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## Spatial Model of Micro Climate Assessment and Recommendation of Mitigation In Semarang City With Remote Sensing Technology

To cite this article: B Sasmito *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **313** 012037

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# Spatial Model of Micro Climate Assessment and Recommendation of Mitigation In Semarang City With Remote Sensing Technology

**B Sasmito, A Suprayogi, M Awaluddin, S P Darlina, N D Andani, I O P Kalinda**

<sup>1</sup>Geodetic Engineering Department, Faculty of Engineering, Diponegoro University, Semarang Central Java, Indonesia

E-mail : bandy.geo96@gmail.com

**Abstract.** The city of Semarang is one of the 10 major cities in Indonesia that are developing towards the metropolis. Urban infrastructure develops, resulting in the use of vegetation land to be converted into build up land. The increasingly hot climate of the city will disrupt the comfort of residents. Urban design and planning should consider land use change. Good planning will have a very good effect on the city's climate system. This study aims to examine the phenomenon of micro-climate change in the city with the algorithm of the Temperature Heat Index (Leisure Index). The assessment starts from the Land Surface Temperature algorithm, from here model of Urban Heat Island (UHI) can be done. The distribution of UHI phenomena is derived from Land Surface Temperature. The UHI mitigation recommendation for Semarang City is based on land cover. The method used is the Remote Sensing approach through some spatial data extraction from satellite imagery. Data processing is done by using multi-temporal data of Landsat 8 satellite imagery. The result is presented in thematic map of LST, UHI, and Mitigation model map. Mitigation that can be done is the physical modification of the building, like the use of material with high albedo, the application of green wall, green roof, greening parking lots, and the addition of vegetation around the building and along the road. Besides, it is also necessary to monitor the change of land function and its suitability with the Urban Land use Plan of Semarang City.

**Keywords:** Land surface temperature, temperature heat index, urban heat island

## 1. Introduction

The development of the city leads to negative consequences on several aspects, including environmental aspects. The increase in the number of urban residents also means an increase in space requirements. Since space not increase, what happens is land use change, which tends to decrease the proportion of lands previously green open spaces. Reduced vegetation causes a change in the climate element one of them temperature. These changes are very important to be considered in the design and planning of the city in the long run. On the other hand, the urban development planning system in Indonesia, the climatic element is still regarded as a static element, where it is assumed that there is no interaction between climate and land use change. Climatic data is more often used as data that supports the land suitability statement and location for the development of a function of a region, especially for the development of agricultural areas. But in the design and planning of urban areas in Indonesia, it is



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hardly ever considered that planned land use changes will have enormous implications for the climate system. Waste of heat generated by factories, Air Conditioners (AC) and motor vehicles in urban areas also contribute to the increase in temperature. [1–4]

Semarang city is one of the 10 major cities in Indonesia that developed to Metropolis City. Urban infrastructure develops, resulting in land use dominated by constructed land and reduced vegetation cover. Development changed the characteristics of microclimate because it changed the natural environment elements into artificial elements. One important factor that is changed is thermal comfort. This indicates a decline in the quality of comfort of the population. The microclimate changes with periodic temperature increases resulted in a decrease in the comfort of the city to live in which ultimately triggered negative impacts causing environmental criticality resulting in increased energy consumption, increased air pollution and greenhouse gases, affecting human health and comfort, and disturbed water quality [5]. The assessment of the phenomenon of climate change in the city needs to be done to mitigate the deterioration of the city climate and can be used as a supporting data of long-term urban planning [6–9].

Remote sensing is a science or art to obtain data and information from an object on the surface of the earth by using a tool that is not directly related to the object it studied, one of the utilization of remote sensing technology is to obtain a visual data which will be processed and used for various interests.[10] Spatial data from satellite imagery has been widely used to map the effect of human activity on the environment using Remote Sensing systems as a tool [11–14]. The link between microclimate and thermal comfort has been widely developed in several bio meteorological indices, in this study used Temperature Humidity Index (THI).

The results of the expected processing are, in the first year, the Semarang City Environmental Assessment Model based on Temperature Humidity Index (THI) of Semarang City presented spatially (Thematic Map), and in the second year Recommendation of mitigation by determining the utilization of green open land and green roof based on spatial data created in the first year.

## 2. Data and Method

This research was conducted in Semarang City Central Java Indonesia. The data used is Landsat Image. Imagery is downloaded from the USGS (United States Geological Survey) site at <https://earthexplorer.usgs.gov/> [15]. The image used in this study is an archive on the path: 120, and row: 65 in which the recording coverage contained Semarang City. Image selected time series 3 years ie on August 16<sup>th</sup> 2009, August 27<sup>th</sup> 2013 ,and August 22<sup>nd</sup> 2017. Terms in the adjacent month are used to minimize seasonal differences during image recording. The list of imagery used is shown in Table 1.

**Table 1.** List of Landsat Imagery used in this Study

| Scene Id                                 | Acquisition                  | File format | Data Type |
|------------------------------------------|------------------------------|-------------|-----------|
| LC05_L1TP_120065_20090816_20161022_01_T1 | August 16 <sup>th</sup> 2009 | GEOTIFF     | L1T       |
| LC08_L1TP_120065_20130827_20170502_01_T1 | August 27 <sup>th</sup> 2013 | GEOTIFF     | L1T       |
| LC08_L1TP_120065_20170822_20170911_01_T1 | August 22 <sup>nd</sup> 2017 | GEOTIFF     | L1T       |

Land Surface temperature extraction on Landsat imagery is performed using thermal sensors, band 6 for Landsat 5 and band 10 for Landsat 8. In this research LST is made from Landsat Image data of TIRS sensor recording from image data list in Table 1. Landsat image is formed into LST using Equation (1), (2) and (3) [15].

$$L_{\lambda} = M_L Q_{cal} + A_L \quad (1)$$

$L_\lambda$  : Value of Spectral Radiance,  
 $ML$  : Radiometric rescaling grup on radians mult band  
 $Q_{cal}$  : Digital Number TIRS Band,  
 $A_L$  : Radiometric rescaling grup on radians add band

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) [15].

$$Ts = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

$T_s$  : LST in Kelvin unit,  
 $K_1 K_2$  : Calibration Constanta of Spectral Radiance  
 $L_\lambda$  : Value of Spectral Radiance

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 [21]. Figure 2 shows the distribution of surface temperature from three different years in the study area.

$$T(C) = T(K) - 273.15 \quad (3)$$

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

the equations used to estimate the air temperature is [16]:

$$Ta = Ts - \left( \frac{H \cdot raH}{\rho_{air} \cdot Cp} \right) \quad (4)$$

$H$  : Air Heating Flux (Wm-2)  
 $raH$  : Aerodynamic Resistance  
 $\rho_{air}$  : Humid air density (1.27 kg m-3)  
 $Cp$  : Heat specific heat at constant pressure (1004 J Kg-1 K-1)  
 $T_s$  : Surface temperature (°C)  
 $T_a$  : Air temperature (°C)

Aerodynamic Resistance uses the formula  $31.9 \times u^{-0.96}$ ,  $u$  for water bodies is 2.01,  $u$  for vegetation is 1.79 and for non-vegetation is 1.41. The Temperature Humidity Index is an index of degrees Celsius as a quantity that can be associated with the thermal comfort level perceived by the human population in urban areas. Temperature Humidity Index is a method used to determine the existence of heat stress and determine the effect of heat conditions on human comfort that combines temperature and humidity. The influence of the state of the atmospheric physical environment or climate on humans is expressed in terms of comfort. Climate factors that affect human comfort are air temperature, solar radiation, rainfall and humidity. However, in determining the thermal comfort level of a region or region not all climate parameters can be used directly. There are three conditions in the modified comfort index for tropical climates, based on the study [17] ie, comfortable conditions at THI range 21-24 ° C, moderate conditions at THI range 25 - 27 ° C, and uncomfortable conditions in the THI

range  $> 27^{\circ}\text{C}$ . THI determination or comfort index can be determined from the value of air temperature ( $^{\circ}\text{C}$ ) and humidity (RH) with the following equation:

$$\text{THI} = 0.8T_a + \frac{(\text{RH} \times T_a)}{500} \quad (5)$$

THI : Temperature Humidity Index

$T_a$  : Air Temperature ( $^{\circ}\text{C}$ )

RH : Relative Humidity (%)

The THI classification used is a combination of the results of the research [18] and [19], here's the classification as illustrated in Table 2.

**Table 2.** THI Value Range

| THI Value Range ( $^{\circ}\text{C}$ ) | Information           |
|----------------------------------------|-----------------------|
| $< 20$                                 | Un comfort (too cool) |
| 20 to 24                               | Comfort               |
| 24 to 26                               | Quite comfort         |
| $> 26$                                 | Un comfort (too hot)  |

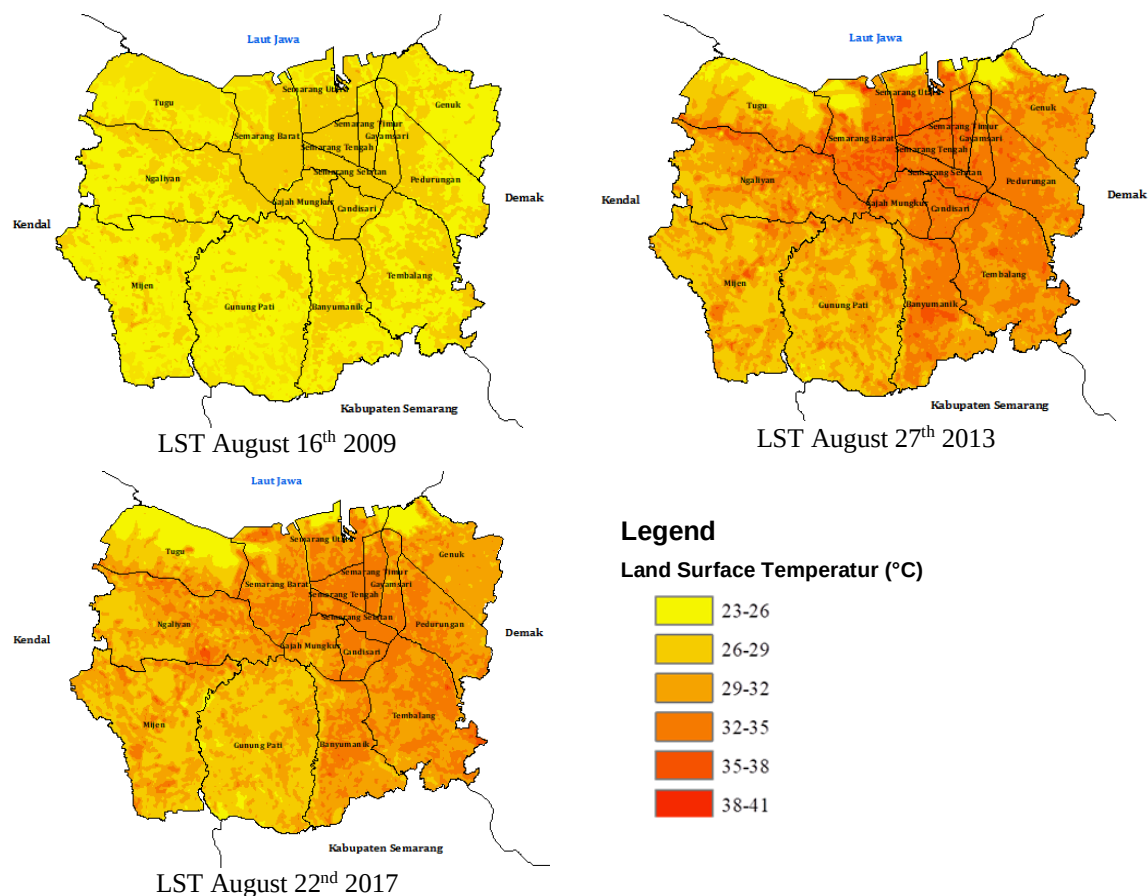
The identification of Urban Heat Island phenomenon is done by threshold of Land Surface Temperature (LST) result in year of 2017. From surface temperature data is done identification UHI phenomenon by subtracting with UHI threshold value according to Ma Y, Kuang Y and Huang N [20]. with the following equation:

$$\begin{aligned} T &> \mu + 0,5 \alpha \\ 0 &< T \leq \mu + 0,5 \alpha \end{aligned} \quad (6)$$

The design of UHI mitigation is done by considering land cover to know the surface condition and design of Urban Planning of Semarang City. In Indonesia mention Urban Planning is *Rencana Tata Ruang Wilayah* (RTRW). This data used for knowing where is the planned spatial planning by government in UHI affected area.

### 3. Result and Discussion

The result of surface distribution analysis (LST) as shown in Figure 2 that the area of Semarang 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 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].

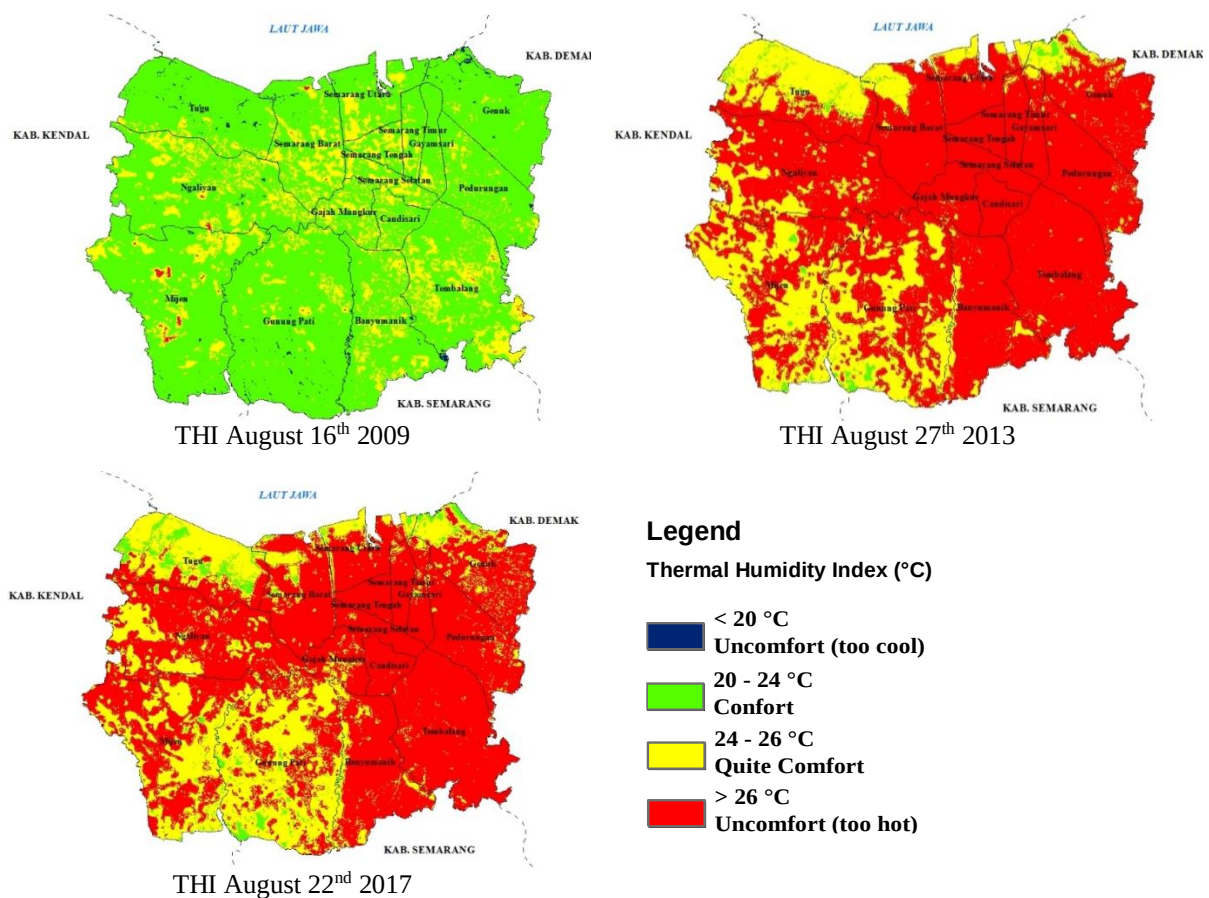


**Figure 1.** Land Surface Temperature (LST) Multi Temporal of Semarang City.

Based on Figure 1, there is an increase in the surface temperature value of 2009 up to 2017. Distribution of surface temperature of processing in 2017 more dominant than the results of processing in 2013 on temperature range 23-26 °C, 26-29 °C, and 29-32 °C. However experienced a decrease in the area compared to processing results 2013 at temperature range 32-35 °C, 35-38 °C and 38-41 °C showed in Graphic 1. This shows that the distribution of surface temperature is high more abundant in the results of the year 2013, due to the number of fire events in 2013.

In 2009 thermal comfort conditions of the City Semarang is in the comfortable category with range values of 20-24 °C whereas in 2013 and 2017 have thermal comfort conditions with uncomfortable conditions (overheated) with values > 26 °C. Decrease thermal comfort from 2009 to 2013 and 2017 occurred throughout the district, Thermal Humidity Index in Figure 2.

However, the thermal comfort level from 2013 to 2017 has decreased the value of the index on average which means an increase in comfort, this is because the value of thermal comfort level influenced by air temperature while the air temperature is affected by the surface temperature. Increased thermal comfort from 2013 to 2017 occurred throughout the district except Mijen District.



**Figure 2.** Thermal Humidity Index (THI) Multi Temporal of Semarang City.

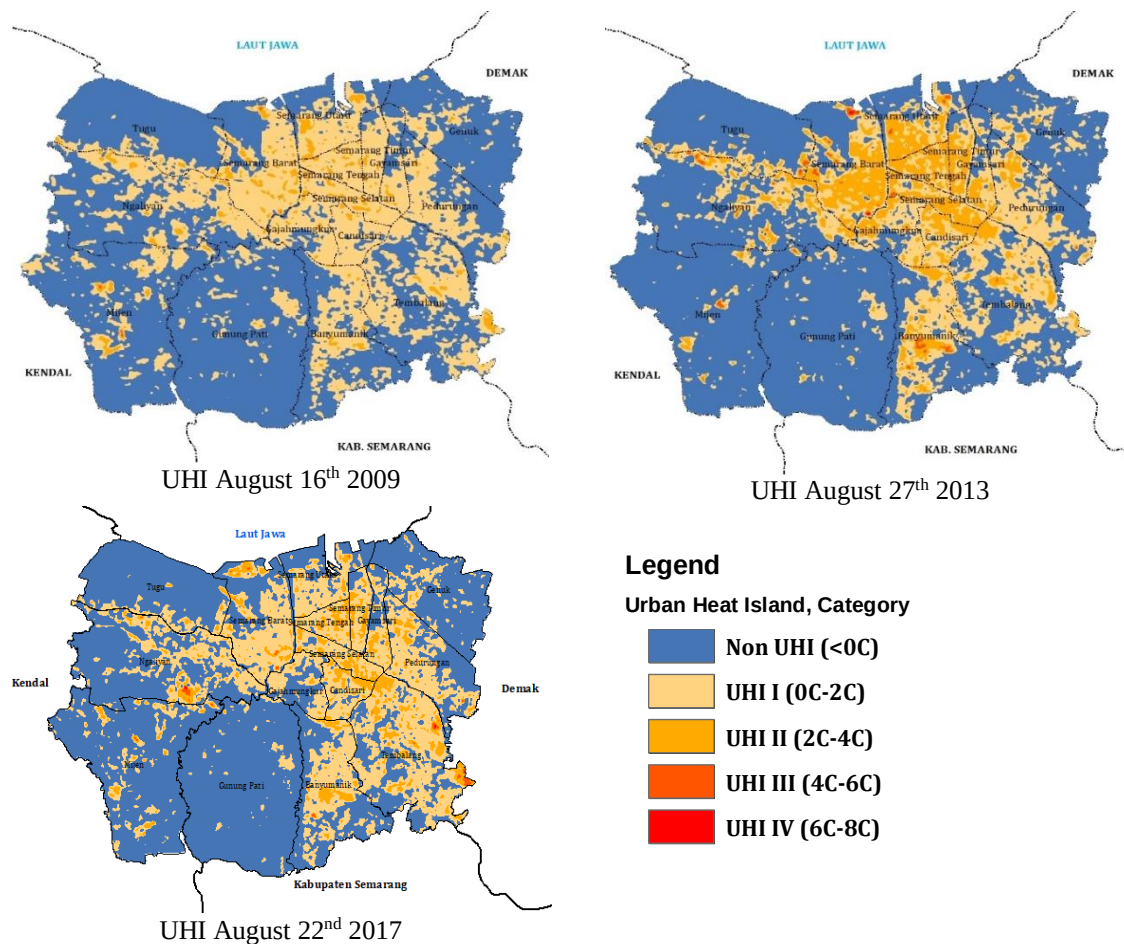
The distribution of UHI phenomena (Figure 3) in Semarang City is obtained based on the threshold value of annual LST processing in Table 3. Surface temperature data for 2009, 2013 and 2017 are classified based on UHI threshold values. The lower value of the UHI threshold is called Non UHI, while the higher is UHI or UHI affected. UHI-affected areas are classified every 2 °C from the UHI threshold, the value of 0 °C-2 °C is called UHI I, the value of 2 °C-4 °C is called UHI II, up to 6 °C-8 °C is called UHI IV.

**Table 3.** Spread of UHI Semarang City

| UHI Criteria | 2009      |        | 2013      |       | 2017      |       |
|--------------|-----------|--------|-----------|-------|-----------|-------|
|              | Ha        | %      | Ha        | %     | Ha        | %     |
| Non UHI      | 24,273.99 | 62.102 | 25,252.83 | 64.61 | 24,664.32 | 63.10 |
| UHI I        | 13,761.45 | 35.207 | 9,319.95  | 23.84 | 12,171.33 | 31.14 |
| UHI II       | 1,043.55  | 2.670  | 4,379.67  | 11.20 | 2,175.12  | 5.56  |
| UHI III      | 8.37      | 0.021  | 128.52    | 0.33  | 72.45     | 0.19  |
| UHI IV       |           |        | 6.39      | 0.02  | 4.14      | 0.01  |
| Total        | 39,087.36 | 100    | 39,087.36 | 100   | 39,087.36 | 100   |

In Figure 3 can be seen UHI phenomenon in the city of Semarang occurred in the central city of Central and South Semarang District and the surrounding sub-district of Candisari, East Semarang, and

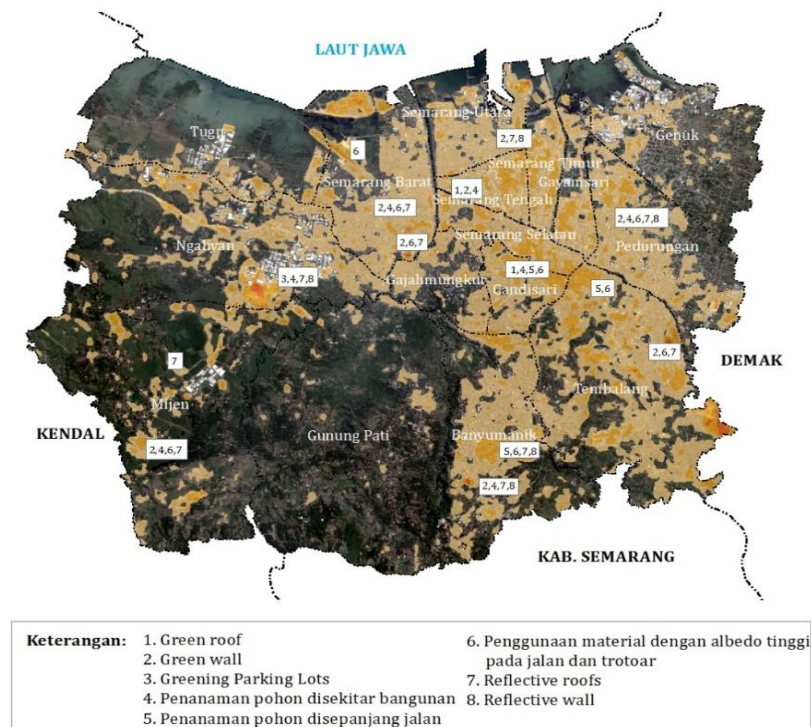
Gajahmungkur. The suburbs, Pedurungan and Tembalang sub-districts are also affected by UHI, indicating an increase in development in the region. The least affected districts of UHI are Gunung Pati, Genuk and Tugu sub-districts[11].



**Figure 3.** Urban Heat Island (UHI) Multi Temporal of Semarang City.

Based on the land cover conditions and adjusted to the land use plan according to RTRW, can be prepared the design of UHI mitigation Semarang City. In built land cover, UHI mitigation can be done in the form of physical modification of the building. In the dense residential areas that lack the space for the addition of vegetation such as settlements in Mijen, North Semarang and Tembalang can be implemented the application of green wall, reflective roof, and reflective wall like the use of white paint. In the market area of Pasar Johar and Banyumanik, green roof, green wall and reflective roof can be applied. For urban areas with densely built land and tall buildings such as Tugu Muda, Simpang Lima and Java Mall can be applied green roof, green wall, reflective wall, greening parking lots, tree planting around the building, tree planting along the road, as well as the use of materials with high albedo on roads and sidewalks.

In industrial areas such as Banyumanik industrial area can be used reflective roofs, reflective wall, greening parking lots, and tree planting around the building. Confirmation of the regulation concerning the transfer of land function in Semarang City also needs to be done by related parties. Due to land use that does not comply with the RTRW and trigger UHI phenomenon, such as in industrial estate in Ngaliyan sub-district and residential area in Mijen should be allocated for Forest area and mining area in Tembalang should be used for agricultural area. UHI mitigation directives of Semarang City can be seen in Figure 4.



**Figure 4.** UHI mitigation directives of Semarang City

#### 4. Conclusion

Temperature change based on LST treatment showed that the average temperature in 2009 was 25,457 °C then increased 30,959 °C in 2013 and decreased to 30,142 °C in 2017. Thermal comfort level (THI) in Semarang City from 2009 to 2017 has changed. In 2009 the city of Semarang as a whole was in a comfortable condition that is in the THI value range of 20-24 ° C with an average thermal comfort level of 23.05 ° C. While in 2013 Semarang City is in the category of uncomfortable (overheated) with a value of > 26 ° C, the overall value of the average thermal comfort level in Semarang City in 2013 amounted to 27.03 ° C. And in 2017 the city of Semarang is in the category of uncomfortable (too hot) with a value of > 26 ° C, overall value of the average thermal comfort level in the city of Semarang in 2017 amounted to 26.53 ° C. The change of land cover area in Semarang City has relation with thermal comfort level (THI), the increase of the land area built, the decreasing of vegetation and open land area, the thermal comfort level increases. Increasing of THI values indicate conditions that are not comfortable for humans.

UHI phenomenon in the city of Semarang occurred in 2013 and 2017. In 2013, obtained UHI intensity of  $\pm 9.01$  °C of UHI threshold value, whereas in the year 2017 obtained UHI intensity of  $\pm 7.38$  °C of UHI threshold value, it was found that the Candisari, Gajahmungkur, Gayamsari, Semarang Selatan, Semarang Tengah and East Semarang areas were potentially strong UHI so there was a need for mitigation efforts in order to avoid the impact on the environment. In densely populated areas such as in Mijen and North Semarang subdistricts, green walls, reflective roofs, and reflective walls such as the use of white paints. For urban areas with compact built-up areas and tall buildings such as Tugu Muda, Simpang Lima and Java Mall, green roof, green wall, reflective wall, greening parking lots, tree-planting around buildings and roads, and the use of materials with albedo high on roads, pavements and buildings. In industrial areas such as in the Banyumanik industrial area can be used reflective roofs, reflective walls, greening parking lots, and tree planting around the building. In addition, it is necessary to monitor the change of land function and its suitability with the urban plan of Semarang which has been set.

## 5. Acknowledgments

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

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