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Analysis of Changes in Distribution of Urban Heat Island in Medan City and Its Relationship with Land Change Using Remote Sensing Data

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A B S T R A C T

Due to its membership in the National Activity Center, Medan had a major impact on its rapid growth include: growth of residential areas; loss of green space; reduction in the number of means of transportation; increased energy consumption and production; and the occurrence of surface temperature conditions. There are a number of variables that cause the surface temperature of Medan City to be much higher than the surface temperature of places included in this region. These factors include growth in built-up areas, decline in green land cover, mobility facilities, energy consumption and production, and other factors. vegetation. Several objectives to be achieved in this research: (1) In 2013–2022, we want to know how much the UHI has changed in Medan City. (2) To understand what causes UHI and how changes in land use affect UHI in Medan. The research strategy used to obtain UHI, NDVI and NDBI values is known as the LST data analysis method. NDVI and NDBI values can also be known from data collected via remote sensing. Imagery from Landsat 8 was used in 2013, while imagery from Landsat 9 was used in 2022. Direct regression was used in the process of conducting an influence determination study. UHI occurs in the eastern, western and central parts of Medan City, but not in the northern part. This study found that the UHI distribution for Medan City in 2013-2022 was similar to the affected areas. Research data shows these results UHI.

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1. INTRODUCTION

Urban densification describes the massive and dense growth of cities caused by an exponential increase in the number of city residents. Currently, the majority of the world's population lives in cities. Despite the fact that in 2018, cities were home to almost 55% of the global population, experts predict that number will increase to 68% by 2050, meaning approximately 2.5 billion people (Aris et al., 2018). According to (Muzaky and Jaelani, 2019), This phenomenon called metropolitan population growth in urban areas causes heat islands. Urban heat island (UHI) phenomena will be brought about by rising air temperatures in cities due to an increase in built-up land cover (Saringatin et al., 2022). According to research conducted by (Rauf et al., 2020), urban heat islands formed when heat was trapped due to urban geometry, surface features of urban areas, surface cover growth versus vegetation replacement, and man-made heat sources.

According to (Husna et al., 2018), the basic concept underlying urban heat islands (UHI) is that the interaction of solar heat energy with objects on the earth's surface results in disparities in heat energy levels in urban and rural areas. The relationship that exists between urban areas and surface temperatures has a significant impact on the temperature differences that can be observed between metropolitan areas and suburban, suburban, or rural locations. According to (Sejati et al., 2019), this environmental phenomenon is called the Surface Urban Heat Island (SUHI) condition.

According to research by (Gaol et al., 2020), This will likely occur alongside regional infrastructure improvements and increased human activity. Significant issues that emerge in urban settings are directly correlated with the fast expansion of urban regions (Dini et al., 2023). According to (Nandi and Dede., 2022), more cars can increase urban air temperature significantly, industrial facilities and hectares of land being developed. According to (Ramsay et al., 2023), these areas are most likely to have informal settlements, due to high population density and limited green space, which may be impacted by a larger urban heat island (UHI). (Adams and Smith., 2014) have determined that the existence of urban structures and infrastructure materials is the root cause of increasing temperatures in urban areas. Something related to heat absorption, reflection, and conductivity is called urban fabric. When compared to road surfaces covered with soil or vegetation, road surfaces covered with asphalt and concrete are much hotter.

Medan is not only the capital of North Sumatra, but also the third largest city in Indonesia. Due to its membership in the National Activity Center, Medan had a major impact on its rapid growth. The results of rapid urban expansion include: growth of residential areas; loss of green space; reduction in the number of means of transportation; increased energy consumption and production; and the occurrence of surface temperature conditions. There are a number of variables that cause the surface temperature of Medan City to be much higher than the surface temperature of places included in this region. These factors include growth in built-up areas, decline in green land cover, mobility facilities, energy consumption and production, and other factors. The temperature disparity between the densely populated Medan area and less vegetated areas is illustrated by the urban heat island effect.

From (Aflaki et al., 2017), this has now been proven. As urban expansion and development is associated with urban heat islands (UHI). According to (Schwartz et al., 2011), cities located in valleys, which are characterized by limited air cooling influence from surrounding rural areas, are usually able to reduce temperatures more quickly than coastal cities. Studies investigating heat islands in the boundary layer, heat islands detected using remote sensing, According to (Stewart., 2011), we are immediately eliminating all surface or subsurface heat islands, daytime heat islands, or heat islands that are not located in urban areas.

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In accordance with (Yang et al., 2016), People call urban heat island (UHI) the effect of heat accumulation. The most obvious component of urban climate is this phenomenon, which is driven by urbanization and human behavior. When the air temperature in the London metropolitan area is higher than the air temperature in the surrounding countryside, this phenomenon is known as an "urban heat island" (Cai et al., 2018).

2. METHODS

The research discussed here is research that uses a descriptive analytical approach combined with quantitative research methodology. To characterize previous data and field conditions before conducting further research, data was collected directly in the research area (Ridwan et al., 2022).

The US Geological Survey website (https://earthexplorer.usgs.gov/) provides the data needed to analyze changes in the distribution of UHI in Medan City. This method requires Landsat 8 and 9 images of Medan City as well as a digital shapefile (.shp) base map from the official website (https://tanahair.indonesia.go.id /portal-web).

Maps of surface temperature (LST), vegetation density index (NDVI), and building density index (NDBI) from the earliest Landsat photos are included in this method to analyze variable correlations. relationship between Medan City UHI and land use changes. The following is a list of data processing methods used in this research :

a. Radiometric & Atmospheric Correction

Radiometric correction improves image quality, which can be affected by surface reflection errors, curvature of the earth, direction of sunlight, weather, air quality, and other factors. Radiometric correction improves the image. To ensure that the information obtained is as accurate as possible, this is done. For the purposes of this particular investigation, changes in the angle of the sun angel were used as a form of correction. Sun angel correction needs to be done to correct inaccurate reflectance values due to the position of the sun. For the purpose of this correction, sun height correction is used, and the shooting time is used to establish the appropriate adjustments.

One method used is known as atmospheric correction, this reduces atmospheric image errors. As electromagnetic waves travel through the atmosphere from the Sun to the Earth and from objects to sensors, they encounter interference. This occurs during the image collection process. According to the nature of the interference, the interference can be in the form of scattering or absorption. As a result, there will be a disparity between the data collected by satellite sensors and the data collected on the object, thus having an impact on the resulting image data.

b. Image Cropping

In this search, the image is cropped with the administrative boundaries of Medan City as the main reference. To achieve the goal of cropping an image, it is necessary to crop the image and select certain areas that can be utilized by utilizing certain administrative boundaries. This image is a corrected version of the image used for cropping.

c. LST

Heat waves are used in this technique, which allows determining the temperature of the land surface. An approach known as the Improved Mono Window Algorithm (IMW) was used in this research. To ensure field conditions provide the most accurate results, the IMW approach is able to assist in the normalization process of band 10 surface temperature readings.

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d. UHI

UHI extraction from remote sensing images is carried out by LST data derivation. This provides further opportunities to model ESG for UHI monitoring purposes at other locations (Rajasekar & Weng., 2009). Specifically, in the following way:

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

Where:
UHI : Urban Heat Island
Ts: Land Surface Temperature (°C)
µ : The mean value of Ts (°C)
α : Land Surface Temperature standard deviation value (°C).

e. NDVI

According to (Karyati et al., 2022), the Normalized Crop Difference Indicator (NDVI) is a well-known indicator that can be used to identify the presence of plant cover. The Normalized Difference Vegetation Index (NDVI) approach has been extensively utilized for vegetation cover monitoring because to its great sensitivity to changes in vegetation cover (Aldiansyah et al., 2021). By referring to the vegetation index, one can ascertain the extent to which the vegetation is green. This is because the vegetation index covers certain periods which can be understood through analysis. The near infrared spectrum was captured by Landsat 8 and Landsat 9, while the red spectrum was captured by Landsat 4.

NDVI formula equation:

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

Where:
NIR (Near Infrared) Band 5
RED Band 4.

f. NDBI

NDBI is a physical parameter that can be measured with the help of images obtained through remote sensing. In terms of land extraction, NDBI is useful for viewing built-up areas through the use of Landsat data. Mid infrared (SWIR) and near infrared (NIR) waves are used in the NDBI algorithm, and one way to utilize these waves is to utilize bands 5 and 6. As shown below, the NDBI equation:

$$(SWIR - NIR) / (SWIR + NIR)$$

Where:
NIR (Near Infrared) Band 5.
SWIR (Shortwave Infrared) Band 6.

3. RESULTS AND DISCUSSION

This research was conducted in Medan, North Sumatra, Indonesia. The city of Medan covers an area of 26,510 hectares. Terrain is in the Philippines, between 3°30' and 3°43' North Latitude and 98°35' and 98°44' East Longitude (Pohan & Sulistiyono, 2023).

a. Surface Temperature in 2013 Medan City

Year after year a map will be displayed illustrating the distribution of changes that have occurred in the UHI phenomenon. Therefore, you will be able to see the spatial variations of the UHI graphically, which will make interpretation much simpler. UHI values of 0 or lower are considered Non-UHI, and UHI values are calculated from annual LST data, average LST values, and LST norms. deviation. sign. According to Chen et al. (2016), there are a number of elements found to influence UHI. These factors fall into two categories: natural factors, which include climate zones and topography, and physical construction factors, which include urban

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areas and land use. Despite the fact that spatial characteristics are immaterial (such as population density and market) (Santamouris, 2015).

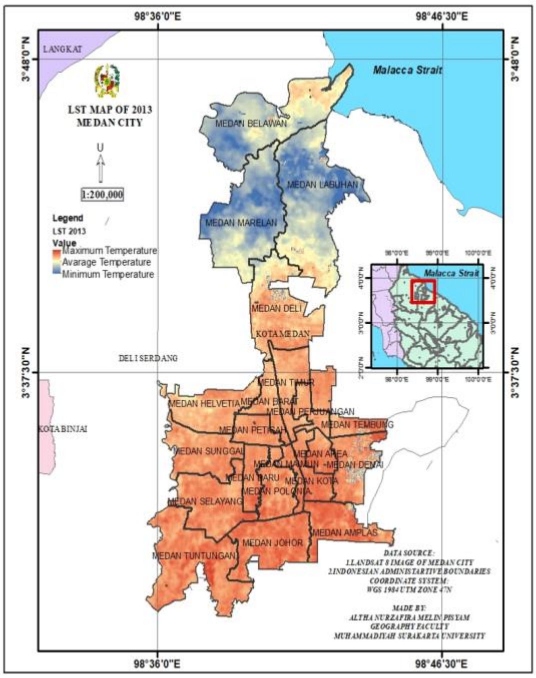

Figure 1. LST Map Of 2013 Medan City

b. Surface Temperature in 2022 Medan City

The minimum and maximum temperature values for Medan City are determined based on analysis of Landsat 9 image data in 2022. If the Landsat image data is processed in 2022, the resulting minimum temperature values are 24.5 degrees Celsius, the maximum temperature is 34.5 degrees Celsius, and the average temperature -average 29.5 degrees Celsius. The blue color on the surface temperature map shows that the temperature in that location is low, while the red color shows that the temperature in that area is high. This can be seen on the map.

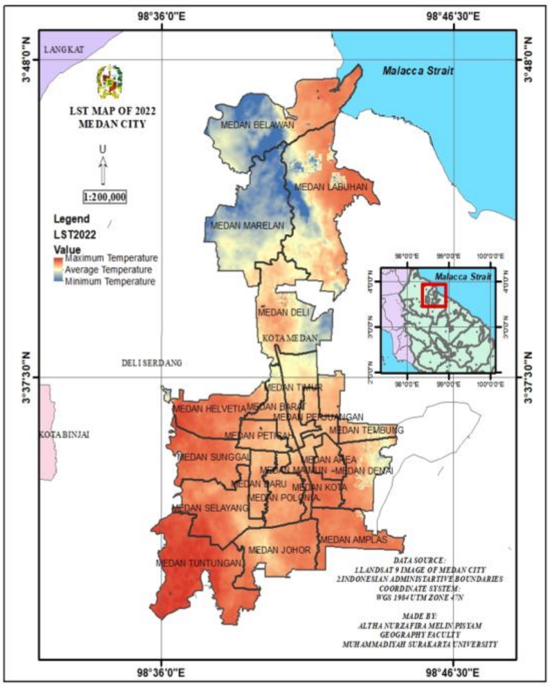

Figure 2. LST Map Of 2022 Medan City

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c. Distribution of changes in the Medan City UHI Phenomenon in 2013 and 2022

There are four categories of areas where UHI is observed based on the results of Landsat image processing from 2013 to 2022. The following types of categories exist: non-UHI environments, environments with low UHI, environments with medium UHI, and environments with high UHI. UHI environment.

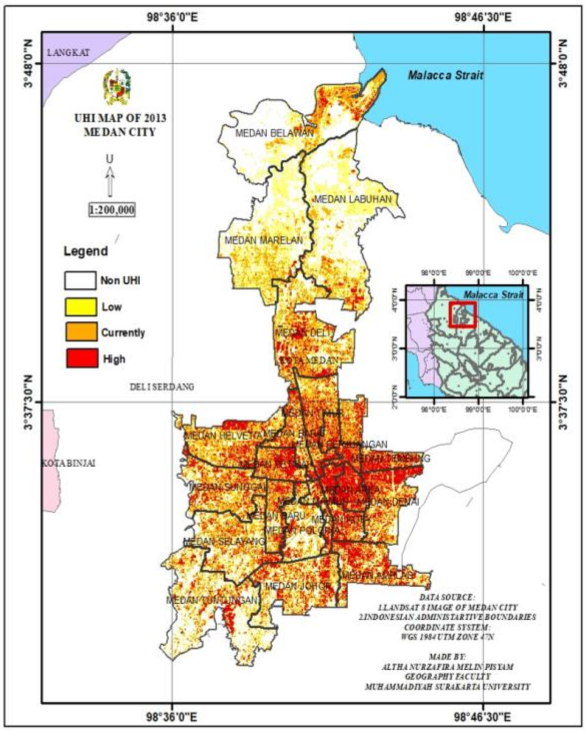

Figure 3. UHI Map Of 2013 Medan City

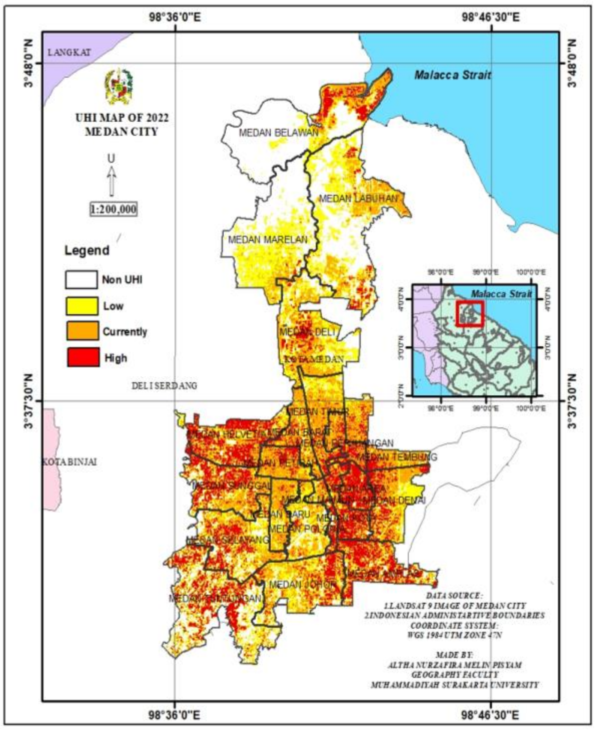

Figure 4. UHI Map Of 2022 Medan City

d. The relationship between land use change and UHI in Medan City

If we look at the impact of land use changes on urban heat islands (UHI), the NDVI and NDBI in Medan City are very enlightening. For two years, specifically 2013 and 2022, plotted against the city construction density index and vegetation index, changes can be seen. In this way, changes in land use can be displayed graphically. explained more clearly.

e. Relationship between UHI and NDVI 2013 and 2022

We investigated the impact of plant cover on UHI distribution in Medan City using logistic and direct linear regression. This research uses direct linear regression to determine how vegetation density affects the urban heat island effect (UHI) in Medan City. The independent variable is vegetation density (NDVI) while the dependent variable is uhi. The following table shows the results of a simple regression test to assess how vegetation density affects the urban heat island effect (UHI) in Medan City between 2013 and 2022.

Table 1. UHI Normality Test for 2013 NDVI

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,189	15	,156	,931	15	,279

a. Lilliefors Significance Correction

Table 2. UHI Normality Test for 2022 NDVI

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,181	15	,200*	,886	15	,058

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 3. UHI simple regression test on 2013 NDVI

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,838[a]	,702	,679	,09520

a. Predictors: (Constant), uhi

b. Dependent Variable: ndvi

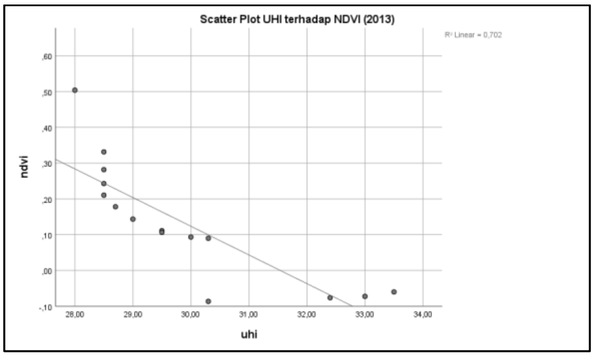

Figure 7. Relationship between UHI and NDVI 2022

Table 4. UHI simple regression test for 2022 NDVI

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,898[a]	,806	,791	,06666

a. Predictors: (Constant), uhi

b. Dependent Variable: ndvi

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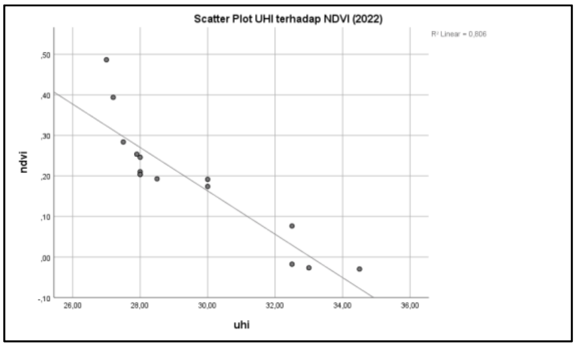

Figure 8. Relationship between UHI and NDVI 2022

f. Relationship between UHI and NDBI 2013 and 2022

The influence of building density on the urban heat island effect (UHI) of Medan City was investigated using direct linear regression analysis. The role of vegetation density on the urban heat island effect (UHI) of Medan City was examined in this research through direct linear regression. At this stage the value of the independent variable is building density (NDBI), while the value of the dependent variable is urban heat island effect (UHI). The following table presents the results of a simple regression test that can be used to determine the magnitude of the impact of UHI on NDBI in Medan City in 2013 and 2022.

Table 5. UHI Normality Test for 2013 NDBI

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,197	15	,120	,871	15	,035

a. Lilliefors Significance Correction

Table 6. UHI Normality Test for 2022 NDBI

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,329	15	,126	,742	15	,001

a. Lilliefors Significance Correction

Table 7. UHI simple regression test for 2013 NDBI

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,865[a]	,748	,728	,07167

a. Predictors: (Constant), uhi

b. Dependent Variable: ndbi

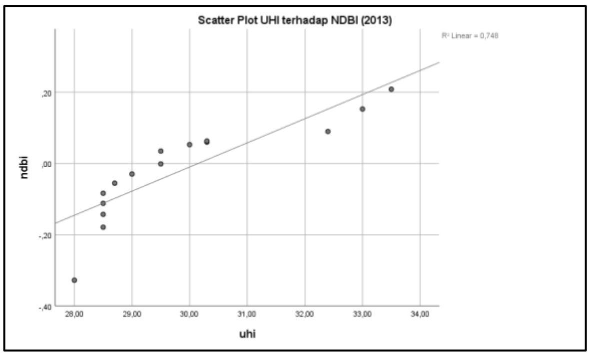

Figure 9. Relationship between UHI and NDBI 2013

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Table 8. UHI simple regression test for 2022 NDBI

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,882[a]	,778	,761	,10077

a. Predictors: (Constant), uhi

b. Dependent Variable: ndbi

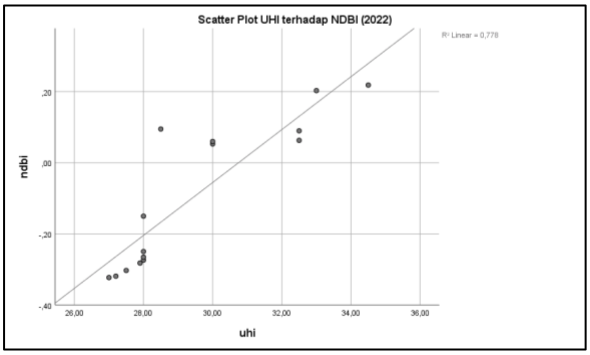

Figure 10. Relationship between UHI and NDBI 2022

4. CONCLUSIONS

1. From 2013 to 2022, the distribution of areas affected by UHI in Medan City is almost the same as the distribution of areas affected by UHI in previous years. However, The areas affected by UHI are in the east, west and central areas of Medan City, while the areas not affected are mostly in the north. Land surface temperature (LST) and UHI maps are interconnected, especially in areas that have a temperature level of more than thirty degrees Celsius, which is classified as a high temperature for the Medan City area.
2. Positive and linear values indicate that there is a relationship between changes in land use and the impact of the urban heat island in Medan City between 2013 and 2022. This fact shows that there is a relationship between UHI and NDVI and NDBI following the same pattern. On the other hand, the degree of correlation that exists between these two variables changes from one year to the next.

5. RECOMMENDATIONS

1. When conducting UHI research in the future, it is recommended to take photos with as little cloud cover as possible to create correct LST values.
2. For the purposes of this UHI research, additional research should, if possible, utilize other factors. Apart from variables, land cover and land use are also included in this category.

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