Surface temperature Across Land-use Change Phenomena in Padang, Indonesia

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Abstract. Intensive anthropogenic activities encourage drastic land-use changes. The changes in land cover, from vegetation to non-vegetation, have the potential to increase heat emissions from the land surface and the atmospheric temperature. A study concerning these aspects is worth conducting in Padang, a city in Indonesia with high land-use changes (1-5 % per year), regarding that this country has controversial issues related to land-use change. In this study, we use the method Land Surface Temperature to examine the surface temperature change in Padang, Indonesia, and assess its relation to the land-use change. Landsat Satellite Imagery was obtained from USGS, through a data mining process meant to help us gather spatial and temporal data for the period 2010-2019. The results show that the city of Padang has experienced an increase of 0.40°C/year in the land surface temperature, whereas the air temperature has increased with 0.01 0C/year. It reveals per 100 hectares change in land-use it potentially raising 0.06°C and 0.006 0C in land surface and air temperature, respectively. These conclusions improve our understanding of the effects that land-use change has on the spatial and temporal surface temperature in the city.

Keywords: Land surface temperature, land-use land cover, urban growth, remote sensing

1. Introduction

City development is facing space competition that occurs in the administrative area of a region. The spaces targeted to improve the economic situation of an area are usually covered in vegetation and converted to housing, industrial or other support facilities, thus transforming vegetation into non-vegetation. City development, which serves as an indicator of increasing anthropogenic activities meant to help people obtain a more decent standard of living, can accelerate the process of drastic land-use and cover change. Changes in land use and cover can affect the climate by increasing temperatures [1-4]. Changes in land use, from vegetation to buildings, are not the only ones with the potential to increase temperature; changes in paddy fields during fallow can also have this effect [5-6].
Being the capital city of West Sumatra Province, Padang City has developed quite rapidly, as the data from BPS Padang City in Figures for 2007 to 2020 suggests. According to this information, the rate of land conversion from vegetation to non-vegetation has reached 1 - 5% of the total administrative area per year. Changes in land use and cover also affect the level of vegetation density and oxygen stock that supports the environment in Padang City [7-8]. The increase in temperature has been proven by Fajrin & Driptufany [9], whereby in 2007 the maximum temperature of Padang City was at a value of 30.25°C, only to increase to 33.23°C in 2016. In addition, Padang City stands under the threat of potential earthquakes and tsunamis, which has prompted a shift in land-use patterns for non-vegetation (settlement) needs to shift from the western city administration to the eastern part, targeting undulating vegetation to hilly areas [10]. The "National Development Planning Agency" sets out to transform Padang City from a Big City into a Metropolitan City in the 2015-2019 RPJMN. The plan is also in line with the wishes of the Padang City Government for the timeframe 2019-2024, as they aim to Padang a Metropolitan City as well. This government policy is the main cause of infrastructure development in Padang City, and due to its rapid implementation, it has the potential to increase the temperature in the area.

The problem of changes in land use and cover that occurred in the city of Padang and the increase in temperature led to the need for an academic approach to prove the phenomenon of land-use change analyze it against the backdrop of temperature changes. This study aims to provide an overview of temperature changes that occur in the areas of Padang where vegetation is replaced with non-vegetation and thus provide an orientation for future land-use management.

2. Materials and Methods

2.1 Research Location
The research was conducted in the Administrative area of Padang City, which consists of 11 districts. Geographically it is located at coordinates 0° 43 ' 45" - 1° 9' 35 " South Latitude 100° 5 ' 49" - 100° 33' 52 " East Longitude, covering a total area of 232.25 km².

2.2 Data processing
Data processing begins with literature studies and collecting satellite image data from USGS, with the LANDSAT image type from 2010-2019. Comparative data is taken from BMKG, considering climate components such as temperature and rainfall for the administrative area of Padang City. LANDSAT data pre-processing is carried out in stages, including: (i) the reprojection process, namely changing the projection system and the geodetic datum; (ii) converting the digital pixel value in the form of a scaled integer (SI); getting the surface reflectance value. The surface reflectance value will then be used to calculate the vegetation index (NDVI) and calculations for LST.

Convert the Digital Number (DN) value to the Radian Top of Atmosphere (ToA) value using the following equation:

\[ L_\lambda = MI \times Q_{cal} + AL \]

Where:
- \( L_\lambda \): spectral value of ToA radians (Watts/(m² * sr * μm))
- \( MI \): Rescalling constant, obtained from image metadata
- \( Q_{cal} \): pixel value (DN)
- \( AL \): enhancement constant, obtained from image metadata
The spectral radian conversion result is then converted into a Brightness Temperature (BT) value using the equation:

\[ T = \frac{K_2}{\ln \left( \frac{K_2}{L_\lambda} + 1 \right)} - 272.15 \]

Where:
- \( T \): satellite brightness temperature (°C)
- \( L_\lambda \): spectral value of ToA radians (Watts/(m² * sr * µm))
- \( K_1 \): Band-specific thermal conversion constant of metadata (\( K_{1\_CONSTANT\_BAND\_x} \), where \( x \) is the Thermal band number)
- \( K_2 \): Band-specific thermal conversion constant of metadata (\( K_{2\_CONSTANT\_BAND\_x} \), where \( x \) is the Thermal band number)

Vegetation is a function that can reduce surface temperature. An analysis of vegetation density was also carried out, using the Vegetation Index (VI) analysis with the Normalized Different Vegetation Index (NDVI) method. This fraction value of the area covered by vegetation is then used to obtain information on land surface temperature. In the process, 2 bands from Landsat 8 imagery are used, namely, Band 4 (red) and Band 5 (NIR), with the following equations:

\[ NDVI = \frac{B_5 - B_4}{B_5 + B_4} \]

Where:
- \( NDVI \): Normalized Different Vegetation Index
- \( B_5 \): Band 5, red channels of Landsat 8 imagery
- \( B_4 \): Band 4, the near infrared channel of Landsat 8 imagery

Furthermore, to calculate the fraction of vegetation cover, a Fractional Vegetation Cover (FVC) analysis was carried out with the equation:

\[ P_V = \left( \frac{NDVI - NDVI_{\text{min}}}{NDVI_{\text{max}} - NDVI_{\text{min}}} \right)^2 \]

To calculate the emissivity value of the surface, the equation used was:

\[ \varepsilon = 0.004 * P_V + 0.986 \]

To calculate the Land Surface Temperature (LST), which determines the surface potential temperature at the time of recording the satellite imagery carried out by Landsat 8 with the equation:

\[ LST = \frac{T}{1 + w \left( \frac{T}{p} \right) \times \ln(\varepsilon)} \]

Where:
- \( LST \): potential surface temperature (°C)
- \( T \): satellite brightness temperature (°C)
- \( w \): radiation wavelength (11.5 µm)
- \( p = \frac{h*c}{j} (14380) \): speed of light \( 2.998 \times 10^8 \) m/s
- \( \varepsilon \): emissivity of the surface
- \( j \): Boltzmann's constant \( 1.38 \times 10^{-23} \) J/K
\[ h : \text{Planck's constant } 6.626 \times 10^{-34} \text{ Js} \]

3. Results and Discussion
The plan for Padang City to become a metropolitan city will have a rapid effect on the regional economy, but some sectors will not be as advantaged, including vegetation. Reducing vegetation space can adversely affect the environment, favoring natural disasters and negatively influencing human health. Natural disasters such as floods, landslides, and flash floods are the result of changes in land use in watersheds [11], which are social spaces that will be affected by the policies aiming to transform Padang into a metropolitan city. Reduced green space in urban areas will lead to a decrease in the supply of O2 and other airborne substances which normally have a positive effect on human health [7,12].

Based on the analysis carried out using Landsay imagery data from 2010 to 2019, the area representing built land in Padang City has reached 8% (Figure 1), while the rate of land change, in general, reached 5% per year, with a tendency for the built area to advance towards the east. This area is a unit of the Bukit Barisan compound in the Sumatra region, and the vast majority of it is vegetated with protected forests. Land changes targeting dense vegetation will greatly affect the availability of O2 in the city and will also increase the potential for serious disasters. The most significant land-use change in Padang City concerns the primary forest [10]. Reducing vegetation density by, for example, eliminating forests, will have lead to an increase in temperatures in the city of Padang [8,13].

![Figure 1. Change of land from vegetation to non-vegetation in Padang City](image)

The issue of global warming highlights the important role that temperature plays in the various ecosystems [14-15]. According to Sudira, the 3°C temperature rise in the Arctic hemisphere has
resulted in a 7% reduction in snow cover since 1900. Nowadays, the lakes and rivers in that area are covered in ice for only 2 weeks per year. Temperature is therefore an important climate parameter that also affects Padang City [14-15].

Based on the temperature analysis carried out with Landsat imagery from 2010 to 2019, there has been an increase in the minimum, maximum and average temperatures registered in the city of Padang. This is illustrated in Figure 2. The increase in temperature is caused by many factors, one of which is the constant decrease in vegetation-covered land, currently replaced by non-vegetation.

![Figure 2. Trend of the surface temperature of Padang City based on Satellite Imagery](image)

The increase in surface temperature for the city of Padang reaches 0.4°C annually. This will have a direct effect on the way agricultural activities are adapted to the for example determining new planting schedules, influencing irrigation management and changing production results. Meanwhile, if you look at the air temperature obtained from the BMGK data, the temperature increase only reaches 0.01 °C per year.
Figure 3. Trend of temperature changes (a) ground surface temperature (b) air temperature

The increase in temperature that is now taking place in the city of Padang will affect agricultural activities, thus having an impact on food itself. Padang City is one of the cities and provincial capitals that has vast rice fields. In 2020, the available data showed that the rice fields stretch over 5112 ha, 31 ha of these being irrigated. The increase in temperature will have the potential to change the cropping index, as Padang City still has plenty of work to do in terms of irrigation and is very dependent on the weather. An increase in temperature will therefore greatly affect the conditions of agricultural production. In addition, the rising temperature will have a negative impact on the quality and quantity of rice, which in turn will slow down production [16-20].

The temperature increase in Padang City is mainly distributed in the western part of the administrative area. This is because the western part corresponds with the center of city activity. To be able to see the temperature trends from cold to hot, we divide the results of the analysis into clusters: cold (<20°C), cool (20°C - 23°C), medium (23°C - 27°C), and hot (> 27°C). Based on the distribution of the temperature increase in the city of Padang, we can conclude that the moderate and hot conditions have intensified, the cool conditions tend to be stable, and there is a decrease in the areas with cold conditions. The increase in the hot area of Padang City has reached 2% annually, which means that there are moderate, cool, and cold areas that decrease and instead become hot.

Figure 4. Trend of increasing temperature in (a) temperature conditions (b) areas with hot temperatures (> 27°C)
4. Conclusion
Satellite images provide an overview of the evolutions in temperature caused by land-use and land-cover changes. The increase in the built-up area of Padang city reaches 1 - 5% of the entire administrative area. An increase in temperature has occurred in Padang City due to changes in land use and cover, as well as other contributing factors. The increase in surface temperature amounts to 0.4 °C annually, and the air temperature is 0.01 °C. Areas of as much as 100 hectares being cleared of vegetation can trigger an increase in temperature of 1 °C every year. The annual shift in hot islands has reached 2% of the administrative area of Padang City.

Acknowledgements
The author would like to thank the Faculty of Agricultural Technology for the financial support. This research was funded through the DIPA Research Grant for the Faculty of Agricultural Technology with the contract number: 01D/PL/DF-DIPA/FATETA-2020.

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