Early detection of the distribution of heat stress hazards for sustainable land use planning In Padang City

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Abstract. The focus of this research is to analyze the spatial distribution of heat hazards caused by urban heat island (UHI) events over a 10-year observation period. Land surface temperature in 2007 is extracted from Landsat 7 ETM+ to convert the value of Digital Number (DN) on the band 6 into radiance. Land surface temperatures in 2013 and 2017 were extracted from Landsat 8 OLI/TIRS imagery with the initial step of the Digital Number (DN) band 10 being converted to spectral radiance. As for the analysis of the heat stress hazard area is done by connecting the land surface temperature with the Universal Thermal Climate Index value. The Universal Thermal Climate Index from 2007 to 2017 shows that the city’s heat stress is increasing every year in observation, where in 2007 the heat stress was in the range of moderate heat stress (2,960.87 Ha). Whereas for 2013 the heat stress increased to strong heat stress reaching 34.35 °C with an area of 77.50 Ha. In contrast to 2013, in 2017 strong heat stress increased significantly to 2,100.81 Ha where heat stress reached a peak of 35.92°C which is spread in almost all districts with concentrations close to the city center in addition to dense residential areas as well seen in industrial areas (semen padang), this change is in line with the development of the city area.

1. Introduction
Population growth and urbanization in urban areas continuously have endless environmental impacts and even increase rapidly. The city of Padang is one of the cities in Indonesia which is predicted to experience a population growth that continues to increase in the span of 2010-2025[1]. Population growth has direct consequences on land cover in the form of an increase in the area of built land. Landcover change from natural land cover to built land have an impact on increasing urban temperatures. The development of an area to become urban if not arranged with the green concept will accelerate the increase in city temperature. Therefore early detection of the surface temperature of Urban Heat Island (UHI) is very important for decision making on sustainable land use planning in the Padang City.

Urban Heat Island (UHI) is a temperature anomaly event that affects large urban areas where the surface temperature of urban land is higher than the surface temperature of the surrounding area. Increased urban surface temperatures triggered by these materials are impermeable such as buildings, concrete, asphalt and industrial activities [2,3,4] and also gedung- tall buildings and narrow streets can
heat trapped air and reduce air flow and are followed by heat from vehicles and factories. Furthermore, energy demand to cool the room increases [5] exacerbating the impact of UHI.

The advent of remote sensing technology and geographic information systems have enabled early detection and study of the spatial patterns of Urban Heat Island tires over a wider area. Observations on UHI are observations made on land surface temperature based on objects on the surface. The combination of remote sensing technology and geographic information systems is very useful for early detection of monitoring patterns, distribution and trends in urban microclimate temperatures and predicting the effects on urban and settlement ecology and assisting in the settlement decision making process and assisting in the decision making process in land use planning in the Padang City. Early detection of the surface temperature of Urban Heat Island (UHI) and distribution of heat stress hazards is very important to be used for decision making in sustainable landuse planning, especially in Padang City. This study aims to determine the spatial distribution of land surface temperatures, especially urban heat islands based on land use in the Padang City from 2007 to 2017 based on remote sensing data from 2007 to 2017.

2. Methodology

2.1. Study area
Padang city as the capital of West Sumatra Province was chosen as the location of the study considering that Padang City has undergone a process of urbanization, urbanization has had an impact on urban land cover which can affect the surface temperature of the city (Figure 1).

![Figure 1. Study Area](image)

2.2. Data collection
The focus of this research is to analyze the spatial distribution of heat hazards caused by urban heat island (UHI) events over a 10-year observation period. The data used in the form of vector data and raster data. Vector data is in the form of Rupa Bumi Indonesia map and Padang City administration map from the Geospatial Information Agency (BIG). Raster data in the form of image data consisting of several sensors namely Landsat 7 ETM + and Landsat 8 OLI / TIRS obtained from three Landsat image recordings.
2.3. Methodology

2.3.1 Land surface temperature data processing. Land surface temperature in 2007 is extracted from Landsat 7 ETM+ to convert the value of Digital Number (DN) on the band 6 into radiance with the following equation:

\[
\text{Radiance} = \frac{\text{MAX} - \text{LMIN}}{\text{QCALMAX} - \text{QCALMIN}} \times (\text{QCAL} - \text{QCALMIN}) + \text{LMIN}
\]  

(1)

Where: \(\text{QCALMIN} = 1, \text{QCALMAX} = 225, \text{QCAL} = \text{DN}, \text{LMAX} \) and \(\text{LMIN}\) are spectral radiances of band 6 on digital numbers 1 and 255 (obtained from the image header file) [6].

Land surface temperatures in 2013 and 2017 were extracted from Landsat 8 OLI / TIRS imagery with the initial step of the Digital Number (DN) band 10 being converted to spectral radiance [7] with the equation:

\[
\text{Reflectan} = \rho \lambda' = M \rho \times \text{Qcal} + A \rho
\]  

(2)

Where \(\rho \lambda' = \text{Reflectant TOA}\) which has not been corrected by the angle of the sun; \(M \rho\) = scale factor (Band-specific multiplicative rescaling factor); \(A \rho\) = Band-specific additive rescaling factor; and \(\text{Qcal} = \text{pixel value (DN)}\)

Furthermore, the brightness temperature of the satellite is obtained from the spectral radial values [8] with the equation:

\[
T = \frac{\text{K2}}{\ln(\frac{\text{K1}}{T} + 1)}
\]  

(3)

Where \(T\) is the satellite brightness temperature in Kelvin, \(\text{K1} = 666.09\) (watt / (meter squared * ster * um)) and \(\text{K2} = 128.71\) (Kelvin) which is the calibration constant. \(\lambda \) is the spectral radiance in watts / (meter squared * ster * um).

2.3.2 Analysis Universal Thermal Climate Index (UTCI). Universal Thermal Climate Index (UTCI) is a method for assessing outdoor heat conditions, especially human biometeorology in a one-dimensional amount from the results of human physiological reactions to outdoor environmental temperatures in a multidimensional manner, such as ambient temperature, wind speed, humidity, long hot liquid waves and short [9]. One way to detect the danger of heat in a city is to use UHI values which are extractions from land surface temperature based on remote sensing imagery and UTCI temperature equations. The UTCI temperature equation is categorized into thermal stress [10] as follows:

| UTCI (°C) Heat Stress | Stress Category |
|-----------------------|----------------|
| +9 to +26             | no thermal stress |
| +26 to +32            | moderate heat stress |
| +32 to +38            | strong heat stress |
| +38 to +46            | very strong heat stress |
| Above +46             | extreme heat stress |

As for the analysis of the heat stress hazard area is done by connecting the land surface temperature with the universal thermal climate index value.
3. Data analysis and discussion

3.1. Spatial pattern of surface temperature of Padang City

Based on the analysis of Landsat 7 ETM+ satellite imagery recording of May 16, 2007 (equation 1), it can be seen that the lowest surface temperature value is 0°C and the highest is 30.51°C, while the average surface temperature is 21.14°C with a standard deviation value of 2.63 °C. Atmospheric disturbance resulted in several research areas experiencing significant temperature differences from the surrounding area, this is indicated by the presence of a temperature at 0 °C identified by cloud cover.

Whereas the Landsat 8 OLI / TIRS image analysis recording on July 25, 2013. It can be seen that the lowest surface temperature value (equation 2) is 13.5 °C and the highest is 34.35 °C. While the average surface temperature of the land area is 24.07 °C with a standard deviation of 3.55°C. Atmospheric disturbances are also found in Landsat OLI / TIRS imagery recorded on July 25, 2013 which resulted in several research areas experiencing significant temperature differences from the surrounding area, this is indicated by the presence of a temperature value of 13.5 °C which was identified as cloud cover.

Based on the results of Landsat 8 OLI / TIRS image processing recording 28 July 2017. It can be seen that the lowest surface temperature value is 15.93 °C and the highest is 35.92 °C. While the average surface temperature of the land surface is 25.83 °C with a standard deviation of 3.11 °C. However, in 2017 there was also a cloud disturbance which was marked by a value of 15.93°C.

Spatio temporal temperature Padang city at 2007 until 2017 are classified into the maximum temperature, minimum and mean, Figure 1 shows that the maximum temperature of Padang in 2007 is at a value 30.51 ˚C, then increased in 2013 to a value 34.35˚C. In the span of years means an increase in the value of the maximum temperature mainland Padang city at 3.84°C. Whereas for 2017 the maximum temperature value reached 35.92°C, when compared with the value of the mainland temperature in Padang city in 2013 which was 34.35°C an increase in temperature of 1.57˚C. For land surface temperature variation and visualization Padang surface temperatures in 2007, 2013 and 2017 can be seen in Figure 2.

![Figure 2. Spatio temporal temperature of Padang City in 2007 - 2017](image)

The spatial distribution of surface heat of the mainland city of Padang has a different pattern each year of observation. The difference in surface temperature is characterized by gradations of color (Figure 3). The maximum temperature for 2007 was at 30.25°C and then increased in 2013 to 34.35°C and then for 2017 the maximum temperature increased to reach 35.93°C. High temperatures in 2007 2013 and 2017 increased, this was caused by city agglomeration, which in 2013 had revealed the direction of distribution to the north then in 2017 the distribution was more evenly distributed from the city center towards the east, north and south of Padang City.
3.2. Spatio temporal analysis of pressure and temperature environmental hazards Padang

Urban heat stress caused by environmental temperature pressure is determined by the UTCI parameter which is connected with the surface temperature value of the land. UTCI is classified based on the physiological response of an organism to environmental conditions with thermal loads (ie heat pressure or cold pressure) (Table 1). In this study the thermal load is obtained from the temperature derived from satellite imagery Landsat 7 ETM + and Landsat 8 OLI / TIRS.

UTCI describes urban bioclimatic and distinguishes it from rural areas. UTCI can be applied through GIS software so as to provide a very clear representation of the spatial differentiation of heat stress caused by changes in urban structure. The city center which is full of buildings and industrial estates is the area with the greatest heat pressure compared to the suburbs.

Based on the UTCI index (Table 2 and Figure 3), it can be seen that in 2007 the heat pressure was in moderate heat stress (2,960.87 Ha), and that year there was no strong heat stress. Whereas for 2013 the heat pressure increased to strong heat stress reaching 34.35 °C with an area of 77.50 Ha. In contrast to 2013 in 2017 strong heat stress increased to 2,100.81 Ha, this change is in line with the development of the city area.

Increased temperature and heat stress in urban areas will cause a reduction in the quality of life and comfort of the population. Meteorological conditions (temperature) are important agents of human well-being [11], temperature supports human mental and physical comfort or can be a limiting factor for outdoor activities [12]. In addition there are local factors that also play an important role in creating a climate that is felt by humans [13].
Table 2. Changes in the area of temperature pressure in Padang City

| UTCI               | Area/year (ha) | Change (ha) |
|--------------------|----------------|-------------|
|                    | 2007           | 2013        | 2017        | 2007-2013 | 2013-2017 |
| No thermal stress  | 66138.45       | 47921.19    | 40134.76    | -18217.26 | -7786.43  |
| Moderate heat stress| 2960.87        | 20999.54    | 26900.68    | 18038.67  | 5901.14   |
| Strong heat stress  |                | 77.50       | 2100.81     | 77.50     | 2023.31   |
| Very strong heat stress |            | -           | -           | -         | -         |
| Extreme heat stress | -              | -           | -           | -         | -         |

Figure 4. Spatial distribution of UTCI of Padang City on 2007 – 2018

As in Figure 4, the spatial distribution of UTCI shows that in 2007 the biggest difference from heat stress was observed at moderate temperatures (<26°C) including cloudy and forest areas east of Padang City. Values in the UTCI clouds and the majority of vegetation are included in the eastern and southern parts of the Padang city, which are in the range of "no heat stress" (9-26°C). Whereas "moderate heat stress" is in the western part of Padang City which is an urban center with a range of 26-32°C.

Furthermore in 2013 the range of "no thermal stress" (9-26°C) was mostly in the eastern part of the forest area and parts of the southern part of Padang city. As for "moderate thermal stress" (26-32°C) covering the entire city area, there was a significant increase in heat stress in 2013. However, in 2013 the value of "strong heat stress" began to appear (32-38°C) with a peak heat stress of 34.35°C located in a dense residential area (Nanggalo district).

In contrast to 2007 and 2013, in 2017 the increase occurred in "strong heat stress" (32-38°C) with a peak of 35.92°C which is spread in almost all districts with concentrations close to the city center in addition to dense residential areas also seen in industrial areas (Semen Padang areas). Meanwhile "moderate heat stress" (26-32°C) is evenly distributed in suburban areas. As for the region "there is no
heat stress" (9-26°C) still dominates the eastern forest region and some parts of the southern of Padang city.

4. Conclusion
The Universal Thermal Climate Index from 2007 to 2017 shows that the city's heat stress is increasing every year in observation, where in 2007 the heat stress was in the range of moderate heat stress (2,960.87 Ha). Whereas for 2013 the heat stress increased to strong heat stress reaching 34.35 ° C with an area of 77.50 Ha. In contrast to 2013, in 2017 strong heat stress increased significantly to 2,100.81 Ha where heat stress reached a peak of 35.92°C which is spread in almost all districts with concentrations close to the city center in addition to dense residential areas as well seen in industrial areas (semen padang), this change is in line with the development of the city area.

References
[1] World Bank 2012 The Rise of Metropolitan Regions: towards inclusive and sustainable regional development. World Bank website. (http://tinyurl.com/wb-rise-metro-indonesia-2012)
[2] Wong, N. H., and Jusuf, S. K. 2010 Study on the microclimate condition along a green pedestrian canyon in Singapore. Architectural science review, 53(2), 196–212. https://doi.org/10.3763/asre.2009.0029
[3] Coutts, A. M., Tapper, N. J., Beringer, J., Loughnan, M., & Demuzere, M 2012 Watering our cities. Progress in physical geography, 37(1), 2–28.
[4] Clive M.J. Warren 2012 Heat Islands; Understanding and Mitigating Heat in Urban Areas, Property management, 30 Issue: 1, pp.105-106, https://doi.org/10.1108/pm.2012.30.1.105.2
[5] Adinna, E., Christian, E. I., and Okolie, A. T 2009 Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM. Journal of Geography and Regional Planning, 2(2), 030-036.
[6] Fajrin, and Driptufany, D.M. 2019 Identification of Urban Heat Island using Technique Remote Sensing and Geographic Information System. Journal of Civil Engineering of Padang Institut of Technology,6(1) p 1-7
[7] Fajrin, and Driptufany,D.M. 2017 Surface Temperature Variation of Padang City Based on Landsat 7 ETM + and Landsat 8 OLI/TIRS Image. Momentum Journal of Padang Institut of Technology. 19 No.2 ISSN: 1693-752X p 35
[8] Tran, H., Uchihama D., Ochi, S., and Yasuoka, Y 2006 Assessment with satellite data of the urban heat island effects in Asian mega cities. International journal of applied earth observation and geoinformation 8(1) 34-48. https://doi.org/10.1016/j.jag.2005.05.003
[9] Bröde, P., Fiala, D., Blažejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., Tinz, B. and Havenith, G. 2012a. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). International Journal of Biometeorology, 56,481-494. (doi: 10.1007/s00484-011-0454-1)
[10] Othman, M. R., Jeevan, J., and Rizal, S. 2016. The Malaysian Intermodal Terminal System: The Implication on the Malaysian Maritime Cluster, International journal of e-navigation and maritime economy 4, 046 – 061. Available at https://doi.org/10.1016/j.enavi.2016.06.005.
[11] BlaŚejczyk K. 2007. Weather limitations for winter and summer tourism in Europe. [in:] A. Matzarakis, C.R. de Freitas, D. Scott (red.). Developments in Tourism Climatology, Commission on Climate, Tourism and Recreation International Society of Biometeorology, Freiburg, p. 116-121.
[12] Scott D., Dowson J. 2007 Climate change vulnerability of the US Northeast ski industry, [in:] A. Matzarakis, Ch. de Freitas, D. Scott (red.), Developments in Tourism Climatology, Commission Climate, Tourism and Recreation, International Society of Biometeorology,
Freiburg, p. 191-198

[13] Kunert A. 2010 Modeling of UTCI index in various types of landscape. [in:] A. Matzarakis, H. Mayer, F-M. Chmielewski (Eds.), Proceedings of the 7th Conference on Biometeorology, Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg, Nr. 20, p. 302-307.
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