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THE RELATIONSHIP BETWEEN URBAN HEAT ISLAND ON LAND USE CHANGES AND ENVIRONMENT CRITICAL INDEX IN SEMARANG CITY

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Abstract

The global climate problem issues have been intensified lately. Many countries have agreed to reduce greenhouse gas (GHG) emissions that harm atmospheric conditions. However, the use of fossil fuels accompanied by a decrease in forest area continues to increase. The land use changes from vegetated into a built area could cause an environmental imbalance, primarily the urban heat island phenomenon. Semarang is one of the big cities in Indonesia with a relatively large urban area development condition. The population growth of Semarang City every year reaches an average of 1%, with population density in 2019 as much as 4,754 people per square kilometers. It makes the Semarang City area vulnerable to the urban heat island phenomenon. Moreover, the widespread use of the non-forest area is not matched by an increase in the area of green open space. The use of remote sensing technology such as satellite imagery is one of the solutions to monitor the urban heat island phenomenon in Semarang City and is used. Landsat 7 and 8 imagery types (Landsat Collection imagery) are used in this study to obtain the urban heat island value of Semarang City from 2003 to 2021. This study will explain how the temporal distribution pattern of the urban heat island phenomenon and the relationship between the urban heat island phenomenon and the existing land use in Semarang. This research is also equipped with an analysis of the environmental criticality index due to the impact of the urban heat island to find out more about how big the environment receives the effect.

Keywords: Urban Heat Island, Landuse Change, Environment Critical Index

A. Introduction

Recently, the world's climate problems are getting out of control. The phenomenon of global warming is increasingly harming life on Earth. The high impact of the global warming phenomenon is directly proportional to the development of activities using fossil fuels, the reduction in forest area and green open space to the increase in urbanization activities. Urbanization activities will increase the potential for increasing the use of built-up land, especially in urban areas, and the occurrence of massive physical environmental changes (Fadlin, Kurniadin, & Prasetya, 2020).

In urban areas, generally, the development process will reduce the area of green open land so that the ability to minimize emission compounds cannot work correctly (Bhargava, Lakmini, & Bhargava, 2017). As a result, such conditions will affect the redistribution ability of solar radiation and trigger the contrast of surface temperature with air temperature in urban and rural areas (Weng, 2004). This phenomenon is known as the Urban Heat Island event. Studies on the urban heat island phenomenon generally focus on research in the city's core area or central business district (CBD). This condition causes many researchers to ignore that suburban areas have the same potential as the city center, causing the urban heat island phenomenon (Sobrino & Irakulis, 2020). The influence of land use is the leading cause in the development of the urban heat island phenomenon in urban areas. Therefore, sub-urban areas and even rural areas can increase the concentration of urban heat islands in an area (Sodoudi, S., Shahmohamadi, P., Vollack, K., Cubasch, U., Che-Ani, 2014).

Satellite imagery is an alternative solution to monitor the urban heat island phenomenon in an area. Landsat 7 and 8 satellite images have a special mission in monitoring terrestrial and aquatic areas with good spatial resolution. They will be instrumental in monitoring the pattern and quality of data from the urban heat island phenomenon (Keeratikasikorn & Bonafoni, 2018). Monitoring the urban heat island phenomenon is in line with decision-making and sustainable development, especially in the Semarang City area.

Semarang City is one of the largest metropolitan city areas in Indonesia. The population of Semarang City in 2017-2019 continues to increase at least 1% every year, while the average population density in the same period is 4754 people per square kilometer (BPS, 2019). These data indicate that high population growth will potentially lead to land conversion and built-up land expansion. Spatial-temporal observations in 2003-2021 were used in this study to determine the expansion and changes in land use in the city of Semarang. The use of fossil fuels, such as motorized vehicles and industrial activities, will worsen the condition of atmospheric quality in the city of Semarang. The threat of the urban heat island phenomenon is more accurate if it is not balanced with control measures such as reforestation to reduce the atmosphere's emission content.

Based on the background above, this study was conducted to determine the development pattern of the urban heat island phenomenon temporally in 2003-2021 in the Semarang City area. UHI monitoring focuses on Surface Urban Heat Island (SUHI) analysis with seasonal, temporal observation types. The threshold value method was chosen to detail the distribution area of UHI events which was then combined with an environmental criticality index analysis to find out which areas were most critically affected by the UHI phenomenon. Furthermore, the incidence and concentration of UHI values will later be analyzed to find out how they relate to land use development in Semarang City.

B. Methodology

1. Research Design

This research used remote sensing and geographic information system analysis methods. GIS technique is used to further analyze the three variables, such as determining the critical zone due to the urban heat island phenomenon. Remote sensing technique is used to obtain information on several variables such as the land surface temperature, environment critical index and landuse changes at Semarang City as the study area.

(Data Source: BingVirtualEarth Basemap and Open Street Map)

Figure 1. Map of Study Area

2. Instruments

The tools used in this study include an infrared thermometer for land surface temperature field measurement and laptop as a data processor equipped with QGIS 3.12 for GIS analysis. The materials used in this study include Landsat 7 and Landsat 8 with data acquisition start from 2003 – 2021 as the time series data.

3. *Technique of Data Analysis*

3.1. Land Surface Temperature and Urban Heat Island Data Processing

The surface temperature is obtained from the radian value received by the sensor (Top of Atmosphere Correction). Atmospheric and water vapor profiles in the atmosphere are measured simultaneously when the satellite records the correction parameters for the radiative transfer equation and surface emissivity. After making a series of corrections, the following analysis calculates the corrected surface temperature using the following formula (USGS, 2015).

$$Ts = \frac{K2}{Ln\left(\frac{K1}{L} + 1\right)}$$

Where:

Ts	: Land Surface Temperature
K1 K2	: Radiance Calibration Value
L	: Radiance value

The results of the land surface temperature are then processed to obtain information about the UHI threshold. A zero to negative value indicates an area that does not experience the UHI phenomenon, while a positive value indicates an area where UHI occurs (Fawzi & Jatmiko, 2018). Mathematically the following is a formula for assessing the UHI threshold.

$$UHI\ Threshold = Tmean - (\mu + 0{,}5\ \alpha)$$

Where μ and α are the mean and standard deviation of the surface temperature processed by the mean value (Tmean) in the study area, meanwhile, to calculate the error value in the land surface temperature data.

3.2. Environment Critical Index

The Environmental Critical Index (ECI) algorithm is used to compare the surface temperature value with the greenness level of the vegetation cover in the NDVI model (Sasmito, B., Suprayogi, 2017). The purpose of using ECI is to find out and distinguish in more detail objects of built-up land in urban areas such as buildings, roads, or housing and analyze their relationship to the value of the land surface temperature. The following is an ECI analysis formula (Xu, 2008).

$$ECI = \frac{(\,Stretched\ LST)}{(\,Strectched\ NDVI)}$$

The environmental criticality index provides information about criticality class distribution caused by the UHI phenomenon. Mathematically, the environmental criticality index formula uses a comparison between the surface temperature value and the NDVI analysis value (Senanayake, Welivitiya, & Nadeeka, 2013). The purpose of stretching the spectral value to 8 bits (1-255) is to bring up the contrast between processing surface temperature data and NDVI data. The 0 value causes no data value bias in the NDVI value. The analysis of the environmental criticality index in the study area was observed in the period 2003-2021 based on observations of the urban heat island phenomenon

3.3. Create Landuse Classification and Validation

This application performs a classification of the input image based on the Model file created with the Train Random Image Image Classifier algorithm. The supervised classification was then performed. The training plots were used to establish a critical numerical feature that could best describe the spectral attributes for each class type. In this case, the parametric algorithm chosen is the maximum likelihood (Kusuma, 2015).

Confusion matrix analysis was used to create the validation from land use data. The confusion matrix, commonly known as the error matrix, compares between category bases, the relationship between known reference data (ground truth), and automatic classification results. The confusion matrix is in the form of a square with the numbers in the rows and columns equal to the numbers in the category of classification accuracy level to be assessed (Lillesand & Kiefer, 2007). The Confusion Matrix is one method that can measure the performance of a classification method. The basis of the confusion matrix is that it contains information that compares the results of the classification performed by the system with the results of the actual classification on the Earth's surface.

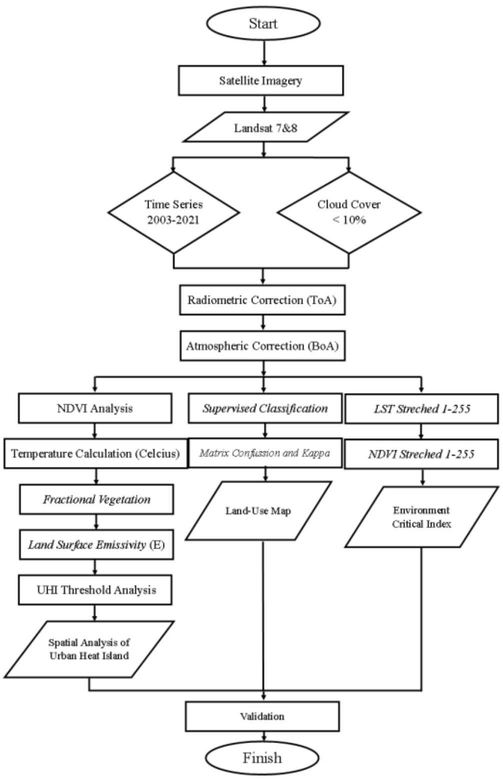
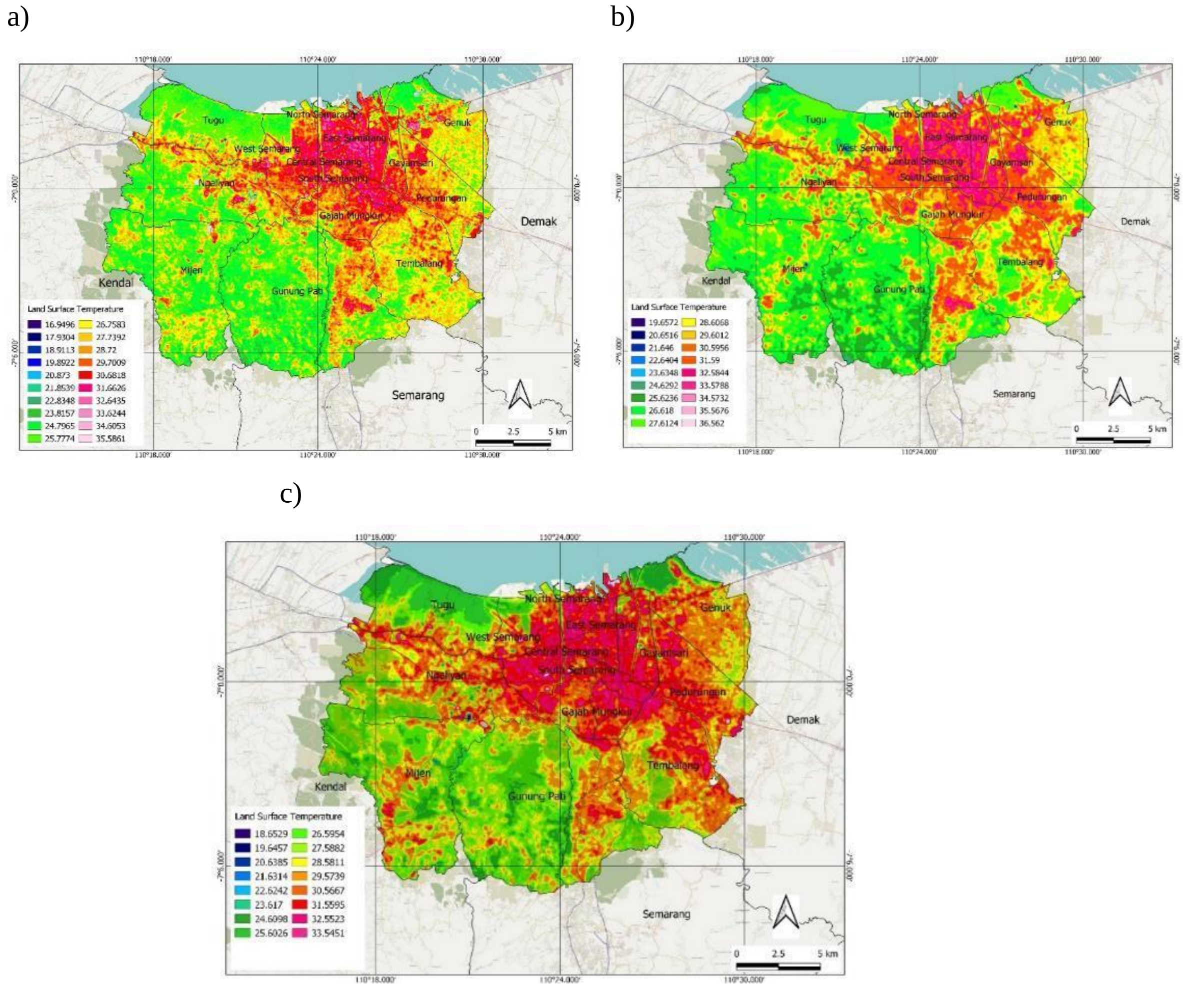


Figure 2. Research Flowchart

C. Findings and Discussion

1. Land Surface Temperature of Semarang City 2003-2021

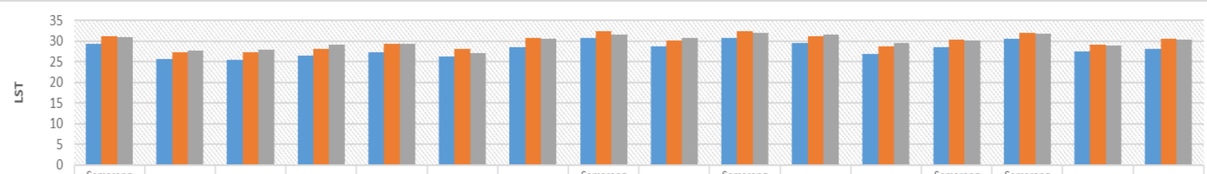
Land surface temperature in 2003, 2013, 2021 in Semarang City can be seen in Figure 3.



Data source: Landsat 7 ETM+ and Landsat 8 OLI-TIRS

Figure 3. Land Surface Temperature in Semarang City a)2003, b) 2013, and c)2021

The result of the land surface temperature analysis of Semarang City in 2003 using Landsat 7 satellite imagery can be seen in (Figure 3). The average land surface temperature of Semarang City in 2003 was 26.84 °C, with a range of values between 16.94 - 32.64 °C. The concentration of the Earth's surface temperature in 2013 was monitored using Landsat 8 satellite imagery on 24 June 2013. The concentration land surface temperature in 2013 throughout Semarang was between 19.65 – 34.57 °C and had an average value of 28.62 °C. Based on these results, the concentration level of the land surface temperature in Semarang City has increased by ± 2°C from 2003-2013. Semarang City's land surface temperature data in 2021 on the recording date occurred on 17 August 2021. The concentration level of Semarang City's surface temperature in 2021 ranges between 18.65 – 32.55°C, and the average surface temperature reaches 28.89°C.



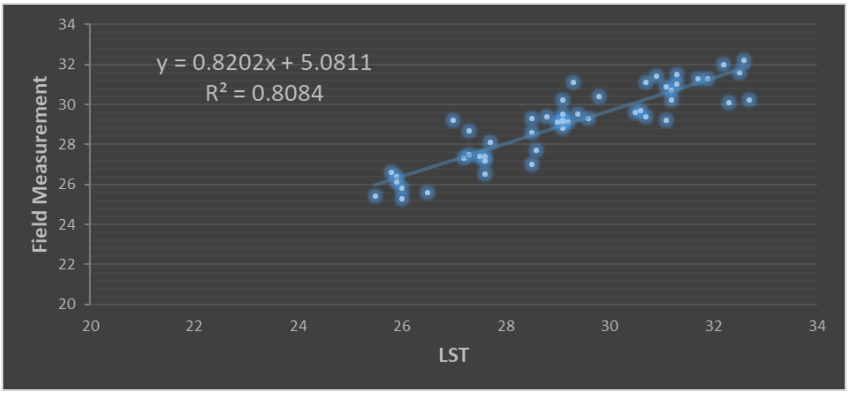
	Semarang Utara	Gunungpati	Mijen	Ngaliyan	Genuk	Tugu	Gayamsari	Semarang Timur
LST 2003	29.35104032	25.592355	25.34520744	26.42269442	27.32752324	26.30845024	28.44340835	30.71131648
LST 2013	31.22069184	27.25360176	27.30528876	27.99808456	29.38294116	28.08378872	30.68522585	32.28521164
LST 2021	30.98561908	27.78557848	27.79092984	29.07895064	29.26388336	27.13722864	30.63162235	31.53713336

	Gajahmungkur	Semarang Tengah	Candisari	Tembalang	Semarang Barat	Semarang Selatan	Banyumanik	Pedurungan
LST 2003	28.6561606	30.8121036	29.5806064	26.90386592	28.50926776	30.57566784	27.41397169	28.13209332
LST 2013	30.08116016	32.43117156	31.18229632	28.64150832	30.34788992	32.06214636	29.02895285	30.45569472
LST 2021	30.75027064	31.97723352	31.64330324	29.49892736	30.16264372	31.84864404	28.97263146	30.37628512

Data source: Figure 3

Figure 4. Land Surface Temperature Concentration in Each District 2003-2021

In general, the center of the land surface temperature in Semarang City from 2003-2021 is located in the Sub Districts of Central Semarang, North Semarang, East Semarang, and South Semarang with an average concentration of >30°C (**Figure 4)**. The area is dominated by built-up areas to heavy industry, resulting in high temperatures on the Earth's surface. The validity test of the land surface temperature is carried out by direct measurement in the field using a tool in the form of an infrared thermometer specifically for the surface of an object. The value of simple linear regression analysis reaches R^2 = 0.8084 (**Figure 5)**, which means that the land surface temperature as a result of Landsat image processing has a strong relationship with the land surface temperature from field measurements.



Data source: Field measurement

Figure 5. Land Surface Temperature Validity Test Graph

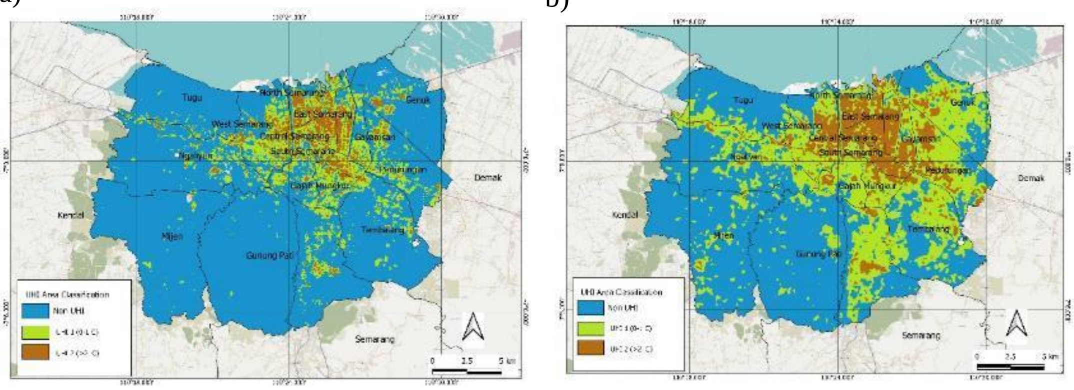
2. *Spatial Distribution of Urban Heat Island in Semarang City*

The processing of the determination of the UHI area uses a threshold value taken from the land surface temperature data in the city of Semarang. Determination of the threshold using Fawzi's equation (2017).

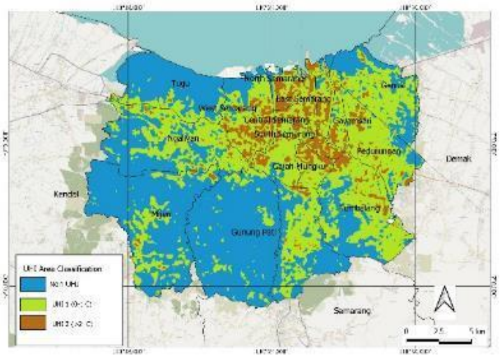
$$SUHI_{threshold} = LST_{mean} + (0{,}5 \text{ x } LST_{st.deviation}) \quad 3.$$

This equation explains that if the LST value > SUHI limits, the area is affected by the UHI phenomenon and vice versa if the LST value > SUHI, the area's boundaries are not affected by the UHI phenomenon.

a) b)



c)



Data source: Landsat 7 ETM+ and Landsat 8 OLI-TIRS

Figure 6. Urban Heat Island Map in Semarang City a)2003, b) 2013, and c)2021

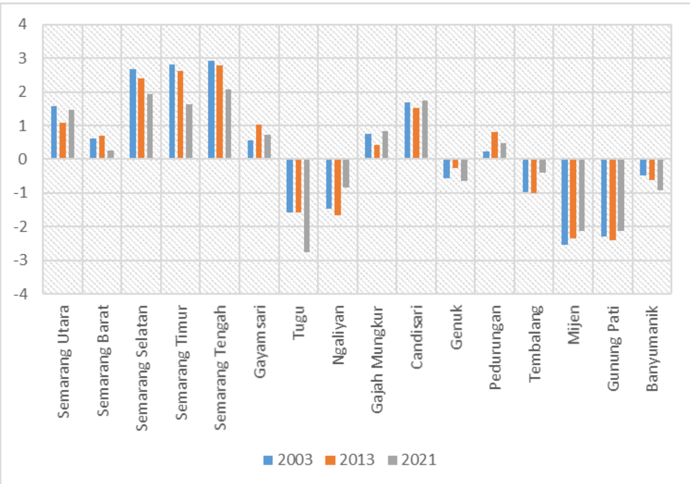
The condition of the UHI phenomenon in Semarang City in 2003 had an average earth surface temperature of 26.84°C with a standard deviation of 2.09°C (Figure 6 (a)). Therefore, the SUHI threshold value in 2003 was 27.88 °C. It means that the area of Semarang City with an Earth surface temperature >27.88 °C is included in the area affected by UHI. The districts of West Semarang, Pedurungan, Gayamsari, and Gajahmungkur sub-districts are most affected by the UHI phenomenon with a difference of ± 0-1 °C from the threshold value. The worst areas are in North and Central Districts, which included in class 2 area with a difference of >2 °C from the threshold.

Table I. Data on Average Land Surface Temperature, Standard Deviation and UHI Threshold for Semarang City in 2003-2021.

Year	Average Land Surface Temperature	Deviation Standard	UHI Treshold
2003	26,84°C	2,09 °C	27,88 °C
2013	28.62 °C	2,06 °C	29,65 °C
2021	28,89 °C	2,01 °C	28,89 °C

Data source: Landsat 7 ETM+ and Landsat 8 OLI-TIRS, processing used QGIS software.

The average temperature of the Earth's surface in Semarang City in 2013 reached 28.62 °C with a standard deviation of 2.06 °C (Figure 6 (b)). The UHI threshold value in 2013 was 29.65 °C. There was an increase of 1.77 °C related to the threshold value from 2003-2013. The area affected by UHI in Semarang City in 2013 is more or less the same as in 2003, but the difference is that the area affected by UHI class 2 is in the Gayamsari Sub District. Furthermore, the Districts of East, Central, and South Semarang experienced a slight reduction in UHI concentration but remained at >2 °C from the threshold.



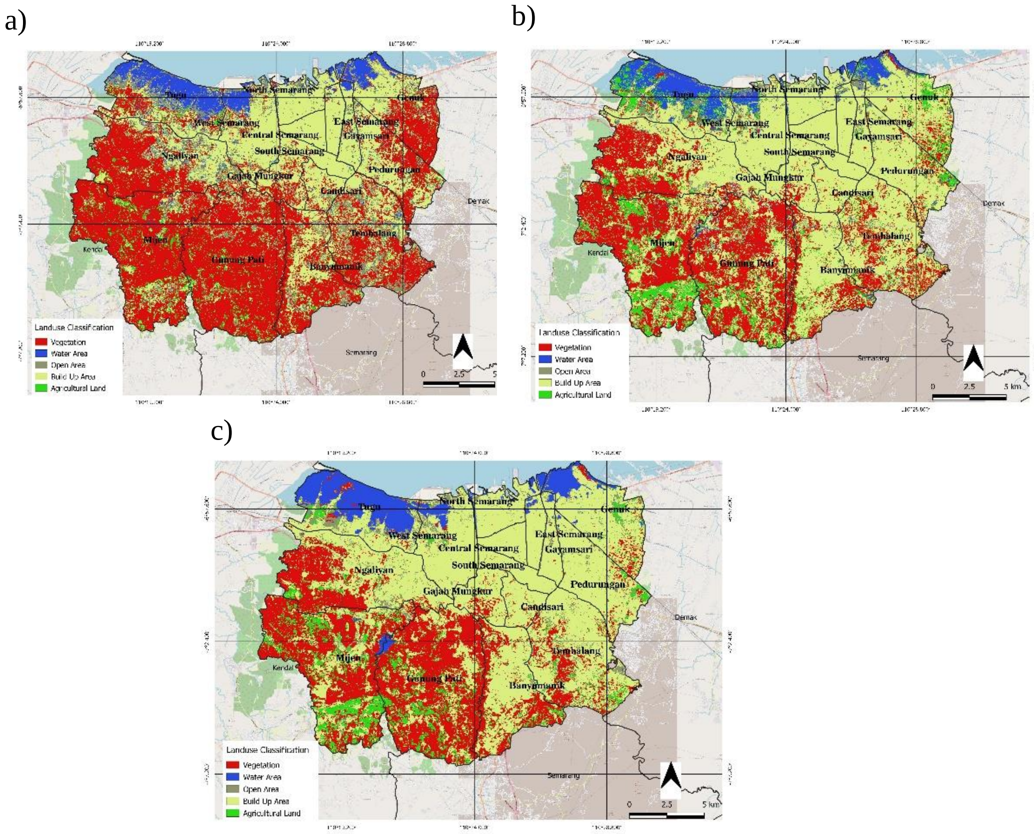
Data source: Figure 6

Figure 7. UHI Concentration Each Sub Districts in Semarang City 2003-2021

In 2021, the average value of the Earth's surface temperature in Semarang City will reach 28.89 °C, and the standard deviation value is 2.01 °C. Therefore, the UHI threshold value of Semarang City in 2021 is 28.89 °C **(**Figure 6 (c)). Gajahmungkur Sub District and in 2021 experienced an area expansion included in the first-class UHI compared to 2013, where the concentration of UHI had decreased. Candisari Sub District also experienced an increase in the UHI value in 2021, even approaching the second-class UHI classification.

3. Landuse Classification of Semarang City in 2003-2021

Landuse Classification of Semarang City in 2003, 2013, 2021 in Semarang City can be seen in Figure 8.



Data source: Landsat 7 ETM+ and Landsat 8 OLI-TIRS

Figure 8. Landuse Map in Semarang City a)2003, b) 2013 and c)2021

In 2003, land use distribution of vegetation types dominated Semarang City, followed by the distribution of built-up land **(Figure 8 (a)).** The sub-districts of Gunung Pati, Mijen, and several areas of the District of Ngaliyan are still very much dominated by vegetation with 18,222 hectares or 46% of the entire area of Semarang City (table 4.2.1). The distribution of built-up land in settlements to industrial areas is in the Districts of Central, North, West, and East Semarang, with 12,637 hectares (32%).

Table II. Landuse Area of Semarang City in 2003-2021.

Year	Vegetation		Water Area		Open Area		Build-Up Area		Agricultural Land	
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
2003	18,222	46	2,382	6	4,356	11	12,637	32	1,777	5
2013	10,925	28	2,239	6	2,106	5	20,435	52	3,668	9
2021	11,113	28	2,477	6	2,265	6	20,520	52	3,000	8

Data source: : Landsat 7 ETM+ and Landsat 8 OLI-TIRS

The land use of Semarang City in 2013 showed a significant change compared to 2003. The built-up area even covered 52% of the entire area. There was an increase of 20% from the built-up land area from 2003. The vegetation and open land area experienced a significant reduction caused by the widespread use of built-up land. Agricultural land increased by about 4% compared to 2003, concentrated in the Mijen and Gunungpati sub-districts (Figure 8 (b)).

In 2021, the land use change process did not show intensive dynamics from 2013. Built-up land is still the most dominant type of land use compared to other land use types. It covers at least 52% of the total area of Semarang City, which is then followed by the vegetation of 28%. Spatially, there is at least an expansion of built-up land in Ngaliyan sub-district by 2,449 ha compared to 2013, covering an area of 2,289 ha. South, East, and Central Semarang sub-districts are almost all dominated by built-up land, and there is a massive difference in area between built-up land and other land use types (Figure 8 (c)).

Land use types in all sub-districts in Semarang City from 2003-2021 were dominated by built-up land. Vegetated land still dominated only Mijen sub-district and Gunung Pati sub-district. The expansion of built-up land dominated the general land use change from 2003 to 2021. As a result, vegetation is increasingly degraded every year, as happened in the Tembalang sub-district. The vegetation area in 2003 was 1,805 ha, then became 756 ha in 2021. While the accuracy of land use data for Semarang City from 2003 to 2021 is approximately 85%. Increased growth and community activities in Semarang City are the main actors in the high dynamics of land use change.

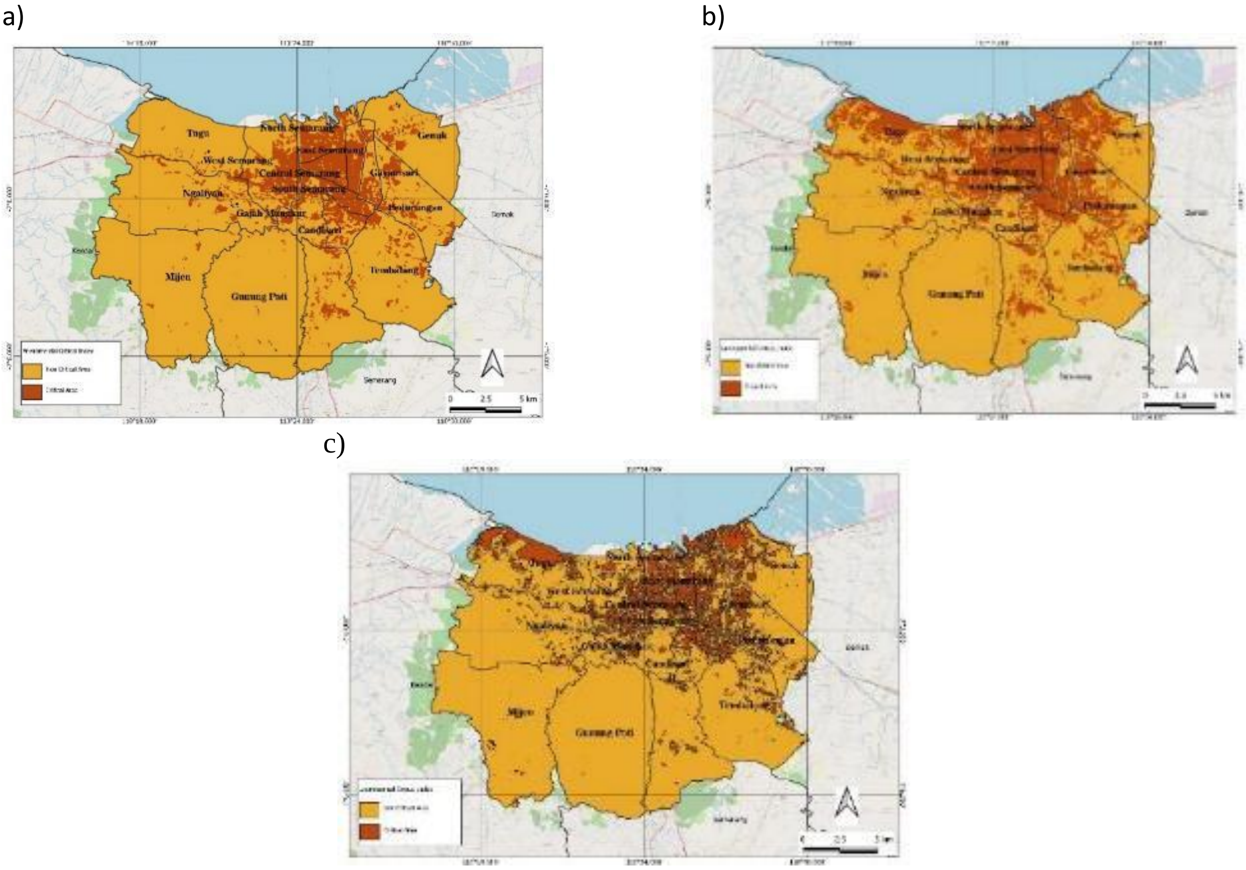
Table III. Landuse Data Matrix Validation

	Landuse Classification	**Land Use Data Processing**					
		Vegetasi	**Water Area**	**Open Area**	**Build-Up Area**	**Agricultural Land**	**Total**
Field Measurement	Vegetation	1156	2	12	23	74	1267
	Water Area	0	577	9	1	0	587
	Open Area	42	13	215	77	39	386
	Build-Up Area	7	0	76	4175	5	4263
	Agricultural Land	48	217	75	75	206	621
Total		1253	809	387	4351	324	6329
Total Accuracy		88 %					

Data source:: Landsat 7 ETM+, Landsat 8 OLI-TIRS, and field measurement

4. *Environmental Critical Index of Semarang City in 2003-2021*

The Environmental criticality index data was obtained from the land surface temperature data and vegetation index data in NDVI. Both data must be converted to an 8-bit data type with a pixel value range of 1-255. The goal is to minimize the appearance of some pixels that have no value and increase the contrast level to facilitate the processing of overlay data. Figure 9 shows the dynamics of the environmental criticality index caused by the urban heat island phenomenon in Semarang City from 2003 to 2021.



Data source : Landsat 7 ETM+ and Landsat 8 OLI-TIRS

Figure 9. Environment Critical Index Map in Semarang City a)2003, b) 2013, and c)2021

The value of the environmental criticality index of Semarang City in 2003 was concentrated in the sub-districts of Central, South, East, West, and parts of North Semarang. Overall, the most critical areas of Semarang City in 2003 were in the city center. It is due to the high surface temperature value, which is directly proportional to the lack of media to absorb emissions and solar radiation (Fadlin, Suparjo, Sajiah, Ransi, & Nangi, 2020). Conditions in 2013, the reach of critical areas due to the urban heat island of Semarang City has expanded significantly by 6184 ha (Table III). If it was concentrated in the downtown area in the previous year, then in 2013 it began to spread to the city's outskirts, such as the Tugu sub-district and Genuk sub-district. Banyumanik and Tembalang sub-districts are some of the southern areas included in the critical class category. The environmental criticality index value in 2021 has a spatial pattern similar to 2013, but there is a decrease in concentration. Some areas in the center of Semarang City have entered the classification of non-critical areas. Only the northern part of Semarang City, from the Tugu sub-district to Genuk sub-district, is evenly distributed in the critical area category.

Table III. ECI Data Area in Semarang City 2003-2021

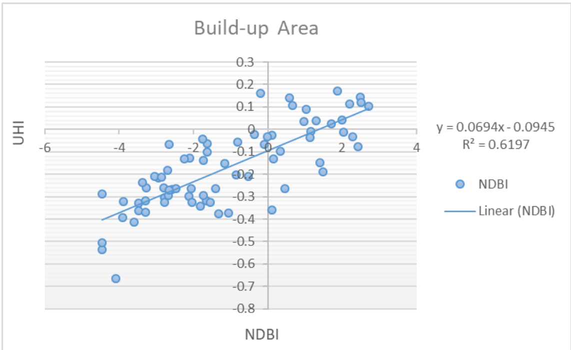
Year	ECI Area (Ha)
2003	2.426
2013	6.184
2021	2.860

Data source: : Landsat 7 ETM+ and Landsat 8 OLI-TIRS

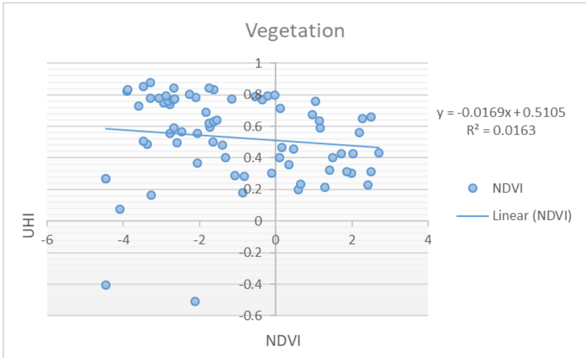
In general, the level of environmental criticality in Semarang City shows fluctuations in value. It started in 2003, which is relatively high in the downtown area. In 2013, environmental criticality was getting higher and extended to the city's outskirts. When entering 2021, there is a slight decline in criticality condition, especially in the downtown part. Furthermore, the area of the critical area decreased by ±3000 ha from 2013 (Table 2). The determination of the critical area is based on the high concentration of the land surface temperature and the minimal distribution of vegetation. If it is related to land use, then the types of built-up land, open land to the dominance of water areas, are considered to have a relatively high level of environmental criticality. Concrete surfaces in buildings or built-up land absorb more heat energy than reflect it, causing the temperature to rise in the surrounding area (Astuti & Nucifera, 2021). Therefore, the expansion of green open space is one of the leading solutions to improve environmental conditions that have been criticized due to the urban heat island phenomenon (Putra, Afidah, Astuti, & Nucifera, 2020).

5. *The Relationship Between Urban Heat Island on Landuse and Environmental Critical Index*

The relationship between urban heat island and the land use of Semarang city can be seen in Figure 10.



(a)



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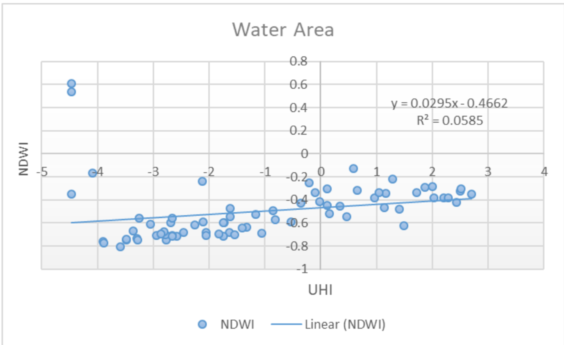

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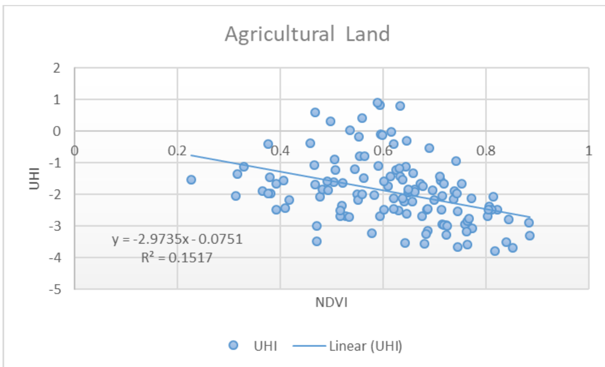

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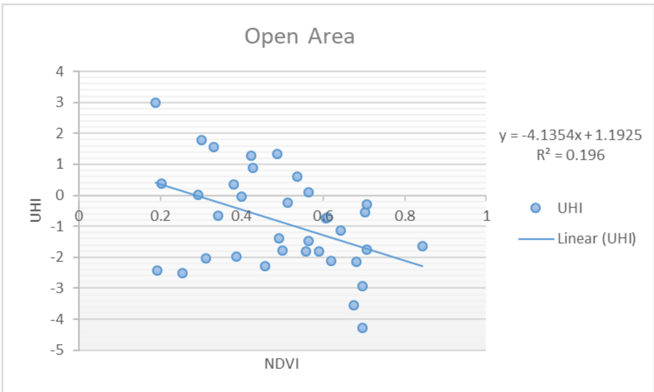


(e)

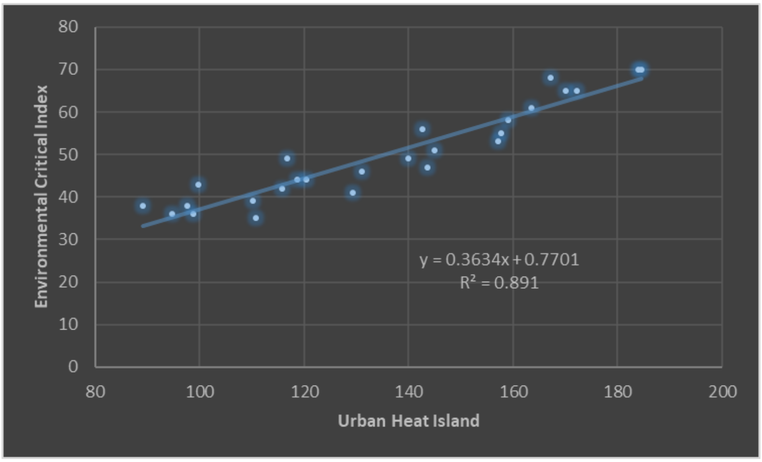
Data source: Landsat 7 ETM+ and Landsat 8 OLI-TIRS

Figure 10. (a) Relationship UHI with Build-Up Area, (b) Relationship UHI with Vegetation, (c) Relationship UHI with Water Area, (d) Relationship UHI and Agricultural Land, (e) Relationship UHI with Open Area

Built-up land is a type of land use that gives the highest contribution to the occurrence of the UHI phenomenon, especially in the city of Semarang. The built-up land index (NDBI) analysis is used to describe how the effect of built-up land on the UHI phenomenon. Based on Figure 10 (a), the regression value between UHI and NDBI concentrations is $R^2 = 0.6197$ or has a reasonably strong relationship between the variables.

Normalized difference water index analysis (NDWI) represents the land use of aquatic land types to find a relationship with the concentration of the occurrence of the UHI phenomenon. The regression value between waters and the UHI phenomenon is at a value of $R^2 = 0.0585$, which shows a fragile relationship between the two variables (Figure 10(c)). In general, the characteristics of the absorption ability of an aquatic area are extensive and only slightly reflect the received sunlight (Trisakti, Tjahjaningsih, Suwargana, Carolita, & Mukhoriyah, 2014).

Normalized difference vegetation index analysis (NDVI) represents several land use, including vegetation, open land, and agricultural land. The function of NDVI, in this case, is to describe the value of the green level of a vegetation area. The land use of the vegetation type was obtained from the NDVI value > 0.6. Regression analysis is at a value of $R^2 = 0.0163$, indicating that vegetation has a fragile relationship to the UHI phenomenon or the two variables contradict each other ((Figure 10 (b)). The occurrence of the UHI phenomenon is in line with the excellent ability of vegetation to absorb emissions and radiation from the sun on the Earth's surface.
The value of land use for open land types is obtained from the range of values 0.14 – 0.18 in the NDVI analysis. The regression value between the UHI phenomenon and open land is $R^2 = 0.196$, where the level of relationship between the variables is relatively low (Figure 10 (e)). As for agricultural land is obtained in the range of values from 0.5 to 0.6 in the NDVI analysis. The regression value at $R^2 = 0.1517$ also shows a relatively weak relationship with its contribution to the occurrence of the UHI phenomenon (Figure 10 (d)). Therefore, it is essential to understand the relationship between the Earth's surface temperature and surface characteristics in urban areas to reduce the UHI phenomenon's concentration and amplitude (Guo, Wu, Xiao, & Chen, 2015)



Data source: Landsat 7 ETM+, Landsat 8 OLI-TIRS, Figure 6 and Figure 10

Figure 11. Simple Linear Regression Between ECI and UHI in Semarang City

Simple regression analysis was again used to determine the relationship between UHI and the environmental criticality index of Semarang City. Prior to that, UHI data were first converted to 8 bits with a spectral value range of 1255. The goal is to equalize the environmental criticality index data that has previously been stretched to 8 bits. The value of the simple regression analysis of the two data reaches $R^2 = 0.891$ (Figure 11) and is included in the strong category. It shows that the occurrence of the UHI phenomenon is in line with the high value of the environmental criticality index that occurs in the region. The increase in heat on the Earth's surface creates an anomaly that makes the mechanism of an environment not work correctly.

A simple example is that if a settlement has a high UHI value, it causes discomfort for the residents who live in the area. It is evidenced by the response of several people who say that the temperature in Semarang seems to be increasing every year. The temperature increase makes people mostly use air conditioning. If this air conditioner is overgrowing, it will increase the potential for increasing greenhouse gas emissions, which negatively impact atmospheric conditions.

D. Conclusion

The highest concentration of land surface temperature in Semarang City from 2003-2021 is located in the Districts of Central Semarang, North Semarang, East Semarang, and South Semarang with an average concentration of >30°C per year. Almost all areas in Semarang City are affected by the UHI phenomenon. In contrast, those not affected by the UHI phenomenon in the 2003-2021 period include Ngaliyan, Tembalang, Mijen, Banyumanik, Gunungpati, and Tugu sub-districts. Every year, these areas have UHI concentrations < 2 °C from the UHI threshold value. Built-up land is still the most dominant type of land use compared to other land use types. It covers at least 52% of the total area of Semarang City from 2003 to 2021. Built-up land is a type of land use that gives the highest contribution to the occurrence of the UHI phenomenon, especially in the city of Semarang. The regression value between UHI concentration and built-up land is $R^2 = 0.6197$. The relationship between UHI and the environmental criticality index is also relatively high, reaching $R^2 = 0.891$.

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