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Land Surface Temperature and its Relationship to Population Density

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Abstract
Population density due to urbanization contributes to the SUHI phenomenon and urban climate change. Understanding the SUHI phenomenon that brings enormous negative impacts to the environment and human life, Land Surface Temperature (LST) assessment is essential for creating a feasible and livable city. By utilizing the data of 1999 and 2018, this study aims to assess the LST value and its relationship to population density in Tanjungpinang city over two decades. As an island, Tanjungpinang has a vulnerability to SUHI and the climate change phenomenon. This study applied GIS and remote sensing models based on the mathematical formula of digital remote sensing images to calculate the LST value, and the relationship between LST and population density was examined using correlation analyses with Microsoft Excel. The results showed that Tanjungpinang city had increased 3.5oC in LST and 94.80% in density population over two decades. SUHI phenomenon has occurred during this period. It also indicated that there was a significant relationship between population density and LST. The LST spatial pattern spread from west to east of Tanjungpinang city was in line with the population density distribution pattern. The area with the highest percentage of population density addition and experienced the highest LST was Tanjungpinang Barat District. This study considers local governments to create effective population control and adaptive planning strategies for SUHI phenomenon mitigation.

Keywords: *SUHI, LST, population density, Tanjungpinang*

1. Introduction

Population density due to urbanization is currently a crucial issue for countries in the world, including Indonesia. Urbanization involves a complex set of economic, demographic, social, cultural, technological, and environmental processes that increase in the proportion of an area's population living in cities and towns, an increase in population concentration in larger settlements in the region, and an increase in population density in the region (Knox, 2009). According to the CIA World Factbook (2016) in Kompasiana Media (2017), Indonesia is experiencing a critical population density since Indonesia's population is in the 4th rank globally. Indonesia has 270 million people with a density of 149 per square km (Indonesia's Central Statistics Agency, 2020).

Recent studies of urban climate reported that the high population density negatively impacts the environment, including air pollution from human activities, resulting in more significant CO_2 gas emissions. Rahman (2017) explained that countries with high population density contribute more to air emissions. According to Lee et al., (2020) the population can affect Urban Heat Island (UHI) intensity by generating anthropogenic heat. UHI harms the quality of the environment and the quality of human life, such as increased energy use, decreased the quality of clean water, emissions of air and greenhouse effect, disruption of health and comfort of life, and other direct and indirect impacts, including social, economic and environmental (Li, et.,al, 2016; Bhargava et al., 2017).

Besides, the most important and needs to be aware of, the UHI phenomenon can affect the increase in land surface temperature, which can potentially cause climate change globally (Ningrum and Narulita, 2018). In archipelagic regions, island systems are among the most vulnerable to climate change, which is predicted to induce shifts in temperature, rainfall, and sea levels (Veron et al., 2019). Therefore, understanding the enormous negative impact of UHI on the environment and humans, the study of UHI is urgent to materialize a better life.

Generally, Urban Heat Island (UHI) is classified into Surface Urban Heat Island (SUHI) and Atmospheric Urban Heat Island (AUHI). SUHI describes the urban surface temperature higher than the surrounding area, generated from indirect measurements with thermal analysis from Landsat images or land surface measurements (B. Zhou, Rybski, & Kropp, 2017). Meanwhile, the AUHI is generated from ambient air temperature measurements using a mobile thermometer or fixed weather stations (Wicahyani et al., 2014). However, In terms of the observation method, meteorological stations describe on a relatively small scale. Meanwhile, satellites' latest advances in remote sensing techniques make it possible to measure UHI based on surface temperature or SUHI measurements (Chen et al., 2016). Hulley et al., (2019) described that SUHI could be identified from Land Surface Temperature (LST) value by measuring thermal light emission from the ground surface of the incoming solar energy interacting with the ground or canopy surface in a vegetated area. LST distribution can be analyzed by utilizing satellite image data, such as Landsat, NOAA, and MODIS. The remote sensing technique makes it easy to analyze large areas and time-efficient.

Discussed the SUHI phenomenon, Li, et al., (2017) reported a close relationship between landscape composition and the SUHI phenomenon. Several studies regarding SUHI on land cover/use, whereas vegetation and built-up areas are indicators (Al Mukmin, Wijaya, & Sukmono, 2016; Utomo, Suprayogi, & Sasmita, 2017; Ali et al., 2017; Sejati et al., 2019). Previous studies (Li et al., 2012, Zhang & Kainz, 2012; Elsayed, 2012; Bhargava, et al., 2017; Seprila, et.al., 2018) explained that the phenomenon of SUHI is closely related to the intrinsic characteristics of cities such as size, population, population density, building density, and external factors such as climate, weather, and season. Based on the literature review works, the triggers for this SUHI phenomenon in several regions are different. As (Imhoff, Zhang, Wolfe, & Bounoua (2010) and (Xiaoma Li, Zhou, Asrar, Imhoff, & Li (2017) explained, the SUHI value would vary in regions with different ecological contexts, levels of urbanization, and urban forms, so it is recommended to carry out further investigations. In our interest, this study presents a Land Surface Temperature assessment concerning population density as a demographic factor to denote urbanization intensity in a region.

Tanjungpinang City is an island that has an area of 239,5 km2. Its geography is very strategic in terms of economy, marine and fisheries, and socio-culture. This city has been developing, signified by Sri Bintan Pura's port for domestic access to the other islands and international access. Because of its strategic geography, Tanjungpinang City has an attraction for migrants to stay. As an implication, the Tanjungpinang population experienced growth of 1.07% and a population density of 1.387 people / km2 (Central Bureau of Statistics of Tanjungpinang, 2019).

Research on the variability of rainfall and air temperature in Tanjungpinang due to population growth and rampant forest clearing for settlements has shown a trend of annual temperature anomaly values ranging from -0.6 oC to 1.4 oC, where describes an area that has experienced climate change (Siregar, et al., 2019). The impact of climate change is triggered globally by rising land surface temperature (Ardiansyah, 2015). As an island with a coastal conservation zone and high population density, Tanjungpinang is vulnerable to climate change impacts and the SUHI phenomenon. Therefore, understanding LST in this region needs more attention. By analyzing LST, sustainable city strategies can be designed early, and health problems due to SUHI can be prevented (Nurwanda and Honjo, 2020).

Given the background above, this study aims to analyze the Land Surface Temperature value and its relationship to population density in Tanjungpinang City. The research questions to be addressed are (1) How the LST value of 1999 and 2008 in Tanjungpinang City?; (2) Is there any relationship between population density and LST?. Furthermore, this study considers local governments for creating effective population control and adaptive planning strategies for SUHI phenomenon mitigation.

Figure 1. Study area

2. Study Area and Methods

2.1. Study Area

The study area is Tanjungpinang City (0º5 'North Latitude, 104º27' East Longitude), the Riau Islands Province's capital city. Administratively, Tanjungpinang City has 4 sub-districts, namely Tanjungpinang Barat District, Tanjungpinang Timur District, Tanjungpinang Kota District and Bukit Bestari District (Figure 1). Its territory is bordered by Bintan Regency and is on an island called Bintan Island. According to its size, Tanjungpinang City is a medium-sized city with 209,280 people (Central Bureau of Statistics of Tanjungpinang, 2019). The area's topography is varied, with slopes ranging from 0 - 2% to 40% and an altitude of 0 - 50 MASL to 400 MASL. In general,Tanjungpinang City has a wet tropical climate, with an average humidity of 86% with rainfall ranging from 2000-2500 mm / year.

2.2. Materials and Methods

This study utilized Geographic Information Systems (GIS) and Remote Sensing (RS) model to provides information on spatial changes in an area. As its function, a Geographical Information System (GIS) is designed to capture, store, analyze and display data related to positions on the earth's surface (Kabak et al., 2018). In this study, Quantum GIS Madeira 3.4 was used as an operational tool.

This study used the Landsat 5 TM (Landsat 5 TM) imagery downloaded from https://earthexplorer.usgs.gov/ acquisition dated 2 April 1999, Path / Row: 125/059 and Landsat 8 OLI downloaded from https://libra.developmentseed.org/ acquisition dated 5 June 2018, Path / Row: 125/059. The secondary data is demographic data on the population density of 2018 and 2006 to represent the population density in 1999, considering the Tanjungpinang Central Bureau of Statistics website's availability.

Land Surface Temperature (LST) value assessments as carried out Sejati et al., (2019) dan Darlina et al., (2018) with the following stages:

1. Convert digital number into spectral radians

   Convert the Digital Number (DN) to a radian spectral value using the information provided by the Metadata Band 10 Landsat 8 OLI and Band 6 Landsat 5 T M using the equation formula (i)

   $$L\lambda = MLQcal+AL \qquad (i)$$

   Where: Lλ is the spectral radian; ML is the Band-specific multiplicative obtained from the value metadata (RADIANCE_MULT_BAND (RMB) _x, where x is the band number used; AL is the Band-specific additive obtained from the value metadata (RADIANCE_ADD_BAND (RMB) _x, where x is the number band used; Qcal is the Digital Number.

2. Calculation of LST Value

   As one of the most important aspects of surface temperature analysis, LSTs have become a major topic in developing methodologies measured from outer space (Darlina et al., 2018). LST is also an important factor in climate change studies, estimating radiation budgets, heat balance studies, and controlling climate dynamics and modelling frameworks (Kayet, Narayan, et al,. 2016).

Tabel 1. Metadata Landsat

Year	Type	Band	RMB	RAB	K1	K2
2018	Landsat 8 OLI	10	0.00033420	0.1	774.8853	1.321,0789
1999	Landsat 5 T M	6	0.055375	1.18243	607.76	1.260,56

Next, LST velue and distribution area has done by converting spectral radians to Kelvin using the equation formula (ii)

$$T = \frac{K2}{\ln\left(\frac{K1}{L\lambda}\right)+1} \qquad (ii)$$

Where: T is the brightness temperature (K); Lλ is the spectral radian; K1 is the constant value of the metadata (K1_CONSTANT_BAND_x, where x is the band number used); K2 is the constant value of the metadata (K2_CONSTANT_BAND_x, where x is the band number used) which can be seen in table 1.

3. Convert surface temperature in Kelvin to degrees Celsius

   The LST value uses the equation formula (ii) using the Kelvin degree unit so that it needs to be converted to degrees Celsius using the formula equation (iii)

   $$T_{celc} = T_{kelvin} - 273.16 \qquad (iii)$$

3. Result and Discussion

a. Population Density of Tanjungpinang City 1999 – 2018

Population density shows the urban population's distribution and urbanization intensity, calculated based on total population divided into an area (Ramírez-Aguilar and Lucas Souza, 2019). Based on the data analysis, the population density of Tanjungpinang over two periods can be seen in Table 2.

Table 2. Population Density of Tanjungpinang City 1999 - 2018

District	Area	Population Density (person/km2)		∆ Pop.Density (%)
	km2	1999	2018	
Tg.Pinang Barat	4.62	1496	10088	574.33
Tg. Pinang Timur	60.04	540	1394	158.15

Bukit Bestari	46.51	789	1312	66.29
Tg. Pinang Kota	36.96	368	453	23.10
Tanjungpinang City	**239,5**	**712**	**1387**	**94.80**

Source: Central Bureau of Statistics for the City of Tanjungpinang, 2006 & 2019

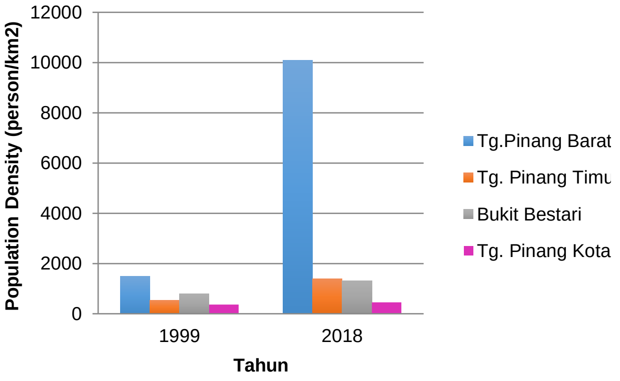
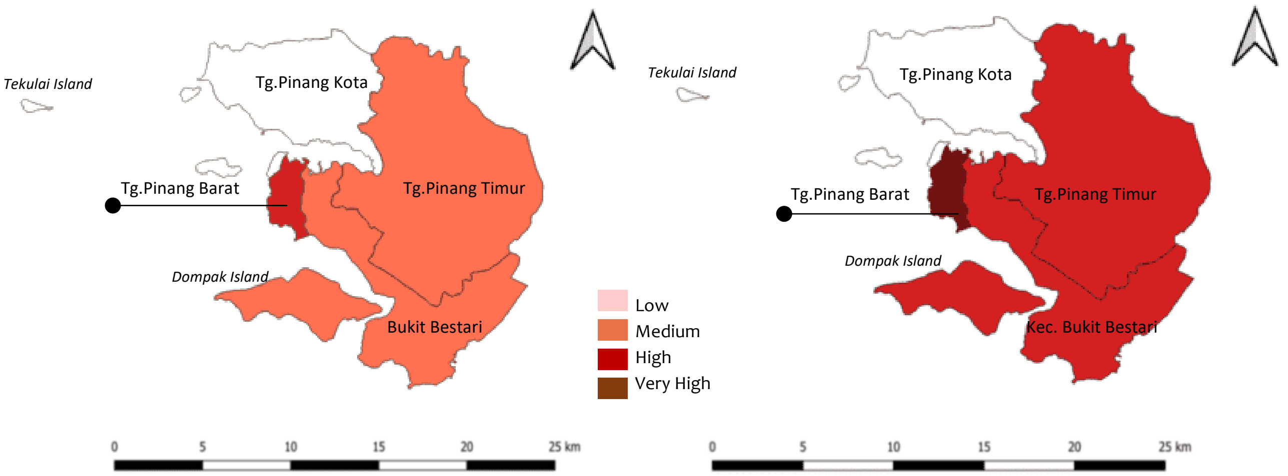


Figure 2. Population Density Diagram

The population density in Tanjungpinang City has increased during the period 1999 – 2018. The highest was Tanjungpinang Barat District, with 1496 people / km^2 (> 1000 people / km^2). Meanwhile, Bukit Bestari District, Tanjungpinang Timur District, and Tanjungpinang Kota District were lower, ranging from 300 - 800 people / km2 (see Table 2 and Figure 2). The population growth that occurred in Tanjungpinang Barat District increased rapidly, reaching 574%. According to Ramírez-Aguilar and Lucas Souza (2019) explained before, the result showed that Tanjungpinang City had had a densely populated area and rapid growth intensity since its inception. The urban population is concentrated in the old town area as Tanjungpinang city centre.

Comparing the population density between 1999 and 2018, the area with the highest density level is still in Tanjungpinang Barat District, reaching 10,088 people / km^2. Meanwhile, Tanjungpinang Timur and Bukit Bestari Districts experienced changes from moderate to high-density levels (Figure 3). Observing the pattern of population density distribution, the image illustrated that the population density in Tanjungpinang City had experienced a density spread to the east. This trend shows that urban activities are no longer located in the West Tanjungpinang District as the city center but have shifted to the Bukit Bestari District and the East Tanjungpinang District. According to (Handayani and Rudiarto (2011), the shift can show suburbanization stages where the core area can be assumed to have reached a saturation point to shift in density concentration. An increasing population in each sub-district will impact the increasing need for housing, which, as a result, has an impact on changes in various fields (Fawzi, 2017).



(a) (b)

Figure 3. Spatial Population Density of Tanjungpinang City (a) 1999 (b) 2018

b. Land Surface Tempetarure (LST)

Landsat 5 TM and Landsat 8 OLI satellite imagery can provide an overview of thermal sensors in analyzing LST and SUHI phenomena. Based on image data processing, we analyze the land surface temperature value recorded from 16.5^{o}C to 31^{o}C during 1999 - 2018. In 1999, the minimum LST was 16.5^{o}C and the maximum was 28^{o}C, while in 2018, the minimum LST was 20^{o}C, and the maximum was 31^{o}C (Figure 2). The widest distribution temperature in 1999 was 23 ^{o}C (44,13 km^2), while in 2019 was 25 ^{o}C (55,25 km^2) (see Figure 4). In general, the LST of 2018 were higher than in 1999.

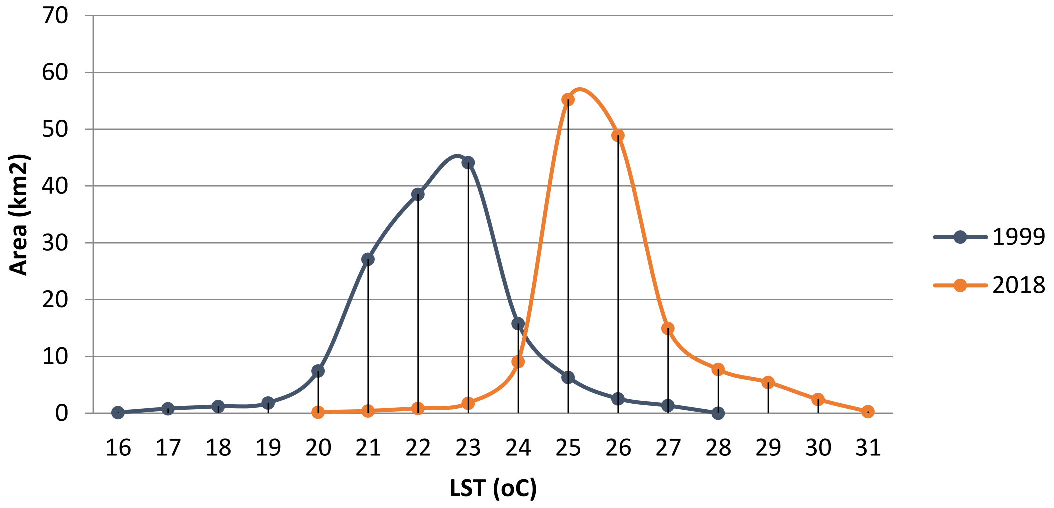


Figure 4. Comparison Graph of Land Surface Temperature (LST) Values in 1999 and 2018

Spatially, Figure 5 describes the results of the spatial calculation of LST values. The colour transformation from green (Figure 5a) to yellow and red (Figure 5b) illustrates that the SUHI phenomenon has occurred in Tanjungpinang City during 1999 - 2018. In 1999, a maximum surface temperature of 28°C arose and dominated in Tanjungpinang Barat District at the city center. Generally, the Tanjungpinang city's temperature was dominated by 16.5 °C - 24°C. While, in the periphery areas, namely Tanjungpinang Kota District, Bukit Bestari District and East Tanjungpinang District, getting lower than the city centre. The result linearly with Darlina et al., (2018) that the SUHI phenomenon is characterized as an island of hot surface air concentrated in the city area than the suburban area's surroundings.

Another change recorded by the thermal image is that there has been an increase in surface temperature of 2018. The yellow and red are increasingly dominant throughout the District (Figure 2b). The red represents a maximum surface temperature of 31°C and has been distributed towards the east.

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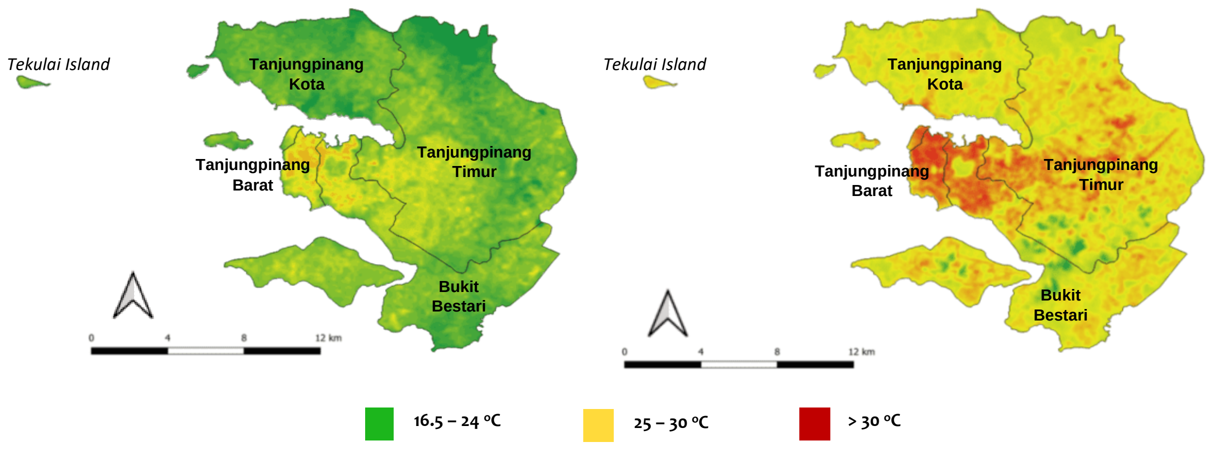

(a) (b)

Figure 5. LST Value in Tanjungpinang City (a) 1999 (b) 2018

Table 3. Area of LST Distribution

LST (°C)	Area (km²)	
	1999	2018
16 - 24	137.0907	12.3651
25 - 30	10.3023	134.7435
>30	0	0.2844

Table 3 describes the distribution of surface temperature in units of area. In 1999, the land surface temperature of 16-24 oC covered 137,0907 km2, which decreased to 12,3651 km2 in 2018. On the other hand, the temperature of 25-30 oC covering 10.3023 and increased to 134.7435 km2 in 2018. The temperature of > 30 oC occurred in 2018 with covering an area of 0.2844 km2. The increase in land surface temperature indicates that the SUHI phenomenon has occurred. It is an important matter that needs to be considered and followed up by its handling because the increasing human population will result in more activities and affect the urban surface temperature. Increasing surface temperatures will harm the environmental quality, health and trigger climate change.

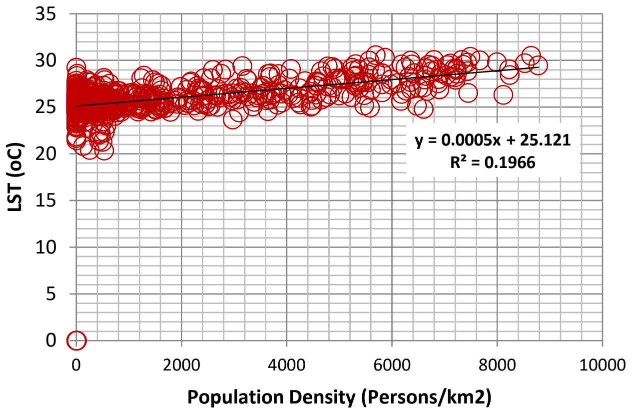

Figure 6. Graph Correlation Between LST and Population Density

The comparison of LST distribution (Figure 5) and population density in Tanjungpinang City (Figure 3) can describe the relationship of population density that affects LST value in the linear regression results in Figure 6. The statistical data processing results equation y = 0,0005x + 25,121, wherefrom this equation has a positive x value. This value showed that population density and LST have a directly proportional relationship, meaning there is a significant relationship between population density and LST. The highest population density area has the highest surface temperature, namely in the West Tanjungpinang District.

Spatially, the two variables showed the linear spatial distribution pattern. The population density distribution from Tanjungpinang Barat District to Tanjungpinang Timur District is in line with the surface temperature distribution pattern in the region. This analysis result pointed to the population density variable as a factor in increasing land surface temperature.

The existence of a relationship between population density and surface temperature, as in the research conducted (Li et al., 2012; M. Elsayed, 2012; Darlina et al., 2018), found a significant relationship between LST and population density. Surface temperature will increase in areas with high population densities and decreased areas with low population densities. In contrast, the research conducted by Chen et al., (2016) found that population density shows a decreasing correlation with surface temperature. It is influenced by government policies and strategies to limit urban development and undertake mitigation efforts in the city centre. Different research results can be caused by changes in spatial patterns, research dates, and the scale of land cover types (Li, et al., 2017).

4. Conclussion

Based on temporal–spatial analysis of LST and demographic population density driving forces, it can be concluded that Tanjungpinang city has increase 3.5ºC in LST and 94.80% in density population over two decades. SUHI phenomenon has occurred during this period characterized by higher LST in the city centre. Meanwhile, the surrounding areas denoted lower LST. It also indicated that there was a significant relationship between population density and LST. The LST spatial pattern spread from west to east of Tanjungpinang city was in line with the population density distribution pattern. The area with the highest percentage of population density addition and experienced the highest LST was Tanjungpinang Barat District. Thus, in this paper, our findings provide valuable information for local governments on appraising effective population control and adaptive planning strategies for SUHI phenomenon mitigation.

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