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Land cover changes, built-up and vegetation density, and the Urban Heat Island (UHI) phenomenon in Pekanbaru City

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Abstract
Pekanbaru city has a high population growth rate and is currently experiencing rapid urbanization, which is driving urban expansion. Urban development alters land cover patterns and reduces environmental quality. The development of residential areas and infrastructure reduces vegetation, affecting Land Surface Temperature (LST) and contributing to the emergence of the Urban Heat Island (UHI) phenomenon. This study aims to analyze changes in land cover, examine the correlation between LST and the Normalized Difference Built-up Index (NDBI) and the Normalized Difference Vegetation Index (NDVI), and then investigate the UHI phenomenon in Pekanbaru City. The research method is quantitative, using data from Pekanbaru City, an administrative map, and Landsat 8 OLI/TIRS imagery, which were spatially analyzed in ARGIS and QGIS. The novelty is the use of guided classification and maximum likelihood algorithms for land cover classification, which revealed significant changes over the five years from 2018 to 2023 in Pekanbaru City. Over 5 years, land cover in the city of Pekanbaru changed, with water bodies increasing by 23%, palm areas increasing by 5%, built-up areas increasing by 34%, and vegetation increasing by 10%, while bare land decreased by 57%. There are significant changes in built-up and vegetation density. The correlation between land surface temperature and built-up density is positive; however, it is negatively correlated with vegetation density. There is an urban heat island phenomenon in Pekanbaru City, characterized by surface temperatures exceeding the UHI threshold.

Keywords:
Building;
Heat;
Land;
Temperature;
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INTRODUCTION

Land conversion and deteriorating environmental quality are driving the city's rapid development and expansion. Due to changes in land use brought about by urbanization, there is a greater demand for available space. The land, initially empty and then filled with vegetation, has been turned into residential areas, offices, and industrial centers that can raise temperatures in the area. Land that has undergone area conversion, initially in the form of water catchment areas or green open spaces, has been converted to urban areas, increasing surface temperatures [1]. The Environmental quality of urban regions will degrade if land conversion is focused on building infrastructure and amenities. This land cover change also has both positive and negative impacts, but the negative impacts occur within urban ecological and environmental systems. Pekanbaru City will have a population of 1,123,000 in 2024, with a population growth rate of 2.99% in 2020-2023 [2]. Rapid urbanization has led to significant improvements in public services, basic infrastructure, and living standards [3]. Population growth and urbanization accelerate urban expansion, ultimately altering land cover and land use patterns [4]. During urbanization, urban expansion results in significant changes to the urban land surface, leading to the irreversible conversion of original rural land to urban land. Through this technique, impermeable materials such as cement, asphalt, brick, tile, and others are used in place of natural soil and vegetation [5]. Besides the positive impact of fulfilling society's needs, negative impacts include increased pollution and higher environmental temperatures due to the growth of the human population and activities, such as reduced vegetation cover in urban areas [3] [6]. It occurs due to the facilitation of population needs caused by population expansion. Raising high temperatures can lead to elevated ecological and environmental problems, such as biodiversity loss [6]. An increase in environmental temperature will reduce environmental comfort and harm people's health and activities. Vegetation has an important role in reducing land surface temperature. Reduced land cover for agriculture and water is linked to higher solar radiation absorption, which raises land surface temperature and has detrimental impacts on the climate and human existence [7, 8, 9].

Land cover change is one of the things that drives the urban heat island phenomenon. This phenomenon is caused by land surfaces that previously absorbed sunlight, which then reflect heat into the air, trapping it in urban areas. The urban heat island, or UHI, is a phenomenon that contributes to global warming. It could be identified using land surface temperature data, as there is a correlation between land surface temperature and the built-up and vegetation densities of the area. The land surface temperature (LST) is the average temperature of the Earth's surface, represented as pixels with different types of Earth's surface. The Normalized Difference Built-up Index (NDBI) measures the density of built-up land to determine the level of built-up area density.

In contrast, the Normalized Difference Vegetation Index (NDVI) indicates the level of vegetation density or the greenness of an area. The impact of the urban heat island phenomenon includes increased air pollution and environmental degradation [6]. A study of the urban heat island phenomenon is important, as air temperatures continue to rise in urban areas, creating an uncomfortable environment for communities. The urban heat island affects comfort levels. The urban heat island effect shows that the closer to the city center, the higher the discomfort percentage [7]. To understand how climate change affects urban thermal comfort, Lugao et al. (2022) modeled four different temperature change scenarios. They stated that all scenarios showed that temperature oscillations between thermal sensation levels indicate a percentage of hours of comfort above 50% in each, because mild cold sensation is reduced, particularly at the start and end of the day [10]. The urban environment, air quality, plant and animal growth and development, and human health are all impacted by the urban heat island either directly or indirectly.

On the other hand, mitigation of the impact of this phenomenon is one of the main issues in sustainable urban development. This study aims to analyze land cover changes, examine the correlation between land surface temperature and built-up and vegetation indices, and define the urban heat island phenomenon in Pekanbaru City in 2018 and 2023. These indices collectively provide valuable data to guide local government efforts in spatial and regional planning. By prioritizing community convenience while ensuring environmental sustainability, authorities can create policies that foster a livable urban environment, promote green space initiatives, and integrate climate resilience into planning practices. The findings can facilitate better decision-making, aligning development with environmental conservation, thereby supporting the long-term well-being of the community and its surroundings. In other words, the study's results inform policymakers' spatial and regional planning that prioritizes community amenities while maintaining environmental sustainability.

METHODOLGY

Location of study

This research was carried out in Pekanbaru City, as shown in Figure 1. Pekanbaru City is located at the geographical coordinates of 101°14' – 101°34' E and 0°25' – 0°45' N, on path/row 127/60, in Figure 1.

Methods

An image or dataset captured by the Landsat satellite, a remote sensing satellite operated by NASA and other affiliated organizations, is known as Landsat imagery.

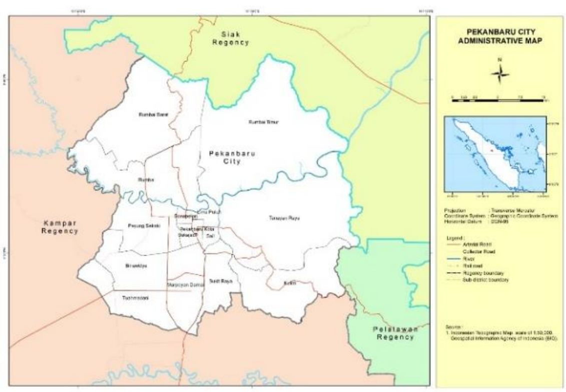

Figure 1. Study location (Pekanbaru City)

The state of the Earth's surface, including changes in the environment, land use, vegetation cover, urbanization, and natural disasters, is tracked, observed, and analyzed using this imagery. Landsat-7 and Landsat-8 imagery from 2014 to 2019 was used to quantify the temporal and spatial features of the UHI effect at the surface in Shenzhen, China [11]. Landsat TM, ETM+, and OLI satellite imagery was used to evaluate spatiotemporal variation in the surface impacts of the urban heat island in Mekelle City, Northern Ethiopia [12]. Then, the Landsat-5 and Landsat-8 satellite imagery were used to investigate the spatiotemporal variations in the UHI's surface impacts in Edmonton, Canada [13]. Compared to other satellite images, Landsat images offer several advantages, including higher spectral and radiometric resolutions and adequate spatial resolution, especially for analyzing changes in land cover, built-up areas, and vegetation. The data sources used in the study are the Pekanbaru City administrative shapefile and Landsat 8 OLI/TIRS imagery, including Bands 1-7 (B1–B7) and Band 10 (B10). The image data were acquired on January 30, 2018, with a cloud cover of 6.16; for 2023, an image from May 20, 2023, with a cloud cover of 8.54 was used. Data is analyzed using QGIS and ArcGIS. The data is validated by comparing it with Google satellite (Google Earth). The research stages are explained below.

By using Landsat 8 OLI/TIRS imageries, the normalized difference built-up index (NDBI) analysis was carried out to measure the density of built-up area using imageries of near infrared (NIR; B5) and short-wave infrared (SWIR; B6), then calculated by (1) [6].

$$\mathrm{NDBI} = \frac{(\mathrm{SWIR} - \mathrm{NIR})}{(\mathrm{SWIR} + \mathrm{NIR})} \qquad (1)$$

The normalized difference vegetation index (NDVI) was calculated to estimate vegetation density using imagery in the red (RED; B4) and near-infrared (NIR; B5) bands, which range from 1 to 1. Its values are near zero or negative in regions without vegetation, such as rocks, sand, and concrete, and positive in regions with vegetation, such as crops, shrubs, grasses, and forests [14]. Therefore, a more vigorous green vegetation cover is indicated by more significant NDVI values [9]. The NDVI is calculated by (2) [6].

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \qquad (2)$$

The NDBI and NDVI categories are classified according to Table 1 and Table 2.

Table 1. Built-up Classification (NDBI) [15]

Class	NDBI Score	Description
1	(-1) – 0	No settlement
2	0 – 0.1	Rare settlement
3	0.1 – 0.2	Dense settlement
4	0.2 - 1	High dense settlement

Table 2. Vegetation Classification (NDVI) [15]

Class	NDVI Score	Description
1	(-1) – (-0.03)	Not vegetated
2	-0.03 – 0.15	Very low vegetation
3	0.15 – 0.26	Low vegetation
4	0.26 – 0.35	Moderate vegetation
5	0.35 - 1	High vegetation

The land surface temperature (LST) is influenced by the interaction among energy at the Earth's surface, the atmosphere, surface thermal properties, and the media below the ground surface. Surface temperatures in each region can be analyzed using Landsat satellite imagery by extracting information from thermal channels. After calculating the land surface parameters NDVI and NDBI, LSTs were generated using surface–temperature inversion [16]. To determine land surface temperature, Band 10 (B10) was used, and the temperature was calculated using (3)-(7). First, the Digital Number (DN) value must be converted to a TOA spectral radiance value, then transformed to a surface temperature value using a predetermined (3) [7].

$$\mathrm{L}_\lambda = \mathrm{M_L} \times \mathrm{Q_{cal}} + \mathrm{A_L} \qquad (3)$$

where: L_λ = TOA spectral radiance; $\mathrm{M_L}$ = Band-specific multiplicative rescaling factor from the metadata; $\mathrm{A_L}$ = Band-specific additive rescaling factor from the metadata; Q_{cal}= Quantized and calibrated standard product pixel values (level 1 pixel value in DN). After radiance, the brightness temperature (BT) was calculated by (4) [15].

$$\mathrm{BT} = \frac{\mathrm{K_2}}{\mathrm{Ln}\left(\frac{\mathrm{K_1}}{\mathrm{L}_\lambda}\right) + 1} \qquad (4)$$

where: BT= brightness temperature (°K); L_λ= TOA spectral radiance; $\mathrm{K_1}$= calibration constant of first thermal line; $\mathrm{K_2}$ = calibration constant of second thermal line. Furthermore, the fractional vegetation cover (F_v) was calculated to estimate the fractional size of an area covered with vegetation by (5) [15].

$$F_v = \frac{(\mathrm{NDVI} - \mathrm{NDVI_{min}})}{(\mathrm{NDVI_{max}} - \mathrm{NDVI_{min}})} \qquad (5)$$

where: F_v = Fractional vegetation cover; $NDVI_{min}$= minimum vegetation index; $NDVI_{max}$= maximum vegetation index.

Then, calculate the emissivity by (6) [15].

$$\varepsilon = 0.004 \text{ x } F_v + 0.986 \quad (6)$$

where: 0.004 = average vegetation emissivity; 0.986 = emissivity of bare land. The land surface temperature (LST) is calculated by (7) [15].

$$LST = \left(\frac{BT}{1+W} \text{x} \frac{BT}{1+p} \text{x} \ln(\varepsilon)\right) - 273.15 \quad (7)$$

where: LST = Land surface temperature (°C); BT = Brightness temperature (°K); W = wavelength of emitted radiation (0.000115 m); ε = object emissivity; $p = \frac{hc}{s}$ (1.438 x 10^{-2} mK); *h* = Planck constant (6.26 x 10^{-34} Js); *c* = light velocity (2.998 x 10^{8} ms^{-1}); *s* = Stefan Boltzman constant (1.38 x 10^{-23} JK^{-1}). The correlation between the normalized difference built-up Index (NDBI) and the normalized difference vegetation index (NDVI) to land surface temperature (LST) was determined by linear correlation analysis. Urban Heat Island (UHI) was carried out using LSTs obtained from previous analysis. The UHI index is calculated using the following (8) and (9) [15].

$$UHI_{threshold} = \mu n + \sigma \frac{1}{2} \quad (8)$$

$$UHI_{index} = T_{mean} - UHI_{threshold} \quad (9)$$

Where: μ = average of LST; σ = standard deviation of LST; T_{mean} = the median value of the LST.

The land cover change was carried out using images of Band 1 – Band 7 (B1-B7), then proceeded with the band composite and determined an image training sample into five classifications. Following the research stages above, the study aims to determine how land cover changes, changes in building density and vegetation, and their relationship to surface temperatures. Based on land surface temperature (LST) results, the main objective of the study is to determine whether an Urban Heat Island (UHI) phenomenon exists in Pekanbaru City.

RESULTS AND DISCUSSION

Land cover changes

Figure 2 shows a map of land cover between 2018 and 2023. This study was classified into five classes: water body, palm plantation, built-up area, bare land, and vegetation, whereas the research about land cover changes in Sharqiyah was separated into four groups: vegetation, built-up, bare land, and water body [7]. The class grouping uses guided classification, a method that groups pixels based on the reflection value within the selected sample area.

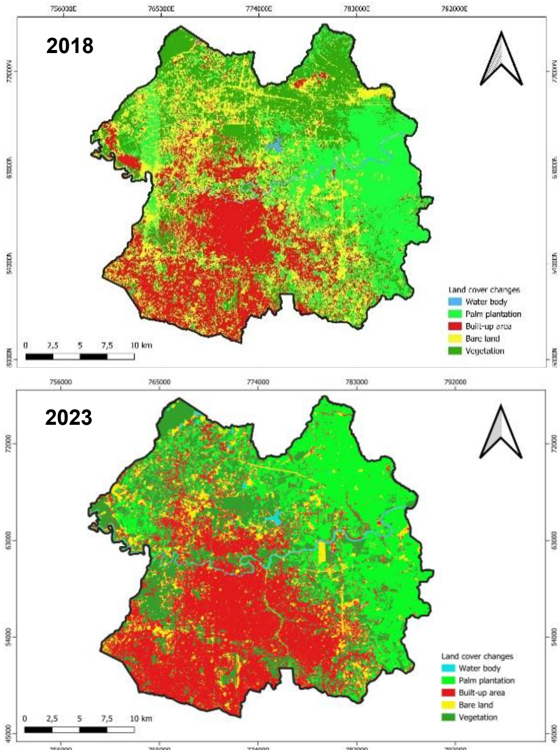

Figure 2. The map of land cover changes

A land cover change map can be created and the effects of urbanization evaluated using a variety of image classification techniques, such as unsupervised classification, Maximum Likelihood (ML), random tree, Support Vector Machine (SVM), and K-nearest neighbor [17]. The sample training was adjusted to Google Satellite. The land cover classification in this study uses the maximum likelihood algorithm.

Figure 3 shows the change in area as a function of size. In 2018, Palm plantations and built-up areas dominated land cover in the Pekanbaru City area, with palm plantations accounting for 26.67%, slightly larger than built-up areas. The land cover of palm plantations in 2018 was the widest compared to others. After the massive forest and land fires in 2015, many people planted palms to replace the forests. In 2023, built-up areas still dominate land cover, but their area has become much more prominent, namely 35.84% of Pekanbaru City's total area, compared to the palm area at 28.05%. Water bodies and vegetation have also increased, but bare land in 2023 is much less than in 2018. The areas of water bodies, palm, built land, and vegetation have increased, while the area of open land has decreased drastically. A significant change occurred in bare land: over 5 years, the area decreased by 8,308 ha, or 57%; in contrast, the built-up area increased by 5,860 ha, or 34%.

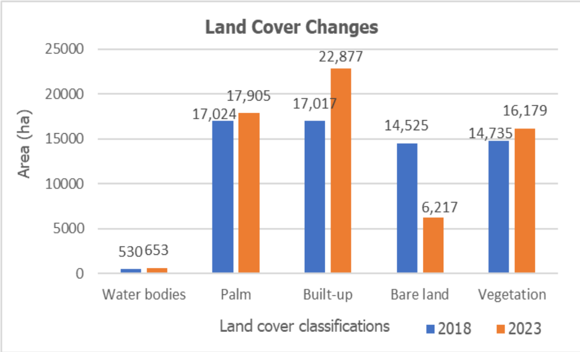

Figure 3. The area of land cover changes

This finding was similarly reported in Melbourne, where population growth and urban expansion caused a notable change in land use and land cover [18]

Normalized difference built-up index (NDBI)

To meet the needs of the settlement's inhabitants, land requirements become the most important aspect of the region or urban area's growth. The density of buildings in remote sensing was identified using the NDBI, which shows the appearance of the built-up area relative to other objects, as it is susceptible to built-up land [19]. The results of built-up density analysis provide a clear picture of land cover change and urban development in the region [19].

The maps of the normalized difference built-up index (NDBI) analysis are shown in Figure 4. There is a very significant difference in built-up distribution between 2018 and 2023. The built-up area in 2023 increased sharply, marked in black; by contrast, the yellow no-settlement areas decreased, following changes in land cover conditions. The large area of built-up distribution between 2018 and 2023 is shown in Figure 5.

Compared with 2018, the area of no settlement in 2023 is larger, as is the area of highly dense settlement. There is a depression in the areas with no settlement and highly dense settlement areas. The non-settlement class in 2023 decreased by about 2% compared to 2018, and the high-density settlement class dropped by about 71%. The rare settlement class was about 2,589 ha in 2023, an increase of around 54% from 2022, or 3,987 ha. It also happened that the dense settlement class was 68 ha, then became 81 ha in 2023. The dense settlement area rose by about 19%. This result is in line with the research [15].

When the 2023 NDBI is plotted in Google Earth with Google Satellite imagery and adjusted to Figure 1, the highly dense built-up areas are in Tuahmadani District, Binawidya District, Pekanbaru Kota District, Sukajadi District,

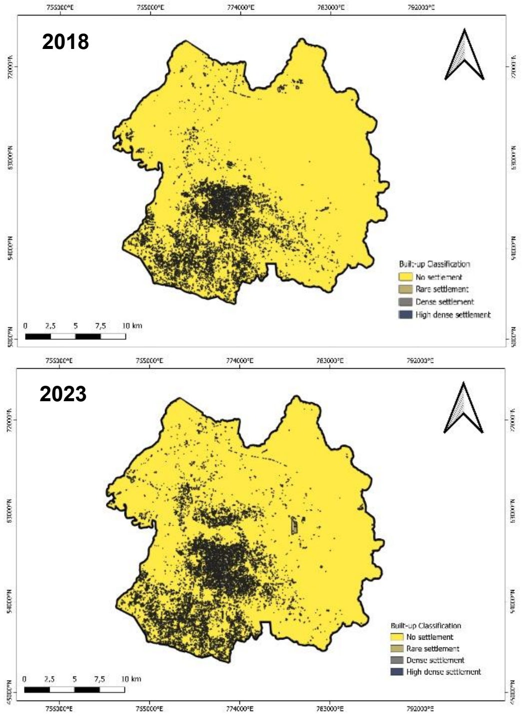

Figure 4. The map of the built-up distribution

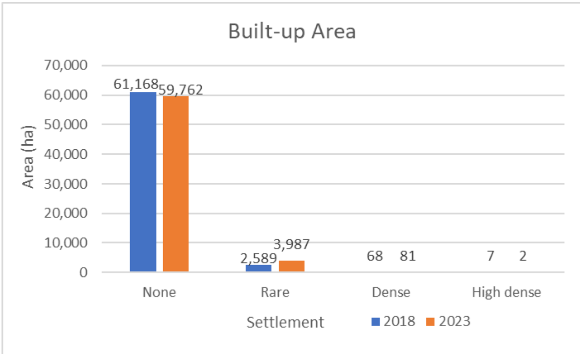

Figure 5. The large area of built-up distribution

Senapelan District, Sail District, and parts of Marpoyan Damai District and Bukit Raya District.

This area is densely populated, the center of government, and the center of activities of the Pekanbaru City population. The comparison data is shown in Figure 6.

Normalized difference vegetation index (NDVI)

The results of the vegetation density analysis illustrate the impact of urbanization and environmental change on vegetation in the study area [19]. The higher the level of vegetation class, the higher the vegetation density. On the other hand, if vegetation density is decreasing, it indicates that the land cover has very low vegetation or is not vegetated. Figure 7 shows the vegetation distributions between 2018 and 2023. The darker greenness means the higher vegetation.

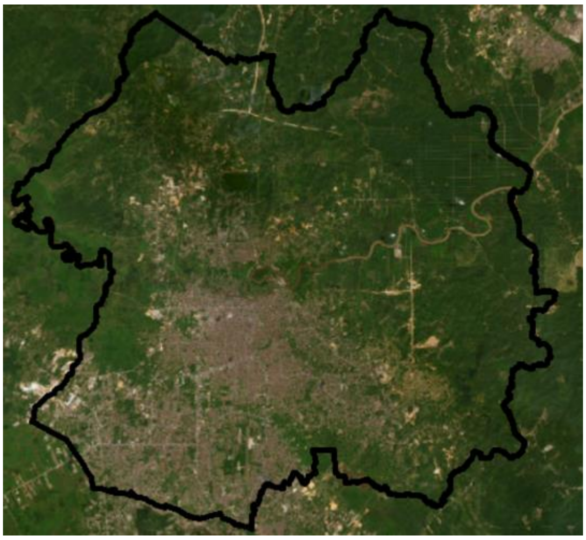

Figure 6. Built-up density in 2023 based on Google Earth

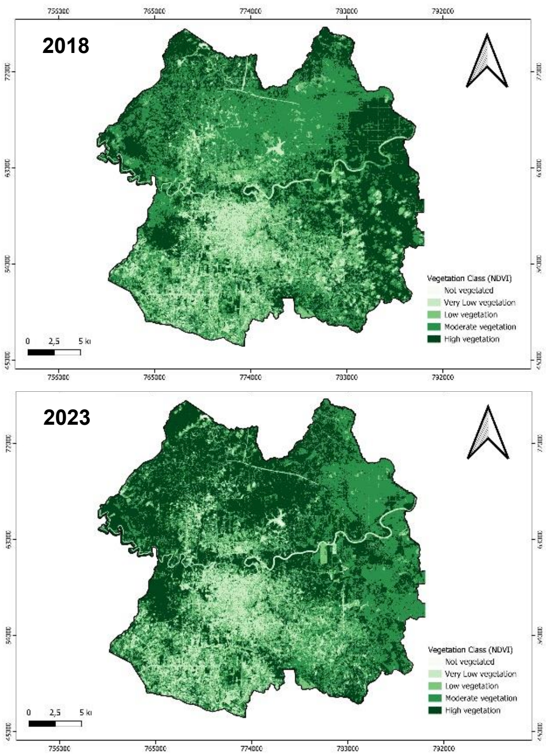

Figure 7. The map of vegetation distribution

The vegetation in Pekanbaru City in 2018 was dominated by dark green colors, found in the eastern, northwestern, and northern areas. It shows that the area is still overgrown with much vegetation. Some areas with a light green color indicate little scattered vegetation, with dominance around the city center. Compared to 2023, vegetation density in the east of Pekanbaru City decreased from high to moderate; in the north, it increased to high greenery.

Figure 8 shows the comparison of vegetation area. In 2023, the high vegetation class was 27,405 ha, up from 25% in 2018. However, the non-vegetated area also increased by 1.225% over 5 years; the high-vegetation class rose by 25%. On the contrary, the low- and moderate-vegetation class area declined by about 17%. Vegetation in Pekanbaru City comprises forests, mixed gardens, shrubs, and palm plantations. If it is associated with land use and land cover, in the city of Pekanbaru, there has been an increase in palm plantations, making palm the dominant vegetation.

Land surface temperature (LST)

Land surface temperature is the average surface temperature resulting from the reflection of an object recorded by satellite images at a particular time. The land surface temperature is influenced by numerous elements, including elevation, slope, water bodies, vegetation cover, and the degree of urban building [6]. The results of the land surface temperature analysis were used to characterize the influence of local conditions on the urban heat island, as shown in Figure 9.

Based on Figure 9, in 2018, the land surface temperature ranged from 20 to 36 °C. The red color describes areas with high temperatures in the southern and southwestern parts of the region, which are areas of high building density. The yellow and green colors depict areas with moderate temperatures scattered over most of the region. The blue color indicates lower temperatures, suggesting the presence of a water body or a relatively high level of vegetation. In 2023, land surface temperature analysis showed temperatures ranging from 22 to 34 °C. The minimum temperature in 2023 is higher than in 2018, but the maximum temperature is lower.

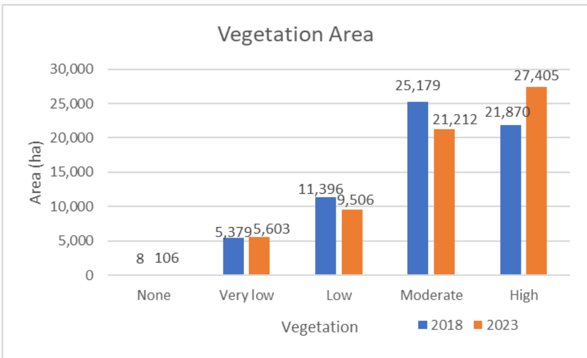

Figure 8. The large area of vegetation

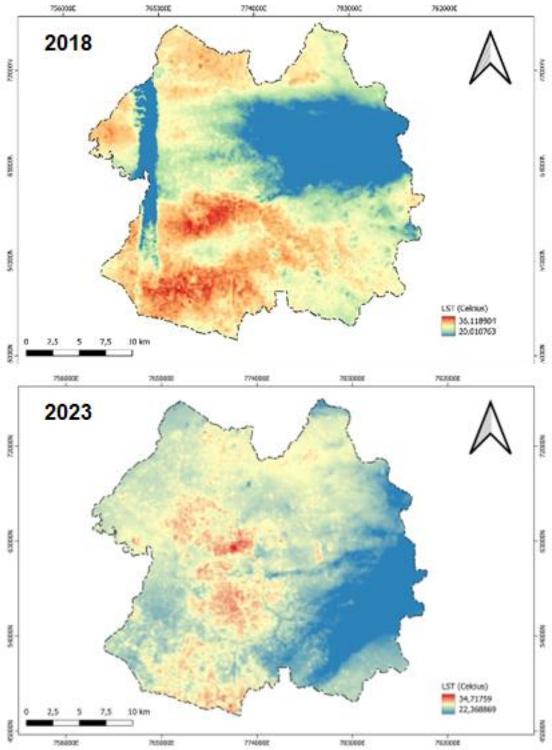

Figure 9. Distribution of land surface temperature (LST) in 2018 and 2023

In 2023, areas with higher temperatures are still visible. However, the distribution has changed slightly, with the area now appearing more concentrated in the city's center and some western parts of the region. The areas with moderate temperatures remain dominant, but the distribution has shifted compared to 2018. The area with low temperatures is more than in 2018, especially in the eastern and northeastern parts of the region. These conditions may indicate an increase in vegetation density or better land management. Vegetation density plays a very crucial role in increasing or decreasing soil surface temperature. Vegetation can minimize air temperature and retain sunlight above the canopy so that the temperature below the stand (ground surface temperature) is lower due to shade. It utilizes evapotranspiration to lower itself and its surroundings.

In 2023, the maximum temperature is lower than in 2018. This year, there has been a change in the distribution of high-class temperatures, most likely due to changes in land cover or differences in vegetation density classes. Based on data sourced from www.sipongi.menlhk.go.id, forest and land fires in Riau in 2015 were the largest, with a burned area of 183,808.59 ha. In 2016, forest and land fires occurred again, affecting a burned area of 85,219.51 ha. These two forest and land fires are likely among the factors contributing to the higher land surface temperatures in Riau, one of which occurred in Pekanbaru City in 2018. After the incident, the dominant land was planted with oil palm. Palm plantations are among the leading causes of deforestation, but their presence has slightly reduced land surface temperatures in Pekanbaru City in 2023.

The analysis of a large area based on land surface temperature (LST) is shown in Figure 10. In 2018, the area recorded at 20-25°C was 20,539 ha; in 2023, it decreased by about 36%. The area recorded at 25-30°C was 28,689 ha in 2018, but rose sharply by around 69% to 48,416 ha in 2023. In 2018, the area with temperatures above 30°C was 14,604 ha, which decreased by about 84% to 2,300 ha in 2023. These changes indicate a shift in ground surface temperatures during that period, with more areas switching to warmer temperatures (25-30°C) in 2023.

Correlation of land surface temperature (LST), normalized difference built-up index (NDBI), and normalized difference vegetation index (NDVI)

The correlation between land surface temperature (LST) and the normalized difference built-up index (NDBI) and the normalized difference vegetation index (NDVI) is used to analyze the impact of the existence of built-up and vegetation density areas on urban heat island (UHI), because UHI can be used as an ecological evaluation index of an urban area [15]. The correlation between LST and NDBI is shown in Figure 11.

Figure 11: In 2018, the built-up index points are concentrated between -0.20 and -0.10, and the land surface temperature between 25°C and 30 °C. Several points indicate a higher land surface temperature, close to 35°C. The linear equation of LST versus NDBI in 2018 is given by (10), with a determination coefficient (R^2) of 0.1878 (18.78%).

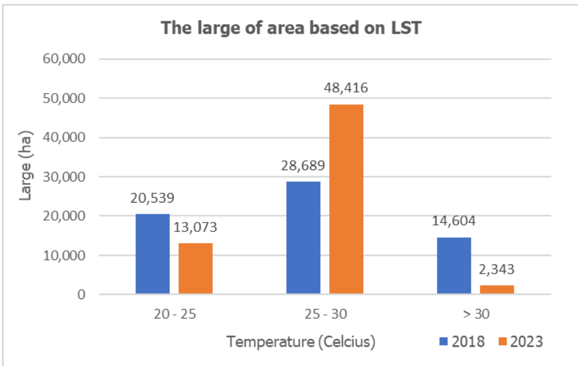

Figure 10. The area of land surface temperature

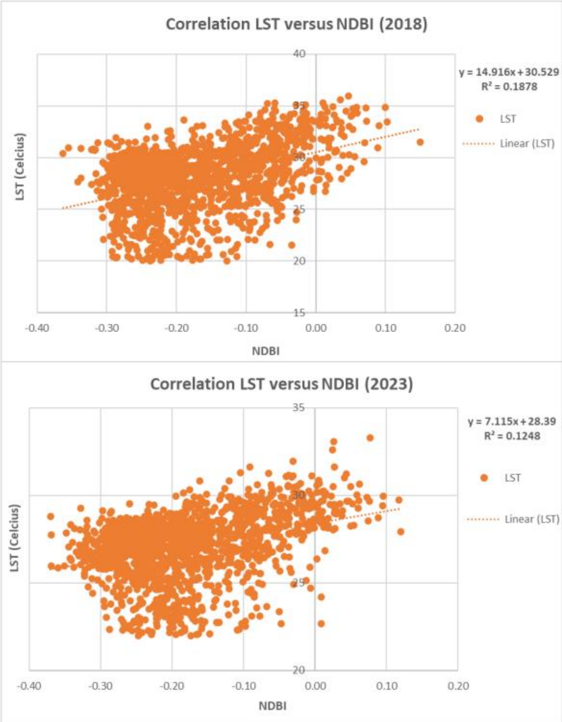

Figure 11. Land surface temperature (LST) versus normalized difference built-up index (NDBI)

$$y = 14.916x + 30.529 \quad (10)$$

In 2023, most of the built-up index points are concentrated between -0.20 and 0.10, and the land surface temperature ranges from 25°C to 30 °C. The linear equation of LST versus NDBI in 2023 is given by (11) below, with a determination coefficient (R^2) of 0.1248 (12.48%).

$$y = 7.115x + 28.39 \quad (11)$$

In both 2018 and 2023, the land surface temperature and built-up density appear to be directly proportional, as indicated by a positive value in front of the regression coefficient. The correlation between land surface temperature and the built-up density index is linear: as the built-up density index increases, land surface temperature tends to increase [6]. Referring to (11), an increase in the built-up index value by one digit will increase the land surface temperature value by 7.115°C, which, if calculated, will make the land surface temperature value 35.505°C in 2023.

Alternatively, if it is projected to increase the built-up Index by 0.25, it will increase the land surface temperature by 1.78 °C, bringing it to 30.17 °C in 2023. Areas with higher building density (higher NDBI) tend to have higher land surface temperatures. The coefficients of the two linear equations are significant and show a close relationship and influence between land surface temperature and built-up density results [6, 7, 16]. In both 2018 and 2023, the determination coefficients were close to 0. The value of the determination coefficient indicates the extent to which the contribution of the free variable in the regression model can explain the variation of its bound variable. This value indicates that the built-up density variable explains the land surface temperature variable very poorly, despite a positive correlation between them. It was explained that if the value is close to 1 (one) and away from 0 (zero), it means that the independent variables can provide all the information needed to predict the dependent variables.

When comparing 2018 and 2023, the built-up density variable had a greater influence on land surface temperature in 2018. The denser the built-up area, the higher the land surface temperature, due to the heat-isolating effect of buildings and highways. Additionally, because of the dense, tall, poorly developed land and water under the same solar radiation circumstances, surface temperatures are high throughout the built-up area. Additionally, due to the tall, dense, and inadequately ventilated artificial structures, surface temperatures are high throughout the built-up region. Large open areas on unused land absorb heat rapidly, resulting in high surface temperatures [20][21]. The land surface temperatures of bare land and built-up areas are higher than those of other land use types, according to earlier research [22][23].

Meanwhile, the correlation between land surface temperature and vegetation index in Pekanbaru City is shown in Figure 12.

In 2018, the plot shows most points concentrated around vegetation index values of 0.30 to 0.49, and land surface temperatures range from 22°C to near 35°C. The linear equation relating land surface temperature and vegetation index is given by (12), with a determination coefficient (R^2) of 0.0589 (5.89%).

$$y = -7.6912x + 30.506 \quad (12)$$

The plot of 2023, a scatter plot, shows that most vegetation index points are concentrated around 0.30 to 0.52, and that the land surface temperature ranges from 22°C to close to 35°C. The linear equation for 2023 is given in equation (13) below, with a coefficient of determination (R^2) of 0.0521, or 5.21%.

$$y = -3.7906x + 28.446 \quad (13)$$

In both 2018 and 2023, land surface temperature shows an inverse correlation with the vegetation index, as indicated by a negative value before the regression coefficient.

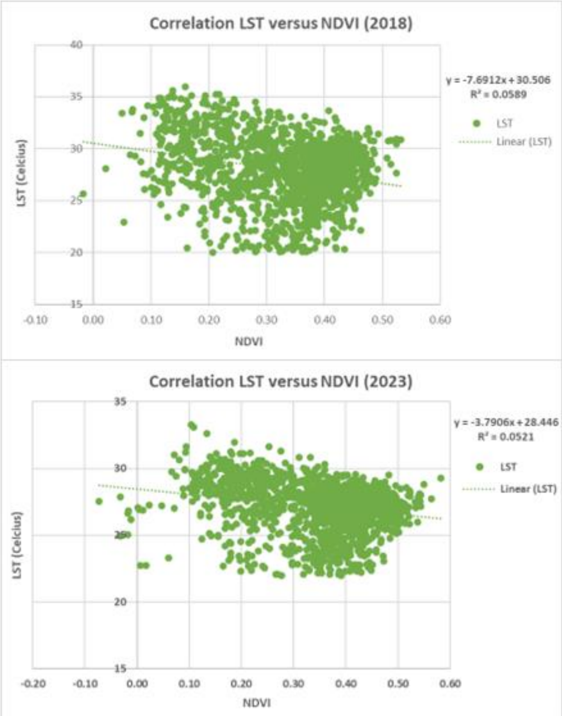

Figure 12. Land surface temperature (LST) versus normalized difference vegetation index (NDVI)

From the two figures, the linear regression line shows that as the vegetation index increases, the land surface temperature tends to decrease. These results are following [6, 7, 16]. If the land surface temperature is high, the vegetation index value is low, and vice versa. Areas with higher vegetation density (higher NDVI) tend to have lower land surface temperatures [6][7]. Referring to (13), increasing the vegetation index value by one digit will decrease the land surface temperature value by 3.7906°C, which, if calculated, will make the land surface temperature value drop to 32.24°C in 2023. If projected to increase the vegetation index by 0.25, it will raise the land surface temperature by 0.95°C, bringing it to 29.39°C in 2023. When compared, 2023 shows a stronger correlation than 2018. In 2018, vegetation availability in Pekanbaru was lower than in 2023. Vegetation can act as a heat filter, reducing surface temperatures by absorbing heat and releasing cool air. With lower vegetation cover, the surface temperature in Pekanbaru City in 2018 was higher than in 2023. For this reason, it is necessary to propagate vegetation under its environmental conditions to reduce the value of land surface temperature.

The phenomenon of Urban Heat Island (UHI) in Pekanbaru City

The land surface temperature results are further processed to obtain the urban heat island value, as shown in Table 3.

The UHI's threshold value in 2018 was higher than in 2023, which aligns with the land surface temperature value in both years. Negative UHI index values of -3.12 in 2018 and -1.57 in 2023 indicate an urban heat island effect. Based on the UHI's threshold, the urban heat island phenomenon occurs in Pekanbaru City. The threshold obtained for the 2018 UHI phenomenon is 28.65°C, while the UHI's threshold value in 2023 is 27.95°C. If in 2018 the ground surface temperature exceeds 28.65°C and in 2023 it exceeds 27.95°C, this indicates the presence of an urban heat island in the Pekanbaru City area. It explained that an urban heat island forms when the surface that is supposed to absorb sunlight reflects more of it into the air, trapping it within the urban area.

The surface reflects more heat due to the conversion of land from vegetation to asphalt, concrete, multistorey buildings, and other infrastructure used to accommodate the needs of an increasing number of people. Urbanization causes land surface temperatures in urban regions to be higher than those in surrounding non-urban areas, a phenomenon known as the urban heat island (UHI) [24]. It commonly happens in the province's capital or the city's center. The development of cities with benthic and specific patterns is related to the spatial pattern of the urban heat island, which is shaped by the dominance of the city center and can lower surface temperatures. At the same time, the more complex the area's shape and the wider the gap between buildings, the higher the temperature.

Based on the results in Figure 13, the blue box on the map highlights the urban area of Pekanbaru City, a large, still-developing area with various ongoing developments and dense waterproof surfaces.

Table 3. Urban heat island (UHI) threshold and Index

Variable	Year	
	2018	2023
Tmax (°C)	36.12	34.72
Tmin (°C)	20.01	22.37
μ	25.54	26.38
σ	6.23	3.13
UHI threshold	28.65	27.95
UHI index	-3.12	-1.57

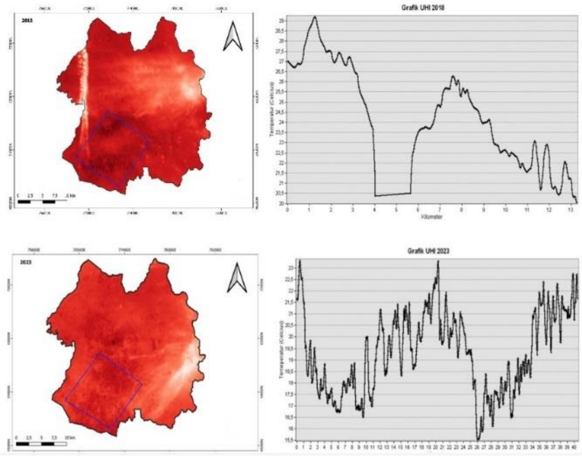
Figure 13. Urban heat island phenomenon in Pekanbaru City in 2018 and 2023

Urban areas are likely to experience urban heat islands more than the surrounding rural areas. Transect analysis determined how the urban heat island affects locations from urban centers to rural areas. The results of the transect analysis are shown in a graph with the x-axis representing distance (kilometers) and the y-axis representing temperature (Celsius). The analysis of the rural urban transect in 2018 shows that the distance very close to the city, about 1-2 km from the city, has the highest temperature; the temperature drops drastically at 3-6 km from the city center, and then the farther away from the city center, the temperature varies.

As in 2018, in 2023, the closest distance from the city center shows the highest temperature, with a transect distance of 20 km. The lowest temperature at the transect distance is around 25-26 km from the city center. The farther away from the city center, the lower the temperature. However, in 2023, the temperature variation along the transect is greater than in 2018, but the temperature distribution is lower. Several factors, such as density level, topographic conditions, wind patterns, land use, and humidity, can cause temperature changes along the variable transect. North-South transect analysis shows that the South-Southwest area has a higher temperature distribution than the West-East transect.

Several studies in other cities have shown that the effects of the urban heat island are more pronounced in the southern part of the city than in the northern part, due to wind patterns that tend to blow from the north, bringing cold air from the countryside into the city. The results of the previous analysis show that the development of Pekanbaru City is more inclined to the South, characterized by a high level of built-up land and a low level of vegetation in the Southern sector, compared to other parts.

According to the analysis, the distribution of the urban heat island tends to occur in residential areas or areas with land cover. The vegetation conditions in the area are rare, so the evapotranspiration process needs to be improved. The study's results also show that the distributions of urban heat islands are influenced by the conditions and activities of land cover types, especially in built-up land cover. The growth and development of this land cover are influenced by the city's centers of activity in Pekanbaru. The center of the activity will encourage diverse land uses around the city's central points. The urban heat island phenomenon is also greatly influenced by local wind conditions [25]. Urbanization affects local winds through urban heat island and surface roughness enhancement [4] [26].

As the population and urban areas grow, the intensity of the urban heat island will likewise rise. The increase in population, directly and indirectly, will affect the rising local air temperature. Emissions from the human body temperature have a direct impact. However, human activities, such as driving more vehicles that emit greenhouse gases and using household items, have an indirect effect. Numerous factors, such as local climate, socioeconomic conditions, urban scale, and urban form, contribute to the urban heat island [21].

To reduce the effects of the urban heat island, several strategies can be implemented in the city of Pekanbaru, for example, by increasing green open spaces and water bodies, using environmentally friendly construction materials, optimizing urban design with the concept of green infrastructure, and encouraging sustainable transportation. Increased vegetation cover and green infrastructure promote evapotranspiration cooling, while cool roofs and pavements reflect solar radiation, reducing solar absorption [27][28]. In addition, law enforcement against violations of regulations that cause environmental damage must be more stringent, and public awareness of the effects of urban heat islands must be enhanced to encourage participation in mitigation efforts and improve city quality. However, employing effective methods for analyzing land cover changes and urban heat islands can lead to a better understanding and mitigation of long-term environmental issues. Such approaches can inform policy decisions and urban planning aimed at addressing sustainability challenges, improving the quality of life in urban areas, and reducing negative impacts associated with climate change and urbanization.

CONCLUSION

This study concludes that over 5 years (2018 – 2023), land cover in the city of Pekanbaru changed, with water bodies increasing by 23%, palm plantations increasing by 5%, and built-up land increasing by 34%. Vegetation increased by 10%, while the area of bare land decreased by 57%. In addition, there are significant changes in building density and vegetation. The correlation between LST and NDBI is positive; by contrast, LST is negatively correlated with NDVI in Pekanbaru City. There were Urban Heat Island (UHI) phenomena in Pekanbaru in 2018 and 2023, characterized by surface temperatures exceeding the UHI threshold. In 2018, the UHI threshold was 28.65°C, while in 2023 it was 27.95°C, indicating that the UHI thresholds in both years exceeded the surface temperature, indicating the presence of urban heat islands in the Pekanbaru City area. However, it can generally be inferred that integrating various methodologies can enhance the robustness of future research by providing a multi-aspect approach to analyzing issues such as land cover changes and urban heat islands. Collaboration between disciplines and the application of advanced analytical tools can also yield more comprehensive insights. Nevertheless, in general terms, the use of reliable techniques, including the analysis of urban heat islands and the maximum likelihood algorithm for land cover classification, provides an essential framework for understanding environmental change. The results of this study can serve as a basis for further research, guiding more thorough studies and influencing environmental management and urban planning strategies.

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