Planning for compact eco-cities: a spatial planning to prioritise green infrastructure development to mitigate urban heat island in Surabaya

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Abstract. The phenomenon of Urban Heat Island (UHI) will be exacerbated in the coming years by rising surface temperatures due to urban growth. Implementation of urban green infrastructure (UGI) such as green roof, green wall, parks, road trees can help reduce temperatures in urban areas, including reducing pollution. Currently, there is no information available for land managers to determine the right strategy for UGI implementation based on a spatial approach. So that a framework is arranged to determine UGI priorities and elections in creating a compact eco-city. The framework is supported by a review of scientific literature related to UHI phenomenon in Surabaya, UGI and urban heat island mitigation in comparative descriptive and gap analysis. UGI implementation priorities are allocated based on observing the location of urban heat island using Landsat 8 OIL TIRS, behavioral Exposure and spatial land-use patterns are taking a result in Kali Rungkut sub-district, East Surabaya.

1. Introduction

The phenomenon of Urban Heat Island (UHI) has caused urban temperatures to increase and trigger the formation of urban fog due to pollutant emissions and atmospheric photochemical reactions (L. M. Gartland, 2012; Howard & A. Arch, 1833). Temperature increases occur around roads, commercial areas, settlements and industries, and experience a decrease in temperature around green spaces because land use materials have different heat absorption abilities (Stewart & Oke, 2012). The condition is that green open space (RTH) in cities as a medium for absorbing heat is increasingly minimal because of the increasing need for land (Agency, 2008). Natural surfaces and vegetation are replaced by waterproof surfaces that tend to absorb solar radiation during the day and are released at night, so the area remains warm (Oke, 1997).

UHI does not only depend on the physical process character, but also on the city management approach (Hsieh et al., 2010). There is a strong relationship between UHI effects and urban configurations, without balanced management, urban temperatures will increase along with the development of land (Arifah & Susetyo, 2018; L. Gartland, 2008). The concept of Compact Eco-City is often a highlighted issue in urban management, specifically UHI mitigation through the allocation of green open space. Because the complexity of land use in urban areas is able to minimize the increase in UHI that occurred. The application of urban green infrastructure is often an alternative to providing green space in response to Compact Eco-City (Moriyama & Tanaka, 2012). Urban Green Infrastructure (UGI) consists of green open space, trees, green roofs and vertical greening (Norton et al., 2015). As infrastructure, UGI can also be in the form of a green line (median road/border)(Dige, Liquete,
Kleeschulte, & Banko, 2014). Quantitatively, UGI is considered to be able to reduce up to 2°C the average surface temperature in urban areas (Arie, 2012).

During the 20 years, Surabaya experienced an increase in temperature of 1°C each year, with UHI conditions in the city of Surabaya having a temperature difference of 1.4°C compared to rural areas (Kurniati, 2017). There is a strong correlation between changes in the area of built land cover in the city of Surabaya with an average temperature of 0.97 and changes in vegetation land cover have a correlation value of -0.75 so that the dominance of very high built land and shrinkage of green space will very significant impact on increasing temperatures and absorption rates carbon (CO2) which is getting smaller in the region (Dionysius S, 2013). The temperature conditions in Surabaya create environmental discomfort for the community (Noviyanti, 2016). Human Temperature Index (THI)> 26 represents the inconvenience of Surabaya, but in 2002 the Surabaya THI reached 32 THI (Tursilowati & Djundjunan, 2007).

This paper focuses on UGI spatial planning into the public sphere to reduce high urban temperatures. A spatial approach becomes important for planning urban UGI on target (Norton et al., 2015). The position of this research is to answer the development of the UHI mitigation strategy model towards Compact Eco-City. Some UHI mitigation studies emphasize the increase in mean surface temperature, not yet explaining how much the intensity of the UHI produced and its distribution (Jatayu & Susetyo, 2018). Urban management in managing UHI is important in order to create thermal comfort because it encompasses very complex urban elements (L. M. Gartland, 2012).

Figure 1. Research Position

2. Methods
2.1. Step 1. Identification Potential Distribution of UHI
The UHI phenomenon is not limited to large urban areas but also occurs in smaller metropolitan areas (Van Hove et al., 2011). The location of the potential distribution of UHI is reviewed based on the distribution of the scope of the development area, the aim is to obtain an area that has the potential to experience significant land growth because land growth will have implications for increased activity, emissions and air temperature (Zulkarnain, 2016). This condition will cause urban surface temperature deviation to be higher than the surrounding area (Sobirin & Fatimah, 2015).
2.2. Step 2. Priorities Neighborhood

Specific neighborhoods are prioritized by identifying areas with the largest numbers of people that may be exposed to excessive UHI. When these risk drivers intersect (C), a high priority neighborhood has been identified.

- **Heat Exposure**
  Heat Exposure is the value of UHI's classification of the surrounding area. Using remote sensing, areas within cities that experience extreme heat are distributed spatially and 'hot-spots' occur where there is intense sacrifice development with little vegetation and/or water. Thermal infrared sensors on satellites obtain quantitative information about the surface temperature associated with the type of land cover (Coutts et al., 2016). This information can be used for UHI urban planning and mitigation because it have data with high enough resolution, consistency, repeat recording, and the ability to measure/record the condition of the earth's surface well (Kuenzer & Dech, 2013). Heat exposure data were obtained from observations of Landsat 8 OLI TIRS image using Normalized Difference Vegetation Index (NDVI) correction with a thermal band. Bands used are bands 4 (red) and 5 (infrared) and thermal bands 10 and 11 (Loyd, 2017). Calculation of intensity and spatial distribution of UHI is done by explaining the value of surface temperature using a 3 x 3 filter in the local neighborhood, to change the value of the pixels in the middle of the environment based on local pixel environmental statistics (Liu, 2009).

\[
\Delta T_p = T_p - T_r, \quad \text{UHI Maps} = T_{\text{max}} - (\mu + 0.5 \alpha) \quad T > \mu + 0.5 \alpha \quad 0 < T \leq \mu + 0.5 \alpha
\]

(a) (b) (c)

**Figure 4.** (a) calculate intensity UHI, (b) value max and min UHI, (c) Distribution UHI using NF 3X3min (Fawzi, 2017)
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Where:

(Equation a) \( T_\mu \) is the surface temperature in a city warmer than the surrounding temperature
\( T_r \) is the surface temperature around the measured area \( T_\mu \)
\( \Delta T_\mu - r \) is the effect UHI

(Equation b) \( T > \) the temperature threshold for the area in which the UHI results from neighborhood filter.
\( 0 < \) area non UHI
\( \mu \) mean Land Surface Temperature
\( \sigma \) standard deviation

(Equation c) \( \mu \) dan \( \sigma \) : mean Land Surface Temperature and standard deviation

This study focuses on surface UHI, because research on UHI using remote sensing only gets surface UHI analysis. Referring to the environment ministry regulation regarding urban microclimate, a grid-based mapping method is needed for areas with an area of less than 300km\(^2\) using a grid with a size of 0.5x0.5km. Then to show the distribution patterns of UHI either clustered, dispersed or random spatial autocorrelation using the morans approach (Legendre, 1993).

b. Spatial Land-use Pattern to temperature
Spatial land-use patterns are identified using multiple linear regression. Input is a time series of land use changes with an area of analysis that is focused on points or areas that have changed land use within that time period. Spatial patterns of land use are carried out multiple linear regression with surface temperature. To explain the value of the relationship of land-use types to surface temperature, where the dependent variable (variable Y) is Land Surface Temperature and the independent variable (variable X) in the form of variables in the Spatial Metric (Jatayu & Susetyo, 2018). Regression is used to estimate the values of one response variable from the values of other variables that are already known or assumed to have a relationship with the response variable to be sought (Kurniawan, 2008).

\[
Y = a + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_kX_k + e
\]

Figure 5. Equation multiple linear regression (Jatayu & Susetyo, 2018)

(Equation d) \( X \): value of variabel Spatial Metric
\( \beta \): koefesien regresi
\( a \): intercept value Y if prediktor value is zero
\( Y \): value of Land Surface temperature

c. Behavioural Exposure
Areas in a city where large numbers of the public are active and central business districts (CBD) should rate highly for heat mitigation, such as industry area, public facilities, and shopping area. These areas may be prioritized to modify the human thermal comfort of large proportions of the population (Norton et al., 2015). The center of the region also has a higher tendency for UHI (Goldreich, 1985). The results of the multiple linear regression of land use patterns previously used in the consideration of activity pressure models that affect temperature changes (Jatayu & Susetyo, 2018). The more diverse land uses will affect the decrease in surface temperature (Moriyama & Tanaka, 2012). In areas with high behavioral exposure characteristics, it will result in an increase in energy use such as air conditioning and vehicle fuel use as well as reducing comfort in the center of activity (Agency, 2008).

2.3. Step 3. Characterise Neighbourhood
Help identify opportunities for improvement in the microclimate and document the landscape for the
next steps. The aim is to identify the location of healthy vegetation that exists, and where UGI is lacking. Characterizing the width of the road and the height of the building will determine the openness of the road to solar radiation, and the shaded area by the building (Norton et al., 2015). This information can be collected from a combination of primary surveys, aerial imagery, GIS databases, etc.

3. Result and Discussions
3.1. Step 1. Identification Spatial Distribution of UHI

Surabaya’s UHI phenomenon from 1992-2011 has a tendency to grow from the direction of the city center towards East Surabaya and West Surabaya (Sobirin & Fatimah, 2015). However, the tendency of emission levels in the city of Surabaya is highest in the East Surabaya Region at 115,610.26 tons/month, due to high industrial activity and significant land growth (Abdullah & Boedisantoso, 2019). So that in the development of UGI, this research will examine the UHI phenomenon in East Surabaya. East Surabaya experienced an increase in temperature in 2001-2016 amounting to 6.612°C, with a pattern of increasing temperatures that tends to occur in the eastern and southern parts of East Surabaya. The eastern part is the area where the pond is converted into a residential area and the southern part is the SIER industrial area (Jatayu & Susetyo, 2018). The high development in the East Surabaya Region will affect the reduction of vegetation lands such as green open space, ponds and agricultural land (Zulkarnain, 2016). Noted from 2001-2016 there has been an increase of the built land area of 1376 Ha or around 14% of the total area and has decreased RTH 1334 Ha or around 13.6% of the area (Arifah & Susetyo, 2018).

Figure 6. Spatial distribution UHI in Surabaya growth in to East Surabaya (Sobirin & Fatimah, 2015)

3.2. Step 2. Priorities Neighbourhood

a. Heat Exposure

Surface temperature processing used Landsat Image 8 OIL TIRS recording October 1, 2019. Used thermal data band 10 and band 11 to produce an estimate of surface temperature (Trad) and data band 4 (red) and band 5 (infrared) produce NDVI values. The surface temperature estimation results are processed again through the operation of a neighborhood filter and produced by $T_{\text{mean}}$ for East Surabaya. $T_{\text{mean}}$ statistics obtained were entered into equation (c), with a value of $\mu = 30.92^\circ\text{C}$ and a value of $\alpha = 3.18^\circ\text{C}$, the threshold value obtained for obtaining a UHI distribution map in East Surabaya was 32.78°C. UHI distribution is shown in figure (b) for classification $> 32.78^\circ\text{C}$ (orange and red).
Using spatial autocorrelation with the global morans approach shows that UHI conditions in East Surabaya tend to be significant in the form of clustered.

**Spatial Landuse Pattern to temperature**

Data obtained from studies conducted by Jatayu and Susetyo (2018), spatial patterns of land use using Equation multiple linear regression were carried out in 2001-2016. To determine the effect of spatial land use patterns represented through spatial metrics for each selected land use category, and surface temperature increase a regression analysis is used.

**Figure 7.** (a) Land Surface Temperature, (b) intensity and distribution UHI using NF3x3, (c) Grid mapping UHI 0.5x0.5km

**Figure 8.** Spatial autocorrelation UHI in East Surabaya

**Figure 9.** (a) value regresi between landuse and land surface temperature, (b) Landuse East Surabaya (Jatayu & Susetyo, 2018)
c. Behavioural Exposure

Based on field observations of public spaces and the central business district (CBD) in East Surabaya consisting of industrial, trade and service areas, as well as public facilities. The industrial estate in East Surabaya includes the SIER industry, the industry around the river, the warehousing industry around Kenjeran and the rest is a partial distribution of small and medium industries. Trade and service areas include Galaxy Mall, East Cost, Gubeng CBD area, and are linearly distributed along main road corridors such as Arief Rahman Hakim street, Kertajaya road, mulyosari highway, Pucang anom road, and other main roads. The area of public facilities in the form of ITS colleges, Ubaya and Unair, the hospital area around Dharmawangsa, the office area in the Gubeng area the rest is a partial distribution of public facilities ranging from village to district/city.

![Center activity maps based on bahviour activity](image)

**Figure 10.** (a) Center activity maps based on bahviour activity (b) illustration center activity maps

Using GIS these intersect risk drivers, a high priority neighborhood has been identified. The high priority has been shown by the red colors. The location has the highest overlay value of the surrounding area.

![Priority neighbourhoods for mitigation of high urban temperature](image)

**Figure 11.** (a) Priority neighbourhoods for mitigation of high urban temperature

3.3. Step 3. Characterise Neighbourhood

The results of the previous stage were in the CBD area of Kali Rungkut, Rungkut District. In this area, especially in the corridor of Jalan Raya Rungkut, it is a center of trade and services, industrial and warehousing areas as well as the presence of Ubaya colleges. Because the block in the area is quite high and is not matched by complex land use, the temperature tends to accumulate in some dense areas and tends to be lower than the surrounding area. Geographically, the area dominates the area in the form of medium to large scale buildings, with an average building height of 2-5 floors. When observed from
field conditions, the UGI corridor is quite minimal and there is no vegetation on the road median. Coupled with the high mobility in the area because it is traversed by heavy vehicles such as trucks that go to industrial areas. Through GIS observation, the percentage of UGI especially vegetation in the area is only about 10% of the total block area. Knowing the high activity in these locations, it is necessary to prioritize the development of UGI in minimizing the increase in UHI and offset the Compact Eco-City in the region.

Figure 12. Existing Kali Rungkut Sub District

4. Conclusions
To answer the Compact Eco-City, it is necessary to optimally allocate UGI to each land use to minimize UHI increase. Some UHI mitigation studies emphasize the increase in mean surface temperature, not yet explaining how much the intensity of the UHI produced and its distribution spatially. So that the observations of UHI were carried out to obtain the intensity and distribution of UHI and non-UHI. The regional center becomes an important factor in allocating UGI priorities. These areas may be prioritized to modify the human thermal comfort of large portions of the population.

East Surabaya has a very significant growth trend in UHI, so UGI optimization is needed. By observing the distribution of UHI through remote sensing, Spatial Landuse Pattern to temperature, and Behavioral Exposure obtained optimal locations in the allocation of UGI. The priority location in the study is the CBD Kali Rungkut area, Rungkut District. In planning this model can be done repeatedly to evaluate the Urban Green Infrastructure and the condition of Urban Heat Island that occurred

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