facilities and infrastructure in the city center also contributes to its attractiveness as a residential area (Taleb, 2014). Consequently, the city center becomes a significant source of air pollution emissions compared to areas outside the city center.

2. Spatial Distribution of Land Surface Temperature in Parepare City in 2014 and 2021

The Land Surface Temperature analysis resulted in land surface temperature values in Parepare City for 2014 and 2021, as shown in Figure 2. The land surface temperature values in Parepare City were classified into three categories: <26°C, 27-30°C, and >30°C.

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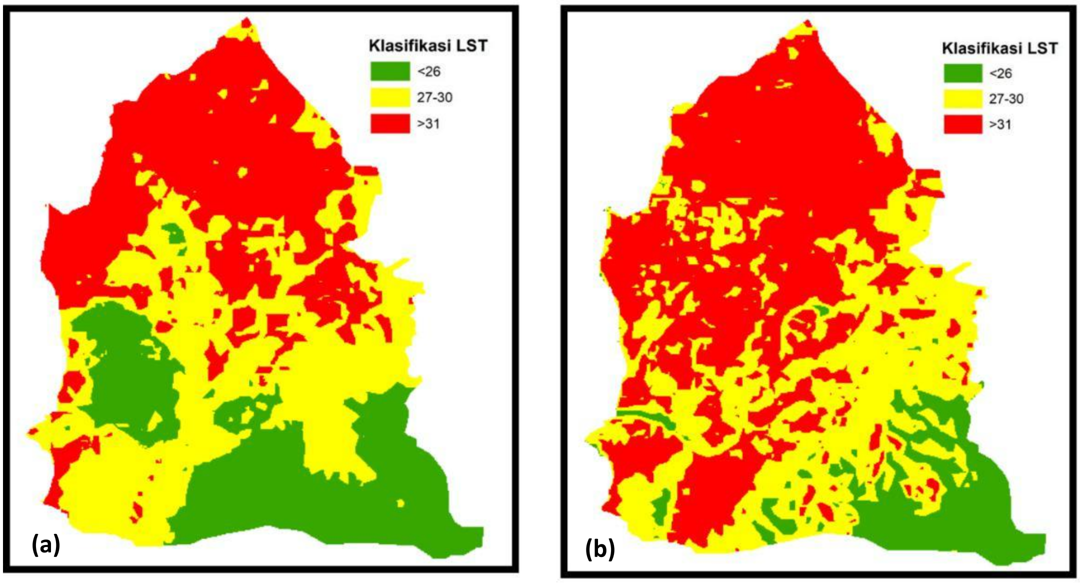

Figure 2. Distribution of Land Surface Temperature in Parepare City (a) Land Surface Temperature in Parepare City in 2014, (b) Land Surface Temperature in Parepare City in 2021.

The land surface temperature values in Parepare City in 2014 ranged from 32.45°C to a minimum of 24.01°C, with an average of 28.41°C. In 2021, the highest land surface temperature recorded was 33.94°C, while the lowest was 26.04°C, with an average of 29.36°C. The spatial distribution of land surface temperature in Parepare City shows varying patterns. In 2014, the dominant classification was in the >31°C category, while in 2021, the 27-30°C category dominated. In 2014, the <26°C classification covered an area of 1,391.73 hectares, predominantly in the Bacukiki District, with some scattered areas in the Bacukiki Barat District, and forming point patterns along the coastal areas of Ujung and Soreang Districts. The 27-30°C classification covered an area of 3,793.89 hectares, mainly °Ccurring in Bacukiki and Bacukiki Barat Districts. The >30°C classification covered an area of 4,747.38 hectares, predominantly in Ujung, Soreang, and the northern part of Bacukiki Barat District.

In 2021, the <26°C classification covered an area of 2,658.06 hectares, dominating Bacukiki Barat and Bacukiki Districts, with scattered point patterns in Ujung District. The 27-30°C classification covered an area of 3,771.68 hectares, predominantly °Ccurring in Bacukiki, Bacukiki Barat, and Ujung Districts. The >30°C classification covered an area of 3,503.26 hectares, predominantly in Ujung, Soreang, the northern part of Bacukiki Barat District, and the coastal areas of Bacukiki District. Over the period from 2014 to 2021, significant land use changes have influenced fluctuations in land surface temperature in Parepare City. In the <26°C classification, the changes mostly °Ccurred in the southern part of Bacukiki District and the eastern part of Bacukiki Barat District, which were moorland (irrigated vegetable fields) and shrublands. In the 27-30°C classification, the changes were predominantly observed in Bacukiki and Bacukiki Barat Districts, involving the conversion of shrublands into moorland (irrigated vegetable fields) and paddy fields. Furthermore, the >30°C classification also experienced a decrease, primarily in Bacukiki, Bacukiki Barat, and Ujung Districts, due to the conversion of paddy fields into moorland (irrigated vegetable fields).

3. Vegetation Density in Parepare City in 2014 and 2021

The analysis of NDVI (Normalized Difference Vegetation Index) resulted in values for vegetation density in Parepare City for 2014 and 2021, as presented in Figure 3.

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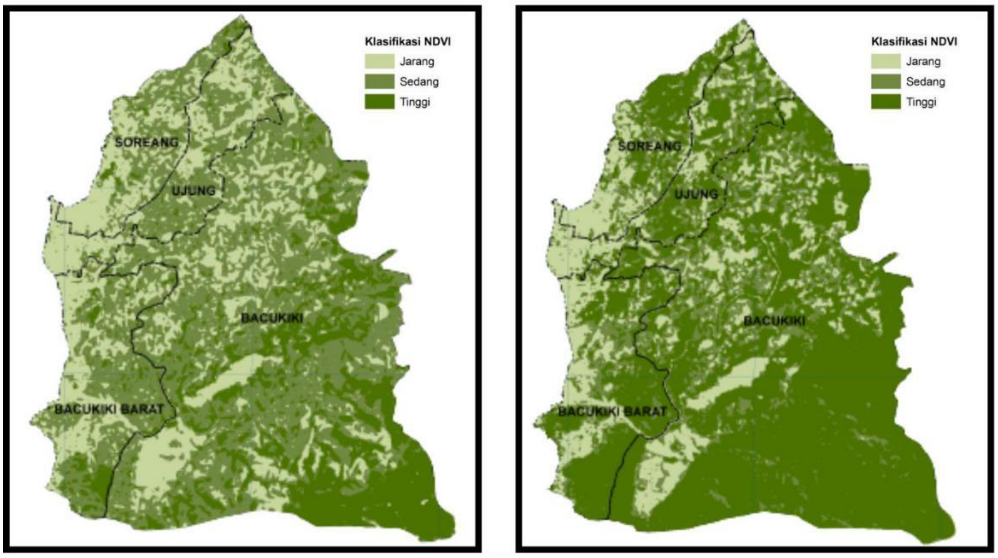

Figure 3. Vegetation Density in Parepare City (a) Vegetation Density in Parepare City in 2014, (b) Vegetation Density in Parepare City in 2021.

Based on the results above, the highest vegetation density value in Parepare City in 2014 was 0.4799, while the lowest value was -0.0349. In 2021, the highest vegetation density value was 0.666, and the lowest was -0.086. This analysis revealed significant changes in vegetation density in Parepare City between 2014 and 2021. In 2014, the city exhibited a moderate level of vegetation density, with a range of values from 0.4799 to -0.0349. This indicates the presence of vegetation cover, although it varied in density across different areas. The distribution of vegetation density classes in 2014 showed that Class 1, representing sparse or non-existent vegetation, covered approximately 29.22% of the city's total area. It was predominantly located in the eastern part of the Soreang, Ujung, and Bacukiki Barat districts, with a smaller extent in the southern part of the Bacukiki district. Class 2, indicating moderate vegetation density, occupied around 37.86% of the city's area, mainly in the western part of the Bacukiki Barat and Ujung districts. This class also had scattered patterns in the Ujung and Bacukiki districts. Class 3, representing high vegetation density, covered approximately 21.67% of the city's area, including a significant portion of Bacukiki district, the western part of Bacukiki Barat district, and the Soreang and Ujung districts in smaller extents.

In 2021, a noticeable increase in vegetation density was observed throughout Parepare City. The highest vegetation density value reached 0.6669, indicating a substantial growth of vegetation cover. Class 1 covered approximately 14.68% of the city's area, primarily in the western parts of Soreang, Ujung, and Bacukiki Barat districts and a smaller portion of Bacukiki district. Class 2 occupied around 49.11% of the area, with predominant distribution in the northern and western parts of Bacukiki District, Bacukiki Barat District, Ujung District, and Soreang District. Class 3 continued to represent high vegetation density, covering approximately 47.46% of the area. It encompassed most of the Soreang, Bacukiki Barat, Bacukiki, and Ujung districts. These findings indicate a significant and widespread increase in vegetation density over the seven years in Parepare City. Increasing vegetation cover can affect environmental quality, biodiversity, and the overall urban climate. Further analysis and monitoring of vegetation dynamics in the city will be crucial for sustainable land management and effective strategies in mitigating urban heat island effects.

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4. Correlation between Vegetation Density and Land Surface Temperature in Parepare City in 2014 and 2021

The Pearson correlation analysis was performed to analyze the relationship between vegetation density and land surface temperature, with vegetation density as the X variable and land surface temperature as the Y variable. Spatial data interpolation techniques were used to determine the values of X and Y variables. The interpolated values were then plotted on graphs, as shown in Figure 4 and Figure 5.

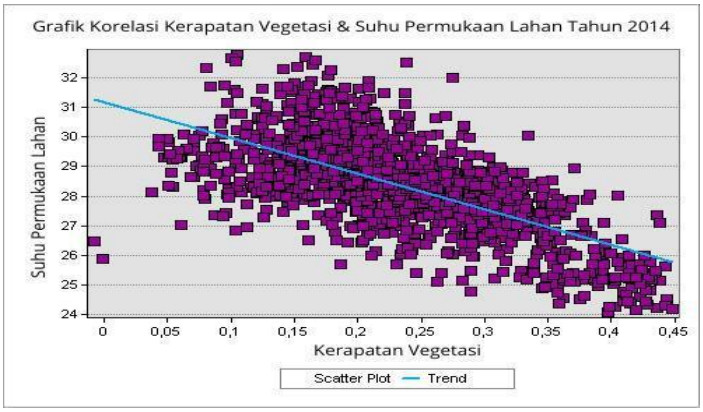

Figure 4. Graph of Correlation between Vegetation Density and Land Surface Temperature in 2014.

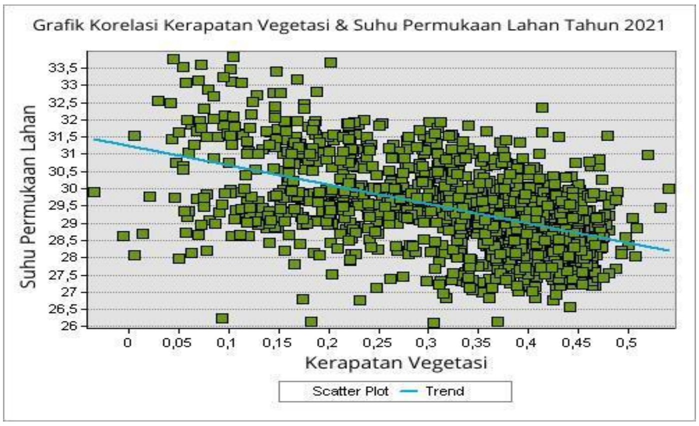

Figure 5. Graph of Correlation between Vegetation Density and Land Surface Temperature in 2021.

Based on Figure 4 and Figure 5, it can be observed that there is a negative correlation between vegetation density and land surface temperature. This is indicated by the inverse trend of the straight line on the graph, meaning that vegetation density decreases as land surface temperature increases. To determine the coefficient of correlation between vegetation density and land surface temperature in Parepare City for 2014 and 2021, the Pearson correlation was calculated using the SPSS Statistics 22 software, as presented in Table 2 and Table 3.

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Table 2. The Pearson correlation test results for the correlation between vegetation density and land surface temperature in Parepare City in 2014

		LST	NDVI
LST	Pearson Correlation	1	-0.653
	Sig. (2-tailed)		0.048
	N	1520	1520
NDVI	Pearson Correlation	-0.653	1
	Sig. (2-tailed)	0.048	
	N	1520	1520

Source: Analysis results, 2022.

The correlation analysis between vegetation density and land surface temperature in Parepare City in 2014 shows that the coefficient of significance (r2) is 0.048. This indicates that vegetation density and land surface temperature correlate (based on the decision-making criteria). The correlation coefficient (r) is -0.653, indicating moderate correlation strength. According to the interpretation of the r value ($0.6 \leq r < 0.8$ = strong), this interpretation can also apply to negative correlation values.

Table 3. The Pearson correlation test results for the correlation between vegetation density and land surface temperature in Parepare City in 2021

		LST	NDVI
LST	Pearson Correlation	1	-0.508
	Sig. (2-tailed)		0.050
	N	1520	1520
NDVI	Pearson Correlation	-0.508	1
	Sig. (2-tailed)	0.050	
	N	1520	1520

Source: Analysis results, 2023.

Based on Tables 2 and 3, the coefficient of significance (r2) values are less than 0.05, indicating a relationship between vegetation density and land surface temperature in Parepare City in 2014 and 2021 (at a significance level of 5%). It is observed that the correlation coefficient (r) values for 2014 and 2021 are both negative. A negative correlation indicates that variables X and Y are inversely related or not in the same direction. In this case, increasing vegetation density would lead to a decrease in land surface temperature. Based on the obtained correlation values, there is a significant relationship and interdependence between vegetation density and land surface temperature in Parepare City. These findings align with previous research conducted by Priyana, dkk., (2018), which found that vegetation density is crucial in determining air temperature, and the relationship is negative. Land use changes in Parepare City have also influenced the spatial distribution of land surface temperature. Changes have occurred in the classification of land surface temperature in several areas, particularly in higher temperature categories. These changes may be attributed to land conversion from moorland (irrigated vegetable fields) to paddy fields or vice versa. Additionally, there have been changes in vegetation density in Parepare City during the same period. The vegetation density has significantly increased, resulting in a reduction in land surface temperature. Furthermore, the correlation analysis indicates a significant relationship between vegetation density and land surface temperature in Parepare City. The coefficient of significance (r2) values, which are less than 0.05, suggest a statistical association between the two variables. The negative correlation coefficients (r) for 2014 and 2021 imply an inverse relationship between vegetation density and land surface temperature.

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The negative correlation implies that land surface temperature decreases as vegetation density increases. This finding highlights the role of vegetation in regulating local temperatures and mitigating the Urban Heat Island effect. Increased vegetation density can provide shading, evaporative cooling, and transpiration, which collectively contribute to lowering land surface temperatures. The changes in land use within Parepare City have significantly shaped the spatial distribution of land surface temperature. Land conversions, such as the transformation of moorland into paddy fields or vice versa, have contributed to alterations in the temperature classifications across different areas. Additionally, the observed increase in vegetation density over time has had a cooling effect on the land surface, leading to a reduction in temperature. These findings emphasize the importance of considering vegetation management and sustainable land use practices in urban planning and development. Promoting the growth and preservation of vegetation, particularly in densely populated urban areas, can help mitigate the Urban Heat Island effect and improve the overall environmental quality and livability of Parepare City.

CONCLUSION

In conclusion, the research conducted in Parepare City reveals a significant relationship between vegetation density and land surface temperature, indicating that land surface temperature tends to decrease as vegetation density increases. Land conversion and high population density influence the Urban Heat Island (UHI) phenomenon, increasing air pollution emissions. However, implementing greening efforts and optimal management of Green Open Spaces have helped mitigate the increase in UHI effect from 2014 to 2021. The negative correlation between vegetation density and land surface temperature highlights the importance of vegetation in regulating temperature and mitigating the effects of UHI. Sustainable land management and continuous greening initiatives in urban areas should be prioritized to combat the Urban Heat Island.

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