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Spatio Temporal Analysis of Urban Heat Stress Using Multispectral Data

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ABSTRACT: The effect of urbanization on the future atmospheric environment of cities around the world remains uncertain in the context of climate change. Using temperature measures can be analyzed how changes in the thermal environment can affect human well-being. The study aims to support city planning authorities in the study of urban heat stress hazards. Therefore, land surface temperatures (LST), as well as Physiological Equivalent Temperature (PET), are applied to take into account the spatial distribution of heat stress. Heat stress conditions are mapped and generated by connecting land surface temperatures with PET values. Landsat 7 ETM+ and Landsat 8 OLI/TIRS remote sensing data are used to capture LST, and PET categories are used to assess heat stress based on LST. Based on the results of the spatial analysis shows there is an increase in the hazard of spatiotemporal heat stress in Padang city, in the year 2007 the highest LST reached 30^{0}C in the category of Moderate Heat Stress with an area of 1.2 hectares, but in the year 2017, the highest temperature reached 33^{0}C with a wide area of Moderate Heat Stress reaching 730.98 hectares. These results demonstrate the need for mitigating heat stress through the city's green open spaces.

Keywords: LST, Landsat, PET

1. INTRODUCTION

The trend of increasing urbanization has an environmental impact and is likely to never end, continuously, and is still projected to increase even more rapidly. More than 48% of the world's population lives in urban areas [1]. Population growth can increase vulnerability to urban warming problems as the number of people living in urban areas is expected to increase to five billion by 2030 [1]. The problem of urban warming also has a disproportionate impact on the quality of life, economy, and local ecosystems in cities and causes the Urban Heat Island (UHI) phenomenon [2, 3, 4]. Climate change and land use change have an impact on people's health and well-being and disrupt ecosystems and their dynamics. Studies have described the direct impacts of climate change, such as heat stress, thermal comfort, air pollution, and infectious diseases [5,6,7].

Thermal comfort is a bio-meteorological index based on the heat exchange between the human body and the atmosphere to evaluate human comfort in climatic conditions. Thermal comfort has an important impact on humans in various fields (such as health, energy consumption, urban planning, and tourism) [8, 9, 10, 11, 12]. Changes in climatic factors such as temperature, humidity, wind speed, solar radiation, and so on will have an impact on thermal comfort. Outdoor thermal comfort is directly related to the urban heat island phenomenon, thermal comfort needs to be focused on the analysis of the urban heat island phenomenon and the inner-city surface temperature for urban planning [13].

The outdoor thermal comfort conditions can be investigated using the Bioclimatic Physiological Equivalent Temperature (PET) index. PET has other advantages over thermal comfort because the widely known unit of measurement uses degrees Celsius (^{0}C) [14], making it easier for city planners to understand the results as an indicator of thermal stress in the context of green open space planning. In this paper, the PET index is used to assess heat stress in Padang city based on land surface temperature (LST), LST is extracted from remote sensing image data, and the LST results will then be classified using the PET index.

2. RESEARCH METHODS

2.1 Study Area

Padang as the capital city of West Sumatra Province has an administrative area of about 1,414.96 km² located on the coast of West Sumatra Island in an astronomical position between 00º 05

'05” 'East Longitude - 100º34'09” 'East Longitude and 00º44'00” South latitude - 01º08'35” South latitude. Biophysically, Padang city consists of unspoiled highlands/hills and lowlands, the development of Padang city is more concentrated and dense in the lowlands and the western coast, while in the east it is a protected forest area that is densely vegetated (Figure 1). This occurs because it is influenced by the steep eastern topography. In addition, Padang city is the central economy of West Sumatra which is growing rapidly and is marked by urbanization. The altitude of Padang city from sea level also varies, ranging from 0 m above sea level (ASL) to> 1,000 m ASL. Urbanization has an impact on the urban land cover which can affect the surface temperature of Padang city [15].

2.2 Data Collection

To measure and map LST, in this study using Landsat 7 ETM + and Landsat 8 OLI / TIRS imagery data (table 1), the selection of dates for Landsat satellite imagery takes into account the image quality, especially the cloud layer. Landsat images used are using the WGS84 datum and the 48 South Universal Transverse Mercator Zone coordinate system.

2.3 Land Surface Temperature Data Processing

Land surface temperature extraction was obtained from Landsat 7 ETM + and Landsat 8 OLI / TIRS user manuals [15]. 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:

$$\text{Radiance} = \frac{MAX - LMIN}{QCALMAX - QCALMIN} * (\text{QCAL} - \text{QCALMIN}) + \text{LMIN}$$

Where: QCALMIN = 1, QCALMAX = 225, QCAL = DN, LMAX and LMIN are spectral radians of band 6 on digital numbers 1 and 255 (obtained from the image header file)

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 with the equation:

$$\rho\lambda' = M\rho * Qcal + A\rho$$

Where ρλ '= Reflectant TOA which has not been corrected by sun angel; Mρ = scale factor (Band-specific multiplicative rescaling factor); Aρ = Band-specific additive rescaling factor; and *Qcal* = pixel value (DN)

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

$$T = \frac{K2}{In(\frac{K1}{L\lambda} + 1)}$$

Where T is the satellite brightness temperature in Kelvin, K1 = 666.09 (watt / (meter squared * ster * um)) and K2 = 128.71 (Kelvin) which is the calibration constant. Lλ is the spectral radiance in watts / (meter squared * ster * um). The next step is to convert the temperature value from Kelvin (K) units of degrees Celsius (^{0}C) [15]

2.4 Thermal Sensation And Stress Level of PET

PET is defined as the ambient temperature at which human energy budgets for indoor conditions are assumed to be balanced with the same skin temperature and sweat levels as the actual outdoor conditions to be assessed. The frequency values inform the appropriate heat and cold stress for leisure and recreation, thus evaluating the physiological thermal conditions significantly [16, 17]. The PET temperature equation is categorized into the thermal stress level as follows (table 2). Meanwhile, heat stress area analysis is carried out by linking the ground surface temperature with the PET index value using Geographic Information System (GIS) software

3. RESULTS AND DISCUSSION

3.1 Spatio-temporal LST in Padang City

Changes in the spatial distribution pattern of LST from 2007 to 2017 are clearly seen in Figure 2 (A),(B) and (C). The lowest temperature in Padang city is less than 23°C which is in a hilly area which is a protected forest area west of Padang city. There are several hot spots with high temperatures identified. Areas with high LST were identified in the nanggalo sub-district (figure 3). The land surface temperature in 2007 was 30.51°C, and in 2013 it was 34.35 ° C, while for 2017 it was 33.23°C. Based on the results of this study indicate a local climate change in the Padang city, allowing the phenomenon of UHI. The effect of UHI is characterized by heating up the urban zone compared to the surrounding environment. UHI has an impact on environmental quality, such as increased energy consumption, increased pollutants, disturbances to people's health and physiological comfort [18, 19]. Land surface temperature varies in lowland areas of Padang city, the expansion of LST in Padang city relates to vegetated land cover for infrastructure development (such as expansion of settlements) in the lowlands.

Table 1 Landsat image characteristic

Satellite	Path/Row	Spectral Band	Spatial Resolution (m)	Date Acquired
Landsat 7 ETM+	127/061	6	15/30/60	16/05/2007
Landsat 8 OLI/TIR		10	15/30/100	25/06/2013
				22/07/2017

Table 2 Thermal sensation and stress levels of PET

PET (˚C)	Human sensation	Thermal Stress Level
-4	Very cold	Extreme cold stress
4.1 - 8	Cold	Strong cold stress
8. 1–13	Cool	Moderate cold stress
13. 1–18	Slightly cool	Slight cold stress
18. 1–23	Comfortable	No thermal stress
23.1–29	Slightly warm	Slight heat stress
29.1–35	Warm	Moderate heat stress
35.1–41	Hot	Strong heat stress
>41	Very hot	Extreme heat stress

Fig 1 study area

3.2 Spatio -Temporal Variation Thermal Heat Stress Distribution Based on PET

The spatio-temporal distribution of the PET values is clearly visible in the maps made. The distribution of PET on the map (figure 4 (A),(B) and (C)) and graph (figure 5) shows the magnitude of the thermal heat stress in the lowlands of Padang City from 2007 to 2017. In terms of thermal heat stress from 2007 to 2017, two levels of thermal heat stress were found, in 2007 The thermal heat stress level for the slight heat stress category was detected covering an area of 15.317,95 hectares, then increased by 30.065,21 hectares in 2013, but there was a decrease in 2017 reaching 22.617,71 hectares. Whereas for the category of moderate heat stress was detected in 2007 with an area of 1.71 hectares, this thermal heat stress increased in 2013 reaching 6,598.04 hectares, spreading almost all over the lowlands of Padang city, but in 2017, the moderate heat stress decreased to 730.98 hectares. In 2017, the thermal heat stress decreased significantly. This decrease is related to the image data acquisition used. Image data for 2017 was image in July when the Madden Julian Oscillation activity occurred which caused high rainfall in the Padang city [20].

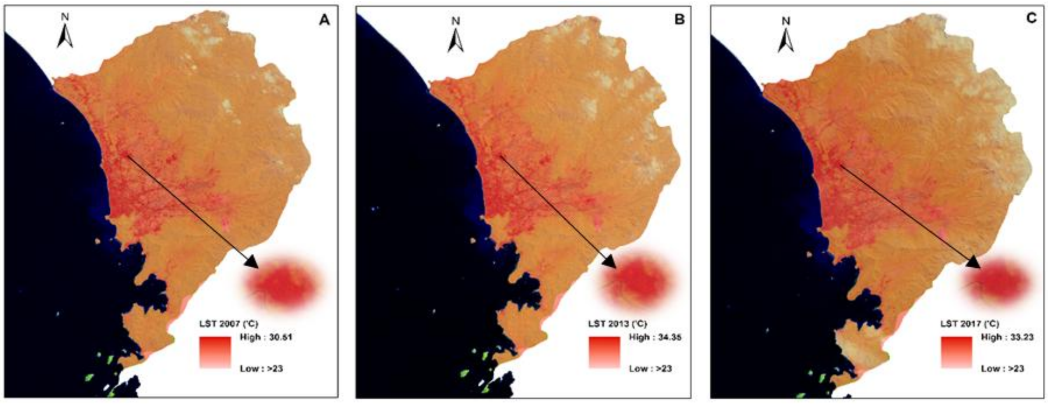

Fig. 2 spatio-temporal LST in Padang city 2007 – 2017

Fig. 3 hotspot area 2017

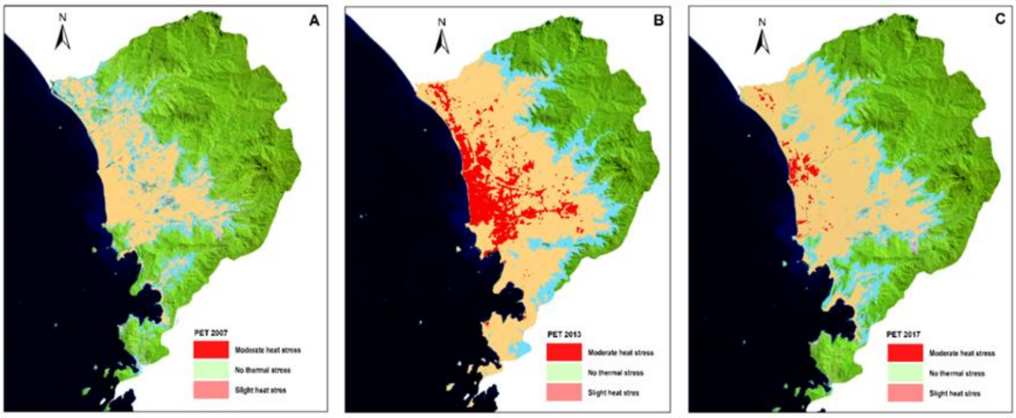

Fig. 4 PET from 2007 to 2017

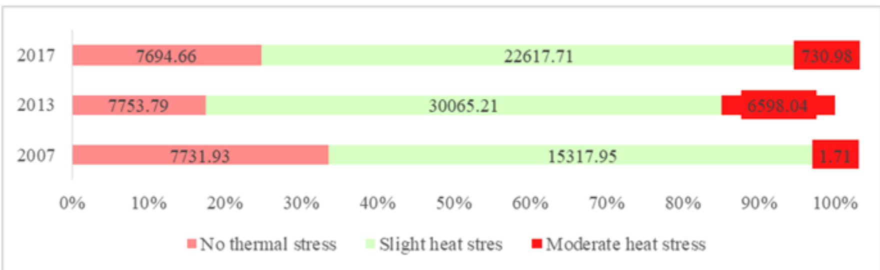

Fig. 5 range of heat stress based on PET from 2007 to 2017

Areas that do not have thermal heat stress in Padang City are basically located in forest areas, although the Padang City Government has allocated green open space to overcome the problem of urban warming, the largest proportion is located in unspoiled hilly areas. However, the thermal heat stress in Kota Padang is in a high-density residential area in the lowlands with little green open space (Figure 3). Green open space and conservation of wetlands are effective in terms of cooling and temperature reduction in the city and also produce clean and fresh air [21]. Heat stress and heat effects are real phenomena that vary with time, region, and population. Heat exposure can cause health problems in the community.

Planning cities under construction are fertile ground for research at the scale of local climate and thermal comfort, thus offering the opportunity to formulate urban planning strategies [22] to tackle the perilous problem of urban warming to sustainable cities that are resistant to the worst effects of future heat stress. Thus, studying the local temperature of the city is a source of knowledge to find out how temperature behavior changes in the urban environment [22]. There are still gaps area for research in sustainable urban planning related to climate change.

4. CONCLUSION

LST in Padang City with a temperature of more than 30oC can threaten the city environment. In most areas of Padang City, changes in local temperature like this can result in more stressful bioclimatic conditions (PET more than 300C means moderate heat stress) for people and can be categorized as an urban heat hazard for everyone living in urban areas. The results recommend the preservation of vegetated land cover in the lowlands of Padang city along with urbanization to mitigate the urban heat stress.

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