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DISTRIBUTION OF URBAN HEAT ISLAND INDEX IN THE SURABAYA, YOGYAKARTA, AND BANDUNG USING REMOTE SENSING

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ABSTRACT

Climate change is a global issue as it drives global warming and heightens the impact of greenhouse gases. In the past decade, the Urban Heat Island (UHI) phenomenon has become a growing concern in major cities due to urbanization and development. This study aims to analyze the distribution and relationship between changes in Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) with UHI changes in Surabaya, Yogyakarta, and Bandung, and propose mitigation strategies. The descriptive quantitative approach is used in the research to explain the calculated area and percentage of NDVI, NDBI, LST, and UHI. Geographic Information System (GIS) technology, specifically ArcGIS 10.8, was utilized to process Landsat imagery data from 1994 and 2024, enabling spatial analysis and visualization of urban heat distribution and land use changes. Simple correlation analysis was also carried out to examine the relationship between LST and NDVI, as well as LST and NDBI. The analysis shows that NDVI decreased, while NDBI, LST, and UHI increased over the 30 years in all three cities. LST and NDVI have a strong inverse relationship, where increasing LST correlates with decreasing NDVI. NDBI shows a positive relationship with LST, meaning more built-up areas lead to higher LST and UHI. Mitigation strategies include expanding green spaces, adopting green building technologies, and utilizing renewable energy.

Keywords: *Urban Heat Island; Climate Change; Geographic Information System; Mitigation*

INTRODUCTION

Data from the United Nations (2018) indicates that Indonesia experienced a significant increase in the urban population from 1960-2017, namely 131.49 million people compared to rural areas, which only reached 44.71 million people. According to Muzaky (2019), predictions that by 2035 the percentage of the urban population is estimated to increase to 66.6%. This indicates a population shift from villages to cities that is increasing yearly. Urbanization in urban areas has had a significant impact on the allocation of land use for development efforts such as industrialization, road infrastructure, and building construction using materials with high thermal capacity (Mas'uddin et al., 2023). According to Sumaryana (2022), urbanization always goes hand in hand with increased changes in land function and affects climate change.

The Intergovernmental Panel on Climate Change (IPCC) (2018) reported that global climate change is intensifying due to human activity, with urban areas playing a critical role in increasing greenhouse gas emissions and driving extreme weather events. It stated that there have been several extreme climate changes with increasing intensity and frequency due to a temperature increase of 0.5°C. The urban building and construction sector, responsible for 37% of global greenhouse gas emissions and 34% of energy consumption, further exacerbates this issue (UNEP, 2022). These changes contribute significantly to the decline in environmental quality, manifesting in air pollution, the Urban Heat Island (UHI) phenomenon, and broader climate change impacts (Syamsudin & Lestari, 2017). A similar observation was made by Khoshnoodmotlagh et al. (2021), who highlighted that urbanization causes an increase in the intensity of the Urban Heat Island phenomenon due to land cover changes that affect local climates.

Climate change is a very important global issue, encompassing the phenomenon of global warming and the increasing impact of greenhouse gases (Patrianti et al., 2020). Climate change also exacerbates urban vulnerabilities by increasing the frequency of heatwaves, altering precipitation patterns, and intensifying urban flooding risks (IPCC, 2022). According to Aini et al. (2021), the Urban Heat Island is a phenomenon where urban areas have higher temperatures compared to the surrounding rural areas. Big cities in Indonesia, such as Surabaya, Yogyakarta, and Bandung have become centers of economic, educational, and cultural growth, driving population growth and the expansion of built-up areas (BPS, 2020). However, this urbanization process is often not balanced with sustainable urban planning. Rapid urban growth can result in increased urban temperatures, loss of green areas, and changes in land use patterns that contribute to the Urban Heat Island phenomenon.

In addition to high urbanization, the selection of study locations is based on the topographical conditions of the regions. Surabaya, located in a lowland area with an elevation of 3–6 meters above sea level, has a humid tropical climate and a heat distribution influenced by low water infiltration and extensive development of concrete and asphalt infrastructure (Anjani, 2024). Yogyakarta, also situated in a lowland area, features a more complex topography with a microclimate influenced by Mount Merapi (Santosa, 2016). Meanwhile, Bandung, with an average elevation of 768 meters above sea level, has a cooler tropical climate but faces increased LST in the city center due to urbanization, exacerbated by the basin effect that traps heat (Amalia, 2011).

A survey by Arifwidodo et al. (2019) found that 50% of respondents in Bandung City experienced difficulties during their workplace journey due to hot weather. Meanwhile, research by Pratiwi & Jaelani (2020) stated that in Surabaya, UHI-affected areas are concentrated in the city center with dense buildings, while the outskirts are less affected. Additionally, Mustikarini (2022) found that in Yogyakarta, UHI is related to the meteorological drought index. The negative impacts of UHI, including its contributions to urban flora degradation, climate alteration, pollutant concentration increases, human health risks, extreme heat-related deaths, global warming, and diminished thermal comfort, further underscore the interplay between UHI and climate change (Firozjaei et al., 2020).

Thus, the UHI phenomenon plays a significant role in urban life quality, necessitating a comprehensive understanding of the spatial-temporal variations of metropolitan areas. This is crucial for developing strategies for sustainable urban development, particularly in mitigating the interconnected impacts of UHI and climate change (Yang et al., 2020). Responding to the complexity of these challenges, this study aims to identify the distribution and relationship between changes in Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI) with changes in the Urban Heat Island (UHI) index, and provide mitigation strategies to suppress Urban Heat Island intensity.

MATERIALS AND METHODS

Location and Time

This study was conducted in Surabaya, Yogyakarta, and Bandung (see **Figure 1**). Data from 1994 can provide a baseline for understanding the condition of the Urban Heat Island in the past. Meanwhile, 2024 was chosen as the endpoint in this study to understand changes in the Urban Heat Island over the past 30 years. The month of image acquisition was chosen in July which is the dry season. The dry season was chosen because there is minimal cloud cover and rainfall, so the Urban Heat Island phenomenon can be clearer and easier to measure (Pratiwi & Jaelani, 2020).

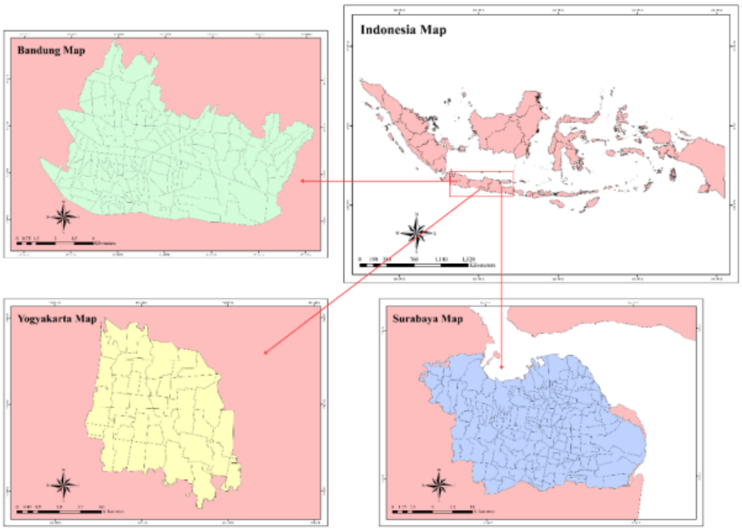

Figure 1. Study Location

Materials

The data needed are Landsat 5 and 8 imagery records with 10% cloud cover via USGS. The use of Landsat was chosen because it can accommodate landscape factors and location associations that can affect surface temperature (Hardianto et al., 2021). The data used in this study consists of raster and polygon data, each serving specific analytical purposes. The raster data includes Landsat imagery, with Landsat 5 utilizing Bands B3, B4, B5, and B6, and Landsat 8 employing Bands B4, B5, B6, and B10. These datasets, sourced from the United States Geological Survey (USGS) Earth Explorer platform, provide spectral data essential for calculating Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index

(NDBI). The polygon data comprises district and city administrative boundaries for Surabaya, Yogyakarta, and Bandung, obtained from the Geospatial Information Agency. These boundaries ensure that spatial analyses are confined to the designated study areas. The study employed hardware in the form of a laptop for data processing and software in the form of ArcGIS 10.8 for spatial analysis, visualization, and interpretation. Together, these datasets and tools enable a comprehensive understanding of the Urban Heat Island (UHI) phenomenon across the selected cities.

Data Processing

To ensure the distribution pattern of the Urban Heat Island (UHI), the data processing process is divided into the following stages:

1. Calculation of Top of Atmosphere (TOA) which is an image correction with radiometric calibration where the value is converted into reflectance or radian value (Oktaviana et al., 2018):
   $TOA=0.000342xBand\ 10+0,1$ …….(1)
2. Calculation of Brightness Temperature (BT) which is the back reflection from pure surface objects and produces radiance on the sensor (Ibrahim et al., 2016):
   $BT=(K_2)/ln(K\hat{}1/L\lambda+1)-273,15$ ……(2)
3. Calculation of the Normalized Difference Vegetation Index (NDVI) obtained by calculating Near Infrared with Red reflected by plants and also comparing Near Infrared and Red data (Philiani et al., 2016):
   $NDVI=(NIR-RED)/(NIR+RED)$ …..(3)
4. Calculation of the Normalized Difference Built-up Index (NDBI) is used to further highlight the built-up areas of urban areas (Isnaeni and Prasetyo, 2022):
   $NDBI=(SWIR-NIR)/(SWIR+NIR)$...(4)
5. Calculation of the Proportion of Vegetation (PVI) to account for NDVI and minimize interference from moist soil conditions and surface energy fluxes (Sagita, 2022):
   $PV=((NDVI-NDVImin)/(NDVImax-NDVImin))^2$………………………….(5)
6. Calculation of Emissivity (E) to determine the ability of an object/surface to emit radiation with a black body at the same temperature (Ar'afii et al. 2024):
   $E = 0,004\ x\ PVI + 0.986$…………..(6)
7. Calculation of Land Surface Temperature (LST) or land surface temperature where the value of LST

is influenced by wavelength, such as the wavelength that is most sensitive to surface temperature is thermal infrared (Nugroho & Dirgahayu, 2015):

$LST=BT/([1+(\lambda xT/\partial)xln(e)])$..........(7)

8. Urban Heat Island (UHI) calculation is the accumulation of heat in urban areas due to various factors such as built-up land cover, non-absorbent surfaces, and human activities (Zhang et al., 2009):

$UHI=(LST-LSTmean)/(Std\ Dev)$....(8)

The next step after LST is calculated is to correlate LST with NDVI and NDBI which allows for an in-depth analysis of the relationship between surface temperature and the presence of vegetation and built-up areas. The research uses a descriptive quantitative approach to explain the calculated area and percentage of NDVI, NDBI, LST, and UHI. A simple correlation analysis is also conducted to examine the relationship between LST and NDVI, as well as LST and NDBI. NDVI, NDBI, LST, and UHI classification shown in **Table 1**.

Table 1. NDVI, NDBI, LST, and UHI classification

NDVI (Mardiatmoko, 2019)		NDBI (Handayani, 2017)		LST (Ramadhan, 2021)		UHI (Pratiwi, 2020)	
Class	**Value**	**Class**	**Value**	**Class**	**Value**	**Class**	**Value**
Non-Vegetation	-1 – 0	Non-Settlement	-1 - 0	1	< 20°C	Non-UHI	≤ 0
Low Vegetation	0.03 – 0.25	Low Settlement	0.1 – 0.3	2	21-24°C	UHI 1	0 - 2
Moderate Vegetation	0.25 – 0.40	Moderate Settlement	0.3 – 0.5	3	25-28°C	UHI 2	2 - 4
High Vegetation	0.40 – 1	High Settlement	≥ 0.5	4	29-32°C	UHI 3	≥ 4
				5	> 32°C		

RESULTS AND DISCUSSION

Distribution of NDVI, NDBI, LST, and UHI Changes

Surabaya City in 1994 and 2024

Changes in NDVI, NDBI, LST, and UHI in Surabaya City between 1994 and 2024 reflect significant transformations due to urbanization and land use changes (see **Table 2**). In the NDVI indicator, there was a decrease in the non-vegetation area by 17.67%, accompanied by a slight increase in the low and medium vegetation categories of 3.78% and 4.96%, respectively. A decrease in the high vegetation area of 2.08% indicates the conversion of natural vegetation land into built-up areas or more degraded vegetation areas (Diener, 2021). This can be caused by the growth of urbanization and the increasing need for land for settlements and infrastructure (Mansour et al., 2022).

In the NDBI indicator, a sharp decrease of 58.37% in the non-settlement category and 41.58% in the low settlement category reflects the reduction in natural areas or empty land due to urbanization. In contrast, the medium and dense settlement categories experienced a significant increase of up to 100% (overload), indicating a major spike in settlement development and human activity. This increase is likely due to rapid population growth, urban sprawl, and increasing intensity of development in city centers and suburbs (Lin et al, 2020).

Table 2. Result of NDVI, NDBI, and LST in Surabaya

City	Class	Value	Area (Ha) 1994	Area (Ha) 2024	Difference (%)
		NDVI			
Surabaya	Non-Vegetation (1)	-1 – 0	5020	4133	-17.67%
	Low Vegetation (2)	0.03 – 0.25	15047	15616	3.78%
	Moderate Vegetation (3)	0.25 – 0.40	8300	8712	4.96%
	High Vegetation (4)	0.40 – 1	4621	4525	-2.08%
		NDBI			
Surabaya	Non-Settlement (1)	-1	8631	3593	-58.37%
	Low Settlement (2)	0.1 – 0.3	15756	9205	-41.58%
	Moderate Settlement (3)	0.3 – 0.5	3970	10410	100% (overload)
	High Settlement (4)	≥ 0.5	4631	9779	100% (overload)
		LST			
Surabaya	1	< 20°C	4527	3647	-19.44%
	2	21-24°C	5538	4361	-21.25%
	3	25-28°C	7089	7841	10.61%
	4	29-32°C	11411	10800	-5.35%
	5	> 32°C	4424	6339	43.29%
		UHI			
Surabaya	Non-UHI	≤ 0	4526	4139	-8.57%
	UHI 1	0 – 2	7082	5701	-19.50%
	UHI 2	2 – 4	13815	11597	-16.06%
	UHI 3	≥ 4	7569	11553	52.64%

These changes have a direct impact on land surface temperatures, as reflected by LST. Areas with low temperatures (<20°C and 21–24°C) decreased by 19.44% and 21.25%, respectively, while areas with moderate temperatures (25–28°C) increased by 10.61%. The most significant is the 43.29% increase in areas with extreme temperatures (>32°C), which is the main indicator of the increasing urban heat island effect (UHI). This condition can be explained by the increasing heat emissions from human activities, the reduction in vegetation that functions as a heat absorber, and the dominance of hard surfaces such as concrete and asphalt that absorb more solar radiation (Muzakky, 2019). The urban heat island effect is also clearly visible from the UHI data, where the Non-UHI and UHI 1 areas decreased by 8.57% and 19.50%. In contrast, UHI category 3, which reflects the most significant impact of this phenomenon, increased drastically by 52.64%. Transformation of NDVI, NDBI, LST, UHI in Surabaya shown in **Figure 2**.

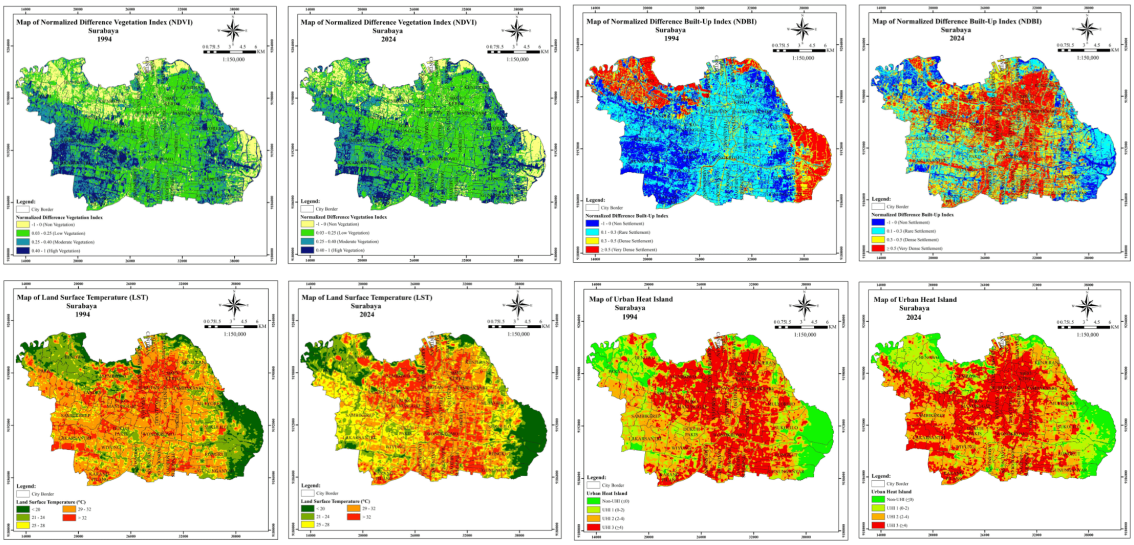

Figure 2. Transformation of NDVI, NDBI, LST, UHI in Surabaya

Yogyakarta City in 1994 and 2024

NDVI shows significant changes in vegetation coverage in Yogyakarta from 1994 to 2024 (see **Table 3**). The non-vegetation category increased by 16.52%, indicating an expansion of areas without vegetation cover such as built-up areas, roads, and other open lands. In the low vegetation category, there was a very small increase of 0.80%, indicating relative stability for areas with sparse vegetation cover. In contrast, the medium vegetation category experienced a significant decrease of -15.37%. Likewise, the high vegetation category decreased by -12.80%. This decrease in medium and high vegetation cover indicates that natural green areas such as forests, productive agricultural lands, and other dense vegetation have been converted into built-up areas. This phenomenon is generally caused by infrastructure development, and increasing population that requires land for settlements, industry, and other facilities (Carillo et al., 2021; Dickinson et al., 2022).

NDBI reflects the level of regional development in Yogyakarta which has increased significantly in the last 30 years. The non-residential category increased by 39.00%, indicating the development of land that was previously not used for construction. In the low-rise residential category, the area increased by 35.29%, indicating the transformation of the area from being rural to an area with new residential development. However, the medium-rise residential category experienced a sharp decline of -42.33%. This decline was most likely caused by land intensification, where areas that were previously medium-rise residential areas were converted into high-rise residential areas, which experienced a remarkable increase of 100%. This change indicates land use densification due to population growth and increasing space needs (Surya et al., 2021). This phenomenon is often found in areas experiencing rapid urbanization, where limited land forces more intensive use of space, for example through the construction of apartments, high-rise buildings, or dense residential clusters (Bibri et al., 2020).

Table 3. Result of NDVI, NDBI, and LST in Yogyakarta

City	Class	Value	Area (Ha)		Difference (%)
			1994	2024	
		NDVI			
Yogyakarta	Non-Vegetation (1)	-1 – 0	9611	11199	16.52%
	Low Vegetation (2)	0.03 – 0.25	13830	13940	0.80%
	Moderate Vegetation (3)	0.25 – 0.40	7441	6297	-15.37%
	High Vegetation (4)	0.40 – 1	2055	1792	-12.80%
		NDBI			
Yogyakarta	Non-Settlement (1)	-1	162.44	225.8	39.00%
	Low Settlement (2)	0.1 – 0.3	540.3	730.8	35.29%
	Moderate Settlement (3)	0.3 – 0.5	2132.9	1229.3	-42.33%
	High Settlement (4)	≥ 0.5	456.7	1107.9	100% (overload)
		LST			
Yogyakarta	1	< 20°C	76.3	108.8	42.56%
	2	21-24°C	255.5	486.6	90.45%
	3	25-28°C	811.5	1041.9	28.37%
	4	29-32°C	1461.6	1213.4	-16.99%
	5	> 32°C	688.4	443.1	-35.63%
		UHI			
Yogyakarta	Non-UHI	≤ 0	253.3	114.2	-54.89%
	UHI 1	0 – 2	900.2	538.7	-67.11%
	UHI 2	2 – 4	1455	1474	1.29%
	UHI 3	≥ 4	684.6	1165.9	41.28%

LST shows the direct impact of land use changes on surface temperature (Puspita, 2023). In 2024, there is an increase in the area in the low to moderate temperature category. The temperature category <20°C increases by 42.56%, while the temperature of 21–24°C increases drastically by 90.45%. This increase in area indicates possible mitigation efforts, such as reforestation and the use of environmentally friendly construction materials in certain areas (Noveri, 2020). On the other hand, the temperature category 25–28°C also increases by 28.37%, while the higher temperature categories 29–32°C and >32°C decrease by -16.99% and -35.63%, respectively.

The UHI phenomenon shows the impact of urbanization on temperature distribution in urban areas. Non-UHI category, the area decreased drastically by -54.89%, indicating that the area not affected by the UHI effect is decreasing due to development. In the UHI 1 category, the decrease was also very significant by -67.11%. This decrease indicates that the intensification of development in Yogyakarta has spread the urban heat island effect to a wider area. However, in the UHI 3 category, there was a large increase of 41.28%. This indicates that the area with the highest heat concentration has increased significantly. Transformation of NDVI, NDBI, LST, UHI in Yogyakarta shown in **Figure 3**.

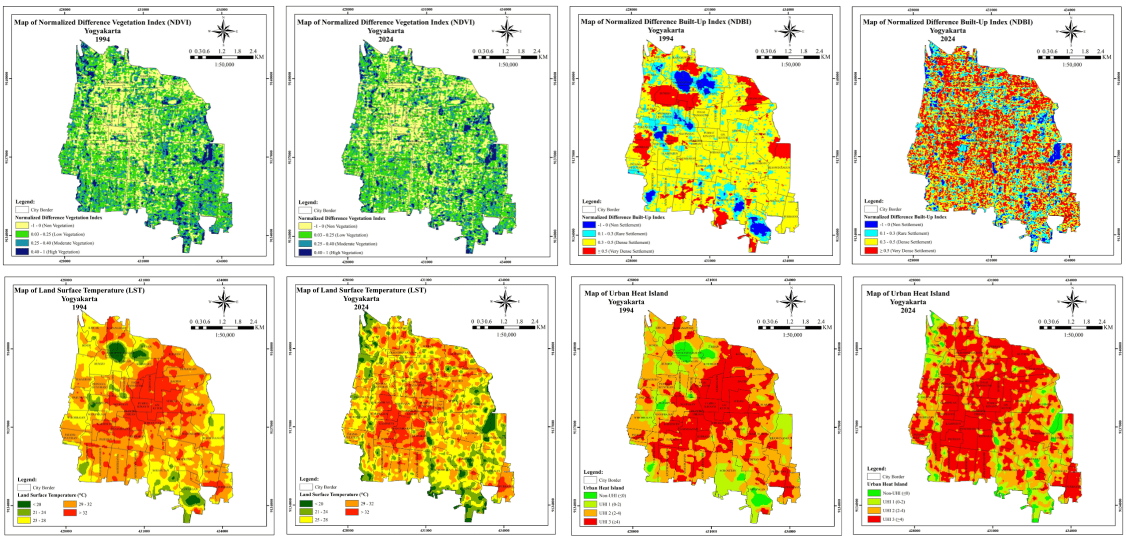

Figure 3. Transformation of NDVI, NDBI, LST, UHI in Yogyakarta

Bandung City in 1994 and 2024

NDVI in Bandung shows a significant trend of change reflecting a decrease in natural vegetation cover (see **Table 4**). The non-vegetation category increased by 13.15%. Due to urbanization and land use conversion, this increase indicates the expansion of built-up land or nongreen areas such as settlements, roads, and industrial areas. In contrast, the low vegetation category decreased by -8.77%, while medium and high vegetation decreased by -11.08% and -10.35%, respectively. This decrease in natural vegetation cover illustrates environmental degradation due to the conversion of green land into built-up areas. This finding is in line with Rahmy and Hoctor (2021), that land use changes in Bandung City are increasing due to urbanization causing a decrease in green cover.

NDBI data shows a significant increase in non-residential areas, which increased by 56.50%. This illustrates new built-up areas, like industrial, commercial, and public facilities. Meanwhile, the low-density housing category experienced the largest decline of -57.92%, followed by medium-density housing which decreased by -9.62%. This decline can be interpreted as a change in settlement characteristics, where low and medium-density areas have changed into high-density housing, which shows a significant increase of 100%. The increase in the high-density housing category indicates land densification in response to population growth, where land is used more intensively, including the construction of high-rise buildings, apartments, or dense settlement clusters (Afriyanie et al., 2020). Transformation of NDVI, NDBI, LST, and UHI in Bandung shown in **Figure 4**.

Table 4. The result of NDVI in Bandung 1994 and 2024

City	Class	Value	Area (Ha) 1994	Area (Ha) 2024	Difference (%)
		NDVI			
Bandung	Non-Vegetation (1)	-1 – 0	7149	8089	13.15%
	Low Vegetation (2)	0.03 – 0.25	5195	4739	-8.77%
	Moderate Vegetation (3)	0.25 – 0.40	2729	2427	-11.08%
	High Vegetation (4)	0.40 – 1	1748	1567	-10.35%
		NDBI			
Bandung	Non-Settlement (1)	-1	1297	2030	56.50%
	Low Settlement (2)	0.1 – 0.3	8819	3711	-57.92%
	Moderate Settlement (3)	0.3 – 0.5	5842	5281	-9.62%
	High Settlement (4)	≥ 0.5	863	5800	100% (overload)
		LST			
Bandung	1	< 20°C	1381	1012	-26.74%
	2	21-24°C	2871	2175	-24.24%
	3	25-28°C	4237	4219	-0.42%
	4	29-32°C	5305	5823	9.77%
	5	> 32°C	3026	3592	18.70%
		UHI			
Bandung	Non-UHI	≤ 0	2687	1541	-42.62%
	UHI 1	0 – 2	3561	3397	-4.60%

City	Class	Value	Area (Ha)		Difference (%)
			1994	2024	
	UHI 2	2 – 4	5716	6696	17.14%
	UHI 3	≥ 4	4856	5188	6.83%

Analysis of LST changes shows an increase in temperature in Bandung due to urbanization. The temperature category <20°C decreased drastically by -26.74%, while the 21–24°C and 25–28°C categories decreased by -24.24% and -0.42%, respectively. The decrease in this area reflects the shrinking of areas with lower temperatures, which are often associated with the presence of vegetation and green open spaces that can cool the ground surface. In contrast, the temperature categories of 29–32°C and >32°C increased by 9.77% and 18.70%, respectively. This increase indicates an increase in areas with higher surface temperatures, caused by urbanization, reduced vegetation cover, and the use of materials that absorb and store heat, such as concrete and asphalt. The UHI phenomenon shows the real impact of urbanization on temperature distribution in the Bandung urban area. The Non-UHI category decreased sharply by -42.62%, indicating that the area not affected by the UHI effect is decreasing. The moderate intensity UHI categories (UHI 1 and UHI 2) decreased by -4.60% and increased by 17.14% respectively, indicating that the impact of UHI is spreading and expanding to areas that were previously not directly affected. In the high intensity UHI category (UHI 3), there was an increase of 6.83%, indicating a higher concentration of heat in certain areas.

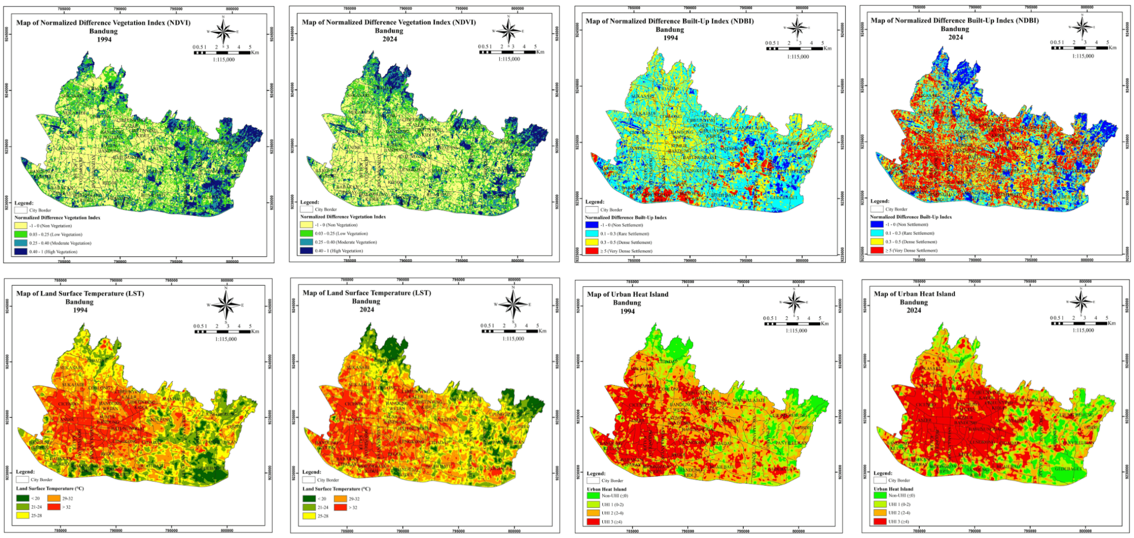

Figure 4. Transformation of NDVI, NDBI, LST, and UHI in Bandung

Relationship between NDVI and NDBI to LST

The relationship between NDVI and NDBI to LST can be explained using a correlation graph, which depicts the dynamic interaction between the three variables from 1994 to 2024 (see **Figure 5** and **Figure 6**). The findings of this analysis indicate a strong inverse relationship between LST and NDVI, meaning that increasing surface temperatures are consistently associated with decreasing vegetation, as measured by NDVI. Conversely, decreasing surface temperatures occur simultaneously with increasing vegetation.

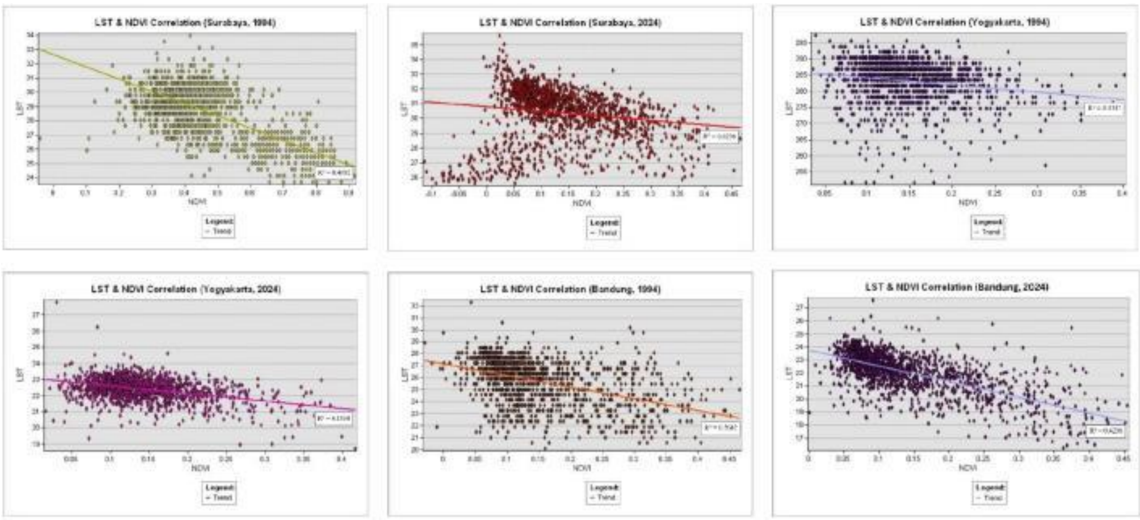

Figure 5. Correlation Result of NDVI and LST

Findings in a study conducted by May et al (2020), stated that LST is negatively correlated with NDVI. A similar opinion was also conveyed in the study by Feldman et al (2023), the lower the vegetation in an area, the LST value will increase. This phenomenon is inseparable from the role of vegetation in providing a cooling effect on the land surface through the evapotranspiration process, which significantly reduces the heat trapped on the land surface. Denser vegetation functions as an absorber of solar radiation and reduces surface heat, which is reflected in higher NDVI values and lower LST (Abulibdeh, 2021).

NDBI shows a positive relationship with LST, indicating that increasing built-up areas, such as infrastructure development and expanding urbanization, are directly correlated with increasing surface temperatures.

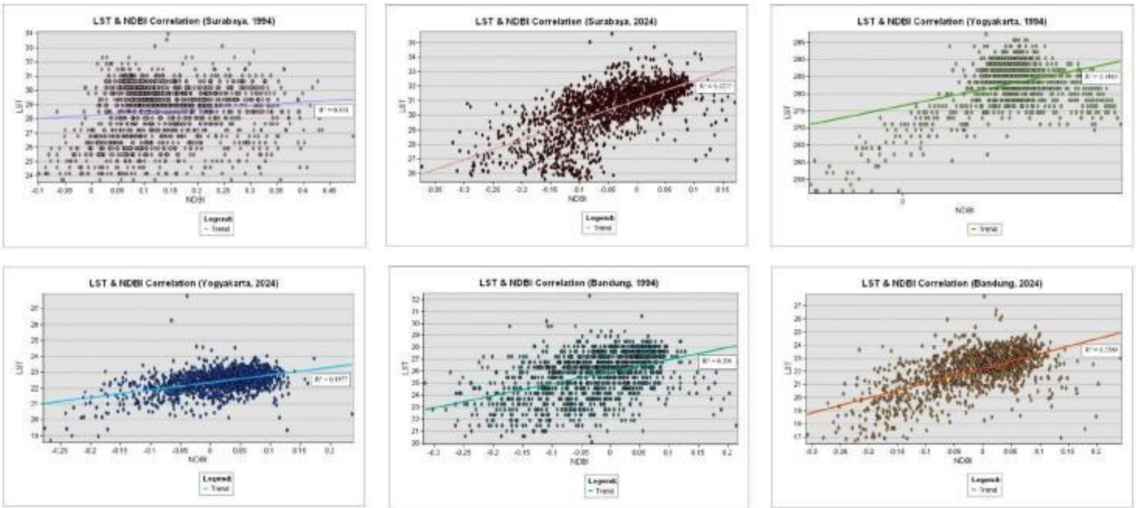

Figure 6. Correlation Result of NDBI and LST

This result is the same as the research conducted by Guha et al (2021) if LST will always be positively correlated with NDBI. This opinion is supported by research by Lu et al. (2023), if dominant in big cities the NDBI and LST values will be very strongly correlated. Built-up areas tend to have lower albedo compared to vegetated areas, thus absorbing more solar radiation and emitting more heat. Building materials such as concrete and asphalt have high heat capacities, causing an increase in ambient temperature, which ultimately contributes to the urban heat island phenomenon (Xu et al., 2021). This can be seen from the increase in NDBI values that reflect the growth of residential areas, industry, and other urban infrastructure, which are simultaneously followed by an increase in surface temperature or LST.

This pattern clearly shows the direct impact of urbanization on the urban environment, where reduced vegetation and increased development lead to a substantial increase in surface temperature. This observation is obtained from data showing that there has been an increase in LST over time due to a decrease in NDVI and an increase in NDBI. This condition especially occurs in rapidly developing urban areas, where increased infrastructure development to support the needs of urban life results in the conversion of green land into built-up areas (Mansour et al., 2022). As a result, the balance of the ecosystem is disturbed, and the urban environment

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becomes more vulnerable to the negative impacts of climate change such as increased extreme temperatures and decreased air quality. The cumulative effect of these land use changes strengthens the trend of increasing LST in urban areas from year to year. With increasingly dense residential areas and reduced green areas that can absorb heat, temperatures in urban areas are significantly higher than in rural areas or more vegetative areas.

Das Sein and Das Sollen Concept

In the analysis of NDVI, NDBI, and LST in the three cities studied, abiotic, biotic, and cultural elements mutually influence environmental changes. Abiotic elements such as temperature and climate are reflected in the increase in LST as vegetation decreases and built-up areas increase. The increase in temperature is triggered by the decrease in vegetation cover, which makes urban areas hotter due to the urban heat island phenomenon (Morabito et al., 2021). Biotic elements, including vegetation, have decreased significantly from 1994 to 2024. Although vegetation plays an important role in maintaining ecosystem balance, development and urbanization reduce green space, impacting ecosystem health and increasing surface temperatures. Meanwhile, cultural elements, including human activities such as development and urbanization, encourage the expansion of built-up areas and the reduction of vegetation. Lifestyle and urban growth accelerate the increase in NDBI, which contributes to the increase in LST (Zaituna et al., 2022). The combination of these three elements creates an increasingly hot and less environmentally friendly urban environment, emphasizing the need for better planning for the balance of development and environmental conservation.

The interplay of abiotic, biotic, and cultural elements in shaping urban environments highlights the complex dynamics of environmental degradation in rapidly growing cities. As built-up areas expand and vegetation diminishes, the ecological services provided by green spaces, such as carbon sequestration and temperature regulation, are significantly reduced (Fan et al., 2022). This not only accelerates the urban heat island effect but also diminishes biodiversity and the overall resilience of urban ecosystems. Cultural elements, particularly the unregulated growth of infrastructure and unsustainable land-use practices, further exacerbate environmental stress. Without a conscious effort to integrate green infrastructure and promote sustainable urban development, these cities risk facing long-term ecological and health challenges. Strategic urban planning that prioritizes green space preservation and the use of climate-resilient building materials is essential to mitigate these negative impacts and promote a more sustainable urban future (Abuwaer et al., 2023).

Mitigation Strategy

Surabaya requires a mitigation approach that reduces the intensity of the Urban Heat Island (UHI) through greening and spatial management. Greening efforts can be expanded by increasing high vegetation areas, especially around dense residential areas, through tree planting programs, city park development, and restoration of green open spaces (RTH). Integrating the concept of green building in new developments, such as green roofs and green walls, can help reduce local temperatures. Surabaya can also adopt the use of road and building surface materials with high albedo to reflect heat. Controlling urbanization through more integrated spatial planning to reduce the conversion of non-residential land into dense residential areas is also important. In addition, the implementation of environmentally friendly transportation policies, such as increasing public transportation and shaded pedestrian paths, can reduce heat emissions from motor vehicles. In Yogyakarta, which shows a significant increase in non-vegetation areas, an approach is needed that balances urban growth with environmental conservation. Mitigation strategies include rehabilitating low and medium vegetation areas with local plants that are resistant to urban conditions. The addition of green corridors around dense residential areas can help reduce temperature increases. Local governments need to encourage the development of low-density areas into multifunctional green areas to maintain environmental balance. Green building technologies such as reflective paint and thermal insulation should be required in new building permits. In addition, introducing incentive policies for buildings that use energy-efficient and environmentally friendly technologies can help reduce the impact of urbanization on local warming.

Bandung, with a significant decline in moderate vegetation, requires an approach that focuses on vegetation restoration and controlling urbanization growth. Replanting moderate vegetation areas on the outskirts of the city and along rivers can increase carbon storage capacity and reduce local temperatures. The "Bandung Sejuk" program can be developed to encourage communities and the private sector to reforest vacant land. In addition, the implementation of environmentally-based spatial planning policies that limit the development of new non-vegetation areas is needed. Sustainable transportation programs, such as the development of renewable energy-based public transportation, can help reduce the contribution of warming from the transportation sector. Bandung can also utilize smart technology to monitor and manage environmental temperatures with an early warning system for extreme temperature increases.

Mitigation strategies for all three cities require a collaborative approach between the government, communities, and the private sector. Evidence-based policies, monitoring environmental changes, and public education programs on the importance of adapting to climate change should be part of long-term efforts. A combination of structural solutions such as greening and non-structural policies such as urbanization control and environmentally friendly incentives will be effective in reducing the impact of UHI and improving people's quality of life.

CONCLUSIONS

Surabaya experienced significant changes, marked by a decrease in non-vegetation areas by -17.67%, while low and medium vegetation increased by 3.78% and 4.96%, respectively, indicating greening efforts. However, high vegetation continued to decline (-2.08%). High settlements increased drastically, accompanied by a significant decrease in non-settlement (-58.37%) and low settlements (-41.58%), reflecting intensive urbanization. High temperatures (>32°C) rose sharply to 43.29%, while low temperatures (<20°C) fell by -19.44%. UHI category 3 in Surabaya increased rapidly to 52.64%, indicating UHI intensification, so that UHI conditions in Surabaya have improved from 1994 to 2024. Yogyakarta showed an increase in non-vegetation areas by 13.5% and a decrease in low vegetation (-9.6%), medium, and high. High-rise settlements also increased drastically while low-rise settlements decreased sharply (-64.5%), reflecting the change of low-density areas to dense areas. High temperatures increased by 21.3%, while low temperatures decreased by -19.1%. UHI category 3 increased by 16.5%, reflecting the impact of urbanization. Overall, UHI conditions in Yogyakarta also increased from 1994 to 2024. Bandung showed a similar pattern with a decrease in moderate vegetation (-11.08%) and an increase in non-vegetation areas (13.15%). High-rise settlements increased sharply, reflecting the growth of dense urbanization. High temperatures increased by 18.7%, while low temperatures decreased drastically (-26.74%). UHI category 3 increased by 6.83%, indicating the impact of urbanization on local warming. UHI conditions in Bandung also increased from 1994 to 2024. Of the three cities, it is known that the order of cities with a significant increase in UHI over thirty years is Surabaya, Yogyakarta, and Bandung. On the other hand, the results obtained if the correlation shows that NDVI is inversely proportional to LST while NDBI is directly proportional to LST.

REFERENCES

Abulibdeh, A. (2021). Analysis of Urban Heat Island Characteristics and Mitigation Strategies for Eight Arid and Semi-Arid Gulf Region Cities. *Environmental Earth Sciences, 80*, 1-26.

Abuwaer, N., Ullah, S., & Al-Ghamdi, S. G. (2023). Building Climate Resilience Through Urban Planning: Strategies, Challenges, and Opportunities. *Sustainable Cities in a Changing Climate: Enhancing Urban Resilience*, 185-206. DOI: https://doi.org/10.1002/9781394201532.ch12

Afriyanie, D., Julian, M. M., Riqqi, A., Akbar, R., Suroso, D. S., & Kustiwan, I. (2020). Re-framing urban green spaces planning for flood protection through socio-ecological resilience in Bandung City, Indonesia. *Cities, 101*, 102710. DOI: https://doi.org/10.1016/j.cities.2020.102710

Aini, A. N., Rapang, S. K., Bayanuddin, A. A. (2021). Utilization of Morning and Evening Sentinel-3 SLSTR Imagery Data for Analysis of Surface Heat Island Phenomenon Intensity (case study of Bandung City). *Jurnal Penginderaan Jauh dan Pengolahan Data Citra, 18*, 1.

Amalia, S. (2011). Desain Interior Sekolah Dasar Internasional Berwawasan Lingkungan. Thesis: Universitas Sebelas Maret.

Anjani, S. J., & Puspaningtyas, A. (2024). Dampak Kondisi Lingkungan Pesisir Terhadap Sosial Ekonomi Penduduk Kenjeran Surabaya.

Eksekusi: Jurnal Ilmu Hukum dan Administrasi Negara, 2(1), 01-14.

Ar'afii, E. A., Sugianto, S., Wijaya, L., Rusdi, M., Basri, H. (2024). The Examination of the Relationship Between Land Cover and Land Surface Temperature in Karang Baru Sub-District, Aceh Province, Indonesia. *In IOP Conference Series: Earth and Environmental Science, 1356*, 1, 012048. https://doi.org/10.1088/1755-1315/1356/1/012048

Arifwidodo, S., Chandrasiri, O., Abdulharis, R., Kubota, T. (2019). Exploring the Effects of Urban Heat Island: a Case Study of Two Cities in Thailand and Indonesia. *APN Science Bulletin*, 9, 1. http://doi.org/10.30852/sb.2019.539

Bibri, S. E., Krogstie, J., & Kärrholm, M. (2020). Compact City Planning and Development: Emerging Practices and Strategies for Achieving the Goals of Sustainability. *Developments in the Built Environment, 4*, 100021.

BPS. (2020). Kota dalam Angka 2020.

Carrillo, G. A., Andrade, J. L., Valdez-Lazalde, J. R., Reyes-García, C., & Hernández-Stefanoni, J. L. (2022). Characterizing Spatial and Temporal Deforestation and Its Effects on Surface Urban Heat Islands in a Tropical City Using Landsat Time Series. *Landscape and Urban Planning, 217*, 104280.

Dickinson, D. C., & Ramalho, C. E. (2022). A Balancing Act: Biodiversity and Human Wellbeing Considerations in the Management of Urban Forest in a Global Biodiversity Hotspot. *Urban Forestry & Urban Greening*, 74, 127656.

Diener, A., & Mudu, P. (2021). How Can Vegetation Protect Us From Air Pollution? A Critical Review on Green Spaces' Mitigation Abilities for Air-Borne Particles From A Public Health Perspective-With Implications for Urban Planning. *Science of the Total Environment, 796*, 148605.

Fan, L., Wang, J., Han, D., Gao, J., & Yao, Y. (2022). Research on Promoting Carbon Sequestration of Urban Green Space Distribution Characteristics and Planting Design Models in Xi'an. *Sustainability, 15*(1), 572.

Feldman, A. F., Short Gianotti, D. J., Dong, J., Trigo, I. F., Salvucci, G. D., & Entekhabi, D. (2023). Tropical Surface Temperature Response to Vegetation Cover Changes and the Role of Drylands. *Global Change Biology, 29*(1), 110-125.

Firozjaei, M. (2020). Modeling Surface Heat Island Intensity According to Differences of Biophysical Characteristics: A Case Study of Amol City, Iran. *Ecological Indicators, 109*. DOI: https://doi.org/10.1016/j.ecolind.2019.105816

Guha, S., Govil, H., Gill, N., & Dey, A. (2021). A Long-Term Seasonal Analysis on the Relationship Between LST and NDBI Using Landsat Data. *Quaternary International, 575*, 249-258.

Hardianto, A., Dewi, P. U., Feriansyah, T., Sari, N. F. S., & Rifiana, N. S. (2021). Pemanfaatan Citra Landsat 8 Dalam Mengidentifikasi Nilai Indeks Kerapatan Vegetasi (NDVI) Tahun 2013 dan 2019 (Area Studi: Kota Bandar Lampung). *Jurnal Geosains Dan Remote Sensing, 2*(1), 8-15. DOI:

https://doi.org/10.23960/jgrs.2021.v2i1.38

Ibrahim, F., Atriani, F., Wulan, R., Putra, M. D., Maulana, E. (2016). Comparison of Brightness Temperature Extraction Landsat 8 TIRS without Atmosphere Correction. *Proceedings of the National Seminar on Geography UMS*.

Intergovernmental Panel on Climate Change (IPCC). (2018). *Annual report of 2018*.

Intergovernmental Panel on Climate Change (IPCC). (2022). *Annual report of 2022*.

Isnaeni, A. Y., & Prasetyo, S. Y. J. (2022). Klasifikasi Wilayah Potensi Risiko Kerusakan Lahan Akibat Bencana Tsunami Menggunakan Machine Learning. *Jurnal Teknik Informatika Dan Sistem Informasi*, *8*(1), 33-42. DOI: https://doi.org/10.28932/jutisi.v8i1.4056

Khoshnoodmotlagh S., Daneshi A., Gharari S., Verelst J., Mirzaei M., & Omrani H. (2021). Urban Morphology Detection and its Linking with Land Surface Temperature: A Case Study for Tehran Metropolis, Iran. *Sustain Cities Soc, 74*. DOI: https://doi.org/10.1016/j.scs.2021.103228

Lin, L., Gao, T., Luo, M., Ge, E., Yang, Y., Liu, Z., & Ning, G. (2020). Contribution of Urbanization to the Changes in Extreme Climate Events in Urban Agglomerations Across China. *Science of the Total Environment, 744*, 140264. DOI: https://doi.org/10.1016/j.scitotenv.2020.140264

Lu, L., Fu, P., Dewan, A., & Li, Q. (2023). Contrasting Determinants f Land Surface Temperature in Three Megacities: Implications to Cool Tropical Metropolitan Regions. *Sustainable Cities and Society, 92*, 104505. DOI: https://doi.org/10.1016/j.scs.2023.104505

Mansour, S., Alahmadi, M., Atkinson, P. M., & Dewan, A. (2022). Forecasting of Built-Up Land Expansion in a Desert Urban Environment. *Remote Sensing, 14*(9), 2037. DOI: https://doi.org/10.3390/rs14092037

Mas'uddin, Karlinasari, L., Pertiwi, S., Erizal. (2023). Urban Heat Island Index Change Detection Based on Land Surface Temperature, Normalized Difference Vegetation Index, Normalized Difference Built-Up Index: A Case Study. *Journal of Ecological Engineering, 24, 11*. DOI: http://doi.org/10.12911/22998993/171371

Mustikarini, D.D., Karlina, K., Sujono, J. (2022). Analysis of The Relationship Between Urban Heat Island and Meteorological Drought Index in The Special Region of Yogyakarta. *Jurnal Riset Rekayasa Sipil, 5,* 2, 108-114. DOI: https://doi.org/10.20961/jrrs.v5i2.5541513

Muzaky, H., & Jaelani, L. M. (2019). Analisis pengaruh tutupan lahan terhadap distribusi suhu permukaan: kajian urban heat island di Jakarta, Bandung dan surabaya. *Jurnal Penginderaan Jauh Indonesia*, *1*(2), 45-51.

Monteiro, R., Ferreira, J. C., & Antunes, P. 2020. Green Infrastructure Planning Principles: An Integrated Literature Review. *Land*, *9*(12), 525.

DOI: https://doi.org/10.3390/land9120525

Morabito, M., Crisci, A., Guerri, G., Messeri, A., Congedo, L., & Munafò, M. (2021). Surface Urban Heat Islands in Italian Metropolitan Cities: Tree Cover and Impervious Surface Influences. *Science of the Total Environment*, 751, 142334. DOI: https://doi.org/10.1016/j.scitotenv.2020.142334

Nugroho, U. C., Dirgahayu, D. (2015). Identification of Land Surface Temperature Distribution of Geothermal area In Ungaran Mount by Using Landsat 8 Imagery. *International Journal of Remote Sensing And Earth Sciences*, 12, 02, 143-148. DOI: http://dx.doi.org/10.30536/j.ijreses.2015.v12.a2708

Noveri, I., Najib, K., & Yusuf, M. (2020). The Analysis of Public Green Open Space Management in Jambi City. Policy & Governance Review, 4(3), 182-196. DOI: https://doi.org/10.1016/j.scs.2020.102476

Oktaviana, I., Kalinda, P., Sasmito, B., & Sukmono, A. (2018). Analisis Pengaruh Koreksi Atmosfer terhadap Deteksi Land Surface Temperature menggunakan Citra Landsat 8 di Kota Semarang. *Jurnal Geodesi Undip*, *7*(3), 66-76. DOI: https://doi.org/10.14710/jgundip.2018.21217

Patrianti, T., Shabana, A., & Tuti, R. W. (2020). Komunikasi Risiko Pemerintah Pada Penurunan Emisi Gas Rumah Kaca Untuk Mengatasi Perubahan Iklim Government Risk Communication On Greenhouse Gas Emission Reduction To Tackle Climate Change. *Jurnal Penelitian Komunikasi Dan Opini Publik*, *24*(2), 156-170.

Philiani, I., Saputra, L., Harvianto, L., & Muzaki, A. A. (2016). Pemetaan Vegetasi Hutan Mangrove Menggunakan Metode Normalized Difference Vegetation Index (NDVI) di Desa Arakan, Minahasa Selatan, Sulawesi Utara. *Surya Octagon Interdisciplinary Journal of Technology*, *1*(2), 211-222.

Pratiwi, A. Y., & Jaelani, L. M. (2021). Analisis Perubahan Distribusi Urban Heat Island (UHI) di Kota Surabaya Menggunakan Citra Satelit Landsat Multitemporal. *Jurnal Teknik ITS*, *9*(2), C48-C55. DOI: http://doi.org/10.12962/j23373539.v9i2.53982

Puspita, B. D. (2021). Urban Sustainable Cooling Approach to Reduce Urban Heat Island in the City of Yogyakarta (Doctoral dissertation).

Rahmy, W., & Hoctor, T. (2021). Landscape Suitability Analysis for Developing a Framework of Green Infrastructure Protection in Bandung Basin Area, Indonesia. Journal of Digital Landscape Architecture, 6, 306-313.

Sagita, A. R., Margaliu, A. S. C., Rizal, F., Mazzaluna, H. P. 2022. Correlation nalysis of Surface Temperature, NDVI, Elevation, and Temperature Change Patterns in the Rendingan-Ulubelu-Waypanas Geothermal Area, Tanggamus using Landsat 8 OLI /TIRS Imagery. *Journal of Geoscience and Remote Sensing*, *3*, 1, 43-51. DOI: https://doi.org/10.23960/jgrs.2022.v3i1.72 22.

Santosa, L. W. (2016). *Keistimewaan Yogyakarta dari Sudut Pandang Geomorfologi*. UGM PRESS: Yogyakarta.

Semeraro, T., Scarano, A., Buccolieri, R., Santino, A., & Aarrevaara, E. (2021). Planning of Urban Green Spaces: An Ecological Perspective on Human Benefits. *Land, 10*(2), 105. DOI: https://doi.org/10.3390/land10020105

Sumaryana, H., Buchori, I., & Sejati, A. W. (2022). Dampak perubahan tutupan lahan terhadap suhu permukaan di Perkotaan Temanggung: Menuju realisasi program infrastruktur hijau. *Maj. Geogr. Indones*, *36*(1), 68.

Surya, B., Salim, A., Hernita, H., Suriani, S., Menne, F., & Rasyidi, E. S. (2021). Land Use Change, Urban Agglomeration, and Urban Sprawl: A sustainable Development Perspective of Makassar City, Indonesia. *Land*, *10*(6), 556. DOI: https://doi.org/10.3390/land10060556

Syamsudin, F., & Lestari, S. (2017). Dampak Pemanasan Pulau Perkotaan (Urban Heat Island) pada peningkatan tren curah hujan ekstrem dan aerosol di Megapolitan Jakarta sejak tahun 1986. *Jurnal Teknologi Lingkungan*, *18*(1), 54-61.

UNEP. (2022). *Global Status Report for Buildings and Construction*. https://globalabc.org/resources/publications/2022-global-status-report-buildings-and-construction. Accessed: August 30, 2024.

United Nation. (2018). *Revision of World Urbanization Prospects*. Retrieved from Department of Economic and Social Affairs: https://ourworldindata.org/urbanization. Accessed: August 30, 2024.

Xu, L., Wang, J., Xiao, F., Sherif, E. B., & Awed, A. (2021). Potential Strategies to Mitigate the Heat Island Impacts of Highway Pavement on Megacities with Considerations of Energy Uses. *Applied Energy, 281*, 116077. https://doi.org/10.1016/j.apenergy.2020.116077

Yang C., Yan F., Zhang S. (2020). Comparison of Land Surface and Air Temperatures for Quantifying Summer and Winter Urban Heat Island in a Snow Climate City. *J Environ Manage*, *265*. https://doi.org/10.1016/j.jenvman.2020.110563

Zaitunah, A., Silitonga, A. F., & Syaufina, L. 2022. Urban Greening Effect on Land Surface Temperature. *Sensors*, *22*(11), 4168. https://doi.org/10.3390/s22114168

Zhang, Y., Odeh, I.O., & Han, C. (2009). Bi-Temporal Characterization of Land Surface Temperature in Relation to Impervious Surface Area, NDVI and NDBI, using a Sub-Pixel Image Analysis. *International Journal of Applied Earth Observation and Geoinformation, 11*, 4, 256-264. DOI: https://doi.org/10.1016/j.jag.2009.03.001 25