Spatial Analysis of Environmental Critically due to Increased Temperature in The Built Up Area With Remote Sensing

Bandi Sasmito\textsuperscript{1*} and Andri Suprayogi\textsuperscript{1}

\textsuperscript{1}Geodetic Engineering Department, Faculty of Engineering, Diponegoro University, Semarang Central Java, Indonesia

bandy.geo96@gmail.com

Abstract. This study aims to detect the environmental crises phenomena as an effect temperature increases in the built area by remote sensing technology. This study is taking place in Surakarta City, Central Java, Indonesia. The methods are used in this research is to spatially compare the distribution of surface temperature that detected using Land Surface Temperature (LST) algorithm with the distribution of built-up area that detected using Built-Up Index (BU) algorithm. Spatial data are used is multi-temporal satellite imagery of Landsat. The result of this research, the surface temperature is detected an increase in Surakarta City every year. The spread of high temperatures is increasingly and widespread followed by the widespread of Built-Area. The central area of Surakarta City is identified as the most critical environmental area based on the temperature and built the region. The northern border area of the city can also be detected with increased Build-Area distribution and surface temperature distribution.

1. Introduction

A city is a place that functions for the central of peoples activities. The city is the central of government, economics, tourism, and entertain. That’s way city become large and many of development. The development of various fields in urban areas is very rapid than other areas. The magnitude of opportunities to improve the quality of live has made the urban areas become populous. Peoples have been coming from suburb-area and the villager who try their luck in the big city.

This study takes Surakarta City as a study area. Surakarta is also known Solo City. Surakarta City is in Central Java, Indonesia. Surakarta City is growing rapidly which is included in the secondary city in Indonesia. Development of infrastructure is growing with the Hotel, Mall, and others. The development of the city of Surakarta this day can be quite high. The city of Solo also has problems, namely slums, unlicensed dwellings and basic infrastructure needs; regional disparities; limited land; and management capacity [1].

Solo or also called Surakarta is a city in Central Java which has an area of 46 km\textsuperscript{2} is bordered by Karanganyar and Boyolali regencies in the north, Karanganyar and Sukoharjo regencies in the west and east also Sukoharjo regency in the south. In the eastern part of Solo City shows the area of the Bengawan-Solo river. Solo also has a population of 510,077 in 2014. The development of development in this city has increased every year which can be seen from the incessant development of high buildings in recent years is located in the central of Surakarta starting from the construction of malls, and the addition of hotels and apartments. The existence of this event then conducted research on the effect of increasing buildings in the city of Surakarta with temperature changes.
The construction of a central building activity increases every year caused some densely built area resulting in reducing vegetation area. The surfaces of concrete and asphalt replaced the growing variety of vegetation. Air temperature will increase drastically in the built area when compared with areas that are still dominated by vegetation. The nature of the materials used in the construction of urban structures leads to heat emissivity. The heat wastes generated by factories, air conditioners (AC) and motor vehicle fumes contribute also to temperature increase [2–5]. Negative impacts cause environmental criticality that causes increased energy consumption, increased air pollution and greenhouse gases, affect human health and comfort, and disturbed water quality. [6].

Detecting the critically of environment by measuring the density of the built area and temporarily temperature changes will be difficult and consuming much time if done by field measurement. So in this study offers a fast, effective and efficient method of utilizing Remote sensing technology. The general conditions that make this technique more interesting than conventional methods such as data obtained in the form of digital data, the measurement includes a more distributed area compared with conventional measurement only certain points (samples). Remote sensing has advantages such as data obtained in the form of digital data; spatial based, and analysis can cover a large area [7,8]. The method used in detecting the density of the built area is Built-up Index (BU) algorithm, and detecting temperature is Land Surface Temperature (LST) algorithm. Critically of Environment will analyze from BU and LST results in multi-temporal with spatial data.

The result of this research is the spatial analysis of environmental criticism index in Surakarta City and its surroundings by measuring the accumulation of heat energy as the impact of built area density over time and presented in the form of Thematic Map.

2. Method
2.1. Data and Method
This research was conducted in Surakarta City Central Java Indonesia. The data used is Landsat Image. Imagery is downloaded from the USGS (United States Geological Survey) site at http://glovis.usgs.gov/ [9]. The image used in this study is an archive on the path: 120, and row: 65 in which the recording coverage contained Semarang City. The image selected time series 3 years ie on 6 August 2008, August 20, 2013, June 14, 2015, and 11 May 2017. Terms of image selection include cloud coverage less than 20% and in the same month each year. Terms in the adjacent month are used to minimize seasonal differences during image recording. The list of imagery used is shown in Table 1.

| Scene Id         | Date of acquisition | Output format | Data Type |
|------------------|---------------------|---------------|-----------|
| LT51190652008219BKT00 | August 6th 2008     | GEOTIFF       | LIT       |
| LC81190652013232LGN00 | August 20th 2013    | GEOTIFF       | LIT       |
| LC81190652015174LGN00 | June 23th 2015      | GEOTIFF       | LIT       |

Based on the flow chart of the processing method in Figure 1, the first step is to detect Land Surface Temperature (LST). LST is the measurement of how hot (temperature) of the ground surface. Temperature is measured from surface soil emissions due to solar radiation. Soil surface heat emissions are captured by satellite image sensors in the range of thermal infra-red spectra. The sensor converts heat emission into a brightness difference on an imagery band (band). Landsat 8 is one of the images that have a thermal infrared channels, the channel is TIRS (Thermal Infrared Red Sensor) on channel number 10 and 11. In this research LST is made from Landsat Image 8 data of TIRS sensor recording from image data list in Table 1. Before the Landsat image is formed into LST, the conversion of the original Digital Number (DN) image becomes Spectral Radiance. Step conversion of Landsat 8 DN TIRS to Spectral Radiance Value using Equation (1). [9]
\[ L\lambda = MLQ_{\text{cal}} + AL \] (1)

\( L\lambda \) : Value of Spectral Radiance,
\( ML \) : Radiometric rescaling group on radians mult band
\( Q_{\text{cal}} \) : Digital Number TIRS Band,
\( AL \) : Radiometric rescaling group on radians add band

\[ T_s = \frac{K_2^2}{\ln\left(\frac{K_1}{L\lambda + 1}\right)} \] (2)

\( T_s \) : LST in Kelvin unit,
\( K_1, K_2 \) : Calibration Constants of Spectral Radiance
\( L\lambda \) : Value of Spectral Radiance

**Figure 1.** Flow chart of processing method

Next is the radiance values obtained from Equation (1) are converted to LST temperature values, the temperature values having a Kelvin unit. LST is obtained by applying the Planck algorithm as shown in Equation (2) [9–11].
The LST temperature value in the Kelvin (K) unit is converted to degrees Celsius (C) using Equation (3). The reason used is Celsius because it has a better range for clarity in image interpretation [2]. Figure 2 shows the distribution of surface temperature from three different years in the study area.

\[
T(C) = T(K) - 273.15
\]  

(3)

\(T(C)\) : LST in Celsius Unit,
\(T(K)\) : LST in Kelvin, and value of 273.15 is the constant to convert Kelvin into Celsius

![LST August 6th 2008](image1)

![LST August 20th 2013](image2)

![LST June 23rd 2015](image3)

**Figure 2.** Land Surface Temperature (LST) Multi Temporal of Surakarta City.

Next is to build a Build-Up Area (BU) index which is derived from the differential of the Normalized Difference Build-up Index (NDBI) and Normalized Difference Vegetation Index (NDVI). Prior to the original NDVI processing, the Landsat original image corrected the Top of Atmospheric (TOA) radiometric, this correction was made to improve the visual quality of the image and simultaneously improve the pixel values that did not match the actual reflectance or spectral value of the object. Band 4 (visible RED) and band 5 (NIR) are given a correction with Equation (4) [9].

\[
\rho_{\lambda} = \frac{M_{\rho}Q_{cal}+A_{\rho}}{SIN(\theta_{SE})}
\]  

(4)

\(\rho_{\lambda}\) : Corrected pixel value Top Of Atmosphere (TOA) reflectance,
\(M_{\rho}\) : Band-specific rescaling factor multiplication of metadata,
\(A_{\rho}\) : Band-specific rescaling additive factor from metadata,
\(Q_{cal}\) : Digital Number (DN) Band, and
\(\theta_{SE}\) : sun angle during image recording.
According to Zha et al. [12] uses the NDVI analogy to develop a built-in area index called the Normalized Difference Built-up Index (NDBI) used to calculate the Built-up area. The NDBI index will focus on highlighting urban areas or built areas where there is usually a higher reflection in the Short-Wave Infrared (SWIR) area when compared to Near-Infrared (NIR) areas. Near Infrared is very sensitive to detect vegetation, whereas the reflectance for open land and built land is very low. Short Wave Infrared (SWIR) can reflect moisture content on various land uses. Therefore, NDBI utilizes both bands. NDBI spectral range values range from 0.1 to 0.3. Equation (5) describes the method of calculating NDVI.

\[ NDBI = \frac{(\rho_{SWIR} - \rho_{NIR})}{(\rho_{SWIR} + \rho_{NIR})} \]  

\( \rho_{NIR} \) : Value of reflectance SWIR,  
\( \rho_{RED} \) : Value of reflectance NIR

NDVI is well known and widely used. NDVI was first revealed by Rouse in 1973 [13,14]. NDVI is an index that describes the greenness of a plant. The vegetation index is a mathematical combination between a red band and NIR (Near-Infrared Radiation) band. Vegetation appears dark in the visible but visible in the near infrared wavelength range [2]. NDVI is calculated on a per-pixel basis of the normalization difference between the red-spectral band of sight and near-infrared/NIR in the image.

In calculating NDVI, the red band represents the visible spectrum compared to the infrared (NIR) spectrum. Equation (6) describes the method of calculating NDVI.

\[ NDVI = \frac{(\rho_{NIR} - \rho_{RED})}{(\rho_{NIR} + \rho_{RED})} \]  

\( \rho_{NIR} \) : Value of reflectance NIR,  
\( \rho_{RED} \) : Value of reflectance Visible-Red.

Build-Up (BU) Index is built from the difference between NDBI and NDVI. The wake area will stand out if the reflectance of the vegetation is reduced. Equation (7) describes the method of calculating Build-Up (BU) Index. Figure 3 describes the Build-Up Index of three different times. [12]

\[ BU_{area} = NDBI - NDVI \]  

NDBI : Normalized Difference Built-up Index,  
NDVI : Normalized Difference Vegetation Index

From LST and BU data, the ECI (Environmental Criticality Index) is identified. Senanayake et al (2013) established the ECI by comparing the LST value with the availability of vegetation cover (NDVI algorithm). The spatial layers of LST and NDVI before being compared first equate their spectral values. Spectral values are equated by spreading the pixel value histogram equalization to 1-255 to increase the clarity and contrast of the spatial layer to avoid the limitations of the ECI index value due to the value 0 on the pixels of the NDVI algorithm. The ECI equation is described in equation (8) [2].

\[ ECI_{(LST-VEG)} = \frac{LST_{(Streched 1-255)}}{NDVI_{(Streched 1-255)}} \]  

ECI : Environmental Critically Index,  
LST (Streched 1-255) : LST stretched to 1-255,  
NDVI (Streched 1-255) : NDVI stretched to 1-255.
While in this research will use the Senanayake’s analogy [2], the difference is using Built-Up Index. From Figure 2 and Figure 3 we can assume LST and BU distribution is directly proportional or it can be said that LST distribution follows BU distribution so that ECI algorithm will be adjusted, ECI will be directly proportional to Built-Up (BU) Index. For that reason the ECI equation will be modified will not dividing LST by BU but multiplying LST and BU. The ECI equation with the BU index is described in equation (9).

\[
ECI_{(LST-BU)} = LST \times BU
\]  

While in this research will use the Senanayake’s analogy [2], the difference is using Built-Up Index. From Figure 2 and Figure 3 we can assume LST and BU distribution is directly proportional or it can be said that LST distribution follows BU distribution so that ECI algorithm will be adjusted, ECI will be directly proportional to Built-Up (BU) Index. For that reason the ECI equation will be modified will not dividing LST by BU but multiplying LST and BU. The ECI equation with the BU index is described in equation (9).

\[
ECI_{(LST-BU)} = LST \times BU
\]

ECI : Environmental Critically Index,  
LST : Value of LST  
BU : Value of BU

The results of the ECI algorithm with BU Index are shown in Figure 4. The red colour indicates a higher vulnerability index which means the wake area will result in increased temperature.
Figure 4. Multi Temporal of Environmental Critically Index (ECI) of Surakarta City.

2.2. Validation
The validation in the field is based on the temperature classes. The Classes has been made previously on the Land Surface Temperature map and evenly distributed the sample point. Temperature sampling is done one by one at each point of the plan by using two temperature measuring devices such as the infrared thermometer. The devices look like in Figure 5.

Figure 5. Infrared Thermometer using in temperature validation
Validation is done following the Landsat 8 tracks. The satellite passes above the equator at ± 10.00 GMT +7. The validation survey shall be conducted within 2 hours from 09.00 - 11.00 hours. Each of the two devices is measured at the planned sample point then recorded according to the sample location point. Meanwhile, position measurement used handheld Global Positioning System tool.

3. Result

The result of surface distribution analysis (LST) as shown in Figure 2 shows that the area of Surakarta City has significant temperature difference to the surrounding area. Surface temperature distribution (LST) according to previous studies indicates higher temperatures are present in densely built areas [15,16]. The surface of the concrete in buildings more absorbs heat energy than to reflect it so as to make the temperature rise in the area around the building [2,17].

The distribution of Build-Up Area shown in Figure 3 shows that from year to year the area built in Surakarta City is increasingly widespread and penetrated into other administrative areas around the border. In accordance with previous research, the distribution of vegetation density is inversely related to the rise in surface temperature (LST) [2,17].

The diminished vegetation and rising temperatures affect the quality of the environment. Environmental quality is assessed by the ratio result index of LST and NDVI, a ratio called the Environmental Criticality Index (ECI) [2]. ECI results Figure 4 shows the distribution of high critical classes in the central city area and spread to areas adjacent to other districts. The high environmental criterion resulted from the ECI algorithm was identified as a hot island (UHI) [18–20]. To clarify the critical area due to UHI is done the overlay with a map that has a larger scale. ECI maps are only used in the next "High" class in overlays with maps from OpenStreet Map, shown in Figure 5 and Figure 6.

![Figure 6. A) Environmental Critically Index (ECI) in central of Surakarta City. (B) Environmental Critically Index (ECI) border of Surakarta City.](image)

The Map of Environmental Criticality Index in Figure 4, it can be seen that a region with high criticality is indicated by the phenomenon of the hot island (UHI) [18–20]. The environmental critique of the "High" class is overlaid with OpenStreetMap to show the most critical areas of Surakarta. The central area with surrounding infrastructure is identified as having high critically and severe heat islands (UHI), the spatial distribution is shown in Figure 6 (A).

In Figure 6(B) describe the border area of Surakarta also seen to be critical. The expansion of the city to the border is accompanied by the level of environmental critically. In this figure, the city expansion seems more dominant towards the south.
The relationship of LST temperature processing results to the temperature of the field validation can be known by using a simple linear regression test. This test yields an equation that can infer a relationship or not from both aspects. Here is the result of simple linear regression of LST temperature processing relationship and Surakarta field temperature.

The relationship of LST temperature processing results to the temperature of the field validation can be known by using a simple linear regression test. This test yields an equation that can infer a relationship or not from both aspects. Here is the result of simple linear regression of LST temperature processing relationship and Surakarta field temperature.

![Figure 7. Linier regression of LST to survey of field temperature](image-url)

**Figure 7.** Linier regression of LST to survey of field temperature
Figure 7, describes the relationship between temperature processing of LST and field temperature using infrared thermometer tool which regression equation is $y = 0.7514x + 9.277$. The positive sign on the equation states that there is a direct correlation between LST and the field temperature with the coefficient of determination of $R^2 = 0.6947$ or 69.47%.

4. Conclusion
Surface temperature in Surakarta City increases every year and the spread of high-temperature class is increasingly widespread in line with the extent of Built-Area distribution in every year. The phenomenon of the rise in temperature indicates a direct relationship with the number of Built-Up Areas, in accordance with previous studies by [2,15,16,18–20]. The environmental criterion due to temperature is directly proportional to the vegetation density.

The central area of Surakarta City is identified as the most critical environmental area based on the temperature and built the region. The development of the city towards the south can also be detected by increasing the distribution of the built area and the surface temperature.

The environmental critically index model with LST and Built-Up Index algorithms can be utilized and adopted in other urban. The results of the environmental index criterion assessment can be recommended as one of the complementary data in urban development and planning.

References
[1] Adhi I S 2016 Development of the city the city of Solo became a reference in urban development planning in Indonesia Solopos.com 2016 Available from: http://www.solopos.com/2016/05/25/pembangunan-kota-kota-solo-jadi-rujukanperencanaan-dan-rancangan-ruang-perkotaan-722909
[2] Senanayake I P, Welivitiya WDDP and Nadeeka PM 2013 Urban Climate Remote sensing based analysis of urban heat islands with vegetation cover in Colombo city Sri Lanka using Landsat-7 ETM + data Urban Climate (Elsevier B V) 2013 5:19–35 Available from: http://dx.doi.org/10.1016/j.uclim.2013.07.004
[3] Fazeli R, Ruth M and Davidsdottir B 2016 Urban Climate Temperature response functions for residential energy demand – A review of models Urban (Elsevier BV) 2016 15:45–59 Available from: http://dx.doi.org/10.1016/j.uclim.2016.01.001
[4] Li X and Norford L K 2016 Urban Climate Evaluation of cool roof and vegetations in mitigating urban heat island in a tropical city Singapore Urban Climate (Elsevier B V) 2016 16:59–74 Available from: http://dx.doi.org/10.1016/j.uclim.2015.12.002
[5] Isima K, Chan A, Aekbal S, Chel M, Ooi G and Yaasiin M 2016 Urban Climate Numerical study on the urbanisation of Putrajaya and its interaction with the local climate over a decade Urban Climate (Elsevier B V) 2016 16:1–24
[6] EPA 2008 Reducing Urban Heat Islands: Compendium of Strategies Urban Heat Island Basics 2008 1–22.
[7] Loveland T R and Irons J R 2016 Remote Sensing of Environment Landsat 8: The plans, the reality, and the legacy Remote Sensing Environment (Elsevier B V) 2016 m185:1–6 Available from: http://dx.doi.org/10.1016/j.rse.2016.07.033
[8] Roy D P, Wulder M A, Loveland T R, Woodcock C E, Allen R G and Anderson M C 2014 Remote Sensing of Environment Landsat-8: Science and product vision for terrestrial global change research Remote Sensing Environment (Elsevier B V) 2014 145:154–72 Available from: http://dx.doi.org/10.1016/j.rse.2014.02.001
[9] USGS 2015 Landsat 8 (L8) data users handbook Vol. 8 USGS 2015 1993-1993 p
[10] Li Y, Zhang H and Kainz W 2012 International Journal of Applied Earth Observation and Geoinformation Monitoring patterns of urban heat islands of the fast-growing Shanghai metropolis, China : Using time-series of Landsat TM / ETM + data International Journal of Applied Earth Observation and Geoinformation (Elsevier B V) 2012 19:127–38 Available from: http://dx.doi.org/10.1016/j.jag.2012.05.001
[11] Shahmohamadi P, Che-Ani A I, Abdullah N A G, Tahir M M, Maulud K N A and Mohd-Nor M F I 2010 The link between urbanization and climatic factors: A concept on formation of urban heat island *WSEAS Transactions On Environment And Development* 2010 6 (11):754–68.

[12] Zha Y 2003 Use of normalized difference built-up index in automatically mapping urban areas from TM imagery *International Journal Remote Sensing* 2003 24:583–94 Available from: https://is.muni.cz/el/1431/podzim2012/Z8114/um/35399132/35460312/ndbi.pdf

[13] Gonsamo A and Pellikka P 2012 The sensitivity based estimation of leaf area index from spectral vegetation indices *ISPRS Journal of Photogrammetry and Remote Sensing* 2012 70 (15) :25

[14] Julien Y, Sobrino J A, Mattar C, Noz N and Oria G S 2011 Temporal analysis of normalized difference vegetation index (NDVI) and land surface temperature (LST) parameters to detect changes in the Iberian land cover between 1981 and 2001 *International Journal Remote Sensing* 2011 32 (7):2057–68.

[15] Sharma R and Joshi P K 2016 Mapping Environmental Impacts of Rapid Urbanization in the National Capital Region of India using Remote Sensing Inputs *Urban Climate* 2016 15:70–82

[16] Lauwaet D, De Ridder K, Saeed S, Brisson E, Chatterjee F, Van Lipzig N P M, Maiheu B and Hooyberghs H 2016 Assessing the current and future urban heat island of Brussels *Urban Climate* 2016 15 pp: 1-1:1–15.

[17] Comarazamy D E, González J E, Luvall J C, Rickman D L and Mulero P J A 2010 Land-atmospheric interaction study in the coastal tropical city of San Juan Puerto Rico *Earth Interaction* 2010 14 (16)

[18] Sarrat C, Lemonsu A, Masson V and Guedalia D 2006 Impact of urban heat island on regional atmospheric pollution *Atmospheric Environment* 2006 40 (10):1743–58

[19] Kikegawa Y, Genchi Y, Kondo H and Hanaki K 2006 Impacts of city-block-scale countermeasures against urban heat-island phenomena upon a building’s energy-consumption for air-conditioning *Applied Energy* 2006 83 (6):649–68

[20] Liu L and Zhang Y 2011 Urban heat island analysis using the landsat TM data and ASTER Data: A case study in Hong Kong *Remote Sensing* 2011 3 (7):1535–52.

**Acknowledgments**

The authors are grateful to the support of the Laboratory of the Department of Geodesy Engineering - Faculty of Engineering, Diponegoro University, and USGS and NASA in Landsat data collection.