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A study of urban heat island of Banda Aceh City, Indonesia based on land use/cover changes and land surface temperature

Ashfa Achmad[1], Laina Hilma Sari*[1], Ichwana Ramli[2]
[1]Architecture and Planning Department, Syiah Kuala University, Darussalam, Banda Aceh 23111, Indonesia
[2]Agricultural Engineering Department, Syiah Kuala University, Banda Aceh 23111, Indonesia
**Corresponding author : ashfa.achmad@unsyiah.ac.id*

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Abstract– This article described the spatial and temporal of land surface temperature (LST) patterns in Banda Aceh City, Indonesia, in the context of urban heat island (UHI) phenomenon. This study used the Landsat imaginary in 1998 and 2018, which represents the conditions before and after the tsunami. The data analysis utilized the Geographic Information System (GIS) and Remote Sensing (RS) technique. The 1998 and 2018 land use/cover (LUC) maps were derived from remote sensing satellite images using a supervised classification method (maximum likelihood). Both LUC maps contained five categories, namely built-up area, vegetation, water body, bare land, and wetland. The 1998 LUC map had a kappa coefficient 0.91, while the 2018 LUC map had 0.84. It was found that the built-up area increased by 100%, while the vegetation category fell 50%. The overall mean of LST in the study area increased 5.9^{0}C between 1998 and 2018, with the highest mean increased in the built-up area category. LST and normalized difference built-up index (NDBI) indicated a positive correlation, while LST and normalized difference vegetation index (NDVI) show a negative correlation. The study recommends that LST should be taken into consideration in the urban planning process to realize a sustainable urban development. It also emphasizes the importance of optimizing the availability of green open space to reduce UHI effects and help in improving the quality of the urban environment.

Keywords: Land use/cover, UHI, LST, NDBI, NDVI, Banda Aceh.

Introduction

Urban areas are dominated by buildings such as housing, offices, commercial, and other urban buildings. In general, urban areas have a temperature of 3.5 to. 4.5^{0}C which is higher than those of rural areas and will continue to increase by around 0.1^{0}C per year (Voogt and Oke, 2003; Zhang *et al.*, 2017). The researchers stated that the phenomenon of Urban Heat Island (UHI), was first introduced and published in 1818 (Zhang *et al.*, 2017). The circumstances where urban areas have a higher temperature than those of rural areas defined as UHI phenomena (Howard, 1818). Agricultural activities generally dominate rural areas. Changes in land use and land cover (LUC), building and road materials, weather, urban morphology, and geographical location, may cause UHI (Estoque and Murayama, 2017). The negative impacts caused by UHI on the quality of human life has become one of the main themes in studies related to urban planning (Chen *et al.*, 2016; Estoque and Murayama, 2017).

Previous studies stated that understanding the factors that influence UHI is important in city development and regional spatial plans. Spatial quality, surface material, and green open space are related to socio-ecological aspects and have the potential to increase UHI (Estoque and Murayama, 2017). Previous research stated that the use of Geographic Information System (GIS) and Remote Sensing (RS) as an analytical technique in studying UHI has greatly helped research activities (Liu and Zhang, 2011; Cai *et al.*, 2017; Bokaie *et al.*, 2016; Kikon *et al.*, 2016; Estoque and Murayama, 2017; Zhang *et al.*, 2017). Previous research also found several variables related to UHI, such as vegetation index and built-up area index. These indices were obtained from satellite imagery (Zhang *et al*., 2017). The factors that could potentially lead to UHI were analyzed using GIS and RS techniques (Liu and Zhang, 2011; Kikon *et al*., 2016; Zhang *et al*., 2017).

Several studies on UHI have explained the relationship between LUC with LST (Kimuku and Ngigi, 2017; Bokaie *et al*., 2016; Estoque and Murayama, 2017; Song *et al*., 2014; Sun *et al*., 2012). In addition, others combined it with normalized difference vegetation index (NDVI), standardized difference built-up index (NDBI), normalized difference water index (NDWI), and LST spatial pattern (Kimuku and Ngigi, 2017; Chen *et al*., 2016; Kikon *et al*., 2016; Liu and Zhang, 2011).

The effect of UHI is an essential consideration in the regional and city spatial planning process in Indonesia. Planning to minimize the increase in LST in allocating urban space is critical in urban planning and development. Research on UHI has studied various metropolitan or mega-city cities, such as Jakarta, Bangkok, and Manila (Estoque and Murayama, 2017), Harare (Mushore *et al*., 2017), Tehran (Tayyebi *et al*., 2018), and Nanchang City (Zhang *et al*., 2017).

There have not been many studies on UHI of small cities, with a population of under five hundred thousands. This study, therefore, explains the relationship between LUC and LST in small cities. The small coastal town of Banda Aceh was chosen in this study, in addition to being the National Activity Centre of Indonesia, and also the only central city that was partially damaged by the earthquake and tsunami disaster (Achmad et al., 2018). Identifying the LST relationship with LUC will provide an essential understanding for urban and regional planning process (Kimuku and Ngigi, 2017).

Materials and Methods

Study area

The study was conducted in the administrative area of Banda Aceh City, Aceh Province, Indonesia, geographically located between 5°16'15”- 05036'16"N and 95°16'15' '- 95022'35' 'E. The city has an area of 61.36 km2, with the average height of the urban area at 0.80 meters above sea level, with a population of 249,499 in 2011 (Central Bureau of Statistics, 2015). Banda Aceh City consists of 9 sub-districts and 90 villages. The position Banda Aceh City is very close to the subduction zone, making it vulnerable to earthquakes and tsunamis. Historically most of Sumatra's offshore earthquakes were a boost to the megathrust, as per events on the West Coast of Aceh on December 26, 2004, and the Nias earthquake on March 28, 2005, and later in September 2007 (Burbidge *et al*., 2008). The research location is shown in Fig. 1.

Satellite Imagery

This study used Landsat 5 TM satellite images captured on March 8, 1998, and Landsat 8 OLI/TIRS satellite images dated June 3, 2018 (http://earthexplorer.usgs.gov/). The satellite image was selected based on cloud cover and had cloud cover <10%. This satellite image was used to identify LUC and LST. Especially for LST 2018, LST was calculated using Bands 10 and 11 on Landsat 8 OLI/TIRS Image on January 10, 2018.

LUC Classification

Using Landsat satellite imagery from 1998 and 2018, Banda Aceh's LUC was classified into five categories based on Banda Aceh City's landscape conditions: 1) built-up area, 2) vegetation, 3) waterbody, 4) wetland, 5) bare land. This LUC classification uses ArcGIS®10.1. The classification method used was via maximum likelihood supervised classification. Furthermore, each land use/cover (LUC) map was tested for accuracy using the ERRMAT module in the IDRISI®Selva application, taking reference points from Google Earth in 2002 and 2018. The scores were selected using stratified random sampling.

NDVI, NDBI, and LST mapping

NDVI values were obtained using near-infrared calculations with visible light reflected by plants. NDVI values were obtained by comparing the reduction of near-infrared and visible light data by summing the two data. Making NDVI maps using the ArcGIS®10.1 application. The following equation is used to determine NDVI (Zhang et al., 2017):

$$\text{NDVI}=\frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

where NIR is near infrared Band 4 for Landsat 5 TM and Band 5 for Landsat 8 OLI/TIRS, while RED is band 3 for Landsat TM and Band 4 for Landsat-8 OLI/TIRS (Kikon *et al.*, 2016; Zha e*t al.*, 2003; Kimuku and Ngigi, 2017).

The NDBI values (Zha *et al.*, 2003) are calculated using the following equation 2) (Zhang *et al.*, 2017):

$$\text{NDBI} = \frac{(MIR-NIR)}{(MIR+NIR)} \tag{2}$$

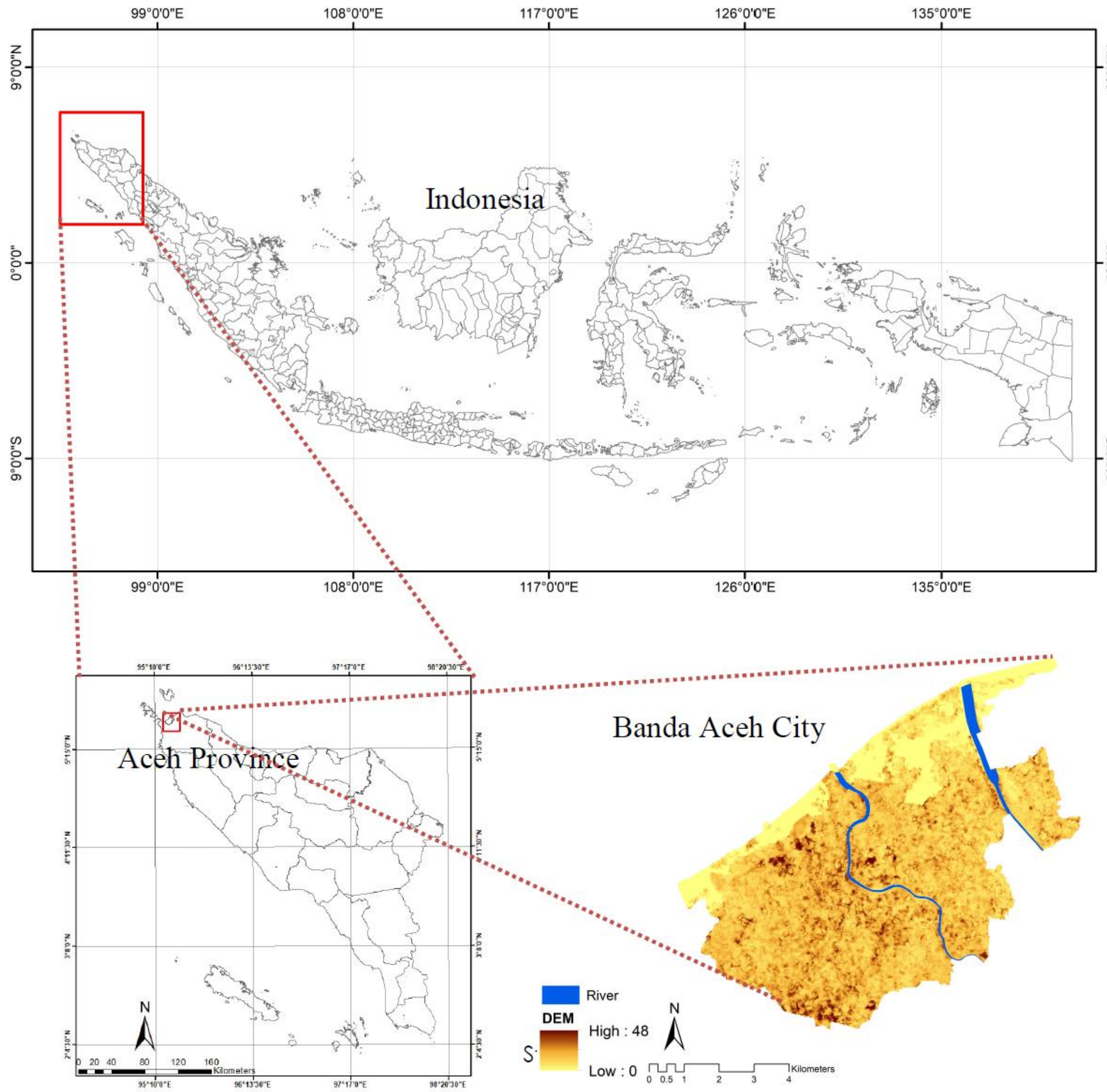


Figure 1. Study area

On Landsat TM, mid infra red (MIR) and near infra red (NIR) used Band 5 and Band 4 (Zha *et al.*, 2003), whereas on Landsat 8 OLI/TIRS, MIR and NIR each used Band 6 and Band 5 (Kikon *et al.*, 2016) (Zha *et al.*, 2003). NDVI is negative or close to zero if the soil surface is in the form of water, a small positive value in baresoil, and a greater positive value on vegetation. Negative NDBI values are generally shown for a water body, close to zero in vegetation, and positive in built-up area (Zha *et al.*, 2003). The LST value is calculated as follows (Equation 3) (Artis and Carnahan, 1982; Zhang *et al.*, 2017):`

$$\text{LST} = \frac{T_B}{1+\left(\lambda\, x \frac{T_B}{\rho}\right) x\ ln\varepsilon} \quad (3)$$

where, for Landsat 5 TM, T_B = Landsat 5 TM Band 6 at satellite-temperature brightness; λ = wavelength of the emitted beam (λ = 11.5 µm, middle wavelength of Landsat TM Band 6); for Landsat 8 OLI/TIRS, TB = Landsat 8 OLI/TIRS Band 10 at satellite-temperature brightness, λ = wavelength of the emitted beam (λ = 10.8 µm, the center wavelength of Landsat 8 OLI/TIRS Band 10) (Estoque et al., 2017); ϱ = h × c / σ (1,438 × 10-2 m K), σ = Boltzmann constant (1,38 × 10-23 J / K), h = Planck constant (6,626 × 10-34 Js), and c = speed of light (2,998 × 108 m/s). In this study, we changed the LST value taken from degrees Kelvin to Celsius (°C).

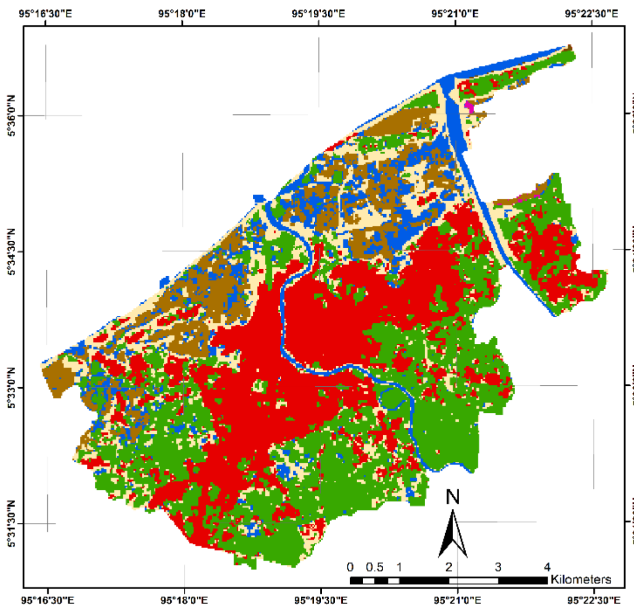
Results and Discussions

The accuracy of a LUC map is influenced by many factors, including image quality, classification methods, and references used in accuracy assessment (Estoque and Murayama, 2011). The classification error is based on the ground truth sample data using Equation 1). The results obtained can be seen in Table 1. The categories of land are classified as water body, built-up area, bare land, vegetation, and wet land. Based on the correct proportions, the overall accuracy for the 1998 LUC was 95% and 2018 LUC was 91%. with kappa coefficients of 0.91 and 0.88, respectively. This accuracy assessment process used ERRMAT module in IDRISI®Selva.

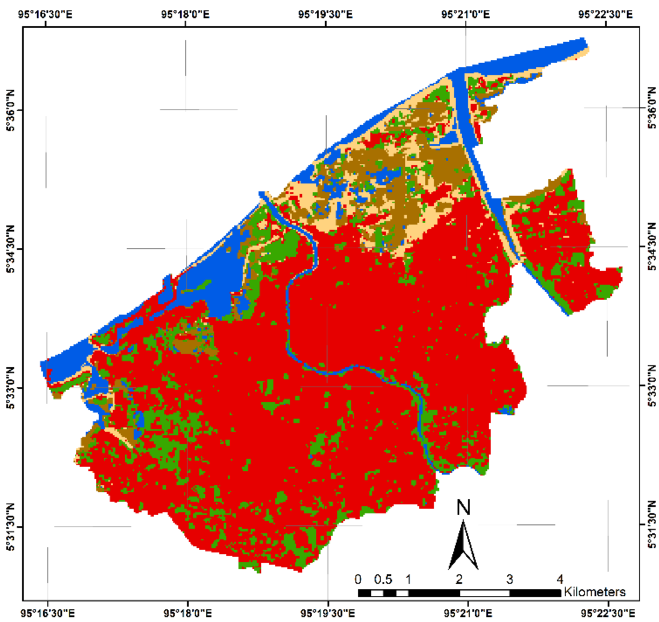
Table 1. Error matrix of LUC classification

LUC Kategori	Reference data						
	Water body	Build-up Area	Bare land	Vegetation	Wet Land	Total	Error
(a) 1998							
Water body	10	0	0	1	0	10	0,028
Build-up Area	0	61	0	0	0	36	0,0000
Bare land	0	0	3	0	0	14	0,0000
Vegetation	0	1	1	14	0	29	0,1818
Wet Land	0	0	2	0	7	11	0,0200
Total	12	31	14	33	10	100	
Error	0,0000	0,0323	0,2143	0,0303	0,0000		
Overall accuracy	95,00						
(b) 2018							
Water body	10	0	0	0	0	10	0,000
Build-up Area	0	28	0	3	0	31	0,2000
Bare land	0	0	11	0	4	15	0,1212
Vegetation	0	1	0	32	0	33	0,0909
Wet Land	1	0	0	0	10	11	0,0100
Total	11	29	11	35	14	100	
Error	0,0909	0,0345	0,0000	0,0857	0,2857		
Overall accuracy	91,00						

Based on Fig. 2, built-up area increased from 31.08% in 1998 to 62.87% in 2018. This shows that there has been an increase in the built-up area up to 100.32% in 20 years. This shows that during this period, there was an increase in urbanization. The high increase of built-up area occurred after tsunami struck Banda Aceh City at the end of 2004. Land for vegetation experienced a wide decline. Fig. 2 shows that the land area for vegetation experienced a very significant decline, from 32.99% to 13.99% or currently around 839 ha. Other categories also experienced declines with varying percentages.



(a) LUC 1998



(b) LUC 2018

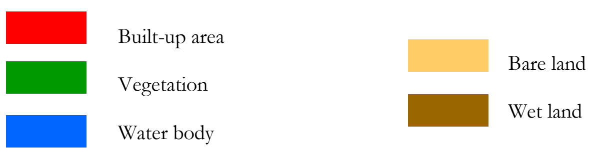


Figure 2. Classified LUC Maps of Banda Aceh City (a) 1998 and (b) 2018

Fig. 3 shows that the LST on June 3, 1998 (03:29:00 GMT) ranged between 21^{0}C and 33^{0}C. The lowest temperature was the LUC's body of water category, while the highest LST was the LUC category of built-up area. The average LST for the city was 26.37^{0}C. Figure 3 also shows the condition of LST on January 10, 2018 (03:52:36 GMT). The lowest LST was 27^{0}C, while the highest LST was 39^{0}C. LST was lowest in LUC vegetation category and highest in LUC category built-up area. The average LST for the city was 32,55^{0}C. This shows that in twenty years there was an average increase of LST of 6.18^{0}C.

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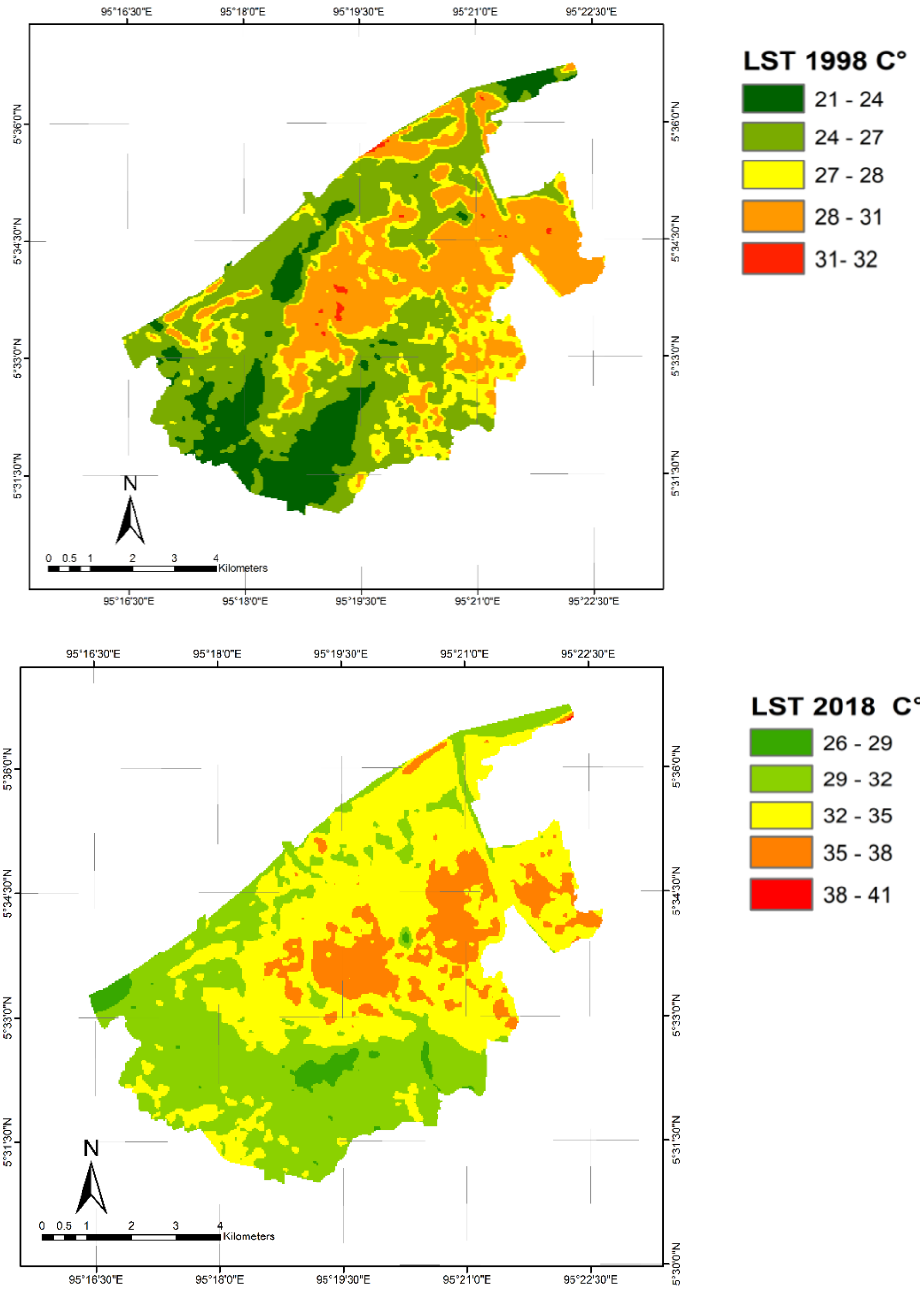


Figure 3. LST Maps of Banda Aceh City in 1998 and 2018

Fig. 4 shows the relationship between LST averages for each LUC category. The built-up area category had the highest average LST, both for 1998 and 2018. An increase in the average LST value occurred in each LUC category. The downtown area had high LST average, while the southern areas of the city had lower LST, both in 1998 and 2018.

NDBI maps of Banda Aceh City for 1998 and 2018 are shown in Fig. 3. NDBI values ranged from -0.60 to 0.39 for 1998. In 2018 NDBI values ranged from -0.29 to 0.18. Scatter plots in each year showed an increasing trend. The higher the NDBI value the LST value will also increase, even with very small R^2 (Fig. 5). Another aspect reviewed was NDVI. Fig 6 shows NDVI scatter plots for 1998 and 2018. NDVI values range from -0.41 to 0.46 for 1998. The NDVI value in 2018 ranged from -0.12 to 0.50. Scatter plots in each year show a decreasing trend. The higher the NDVI value, the lower the LST value, even with a very small R^2.

Fig. 4 shows the relationship between LST averages for each LUC category. The built-up area category

had the highest average LST, both for 1998 and 2018. An increase in the average LST value occurred in each LUC category. The downtown area had high LST average, while the southern areas of the city had lower LST, both in 1998 and 2018.

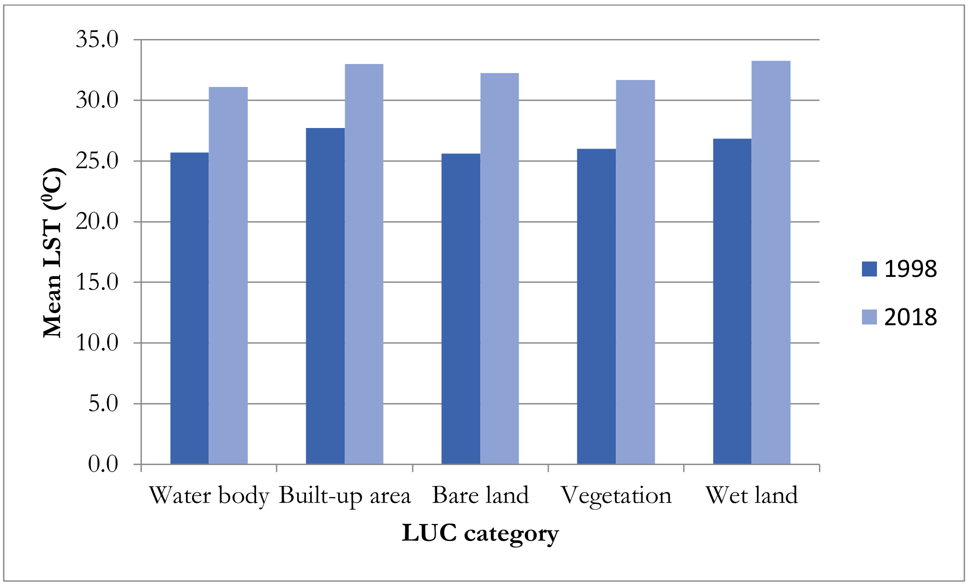
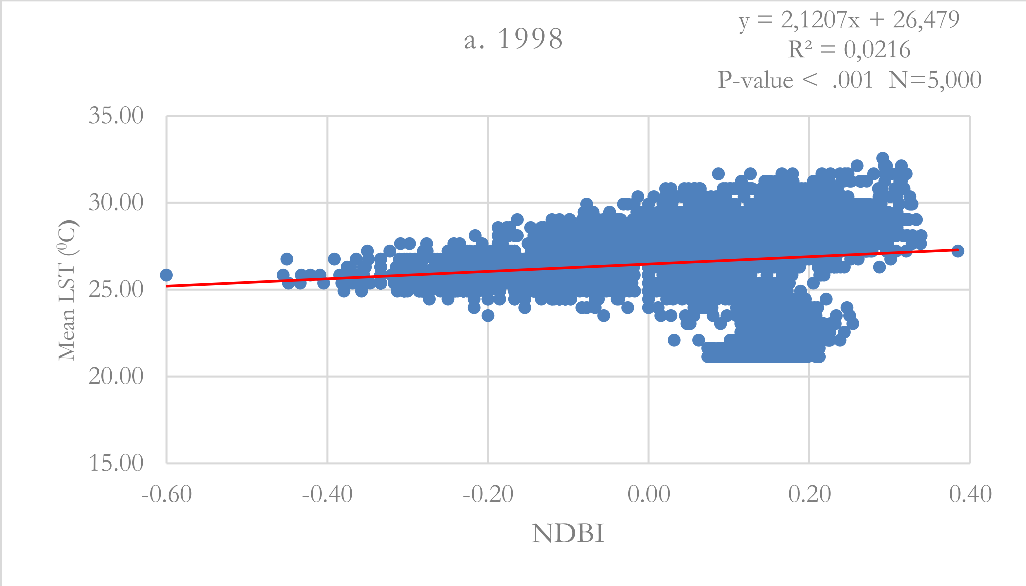


Figure 4. Relationship between LST averages for each LUC category

Based on the results, Banda Aceh City experienced urbanization over twenty years (1998-2018). The growth of the city clearly looks very significant, where the built-up area doubled. Vegetation and bare land were utilized as built-up area, in the form of buildings, roads, and other pavements. In the context of the UHI phenomenon, this is an important consequence (Zhang *et al.*, 2017). Surfaces such as buildings, roads, and other pavements absorb heat from solar radiation more than vegetation (Estoque and Murayama, 2017; Zhang *et al.*, 2017). In 1998, wet land dominated the coastal areas of the city, but by 2018 many wetlands were transformed into bodies of water (sea) categories. This was caused by the tsunami which severely affected coastal areas, so that the wet land was transformed into bodies of water. In addition, there were also settlements which became water body.

Developments took place in almost all parts of Banda Aceh, except in the northern part of the city. The northern part of the city, in accordance with city spatial regulations, functioned as a restricted (low density) area. Settlement growth and built up land in coastal areas were not as dense as before the tsunami (Achmad *et al.*, 2015). This was regulated by the government to minimize and avoid the settlement of victims if the tsunami hits the city again. Land use in the northern coastal areas of the city was utilized for important public facilities, such as ports, schools, and escape buildings. The school building is designed to serve also as evacuation building for evacuation. New development of settlements are is directed away from the coast, so that the eastern and southern parts of the city have become new growth points.

In 2018, built-up area dominated the land use of Banda Aceh city (Fig. 2b). The built-up area covers reached 62.87% of the city area, while vegetation cover only 13.99% of total area. The increasing number of in built-up area also triggered the increase of average LST. This may be caused by the changes in urban microclimate, the utilization of building pavement materials that store heat, and the lack of the implementation of green building principles. High energy consumption in buildings contributes to UHI (Kurniati and Nitivattananon, 2016), although further study is needed, as the size of cities varies considerably. Based on Fig. 5, the higher the NDBI index, the higher the LST (P-value < 0.001) (Estoque and Murayama, 2017 and Zhang, *et al.*, 2017). Both time points show the same condition.



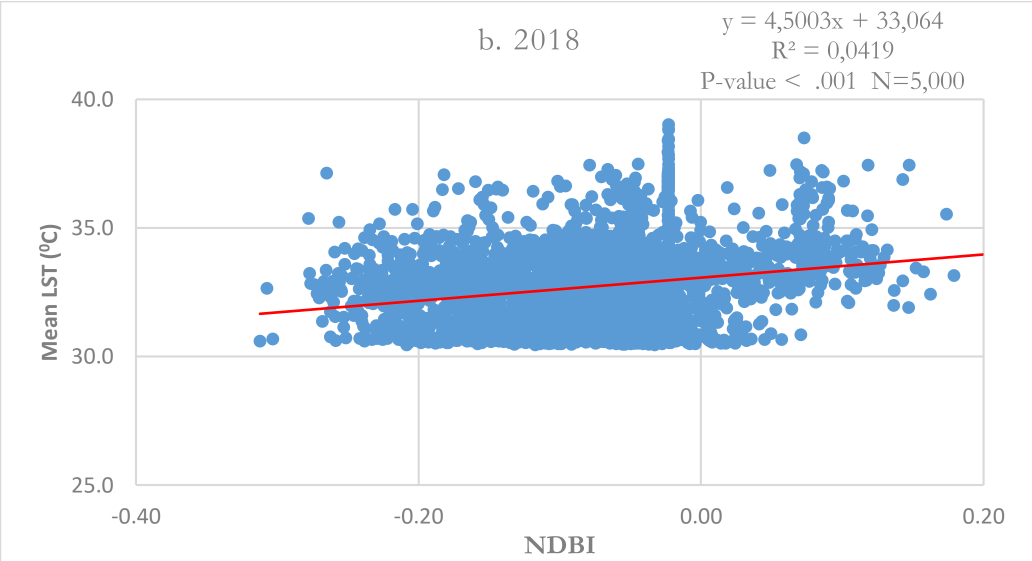


Figure 5. Scatter plots between NDBI and LST in 1998 (a) and 2018 (b)

The scatter plots in Fig. 6 shows a negative relationship between LST and NDVI, which is statistically significant for both time points (P-value < 0.001), 1998 and 2018. This result is consistent with findings from several previous studies (Estoque and Murayama, 2017, Zhang, *et al.*, 2017, Bokaie *et al.*, 2016, Kikon *et al.*, 2016). Based on Fig. 2, the vegetation area in Banda Aceh has decreased in 2018.Vegetation in Banda Aceh are generally located in the city park dominated largely by ornamental plants, shrubs, and plants with a wider canopy. Addition of green space and vegetation cover in urban area will have a significant influence on the thermal conditions of the city and reduce the effects of UHI. Through the evapo-transpiration process, vegetation can adjust and reduce soil surface temperature (Yuan and Bauer, 2007). One effort to reduce the effect of UHI is to increase vegetation cover (Rizwan *et al*, 2008), especially trees (Gaffin *et al*, 2008). Vegetation is useful to reduce the effect of UHI, while the built up area will enhance the UHI effect (Tran *et al.*, 2017).

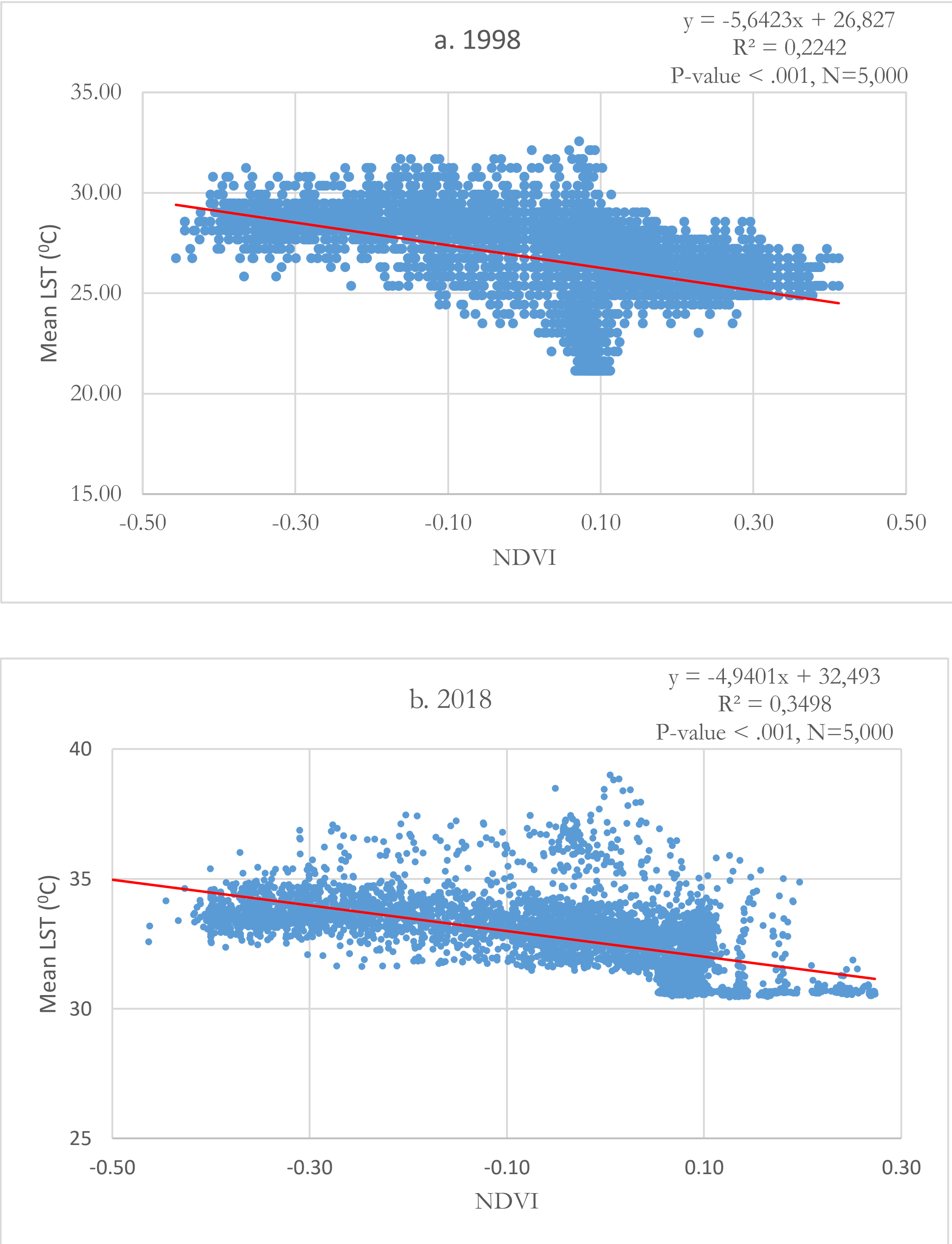


Figure 6. Scatter plots between NDVI and LST in 1998 (a) and 2018 (b)

The average LST in the LUC category was consistently higher for built-up area than other LUC categories (Fig. 3). Varying increases in other categories also occurred. The difference in satellite imagery used in this study also influences LST variations, in addition to the intensity of solar and wind speed. There was a positive significant relationship between LST and NDBI (Estoque and Murayama, 2017; Zhang, *et al.*, 2017; Bokaie, *et al.*, 2016; Kikon *et al.*, 2016). It is different from NDBI, where LST had a negatif relationship to NDVI (Estoque and Murayama, 2017 ; Zhang, *et al.*, 2017; Bokaie, *et al.*, 2016; Kikon *et al.*, 2016).

As a provincial capital, Banda Aceh City continues to experience growth. This growth is characterized by increasing population and building needs for housing, infrastructure and city facilities. Urban development is expected to improve social and economic life of the community, but development activities are also inseparable from the environmental impacts that arise (Estoque and Murayama, 2011). Development is currently being carried out to use bare land and vegetation. Conditions like these should be controlled using existing spatial arrangements, in an effort to create sustainable development, which balances between green spaces and built-up spaces (Mitsova *et al.*, 2011). The density of the city center with the lack of green open space will cause higher temperature and pollution, making life less comfortable (Mitsova *et al.*, 2011) (Gómez-Baggethun and Barton, 2013). For this reason, green spaces need to be planned in urban areas such as the east, southeast and south of the city. This aims to encourage growth in the region so that it can reduce growth trends to the city center. The development of green open space in the northern part of the city, especially in coastal areas, is not to encourage growth, but to minimize the impact tsunamis that may recur (Tanaka *et al.*, 2011; Tanaka, 2009).

Urban planning that takes into account the effects of UHI needs to be done. This is a challenge for city planners and government, especially in developing city plans and designs that can minimize the effects of UHI. The high LST in the built-up area in the city requires policies to build more environmentally friendly urban buildings that are energy efficient and green. The city, as the center of human activities and human activities, is the source of CO_2 emissions and the development of a low carbon city (LCC) city (Yang and Li, 2013), is needed to control LST.

The policy of increasing green space with adequate vegetation is also important in pursuing a sustainable city. Fig. 3 shows that average LST in the vegetation category is lower than the built-up area. Vegetation areas transformed into built-up areas will increase heat reducing evapotranspiration. Green space or vegetation can absorb air emissions, absorb solar radiation, evapotranspiration and even reduce AC consumption. While the consumption of electrical energy can be attributed to carbon emissions, which can lead to an increase in greenhouse gas effect (Kurniati and Nitivattananon, 2016).

Conclusion

This study describes spatial changes and LST patterns that occur in Banda Aceh City, Indonesia between 1998 and 2018. This study is an initial study to investigate the UHI phenomenon. The rising temperatures and changes in urban landscapes that occurred over the past decades have prompted this study. The results showed that changes in LUC occurred in the city of Banda Aceh between 1998 and 2018. In addition, there was also a significant increase in LST during the periods. The increase was very high, overall reaching 5.9^{0}C. The average height of the LST increase involved the city area, which has no forest area. The results may be different if the study included the area around the city of Banda Aceh, i.e. Aceh Besar District. Differences in satellite imagery (Landsat 5 TM and Landsat 8 OLI/TIRS) and wind speed also contributed to the LST value. The built-up area has doubled in two decades. LST in the built-up area category ranged from 30.5^{0}C to 39^{0}C on January 10, 2018, while on March 8, 1998, LST ranged between 21^{0}C to 32^{0}C. As a preliminary study, other variables and subsequent research are needed, to be useful for future regional and city planning processes. Furthermore this study suggests an increase in the quality and quantity of green open spaces, improving green building planning and design, to realize low carbon city, as an effort to mitigate UHI effects.

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