Assessing the impact of land cover changes on land surface temperature and the relation to urban heat island in Makassar City, South Sulawesi

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Abstract. Makassar City, the capital of South Sulawesi Province, is the largest metropolitan city in the eastern part of Indonesia, with a population development rate of 1.19% in 2019. An increase in population impacts city development and results in land use and land cover changes. Changes in land use and land cover pattern bring impact to Land Surface Temperature (LST). This study examines land cover's influence on land surface temperature in Makassar City using multi-temporal satellite data. Land cover and LST data were extracted using Landsat 7 and Landsat 8 over the period of 1999, 2009, and 2019. The result shows that the highest increase in land cover changed was a built-up area of 13.1%, and vegetation decreased by 8.6%. The change in average LST value in the last 20 years was 0.39°C with the highest LST distribution areas was in 30-32°C and 32-34°C classes. The result of LST analysis in 2019 shows that the Urban Heat Island phenomenon has occurred in Makassar in the downtown area and several areas with the densely built-up area. With an overview of the UHI phenomenon in Makassar, the government is expected to raise public awareness of this phenomenon so that preventive actions can be taken, so the effects of UHI do not spread more widely.

Keywords: GIS, land surface temperature, urban heat island

1. Introduction
Makassar City, the capital of South Sulawesi Province, is the largest metropolitan city in the eastern part of Indonesia, with a population development rate of 1.19% in 2019 [1]. An increase in population in urban areas has an impact on city development by modifying the biological and physical surface characteristics and can lead to climate change, land degradation, and changes in biological diversity and ecosystem services, and this development impact associated with land use and land cover changes [2]. Urban development in Makassar city results in a land conversion from green open spaces and open fields to build-up areas to fulfil urban communities' needs.

Transformation in land use and land cover was an essential driving factor for the Land Surface Temperature (LST) increase in the city [3]. The uneven and centralized development in the downtown areas in Makassar City has a possibility to bring adverse impact like Urban Heat Island (UHI) phenomenon. Investigating the spatial distribution of LST is essential to understanding the progression of land use and land cover in the city and its relation and shows the spatial pattern of UHI [4] so that prevention can be done and the UHI phenomenon doesn't spread wider in urban areas.
This study examines the influence of land cover changes on land surface temperature in Makassar City by using multi-temporal satellite data. Land cover and Land Surface Temperature data are extracted using Landsat 7 ETM+ and Landsat 8 OLI over the period of 1999, 2009, and 2019. The year’s selection in this study was based on the latest data, namely 2019, and was pulled back for 20 years with a time interval of 10 years. This study’s results are expected to be the basis of determining policies to prevent or decrease the phenomenon of urban heat island that occurs in Makassar City.

2. Data and Methods

Three main steps were taken to assess the influence of land cover changes on LST in Makassar City. First of all, classifying land cover maps of Makassar City in three periods of time in 1999, 2009, and 2019. Second, identifying spatial distribution LST of Makassar City also in three time periods. Third, assessing the impact of land cover changes on LST in Makassar City. To classifying and identifying the land cover and LST of Makassar. Primary data used was Digital Satellite Landsat 7 ETM+ and Landsat 8 OLI path 114-row 64 from United States Geological Survey (USGS) website. The Landsat 7 satellite images were acquisition on 20 September 1999 and 17 October 2009, and Landsat 8 satellite image was acquisition on 19 September 2019 when the season is the dry and relatively clear atmospheric condition under 30% cloud cover. Makassar City administrative boundary as the study area was obtained from the Development Planning Agency (BAPPEDA) of Makassar City.

2.1. Land cover map classification

The land cover analysis was carried out using ERDAS Imagine 2014 with a supervised classification method. To classify land cover classes, an image classification sub-menu was used with the maximum likelihood classification. The first step of this analysis was layer stack by combining three bands to make a natural colour; in this study, bands 4, 3, and 2 were combined to get the results. The next step is pan sharpening using haze reduction to sharpen the objects' showing in visual analysis. Then cut the study area based on the administrative boundary map of Makassar City using a subset. The next step was to create a training sample area in polygon shape in each class that will be classified. Training sample areas should be spread and evenly distributed to each classification class. The five types of land cover identified are (1) cloud, (2) build-up areas (commercial buildings, office, settlements, etc.), (3) water body (river and lake), (4) bare ground, and (5) vegetation (forest, green open spaces, and land that has sparse, medium, or high densities vegetation). After that, the accuracy test is carried out using a reference point generated by a random sample point with the final result accuracy of not less than 75%.

2.2. Land surface temperature map distribution

To analyze LST, the converted thermal image data from satellite images were used. The first step is to define the subset of the study area. Second, converting the Digital Number into Spectral Radiance ($L_\lambda$). In Landsat 7, ETM+ band six is used, and in Landsat 8 OLI, it is used band 10 and 11 converted from raw image to Top of Atmospheric (ToA) spectral radiance [5]. The equation to be used is as follows:

$$L_\lambda = \frac{L_{\text{max}} - L_{\text{min}}}{Q_{\text{CAL}_{\text{max}} - Q_{\text{CAL}_{\text{min}}}}} \times (Q_{\text{CAL}} - Q_{\text{CAL}_{\text{min}}}) + L_{\text{min}}$$

Where: $L_\lambda$ is Top of Atmospheric Spectral Radiance (W/m².sr.µm); $L_{\text{min}}$ is spectral radiance scaled to QCALMIN (W/m².sr.µm); $L_{\text{max}}$ is spectral radiance scaled to QCALMAX (W/m².sr.µm); $Q_{\text{CAL}_{\text{min}}}$ is a minimum quantized calibrated pixel value in DN = 1;
QCal_{max} is a maximum quantized calibrated pixel value in DN = 255, and QCal is quantized calibrated pixel value in DN.

Third, Thermal band was taken to estimate Brightness Temperature (BT) in Kelvin by converting spectral radiance to BT for every thermal band in Landsat 7 and Landsat 8 [5] by using the following formula:

\[ BT_n = \frac{K2}{\ln\left(\frac{K1}{L_{\lambda}} + 1\right)} \]

Where: BT is ToA brightness temperature (°K); \( L_{\lambda} \) is ToA spectral radiance (W/m².sr.µm); \( K1 \) is Band-specific thermal conversion constant from the metadata, and \( K2 \) is Band-specific thermal conversion constant from the metadata.

And then, for Landsat 8, the combination of BT band ten and band 11 generates mean with the following formula:

\[ BT = \frac{BT_{10} + BT_{11}}{2} \]

Furthermore, to convert BT to LST, it’s important to calculate land surface emissivity (\( e \)) value. To get \( e \) value, Sobrino and Raissouni proposed a methodology by using a normalized difference vegetation index (NDVI) estimation algorithm [6]. To estimate the value of NDVI using the near-infrared band and red band, with the following formula:

\[ NDVI = \frac{(NIR - RED)}{(NIR + RED)} \]

Where: Near-infrared (NIR) represented by band 4 in Landsat 7 and band 5 in Landsat 8; and Red represented by band 3 in Landsat 7 and band 4 in Landsat 8.

The proportion of Vegetation (Pv) can be calculated by using this formula:

\[ Pv = \left[ \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right]^2 \]

After getting the Pv value, the land surface emissivity (\( e \)) value is then calculated using the following formula:

\[ e = m \cdot Pv + n \]

Where: \( m = 0.004 \), \( Pv \) is proportion of vegetation, and \( n = 0.986 \)

The final step to estimate the LST, using the following formula [7] and the temperature acquired in Kelvin, was converted to a Celsius scale by subtracting 273.15.

\[ LST = \frac{BT}{[1 + \left(\frac{\lambda \cdot BT}{a} \right) \ln(e)]} \]

Where: LST is Land Surface Temperature; BT is ToA brightness temperature (°K); \( \lambda \) is wavelength of emitted radiance (Landsat 7 band 6 = 11.45 and Landsat 8 band 10 = 10.8; band 11 = 12); \( a = 14388 \) µmK is constant obtained from \( \frac{hc}{\sigma} \) (where \( h \) is the Plank’s constant = 6.626*10^{-34} Js; \( c \) is the velocity of light = 2.998*10^{8} ms^{-1}; and \( \sigma \) is Boltzmann constant = 1.38*10^{-23} J K^{-1}); and \( e \) is land surface emissivity.
3. Result and Discussion

3.1. Land cover changes

The results of a land cover classification in Makassar can be seen in Figure 1. Figure 1a shows that in 1999 there were many built-up areas and bare grounds cover, that is 6,040 Ha (34.4%) and 5,187 Ha (29.6%), respectively. Meanwhile, vegetation area covering 4,984.4 Ha (28.4%) of the total area of Makassar, and water body 854.2 Ha (4.9%), which is Jeneberang watershed and Tallo river. The presence of clouds in Landsat satellite images requires the clouds cover class in the land cover classification because Indonesia has no seasonal cloud-free moment offering the opportunity to capture cloud-free Landsat satellite image [8].

Figure 1 Land cover map of Makassar City in (a) 1999, (b) 2009, and (c) 2019

In 2009 (Figure 1b), bare grounds in the north of Makassar have begun to decrease and turn into built-up and vegetation. Still, in the downtown area, the built-up areas have increased and become 8540.3 Ha, or 48.9% of the total area of Makassar. Vegetation has decreased to 24.8%, while the water bodies have not experienced drastic changes. Changes in water bodies can be due to the conversion of water bodies into the built-up area or vegetation on river boundaries detected as vegetated land cover. In the 1999 to 2009 period, built-up areas increased by 14.5% and mostly in the north and downtown area. Bare grounds, vegetation, and water bodies have decreased by 12%, 3.6%, and 0.2%, respectively.

In 2019, Figure 1c clearly showed that the built-up areas in the downtown area have increased; on the contrary, vegetation has decreased. The total Built-up area is 47.5%, water bodies 4%, bare ground 23.7%, and vegetation covering 19.8% of the total area in Makassar. Also, cloud cover has 5% of the total study area.
Based on land cover changes in Table 1, from 2009 to 2019, built-up areas, vegetation, and water bodies have decreased, while the cover of clouds and bare grounds has increased. Although the built-up areas in the downtown area increase, total built-up areas in 2019 are not consistent increase because of the increase and existence of clouds cover. So the built-up areas decreased by 1.4% in the Landsat satellite images because the actual land cover under clouds couldn’t be detected accurately. Meanwhile, the increase in bare grounds by 6.1% could come from the land cover of vegetation, which turned into bare grounds or dry vegetation due to drought and then classified as bare grounds.

| Land Cover Classifications | Areas | Land Cover Changes |
|----------------------------|-------|-------------------|
| Cloud                      | 486.7 | +220.6           |
| Water body                 | 854.2 | -43.8            |
| Built-up area              | 6040.0| +2500.3          |
| Bare ground                | 5187.2| -2112.2          |
| Vegetation                 | 4984.4| -646.8           |

In 20 years, land cover changes that occurred in Makassar based on the results of land cover classification analysis, built-up areas have increased by 13.1%, and water bodies, bare grounds, and vegetation each have decreased by 0.9%, 5.9%, and 8.6%. After obtaining the results of the land cover map classification, the accuracy-test was carried out. The accuracy-test results with an overall accuracy of the land cover classification map in 1999 it was 78.81%, for 2009 it was 77.48%, and for 2019 it was 81.46%.

3.2. Land surface temperature

Based on the analysis result of the Land Surface Temperature distribution of Makassar City in three periods of time, Table 2 shows the average increased temperature from 1999 to 2019. Still, in 2009 it tends to be lower than in 1999 and 2019. The lower mean temperature in 2009 is expected to occur because the Landsat satellite image’s acquisition date has entered the beginning of the rainy season, so the recorded temperature is lower than the others. The LST is likewise influenced by the cloud cover pattern from Landsat satellite images [9] so that the presence of cloud cover affects the average value of LST in 2009. Changes in the average value of LST in 20 years in Makassar is 0.39°C.

| Land Surface Temperature | 1999 (°C) | 2009 (°C) | 2019 (°C) |
|--------------------------|-----------|-----------|-----------|
| Minimum                  | 20.64     | 14.93     | 15.93     |
| Maximum                  | 38.79     | 36.82     | 39.92     |
| Mean                     | 30.11     | 29.10     | 30.50     |

Land surface temperature distribution in Makassar can be seen in Figure 2. Table 3 shows the classifications of LST distribution classes and contains the area per class changes in 11 distribution classes. Distribution of LST in 1999 shows that the LST classes that have the most extensive area are in the range of 30-32°C with an area of 5,394.60 Ha and the sub-district that have the highest LST are in Biringkanaya and sub-districts located in downtown areas such as Bontoala, Ujung Tanah, Wajo and Mariso with temperature ranges in the 32-
In 2009, the lowest LST was around 14-22°C, classified as clouds land cover, and the highest LST was in the class >34°C. The LST class had the most area still in the 30-32°C range increased by 578.97 Ha from 1999, while LST class 32-34°C and >34°C has decreased by 1,375.47 Ha dan 885.69 Ha respectively. Meanwhile, the 2019 LST analysis (Figure 2c) shows temperatures in the range of 14-22°C, classified as clouds land cover on the land cover classification map (Figure 1c). Distribution of LST classes shows, LST in classes 30-32°C, 32-34°C, and >34°C respectively have increased to 3,402.45 Ha, 2,717.64 dan 540.72 Ha since 2009; while the distribution area of LST classes under 30°C was decreased.

**Table 3** Land surface temperature classes distribution of Makassar in 1999, 2009 and 2019

| Land Surface Temperature (°C) | Area (Ha) | Changes in Area (Ha) |
|------------------------------|-----------|----------------------|
|                              | 1999      | 2009 | 2019 | 2009-2019 | 1999-2019 |
| 14-16                        | 0.00      | 33.75 | 0.00 | +33.75     | -33.75     | +0.00     |
| 16-18                        | 0.00      | 67.14 | 98.64 | +67.14    | +31.50     | +98.64    |
| 18-20                        | 0.00      | 78.84 | 101.79 | +78.84   | +22.95     | +101.79   |
| 20-22                        | 0.99      | 75.24 | 88.02 | +74.25     | +12.78     | +87.03    |

**Figure 2** Land surface temperature (°C) of Makassar City in (a) 1999, (b) 2009, and (c) 2019

34°C and >34°C classes. Simultaneously, the lowest temperature is in the 22-24°C range covering three sub-districts such as Tamalanrea, Tallo dan Panakukang.
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| Land Surface Temperature (°C) | Area (Ha) | Changes in Area (Ha) |
|------------------------------|----------|---------------------|
|                              | 1999     | 2009    | 2019    | 1999-2009 | 2009-2019 | 1999-2019 |
| 22-24                        | 39.96    | 446.76  | 107.46  | +406.80    | -339.30    | +67.50     |
| 24-26                        | 1671.03  | 2207.25 | 596.79  | +536.22    | -1610.46   | -1074.24   |
| 26-28                        | 2215.17  | 2275.20 | 1817.01 | +60.03     | -458.19    | -398.16    |
| 28-30                        | 3811.14  | 4236.30 | 2982.0  | +425.16    | -1254.24   | -829.08    |
| 30-32                        | 5394.60  | 5973.57 | 9376.02 | +578.97    | +3402.45   | +3981.42   |
| 32-34                        | 3382.90  | 2007.4  | 4725.09 | -1375.47   | +2717.64   | +1342.17   |
| >34                          | 954.72   | 69.03   | 609.75  | -885.69    | +540.72    | -344.97    |

Within 20 years, the area of LST distribution in Makassar has experienced a relatively large increase, specifically in LST 30-32°C and 32-34°C classes, respectively experiencing an increase in the area of 3.98142 Ha dan 1.34217 Ha. Meanwhile, LST >34°C decreased by 344.97 Ha, and LST classes below the 30°C also experienced a wide decrease in area.

Based on the LST distribution analysis in Makassar in 2019, it can be seen that in the downtown area and several areas with dense built-up areas forming a pattern like an island with the highest temperature than the surrounding area. Xiong et al. found that built-up areas and thickly populated areas were firmly related to high-temperature anomalies [10].

With the LST analysis results, it can be illustrated that the UHI phenomenon has occurred in Makassar, so prevention action needs to be taking, so its effect doesn't spread more widely. The UHI impact in urban areas can be mitigated by making changes in construction structure, material determination, and land use ratio in urban areas to increase the albedo value and cool the surrounding environment [11]. To make a better proportion of land use in urban areas to reduce UHI effects, the use of greens, trees, and vegetation is significantly useful to decrease the UHI effects by evaporation and shade mechanisms, which can ultimately cool the surroundings [12].

3.3. Relation between land cover changes, land surface temperature, and urban heat island

According to land cover results and land surface temperature analysis from Landsat satellite images, temperature changes based on the land cover classes were obtained (Table 4). In the last 20 years, there has been an increase in LST in Makassar on four land covers: bare grounds, built-up areas, vegetation, and water bodies. The highest increase occurred in water bodies by 1.477°C, then in vegetations increased by 0.984°C, in bare grounds also increased by 0.242°C and in built-up areas was 0.023°C.

Although the highest temperature changes occurred in water bodies and vegetations, the average temperature of both land cover was lowest in three years in this study. Meanwhile, the built-up areas and bare grounds have a relatively high temperature than the other two land covers. These results are consistent with the research results of Adulkongkaew et al. and Feizizadeh et al. that bare grounds and built-up areas had a positive correlation pattern with LST and overall have higher temperatures than water bodies and vegetation areas [13,14].
Table 4 Average land surface temperature changes based on land cover classes

| Land cover classes | LST Average per Year (°C) | LST Changes (°C) |
|-------------------|---------------------------|------------------|
|                   | 1999 | 2009 | 2019 | 1999-2009 | 2009-2019 | 1999-2019 |
| Cloud             | 30.444 | 23.608 | 25.546 | -6.836  | +1.938  | -4.898    |
| Water body        | 25.393 | 25.141 | 26.869 | -0.252  | +1.728  | +1.477    |
| Build-up area     | 31.452 | 30.393 | 31.475 | -1.059  | +1.081  | +0.023    |
| Bare ground       | 31.562 | 31.059 | 31.803 | -0.503  | +0.745  | +0.242    |
| Vegetation        | 27.774 | 26.981 | 28.758 | -0.793  | +1.777  | +0.984    |

Changes in vegetation land cover by 8.6% and an increase in built-up area by 13.1% resulted in an increase in the average LST in Makassar for 20 years by 0.39°C. The significant difference in LST occurred in different land cover types. Built-up area positively affects LST because the built-up area holds the maximum LST compared to the other land covers [15]. Moreover, a decrease in vegetation land cover also increased LST distribution in the 30-34°C range and decreased LST area over the 24-30°C range. Vegetation was the way to bring down the LST, and the more vegetated land cover, the lower LST will be [13].

Urban heat island phenomenon in Makassar City in 2019 can be seen in Figure 2c. From this figure shows isotherm lines form the heat islands in the city. Isotherm lines can be seen in several subdistricts in downtown areas such as Makassar, Bontoala, and Panakkukang. This phenomenon mostly found in areas with a high density of built-up areas when comparing to Figure 1c. Urban heat island is dominant in areas with high building density due to the structures and materials used, such as asphalt, concrete, cement, etc. Those materials increase solar energy absorption and increase the temperature in urban areas and then affect the surrounding environment and form the isotherm line [16,17].

4. Conclusion
The highest increased land cover change in Makassar City in 1999 to 2019 was the built-up area, which increased by 13.1%, while the land cover that was decreased the most was vegetation by 8.6%. The change in average LST value in the last 20 years in Makassar was 0.39°C with the highest LST distribution areas was in 30-32°C and 32-34°C classes. The result of LST analysis in 2019, it can shows that the Urban Heat Island phenomenon has occurred in Makassar in the downtown area and several areas with the densely built-up area. With an overview of the UHI phenomenon in Makassar, the government is expected to raise public awareness of this phenomenon so that preventive actions can be taken, so the effects of UHI do not spread more widely.

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