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Monitoring the Impact of Land Cover Change on Urban Heat Island with Remote Sensing & GIS

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ABSTRACT

The increasing need for land has resulted in a higher rate of land conversion and urbanization, leading to a rise in urban density and the occurrence of an Urban Heat Island (UHI) effect. The application of remote sensing and GIS can serve as a substitute for data collection in monitoring the UHI phenomena. This work utilizes Landsat 8 OLI satellite image data, namely band 10, to analyze Land Surface Temperature (LST). Bands 5 and 4 are employed to assess the distribution of Normalized Difference Vegetation Index (NDVI) in Bekasi Regency during the years 2014 and 2020. The relationship between NDVI and LST is highly correlated as they can effectively forecast the influence of areas with sparse vegetation on temperature. The guided classification approach, employing the maximum likelihood algorithm and kappa validation, is utilized to evaluate alterations in land use. The kappa accuracy test yielded a score of 0.90% for 2014 and 0.99% for 2020. The research conducted between 2014 and 2020 revealed changes in land distribution. Specifically, the built-up land area increased by 99.92 Km^2, empty land expanded by 280.82 Km^2, bodies of water covered an additional 46.13 Km^2, and vegetation expanded by 293.91 Km^2. According to the UHI research, it is evident that there has been a rise in surface temperature in Bekasi Regency from 2014 to 2020. In 2014, the minimum temperature reached 30 °C, and the maximum temperature reached 51 °C. In 2020, the minimum temperature was recorded at 34 °C, while the maximum temperature reached 52 °C.

Keywords : Urban Heat Island (UHI); Land Change; Remote Sensing & GIS; Monitoring

INTRODUCTION

Bekasi Regency is a highly urbanised city in Indonesia, characterised by its extensive industrial activity and being a prime target for urbanisation. Bekasi Regency within a period of 5 years (2016-2020), the population density tends to increase along with the increase a population

(BPS, 2021). An increase in population can demand development by transferring land functions, especially vegetation to built-up land. Being a metropolitan city, the Bekasi Regency faces intricate issues including escalating pollution caused by car emissions, industrial zones, green spatial design, and rising building density (Nandi & Dede, 2022). These problems will result in a significant increase in surface temperature in downtown areas compared to suburban areas (Blooshi et al., 2020). This considerable temperature difference between the downtown area and the suburbs are referred to as the urban heat island phenomenon (Kumar et al., 2021).

In 2020, the population of Bekasi Regency, as determined by the Civil Registry Service's population registration, was 3,113,017 persons. The average population density was calculated to be 2,444 persons per square kilometer. The South Tambun District has the highest population density, with 10,001 people per square kilometer, whilst the Muara Gembong District has the lowest density, with 288 people per square kilometer (BPS, 2021).

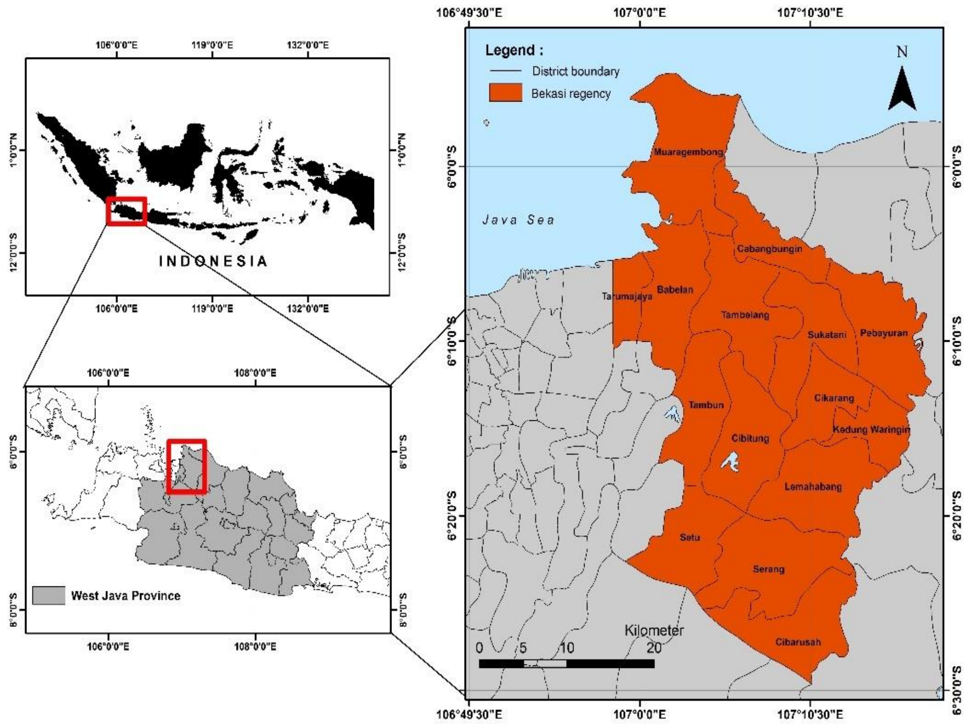


Figure 1. Bekasi Regency

The metropolitan Urban Heat Island (UHI) phenomenon refers to the disparity in air temperature between metropolitan centers and their surrounding regions, leading to a notable increase in temperatures within the urban environment (Lee et al., 2020). Previous research has demonstrated a significant rise in the average temperature in urban areas of West Java during a span of 20 years, specifically from 1998 to 2018. The temperature increase reached a magnitude of 4.44°C (Nandi & Dede, 2022). A study conducted in Tangerang city analysed data from 2004 to 2020, revealing a 0.3°C rise in the UHI index (Prastiwi, 2022). Between 2008 and 2018, DKI Jakarta had a substantial increase in the average intensity of UHI, resulting in a temperature rise of 3°C (Putra et al., 2021). Fitriana et al. (2021) observed a decrease in vegetation over a period of seven years, with the quantity declining from 0.159 to 0.156.

UHI phenomenon significantly contributes to global warming by elevating the Earth's temperature (Manoli et al., 2019). The present situation is becoming more intense as urbanization and the expansion of metropolitan hubs occur simultaneously. The UHI phenomenon is partly attributed to the decrease in green open spaces resulting from the growth of residential, industrial, commercial, and office districts (Maheng et al., 2019). It may be inferred that there is a significant increase in urbanization, marked by a growing population of individuals residing in urban regions.

Population growth is increasing every year, thus encouraging an increase in land demand (Nugroho & Al-sanjary, 2018). With the increase in land demand, the rate of land change is higher. Land use that was initially an agricultural area or green area is converted into a built-up area. In addition with the trend of urbanization continues to increase every year, which results in human activities and industrial activities (Oloke et al., 2021). These activities can encourage the greenhouse effect in urban areas (Hoornweg et al., 2018). In addition to the rapid development that is unavoidable, there are often conflicts of interest in land use. An issue that is often faced is the lack of compatibility between land use and the original land-use plan (Hersperger et al., 2015). Urban regions experience a decline in environmental quality as a consequence.

Remote sensing imagery is a technology that has experienced significant advancements throughout the fourth industrial revolution. Remote sensing image technology can be utilized to investigate the UHI phenomenon (Zhou et al., 2019). By utilizing remote sensing satellite photos and advanced processing techniques, it is feasible to conduct observations in the Bekasi Regency area at various time intervals. The research utilizes Landsat satellite images as the primary visual data source. The utilization of Landsat imagery enables the identification of alterations in land cover and the spatial arrangement of surface temperature inside the Bekasi Regency. Moreover, in the analysis of UHI the NDVI is employed to quantify the vitality and concentration of vegetation. The NDVI can be employed to examine the impact of UHI phenomenon, as vegetation plays a role in alleviating its effects (Florim et al., 2021). Reduced NDVI values in urban settings might signify a scarcity of vegetation, resulting in increased intensity of the UHI effect. NDVI can also facilitate the identification of the most impacted regions, hence providing valuable insights for urban planning and green infrastructure efforts that attempt to mitigate the UHI phenomenon (Prastiwi, 2022). The process involves analyzing satellite photos by comparing the reflectance of near-infrared and red light. This is because plants tend to reflect more near-infrared light and less red light. Hence, this study use remote sensing technologies to examine the urban heat island phenomena in Bekasi Regency. The objective of this study is to examine the UHI phenomena in Bekasi Regency by analyzing the effects of land cover changes on surface temperatures.

METHODS

Research Design

In order to examine the impact of land change on the UHI phenomenon in Bekasi Regency, Indonesia, image data from 2014 and 2020, spanning a period of 7 years, are utilized. Through the utilization of multi-spectral and thermal bands extracted from Landsat imagery. Figure 1 displays the flowchart illustrating the methodology employed. The Bekasi Regency area experienced the highest incidence of modest cloud cover in both 2014 and 2020. Unlike previous years, which exhibit a significant amount of cloud cover. Furthermore, it was discovered that in 2017, the Bekasi Regency region had noise levels within the frequency ranges of bands 10 and 11. Consequently, the categorization process and surface temperature study could not be conducted. To overcome this, a cloud masking process is needed with the BQA band on Landsat 8 so that the image can be analyzed without interference from clouds (Sinabutar et al., 2020).

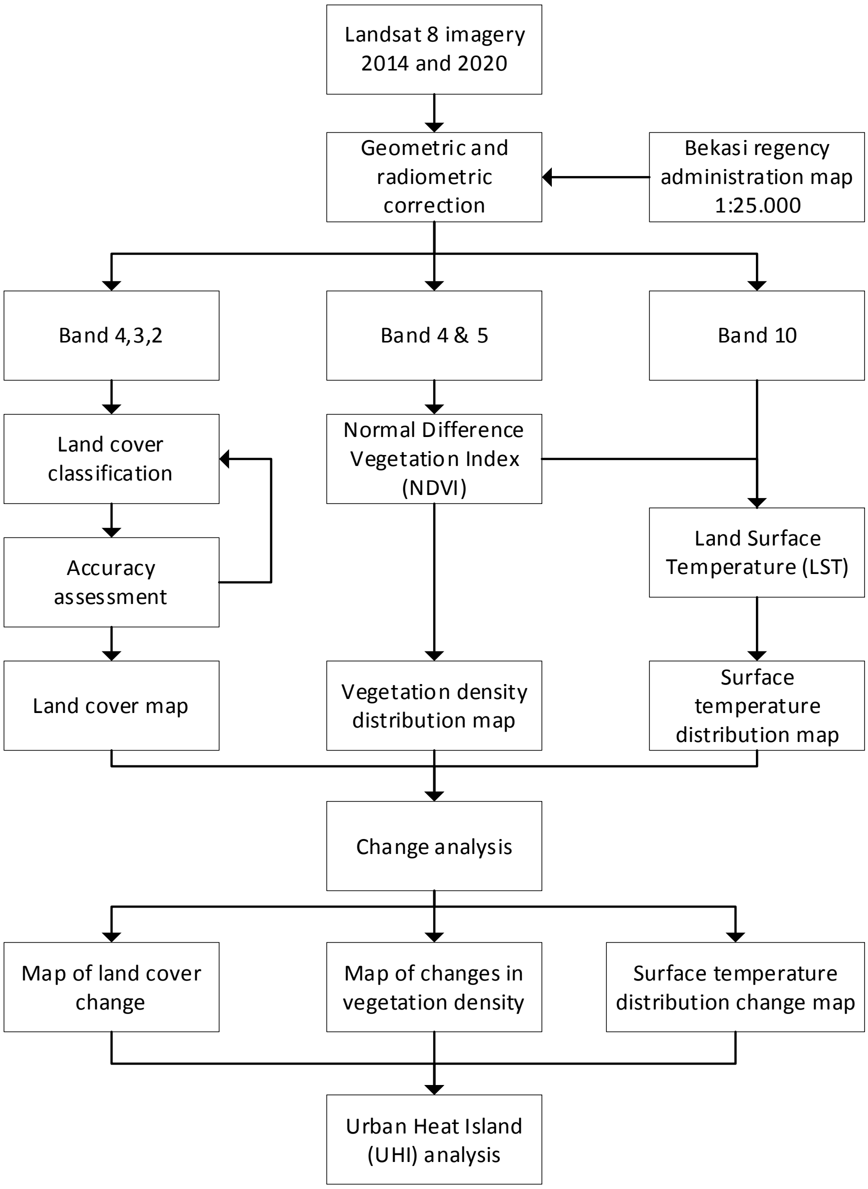


Figure 2. Research flowchart

Data

In the analysis of UHI and landuse cover change, Landsat 8 OLI images were used with acquisitions in 2014 and 2020. To determine the administrative boundaries of the Bekasi regency, it was obtained from the Geospatial Information Agency (BIG).

Table 1. Dataset acquisition

Date	Dataset	Path/Row	Source
2020-05-24	Landsat 8 OLI	122/64	Earth Explore USGS
2014-09-13	Landsat 8 OLI	122/64	Earth Explore USGS

Source: https://earthexplorer.usgs.gov/

Image Pre-processing

During the pre-processing stage, the satellite imagery from Landsat 8 is transformed and aligned with the UTM projection system in the 48 S zone, using the 1984 World Geodetic System (WGS) datum. In order to mitigate the effects of panorama distortion, which alters the appearance of satellite scans, it is necessary to apply geometric correction (Tawfik et al., 2017). The technique of geometric correction involves adjusting the position of each pixel in the image to match the corresponding location of the object on the Earth's surface. This is achieved by utilizing several ground control points collected from GPS. Next, radiometric correction is applied to mitigate the effects of sunlight distortion, resulting in the optimization of the UHI analysis outcomes. The Bekasi regency administration utilizes a map with a scale of 1:25,000 to precisely establish the boundaries of different areas.

Land Cover Change

Identification of land cover changes is essential to know how big the rate of change is. The land change has an impact on the intensity of changes in surface temperature. The more vegetation area changes to built-up land, it will affect the increase in surface temperature. In the analysis of land cover changes, comparing land cover in 2014 with land cover in 2020. Supervised classification using the change analysis methodology utilizes the Maximum Likelihood Classification (MLC) approach. The classification is categorized into four distinct classes, specifically built-up land, water, vegetation, and bare land.

Table 2. Land cover classes

Land cover classes	Description
Built-up	The area encompasses a hamlet, town, residential and commercial zones, industrial facilities, a communication and utility hub, as transportation infrastructure.well as
Vegetation	It consists of grassland, shrubland, flooded grassland, flooded shrubland, parks, agriculture areas such as rice fields and forests.
Waterbody	It consists of a river, stream, pond, and lake.
Bare Land	The area has no building on it and is not being used.

Source: (Dangulla et al., 2020)

The rate of land cover change is expressed as a percent value with the following formula (Zaitunah et al., 2018):

$$V = N_2 - N_1 / N \quad (1)$$

Where V is landcover change (hectare), N_2 is a large area of time 2 (hectares), N_1 is large area of time 1 (hectares), and N = total area (hectares).

Accuracy Assessment

Assessing the accuracy of the classification process is essential. The objective of accuracy evaluation is to statistically evaluate the sample's efficacy in accurately identifying pixels within the relevant land cover category. Moreover, the main emphasis in selecting pixels for accuracy assessment is on areas that are distinguishable in high-resolution pictures, such as those acquired from Landsat, Google Earth, and Google Maps (Rwanga & Ndambuki, 2017).

The Kappa statistics are utilised to accurately evaluate the quality of categorization and to examine the overall correctness of classes in a statistically valid manner. Pontius (2000) stated that a Kappa value of 0.5 is deemed acceptable for land-use change modelling. The description of the agreement for the Kappa coefficients is as follows: Values beyond 0.79 are classified as excellent, values ranging from 0.6 to 0.79 are classified as substantial, and values of 0.59 or below indicate moderate or poor agreement. The Kappa coefficient (K^) is then calculated using the following Equation (Rwanga & Ndambuki, 2017):

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(x_i + Xx_{+1})}{N^2 - \sum_{i=1}^{r}(x_{ii}Xx_{+1})} \quad (2)$$

Where:

r	=	The dimensions of the error matrix, representing the total number of land-use types, including both rows and columns.
N	=	The total number of observations (pixels), the total area of all land use types.
x_{ii}	=	Observation in row i and column i, (the result scale land use type i simulation, which corresponds to the result scale land-use type i observed).
Xi+	=	Marginal total of row I.
X+I	=	Marginal total of column i.

Normalized Difference Vegetation Index (NDVI)

NDVI is employed to detect vegetated regions through the utilization of remote sensing technology. The utilization of bands 5 (near-infrared) and 4 (red) in the Landsat 8 OLI image enables us to discern the spatial arrangement of vegetation. NDVI calculation is used to determine the degree of vegetation density because NDVI has a correlation with chlorophyll content with a distribution range of -1 to +1 (Zaitunah et al., 2018). NDVI is formulated as below (Syukri, 2018):

$$NDVI = \frac{NIR-R}{NIR+R} \quad (3)$$

The reflectance value of the near-infrared band is denoted as NIR, while the reflectance value of the red band is denoted as R.

Land Surface Temperature (LST)

Several methods have been developed to compute LST values. Certain techniques necessitate the usage of many thermal bands, such as the split window algorithm and the multi-angle algorithm. Nevertheless, it is possible to utilize a solitary thermal band using several approaches, such as employing a single-channel algorithm, employing a mono-window technique, or employing methods that rely on Planck's law. The calculation of LST in Landsat 8 utilizes two specific bands, namely bands 10 and 11. However, in band 11, there is a lack of assurance, hence the USGS advises users to utilize TIRS Band 10 data as a singular spectral band. This study utilizes a technique that involves only one thermal band. The primary rationale for employing this approach is its ability to compute LST only based on the emissivity value, without the need for air conditions during image acquisition. The steps taken in determining LST in Bekasi Regency include:

The TOA Spectral Radiance value is obtained by using the Radiance rescaling factors as defined in the following Equation (Pontius, 2000):

$$L\lambda = M_L Q_{cal} + A_L \quad (4)$$

Where, Lλ is the TOA spectral radiance (Watts/(m2*srad*μm)), M_L is the Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number), Q_{cal} is the Quantized and calibrated standard product pixel values (DN), and A_L is the Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number). The brightness temperature was determined by utilising the spectral radiance in accordance with the given equation (Prastiwi, 2022):

$$T_B = \frac{K_2}{(\ln(\frac{K_1}{L_b}+1))} \quad (5)$$

where TB is the brightness temperature, and K_1 and K_2 are band-specific thermal conversion constants from the metadata; for Landsat 8 TIRS: K_1 = 774.89 and K_2 = 1321.08.

Then, the surface temperature (TS) was derived using Equation (7), and it was converted to Celsius (TC) (Ruthirako et al., 2015).

$$T_S = T_B / (1 + \left(Λ * \frac{T_S}{\alpha}\right) * \ln(\varepsilon)) \quad (6)$$

Where, ε is the emissivity, Λ is the average wavelength of the band, and α = 1.438 x 10^{-2} mK.

$$T_C = T_S - 273.15 \quad (7)$$

The land surface emissivity of band 10 is determined based on the NDVI, the P_V values in Equation can be calculated using Equation (Priana et al., 2019):

$$P_V = \left[\frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}\right]^2 \quad (8)$$

Whare, P_V is the vegetation proportion, $NDVI_V$ = 0.5 and $NDVI_S$ = 0.2.
Moreover, the emissivity value of a surface can be calculated using Equation (Yin et al., 2020):

$$\varepsilon = \varepsilon_V P_V + \varepsilon_m (1 - P_v) + d\varepsilon \quad (9)$$

Where, ε is emissivity, ε_V is the emissivity of vegetation, ε_m is the emissivity of man-made materials, Pv is the vegetation proportion, and $d\varepsilon$ is the fraction of emissivity caused by internal reflections/cavity effect (Yin et al., 2020).

$$d\varepsilon = (1 - \varepsilon_m)\varepsilon_V F(1 - P_v) \quad (10)$$

Where F is the shape factor regarding the geometrical structure of vegetation.

RESULTS AND DISCUSSION

Land Cover Analysis

Image processing using supervised classification with the MLC method, which is divided into four classes. If the accuracy test results are obtained above 85% annually, then the data can be used for further analysis (Hanafi et al., 2021). The result accuracy is obtained in Table 3.

Table 3. The computed values for producer's accuracy (PA), user's accuracy (UA), and overall accuracy for the years 2014 and 2020 are stated below.

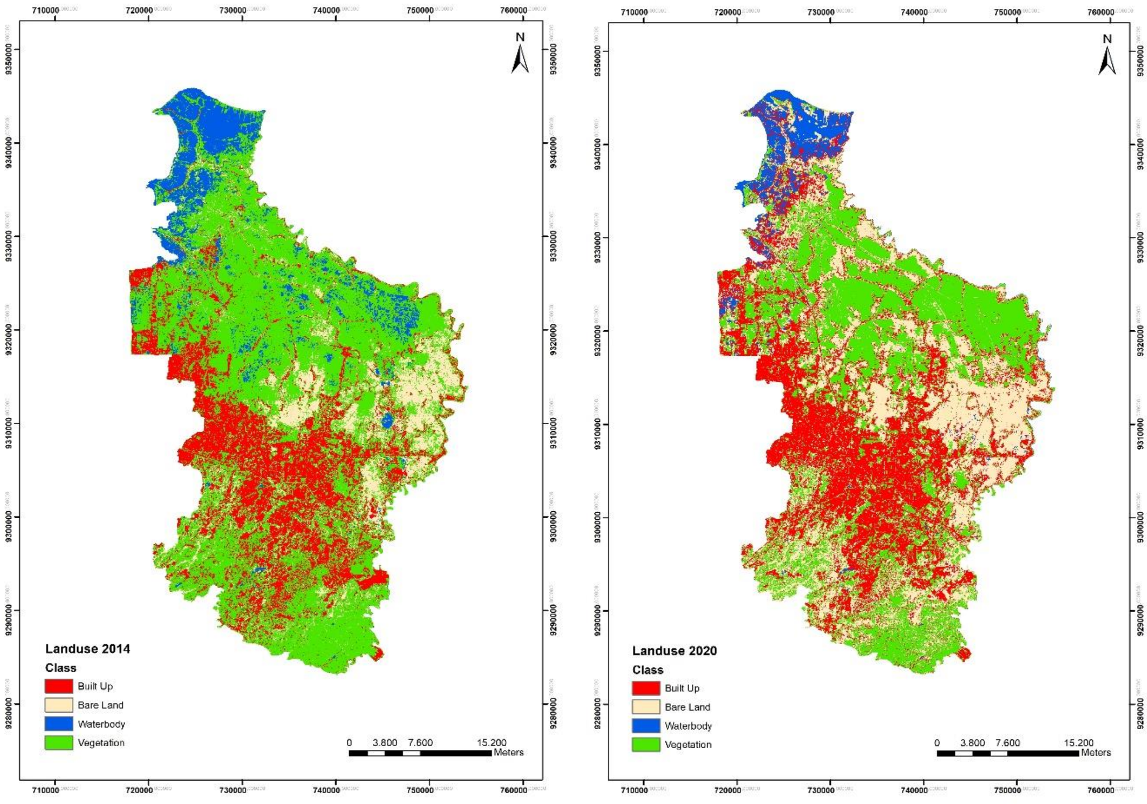
	Built-up		**Bare land**		**Waterbody**		**Vegetation**		
	PA	UA	PA	UA	PA	UA	PA	UA	Overall accuracy (%)
2014	91.27	97.80	97.13	97.13	96.68	94.17	88.31	77.78	93.29
2020	98.72	100	99.59	97.98	100	99.34	100	100	99.36

The overall accuracy result is 93.29% for 2014 and 99.36% in 2020. In selecting the acquisition area, the cloud content below 10% is chosen so that the classification and analysis process of surface temperature gets maximum results. The magnitude of the land change can be seen in Table 4.

Table 4. Land cover classes

Land use	**Built up (Km^2)**	**Bare land (Km^2)**	**Waterbody (Km^2)**	**Vegetation (Km^2)**
2014	289.02	160.92	108.85	720.48
2020	388.94	391.74	62.72	426.57
Change area 2014-2020	99.92	280.82	46.13	293.91

These results show that the most significant land change occurs in the vegetation and bare land areas followed by the built-up area. This change is based on the vegetation area including agricultural areas that turn into vacant land after the harvest season. From the harvest season, the bare land area is getting wider because there is no vegetation area. The results of the classification can be seen in Figure 2.



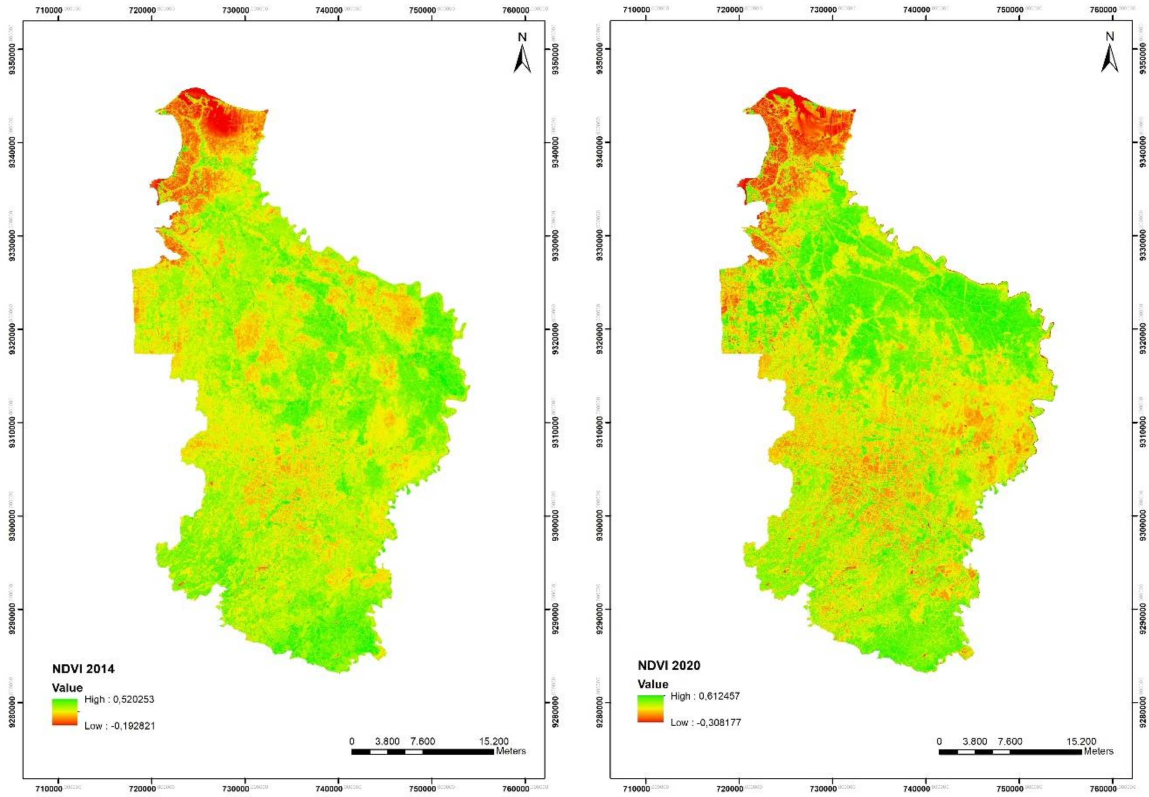
(a) (b)

Figure 3: (a) Land use in 2014, and (b) 2020

The image illustrates alterations in land-use between the years 2014 and 2020. These alterations have a profound impact within a span of 7 years. This figure is the result of the area classification process in Bekasi Regency.

Correlation between NDVI and LST

The NDVI approach is employed to assess the vegetation density inside the research region. The vegetation analysis results are associated with the impacts of land cover classification and surface temperature. Surface temperature is affected by several activities, including residential, agricultural, industrial operations, and other factors. The vegetation area in Bekasi Regency saw significant discrepancies between 2014 and 2020, mostly attributed to the influence of agricultural operations and the expansion of residential and industrial zones. The NDVI values function as a metric for the distribution of vegetation and can be employed to determine LST. NDVI is commonly used in correlation studies to analyse the relationship between temperature and vegetation in UHI study (Ruthirako et al., 2015). The study findings suggest that the NDVI varied between -0.19 and 0.52 in the year 2014. The NDVI varied between -0.30 and 0.61 in the year 2020. The outcome of analysing the NDVI:



(a) (b)

Figure 4. Results of NDVI processing in 2014 (a) and 2020 (b).

Regarding the relationship between NDVI and LST, a regression model is used because the model produces an explanation where NDVI is negatively correlated with surface temperature.

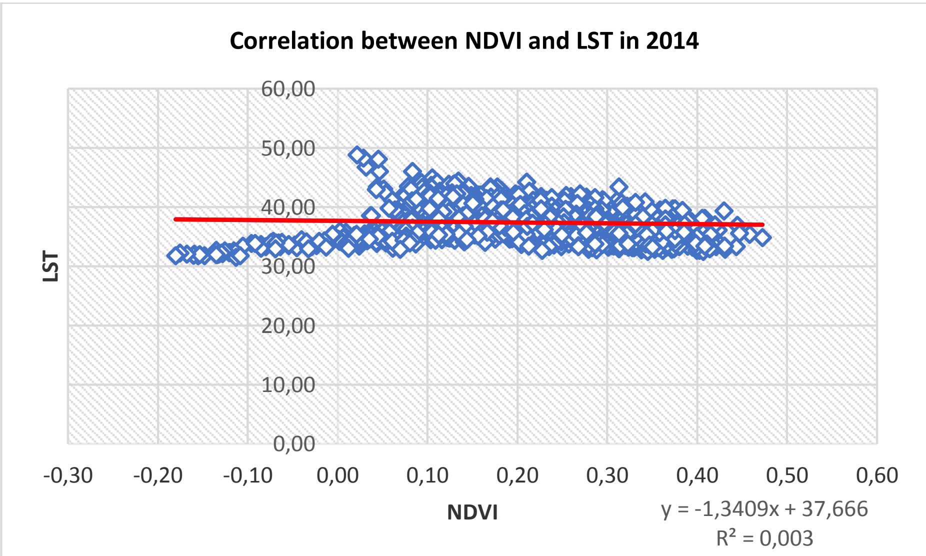


Figure 5. Correlation between NDVI and LST in 2014

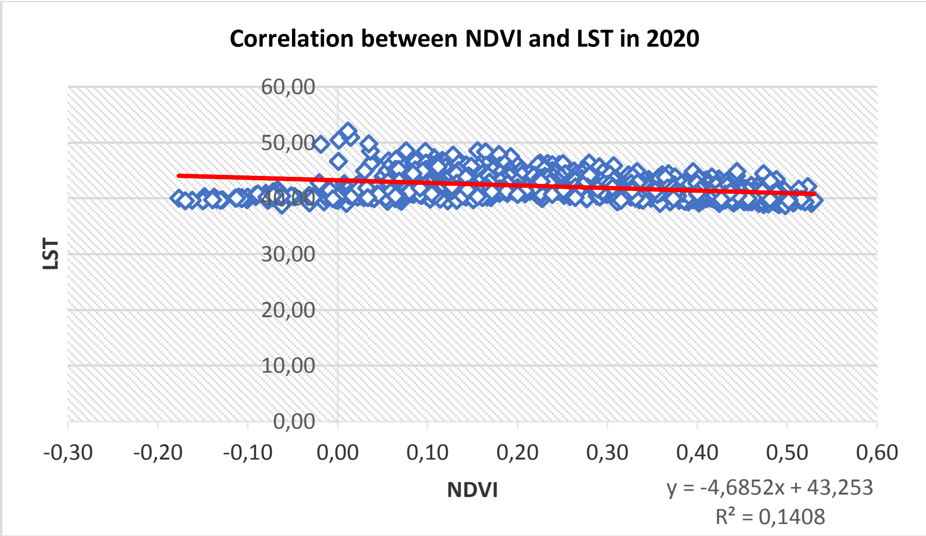
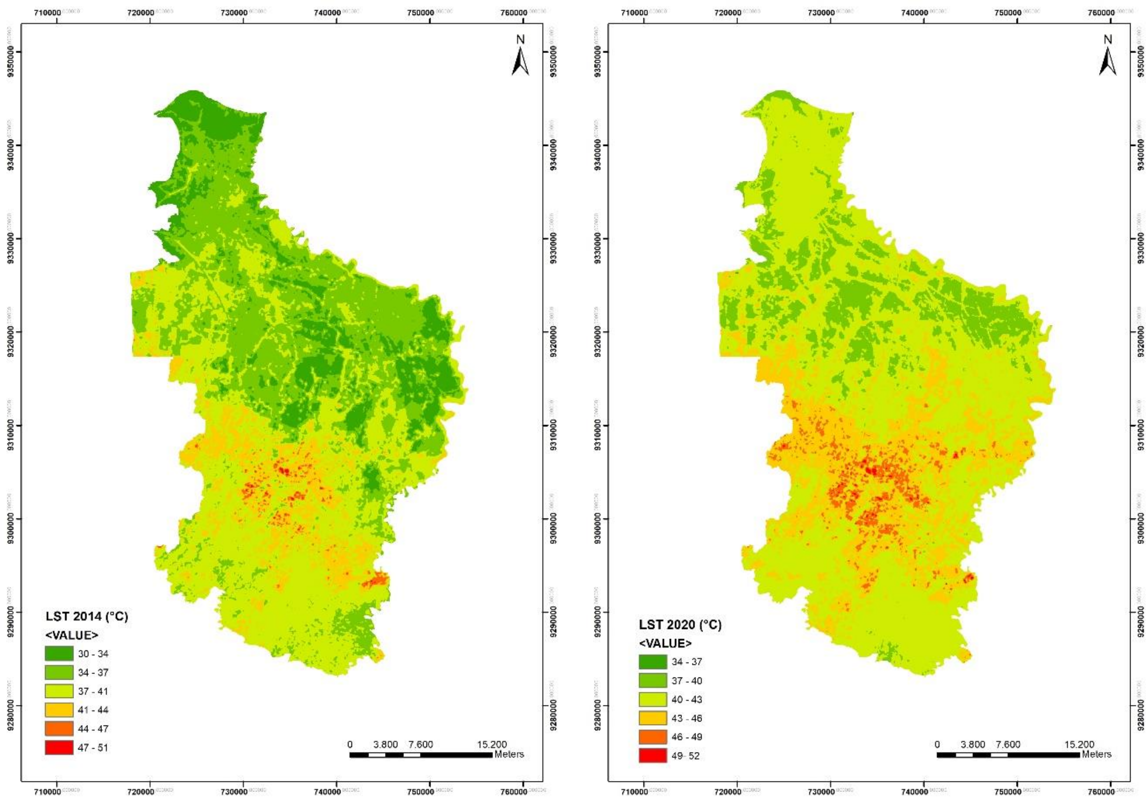


Figure 6. Correlation between NDVI and LST in 2020

From the graph of the regression results, it can be seen that the higher the NDVI value, the lower the LST value and otherwise. The correlation and regression tests between NDVI and LST in 2014 and 2020 show a subordinate linear relationship where the value of R^2 = 0.003 in 2014 and R^2 = 0.1408 in 2020. This is in line with the surface temperature, which is negatively correlated with the vegetation index (Priana et al., 2019).

Surface Temperature Analysis

A surface temperature analysis was conducted to assess the extent of the urban heat island (UHI) phenomena in Bekasi Regency. The application of digital images obtained through remote sensing is advantageous for analyzing surface temperatures by utilizing thermal band channels. The advancement in air temperature measurement is intricately linked to the fundamental principles of physics, namely the notion of black body temperature (Giofandi, 2020). The LST value's magnitude is affected by the wavelength, with thermal infrared having the greatest sensitivity to surface temperature. The temperature fluctuations will impact the object's reflective properties at different wavelengths (Sajib & Wang, 2020). The procedure of determining LST data involves using thermal waves included in satellite imagery to detect the LST. The existence of UHI can be identified in Figure 7 by analysing two photographs taken in different years. Figure 2, depicts the projected rise in surface temperature in Bekasi Regency in 2020, which corresponds to changes in land usage.



(a) (b)

Figure 7. LST in 2014 (a) and 2020 (b).

Besides being caused by various land uses such as vegetation areas turning into built areas. The difference in surface temperature in Bekasi Regency is also caused by human activities in the form of industrial activities and transportation activities. Bekasi Regency is an area that has a lot of industrial activity, with a total of approximately 4000 industries from home, small, medium, to large scale industries in 2020. So many industrial activities, it has pushed the LST to rise in Bekasi Regency. In addition, with a lot of vehicle activity and congestion that occurs adds to the increase in LST. The highest surface temperature that occurred in the Bekasi Regency was 51°C in 2014, and 52°C in 2020 appears in urban are-as, which are land uses in the form of the industrial areas (built-up). In comparison, the lowest temperature is 30° C in 2014 and 34° in 2020, which is located in an agricultural area (vegetation). The highest surface temperature point was in the Cibitung area, which resulted in the largest urban heat island phenomenon in Bekasi Regency.

The purpose of this study is to convey information about the impact of land use change on UHI, with the relation to the vegetation index value in Bekasi Regency during the 2014 and 2020 conditions and to support the green open space restoration program to minimize the increase in UHI in the area. The method in this study uses the Normalized Difference Vegetation Index (NDVI) algorithm to determine the greenness of vegetation and Land Surface Temperature (LST) to determine the temperature of the soil surface. NDVI values are obtained from the red band and near infrared band. The LST values were obtained from the TIRS band, namely band 10. This study utilized remote sensing technology based on Landsat 8 imagery data. The LST values based on conditions in 2020 were higher than in 2014. This correlates with the NDVI value which has also changed, where the NDVI value at when conditions in 2020 were lower than in 2014. Thus, there is a relationship between soil surface temperature (LST) and the vegetation index value (NDVI), that is, the lower the vegetation index (NDVI) value, the higher the land surface temperature (LST) and vice versa. This is also reinforced by the results of the correlation test which are displayed in the form of a scatter diagram (Figures 6 and 5). The entire scatter diagram for Bekasi Regency produces negative correlation values, indicating that in Bekasi Regency, in the conditions of 2014 and 2020, the increasing ground surface temperature correlates with a decrease in the value of the vegetation index and vice versa. Based on the results of the scatter diagram, it can be stated that there is a negative or inverse relationship between the LST value and the NDVI value.

CONCLUSION

This work use the supervised image classification approach, specifically utilising the maximum likelihood classifier algorithm, to assess changes in land cover. Landsat 8 data from 2014 and 2020 were utilised to analyse the transformations resulting from urbanisation. The Landsat thermal bands were utilised to compute the land surface temperature (LST) for the purpose of analysing the effects of urbanization-induced land change. Between 2014 and 2020, there were significant changes in land use. Specifically, the area of built-up land increased by 99.92 square kilometres, bare land increased by 280.82 Km^2, waterbody increased by 46.13 Km^2, and vegetation increased by 293.91 Km^2. From LST data for 2014 and 2020, there has been a minimum temperature increase of 4°C. Additionally, there is an inverse relationship between fluctuations in NDVI, leading to a decrease in the quantity of green vegetation. Consequently, the surface temperature will rise. The rise in surface temperature that led to the formation of an urban heat island in Bekasi Regency was mostly caused by industrial activities. Bekasi Regency has emerged as one of the premier industrial hubs in Indonesia, thanks to its significant industrial growth. To mitigate the rising surface temperature and the subsequent Urban Heat Island (UHI) effect in Bekasi Regency, regional spatial planning authorities should enhance the green infrastructure. Implementing environmentally sustainable architectural designs, constructing well-maintained pedestrian pathways, increasing the number of trees, establishing industrial zones with low levels of air pollution, and planning efficient regional landscapes inside urban areas could be beneficial solutions.

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DECLARATIONS

Conflict of Interest

The authors declared that they had no known competing interests.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

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