The relationship between land surface temperature and water index in the urban area of a tropical city

A Achmad*, Zainuddin1, M Muftiadi1
1Architecture and Planning Department, Engineering Faculty, Universitas Syiah Kuala, Jl. Tgk. Syech Abdurrauf No. 7, Kopelma Darussalam, Banda Aceh 23111, INDONESIA

*Email: ashfa.achmad@unsyiah.ac.id

Abstract. This study investigated the pattern of urban heat island changes based on the relationship between land surface temperature and the water index in Banda Aceh City for 1998 and 2018. Landsat TM 1998 and Landsat OLI-TIRS 2018 were used in this study, which represents the conditions before and after the tsunami. Analysis of data used Geographic Information System (GIS) and Remote Sensing (RS). The Land Surface Temperature (LST) was negatively related to the normalized difference water index (NDWI).

1. Introduction

In general, urbanization emerged as a driver of economic, social, demographic, and environmental change. Urbanization is characterized by the rapid conversion of agricultural land, vegetation, and water bodies, into a built-up area [1]. This land use/cover (LUC) changes can lead to the emergence of an urban heat island (UHI), the main themes in the study of urban planning [2] [3]. Uncontrolled changes in LUC causes serious environmental problems, where the reduction of vegetation will help form UHI [4].

According to several studies, there are many factors that led to the formation of a UHI, which included the normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), normalized difference water index (NDWI), and population [3] [5]. The land surface temperature (LST) results from the effects of the UHI [6]. NDWI shows the prevalence of regions that have water content in the region recorded using reflectance ratios from NIR and green channels to penetrate light on soil surfaces that have water content and calculate absorptions [7]. NDWI is an indicator of moisture content in vegetation [2]. The higher the vegetation cover, the lower surface temperature [5]. Analysis techniques using Geographic Information System (GIS) and Remote Sensing (RS) are needed in identifying LST and NDWI [3] [5].

The relations between LST with UHI variables have been carried out by many previous researchers, who generally took locations in major urban areas such as as Harare [8], Jakarta, Manila, Bangkok [9], and Tehran [10]. For small cities with tropical climates, it has been studied for Banda Aceh City [11], but it is still limited to the relationship of LST with NDBI and NDVI. The results showed that LST had a positive relationship to NDBI, and had a negative relationship to NDVI [9] [2] [5] [11].

Banda Aceh City is in the tropical area, which lies between the isotherm line in the northern and southern parts of the earth, the area found in 23.5° north latitude and 23.5° south latitude. In the
tropical area, the average air temperature is high because the sun is always vertical, generally, the air temperatures lie between 20-30°C and can even reach 30°C in areas with wet tropical climates, high rainfall, and which get rays of the sun all year long. With these conditions, it is necessary to investigate further the relationship between LST and NDWI in Banda Aceh City. The relationship between LST and NDBI and NDVI has been done before [11].

2. Materials and Methods

2.1. Study location

This research was conducted in the administrative area of Banda Aceh City (61.36 km²) (figure 1), Aceh Province, Indonesia, which is geographically located between 5°16'15" - 05°36'16" N and 95°16'15" - 95°22'35"E. Its position is very close to the subduction zone, which makes this city very vulnerable to earthquakes and tsunamis. Historically most of the Sumatra offshore earthquakes were a boost to the megathrust, such as that which occurred on the West Coast of Aceh on December 26, 2004, the Nias earthquake on March 28, 2005, and more recently in September 2007 (Burbidge et al., 2008). The average height of urban areas is 0.8 meters above sea level, with a population in 2017 of 259,913 inhabitants (https://bandaacehkota.bps.go.id). Banda Aceh City consists of 9 sub-districts, 70 villages, and 20 sub-districts.

![Figure 1. Study area](http://portal.ina-sdi.or.id/home/; http://tides.big.go.id/DEMNAS/)

2.2. 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/) [11]. The satellite images were selected based on a cloud cover, with cloud cover of less than 10%.
2.3. **NDWI**

NDWI is formulated as follows [7] [5] [12] [13]:

\[
\text{NDWI} = \frac{\text{NIR} - \text{MIR}}{\text{NIR} + \text{MIR}}
\]

where MIR = Band 6 (Landsat 8) and Band 5 (Landsat TM); NIR = Band 5 (Landsat 8) and Band 4 (Landsat TM) [5]. There were 5,000 random points were determined in the study area, used for finding the relationship between LST and NDWI for 1998-2018. Scatter plots and linear regression were created for this relationship.

3. **Results and Discussion**

The built-up area increased to 62.87% (1998-2018) [11]. This increase reached 100.32% in 20 years. This indicates that during this period there was an increase in urbanization and land conversion for development. A high increase in the built-up area occurred after the tsunami struck Banda Aceh City in late 2004. The average LST also experienced an increase in this period, which reached 5\(^\circ\)C [11].

Banda Aceh City has experienced an increase in population in twenty years (1998-2018). The growth of the city is clearly visible, marked by a built-up area that increases in width by two times. Land for vegetation and bare land is used as the development of built-up areas, such as for buildings, roads, and other pavements. Surfaces in the structure of roads, buildings, and different pavements soak up more heat from daylight radiation than vegetation [9] [5].

In 1998, wet land dominated the city coastal areas, but in 2018 many wetlands turned into water body (sea) categories. This was caused by a tsunami that was very effective in changing the condition of the coastal area. In addition, there are community settlement areas that fall into the category of built-up areas, which become water bodies [11].

The urban development took place in almost all parts of Banda Aceh City, except in the north-west. The north-west part is developing with low intensity, related to government regulations (2009-2029) which makes this section with low intensity. The growth of settlements and built-up area in coastal areas is not as dense as before the tsunami [14]. This is regulated by the government in order to minimize and avoid casualties if the tsunami hits the city again. Land use in the northern coastal area of the city is only for important public facilities, such as ports, schools, and escape building. For school buildings, a design that can also function as an evacuation site is sought. The construction of settlements is currently directed to locations away from the coast, so that the eastern and southern parts of the city become new growth points [15].

The density of the city centre, with the lack of green open space, will cause high heat and pollution, making the population less comfortable [16] [17]. 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 into those regions so that it can reduce the trend of growth into the city centre. The development of green open spaces in the northern part of the city, especially in the area around the coast is not to encourage growth, but to minimize the impact of tsunamis that may be recurred [18] [19].
Figure 2 shows NDWI maps in 1998 and 2018, while figure 3 shows the relationship between LST and NDWI. The results of the analysis in 1998 and 2018 showed a declining trend. The more positive the NDWI, the lower the LST value. This shows that the more green space will make the temperature
decrease. In 1998, the NDWI value was in the range between -0.55 to 0.60, while in 2018 it is in the range between -0.4 to 0.2. The results from NDWI are indices that have a range of values of -1 for non-water bodies and 1 for water bodies. The LST has a negative relationship with NDWI (\( p < 0.001 \)) for 1998-2018. [5].

![Figure 3](image-url)

**Figure 3.** Scatter plots between LST and NDWI for (a) 1998 and (b) 2018
4. Conclusion
The development of the built-up area of Banda Aceh City in 1998 and 2018 has doubled, indicating that urbanization is significant in this city. As a result of changes in the LUC, there is a UHI effect, which is shown by an increase in the average LST. LST has a significant negative effect on NDWI. We recommend for sufficient allocation of vegetation and water body in the city and applying green city principles. This is done by increasing city parks, ponds which can also function economically, socially and environmentally.

References
[1] H. Ding and W. Shi, “Land-use/land-cover change and its influence on surface temperature: a case study in Beijing City,” *International Journal of Remote Sensing*, vol. 34, no. 15, pp. 5503–5517, Aug. 2013.
[2] W. Chen, Y. Zhang, W. Gao, and D. Zhou, “The Investigation of Urbanization and Urban Heat Island in Beijing Based on Remote Sensing,” *Procedia - Social and Behavioral Sciences*, vol. 216, pp. 141–150, Jan. 2016.
[3] R. C. Estoque and Y. Murayama, “Monitoring surface urban heat island formation in a tropical mountain city using Landsat data (1987–2015),” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 133, pp. 18–29, Nov. 2017.
[4] D. Choudhury, K. Das, and A. Das, “Assessment of land use land cover changes and its impact on variations of land surface temperature in Asansol-Durgapur Development Region,” *The Egyptian Journal of Remote Sensing and Space Science*, Dec. 2018.
[5] X. Zhang, R. C. Estoque, and Y. Murayama, “An urban heat island study in Nanchang City, China based on land surface temperature and social-ecological variables,” *Sustainable Cities and Society*, vol. 32, pp. 557–568, Jul. 2017.
[6] C. Yin, M. Yuan, Y. Lu, Y. Huang, and Y. Liu, “Effects of urban form on the urban heat island effect based on spatial regression model,” *Science of The Total Environment*, vol. 634, pp. 696–704, Sep. 2018.
[7] B. Gao, “NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space,” *Remote Sensing of Environment*, vol. 58, no. 3, pp. 257–266, Dec. 1996.
[8] T. D. Mushore, O. Mutanga, J. Odindi, and T. Dube, “Linking major shifts in land surface temperatures to long term land use and land cover changes: A case of Harare, Zimbabwe,” *Urban Climate*, vol. 20, pp. 120–134, Jun. 2017.
[9] R. C. Estoque, Y. Murayama, and S. W. Myint, “Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia,” *Science of The Total Environment*, vol. 577, pp. 349–359, Jan. 2017.
[10] A. Tayyebi, H. Shafizadeh-Moghadam, and A. H. Tayyebi, “Analyzing long-term spatio-temporal patterns of land surface temperature in response to rapid urbanization in the mega-city of Tehran,” *Land Use Policy*, vol. 71, pp. 459–469, Feb. 2018.
[11] A. Achmadi, L. H. Sari, and I. Ramli, “A study of urban heat island of Banda Aceh City, Indonesia based on land use/cover changes and land surface temperature,” *Aceh International Journal of Science and Technology*, vol. 8, no. 1, pp. 41–51, May 2019.
[12] H. Xu, “Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery,” *International Journal of Remote Sensing*, vol. 27, no. 14, pp. 3025–3033, Jul. 2006.
[13] K. R. Ahmed and S. Akter, “Analysis of landcover change in southwest Bengal delta due to floods by NDVI, NDWI and K-means cluster with landsat multi-spectral surface reflectance satellite data,” *Remote Sensing Applications: Society and Environment*, vol. 8, pp. 168–181, Nov. 2017.
[14] A. Achmad, S. Hasyim, B. Rangkuti, and D. N. Aulia, “Spatial relationship between city center and economic activity center on urban growth in tsunami-prone city: The case of Banda Aceh, Indonesia,” Jurnal Teknologi, vol. 75, no. 1, Jun. 2015.

[15] A. Achmad, M. Irwansyah, and I. Ramli, “Prediction of future urban growth using CA-Markov for urban sustainability planning of Banda Aceh, Indonesia,” IOP Conference Series: Earth and Environmental Science, vol. 126, p. 012166, Mar. 2018.

[16] E. Gómez-Baggethun and D. N. Barton, “Classifying and valuing ecosystem services for urban planning,” Ecological Economics, vol. 86, pp. 235–245, Feb. 2013.

[17] D. Mitsova, W. Shuster, and X. Wang, “A cellular automata model of land cover change to integrate urban growth with open space conservation,” Landscape and Urban Planning, vol. 99, no. 2, pp. 141–153, Feb. 2011.

[18] N. Tanaka, “Vegetation bioshields for tsunami mitigation: review of effectiveness, limitations, construction, and sustainable management,” Landscape and Ecological Engineering, vol. 5, no. 1, pp. 71–79, Feb. 2009.

[19] N. Tanaka, K. B. S. N. Jinadasa, M. I. M. Mowjood, and M. S. M. Fasly, “Coastal vegetation planting projects for tsunami disaster mitigation: effectiveness evaluation of new establishments,” Landscape and Ecological Engineering, vol. 7, no. 1, pp. 127–135, Jan. 2011.