JUEE

Journal of Urban and Environmental Engineering, v. 13, n. 1, p. 125-133

ISSN 1982-3932
doi: 10.4090/juee.2019.v13n1.125133

Journal of Urban and Environmental Engineering

www.journal-uee.org

IDENTIFICATION OF URBAN HEAT ISLAND SPREADING TO CONCENTRATION OF NO_2, O_3, AND PM_{10} POLLUTANT IN DKI JAKARTA

Alfiyah Nur Fitriani[1], Kania Dewi[2], and Laras Tursilowati[3]

[1]*Department of Environmental Engineering, Bandung Institute of Technology, Indonesia*

[2] *Department of Environmental Engineering, Bandung Institute of Technology, Indonesia*

[3] *Department of Center for Atmospheric Sciences and Technology, Indonesian National Institute of Aeronautics and Space, Indonesia*

Received 24 October 2018; received in revised form 15 April 2019; accepted 18 April 2019

Abstract: Urban Heat Island is usually caused by Land use Land-Cover Changes (LULCC), including in Jakarta-Indonesia. Rapid development in Jakarta causes green open space to decrease and surface temperature in urban areas to increase. In addition, Urban Heat Island also causes the spread of pollutants based on increased turbulence. Therefore, this study aims to find the relationship between temperature rise in DKI Jakarta with land cover changes and distribution of pollutants such as NO_2, PM_{10}, and O_3. This research begins with observation data processing of average temperature of DKI Jakarta area with Meteorological Station Tangerang, Banten for spatial calculation from 2011-2016. In addition, LANDSAT 8 satellite image data is processed for spatial land and temperature distribution with Remote Sensing software from 2013-2015. As a result, in 2013 and 2015 there is a reduction in the area of vegetation in the area of non-vegetation (residential and industrial areas) which cause the temperatures of the DKI Jakarta region to increase. After that, sought the linkage between Urban Heat Island and the spread of pollutant concentrations in DKI Jakarta in 2013 and 2015. As a result, increase in Jakarta area temperature, especially in pollutant observation area at five points, influenced by the distribution of pollutants NO_2, O_3, and PM_{10}. Each pollutant concentration represents the area where the dominant pollutant expenditure is according to designation such as roadside, industry, settlement in the time and area study in DKI Jakarta.

Keywords: Urban Heat Island, Land use Land-Cover Changes, air pollution.

INTRODUCTION

In urban areas, there are conditions where temperatures in the city center are higher than in the vicinity of what is commonly referred to the Urban Heat Island (Kim, 2005). Urban Heat Island is a phenomenon where atmospheric and surface temperatures in urban areas are higher than in surrounding areas. This increase in temperature can be caused by various things, such as reduced green open space, heat absorption by building materials or roads, as well as from human activities such as fuel combustion (Voogt, 2003). Urban Heat Island also affects the spread of pollutants in urban areas due to increased turbulence (Sarrat et al., 2006).

Jakarta is the capital city of Indonesia which is one of the most populous cities in Indonesia. The rapid place of development can have negative impacts such as population growth, reduced green open spaces, and less healthy environments (Tursilowati, 2007). Belgaman (2006) shows that in 2001 there was Urban Heat Island in Jakarta area with highest point in North Jakarta and Central Jakarta area. Spatial distribution of surface temperature is affected by land cover, where areas with built land cover have higher surface temperatures compared to surface temperatures in open areas. Land use and Land Cover Changes (LULCC) in urban areas makes the meteorological conditions in this area also change. Therefore, there is a need to study the effect of land cover change on the Urban Heat Island distribution pattern and its effect on pollutant distribution such as NO_2, PM_{10}, and O_3 in DKI Jakarta (World Health Organization, 2006).

The purpose of this study is to calculate the extent of land cover change and temperature change in DKI Jakarta, to examine the relationship between land cover change and the spread of Urban Heat Island in DKI Jakarta, to calculate the pollutant pollutant of DKI Jakarta and to examine the link between Urban Heat Island distribution of pollutant pollutants, and calculate Temperature Humidity Index showing the comfort level in DKI Jakarta.

METHODOLOGY

This research focuses on the relationship between land cover change or so called Land Use Land Cover Change (LULCC) with Urban Heat Island (UHI) spread in DKI Jakarta area. After that, we will look for the relationship between Urban Heat Island phenomenon that closely related to temperature difference between urban area with surrounding area to the spread of pollutant (Feizizadeh, 2013). The existing pollutants will be focused only on the pollutants of Nitrogen Dioxide (NO_2) (Novianti, 2010), Ozone (O_3), and Particulate Matter (PM_{10}) from transportation activities, industry and various sources in Jakarta from the study period from January 2011 to December 2016.

Furthermore, the research method is done by collecting primary and secondary data. Primary data were obtained from observation data in the field consisting of temperature data, humidity, rainfall, and wind speed of DKI Jakarta area and pollutant concentration data from Local Environmental Management Agency (BPLHD) such as NO_2, O_3, and PM_{10}. These two primary data types will be processed using statistical software to search for monthly averages, graphs, and look for links to each of the meteorological parameters and environmental parameters of pollutants. In addition, the secondary data in the form of topographic data, temperature data, and spatial land cover data of DKI Jakarta were obtained from LANDSAT 8 Satellite Imagery (Kurnia, 2010).

By using Remote Sensing software, both data are processed into spatial results. Furthermore, validation of LANDSAT 8 satellite image processing results by spatial with measurement or observation data. The output of Remote Sensing Software and LANDSAT 8 satellite image validation with observation data will be used for the overall analysis of the main focus of this research mentioned above (Hart, 2008). As a result of additional research, the authors will calculate Temperature Humidity Index in DKI Jakarta area.

RESULTS AND DISCUSSION

Characteristics of Study Areas

Elevation of the study area has an important role in determining the pattern of pollutant dispersal and the concentration of pollutants received at each receptor. The study area covers five cities in DKI Jakarta that have characteristics such as elevation and various land cover, which can be seen in **Fig. 1**. Viewed from the topographic condition of DKI Jakarta area is categorized as flat and sloping area. This characteristic causes the wind patterns in DKI Jakarta and its surroundings to be influenced by local phenomena such as land breeze and sea breeze with speeds that tend not to vary too.

Table 1. Band channel and usage

No.	Type of Land Cover found in the Field
1.	Industrial Area
2.	Medium density settlement
3.	Densely populated settlements
4.	Settlement
5.	Waters (Sea)
6.	Waters (Rivers)
7.	Shallow Waters
8.	Low vegetation (grass / weeds)
9.	High vegetation (tree)

Source: USGS and Google Earth

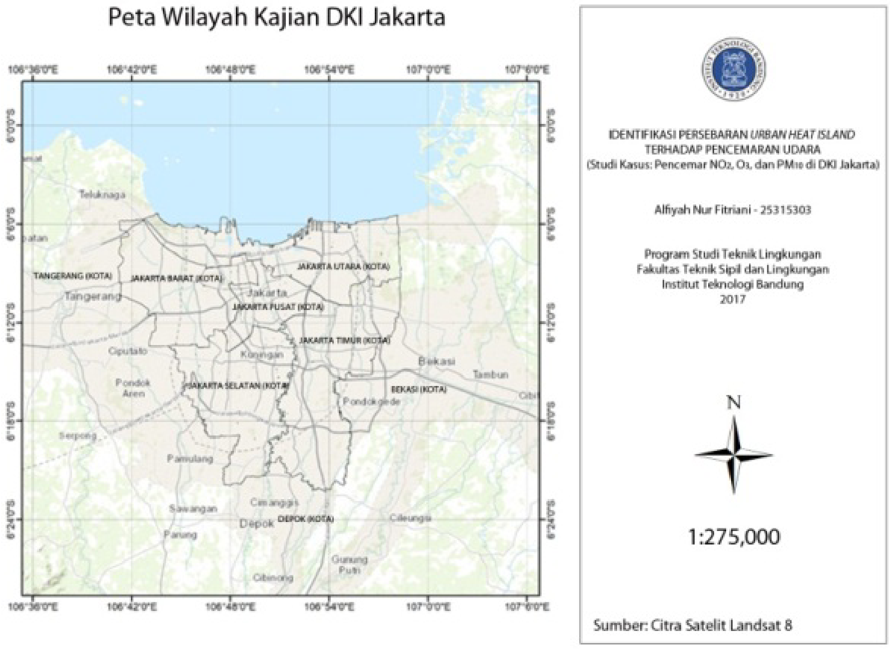


Fig. 1 Map of the administration of the study area (Source: https://landsat.usgs.gov/landsat-data-access)

Field observations were made to adjust the state of land cover seen in the visual image to the actual situation in the field. Based on the results of determining the coordinates of land cover points by purposive in the field obtained 9 types of land cover in the field. The coordinates of points taken cover the area of DKI Jakarta. The types of land cover found in the field through Google Earth are presented in **Table 2** below.

Apart from the 9 types of land cover in **Table 1** above, there are 2 types of additional land cover objects that are clouds and cloud shadows. Information of land cover types cloud objects and cloud shadows are known from the appearance of the imagery. Therefore, the type of land cover acquired by 11 land cover. This is done to determine the ability of the image in identifying the type of land cover.

Classification of Land Cover by Digital

Image classification aims to classify or segment a homogeneous appearance by using quantitative techniques of inserting pixels into class or predefined categories based on the corresponding pixel brightness values. Result of classification of image 11 class of land cover can be seen in **Fig. 2**.

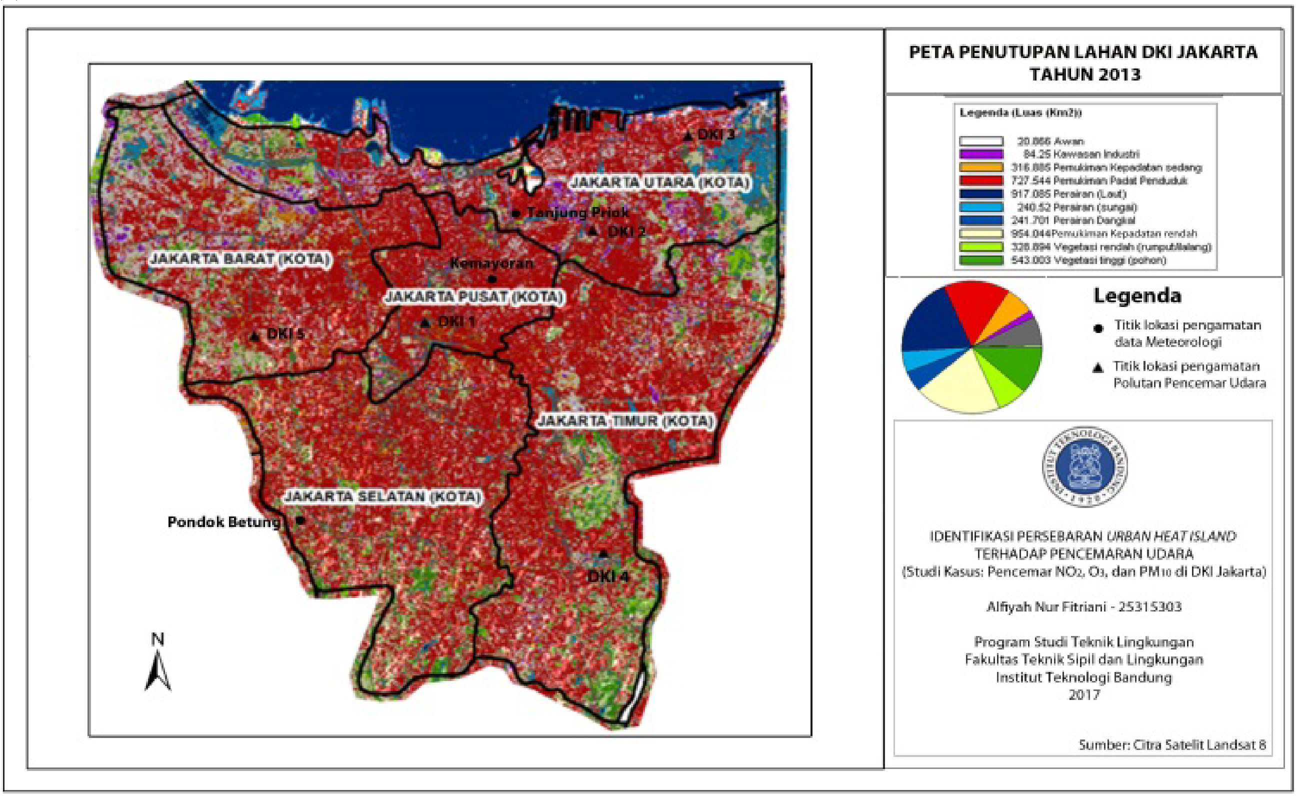
From the land cover of the DKI Jakarta area shown in **Fig. 2** illustrates that from the classification of 11 land cover types, the Landcover changes show results with the classification controls applied to the LANDSAT 8 image of the Jakarta area at (a) August 25, 2013 and (b) 31 August 2015. The adopted land cover category is residential, industrial, vegetation, cloud, and water. The width of the clouds in this classification is relatively small, and is not even present in the second year. The statistics of the type of land cover produced, shown in **Fig. 3** and **Table 2**. The land cover of Jakarta in 2013 is dominated by settlements (2198.473 km^2), then waters (1399,306 km^2), vegetation (671,891 km^2), industry (420,878 km^2), and clouds (20,886 km^2). By 2015 land cover in Jakarta still has the same composition, which is dominated by settlements (2308,042 km^2), then waters (1499,981 km^2), vegetation (431.92 km^2), industry (531,477 km^2), and clouds (0 km^2). Increased land area located in settlements (109,569 km^2), industry (110,599 km^2) and water (40,675 km^2), besides the decrease of land area in vegetation (239.977 km^2) and cloud (20,866 km^2).

A more detailed change of land cover types in Jakarta can be investigated using detection of changes by the overlay matrix method, and the results are shown in **Table 2**. Within 2 years, significant conversion of land cover types was found from vegetation to non-vegetation (i.e., vegetation to the Residence -125,864 km^2, vegetation to industry -105,86975 km^2, and vegetation against waterbody -59,99425 km^2).

Relationship between UHI, Land Changes, and Climate Change The development of the city of Jakarta has led to an increase in residential and industrial areas, and Human activity, as a whole, has led to the intensification of the UHI phenomenon.

The resulting temperature will vary due to differences in heat capacity. The temperature change in the research area depends on the thermal conductivity of the material. In the case of UHI studies, surface temperatures are higher in urban areas (residence, industry) than in vegetation and waterbody areas, due to the contribution of evaporation and transpiration in non-vegetation areas. It is noted, however, that sometimes the vegetation area may show higher temperatures when the area is covered with relatively shorter plants such as

(a)



(b)

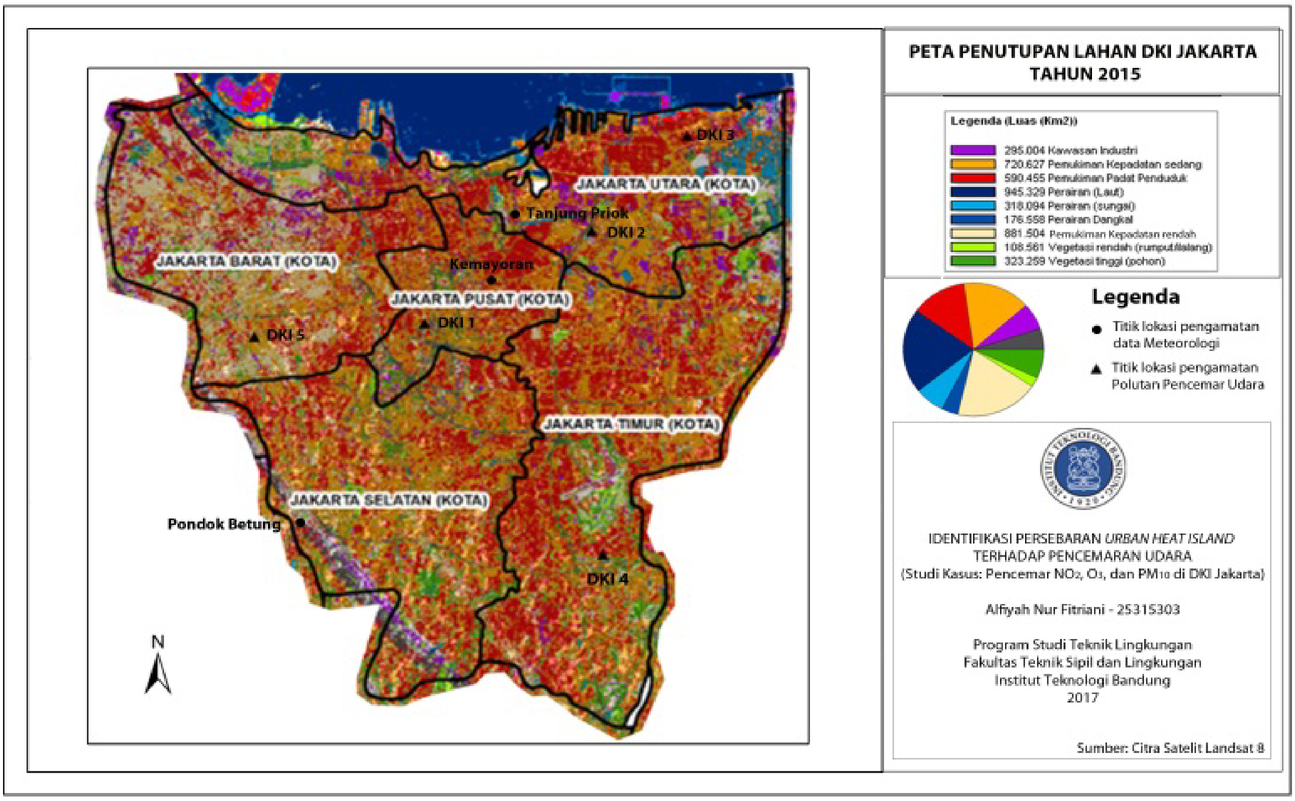


Fig. 2 DKI Jakarta land cover map in 2013 (a) and 2015 (b).

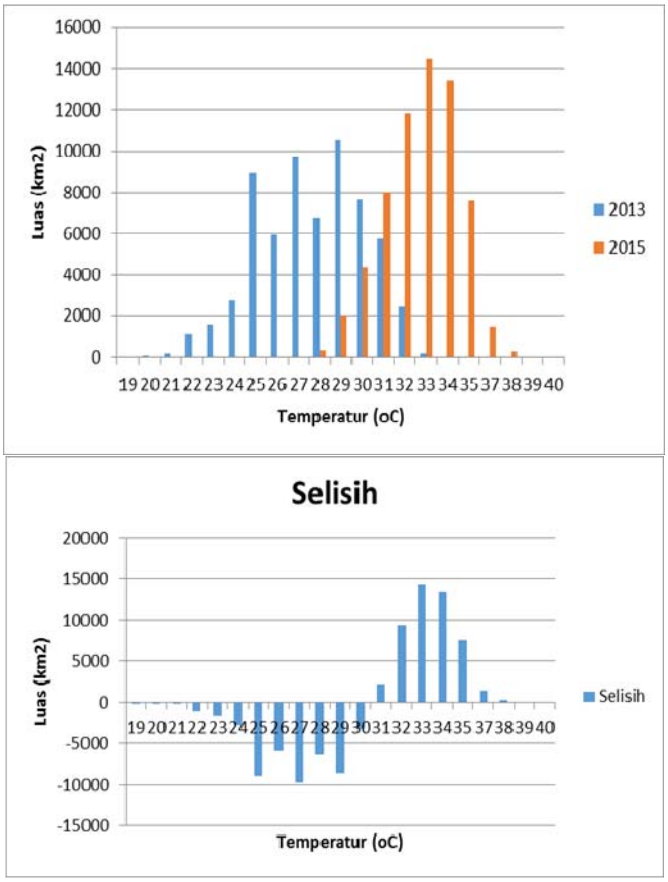


Fig. 3 Temperature statistics and change of DKI Jakarta land cover 2013-2015

Table 2. Land cover data of DKI Jakarta 2013 and 2015 (km^2)

Tahun	2013	2015
Cloud	20,866	0
Industry	420,878	531,477
Water	1399,306	1439,981
Settlement	2198,473	2308,042
Vegetation	671,897	431,92

shrubs or dry rice fields. Statistical analysis was performed by using the diagram method to study in more detail the relationship between land cover and surface temperature.

Plotting Temperature spatially

Changes in UHI in **Fig. 4** shows the temperature trends of DKI Jakarta observed between 2013 and 2015 from LANDSAT 8 satellite images that have been processed using Remote Sensing software. There is a positive temperature trend for the region observed and compared with the observed temperature of the Jakarta Meteorological station.

The first, in the area of Tanjung Priok Meteorological Station located near the coast, shows the average temperature in 2013 is 34.6°C and in 2015 is 37.7°C. The Jakarta Observatory is the Kemayoran Meteorological Station located in Central Jakarta, showing the average temperature in 2013 which is 35.3°C and by 2015 is 38.5°C. The Soekarno-Hatta Meteorological Station in the suburbs near the international airport in north-west Jakarta, shows the average temperature in 2013 which is 28.4°C and by 2015 is 32.1°C. Also a temperature of 30.2°C is seen at

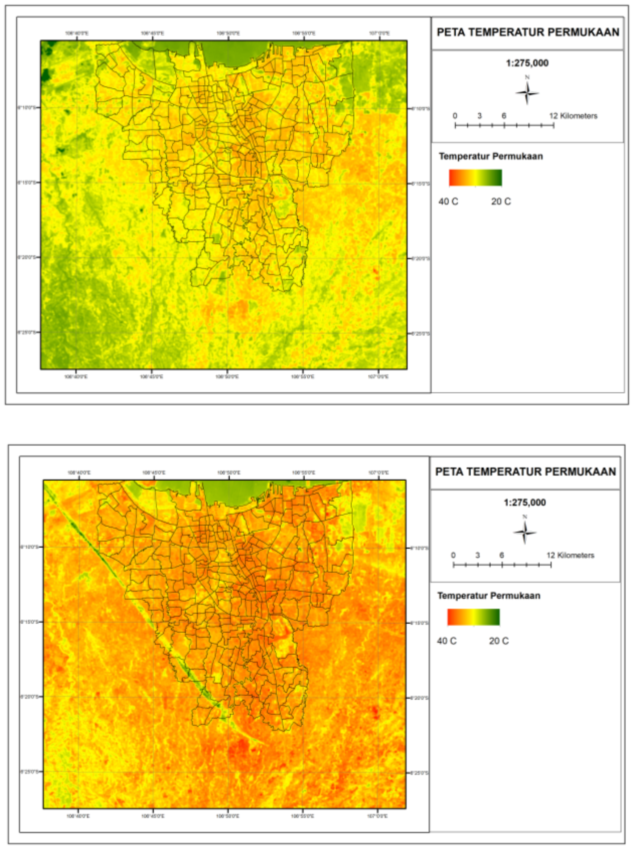


Fig. 4 Temperature of DKI Jakarta August 25, 2013 (left) and August 31, 2015 (right)

Pondok Betung Meteorological Station in 2013 and 35.8°C in 2015.

Thus, the average temperature observed at the meteorological station in DKI Jakarta is mostly higher than the temperature located on the outskirts of DKI Jakarta. This observation strongly supports the occurrence of UHI in urban Jakarta area, in addition to the possible impact of urban climate change.

Condition of Study Area Temperature

Before analyzing the distribution pattern and intensity of the Urban Heat Island, the surface temperature processing obtained from the LANDSAT 8 satellite imagery needs to be verified with observational data to see the accuracy of the calculated surface temperature. Observation data used in verification is air temperature data in four observation stations, namely Kemayoran, Tanjung Priok, Pondok Betung, and Soekarno-Hatta Airport in 2011-2016. Verification is done by calculating R^2 and RMSE (Root Mean Square Error) from the surface temperature of LANDSAT 8 satellite image with air temperature observation data at four observation stations.

According to **Fig. 5**, surface temperatures with air temperature have a linear relationship. The value of R^2 indicates the compatibility of the verification result and the RMSE indicates an error that can be generated by the surface temperature calculation results. In the calculation obtained RMSE value of 1.5198 and R^2 0.72982, so it can be said that the temperature obtained from LANDSAT 8 satellite imagery can show the actual temperature conditions.

The estimated surface temperature of the LANDSAT Satellite is shown in the form of a spatial map. **Figure 5** above shows the verification data of surface temperature distribution in Jakarta derived from LANDSAT 8 satellite image data observed on 25 August 2013 and 31 August 2015. Surface Temperature estimation has been validated by data observation from Meteorology, Climatology and Geophysics Agency (BMKG) Indonesia to confirm the accuracy of the estimates on the same act and the same location. Four locations from observation data are coming from Kemayoran Station, Tanjung Priok Station, Pondok Betung Station

Urban Heat Island Identification of Air Pollution

The main focus of the image above is on the distribution of air pollutant concentration at the five observation points of pollutant concentration consisting of the area of DKI 1 (Hotel Indonesia Roundabout) representing the designation of roadside, DKI 2 (Kelapagading) representing commercial allocation, DKI 3 (Jagakarsa) representing allocation of settlement, DKI 4 (Lubang Buaya) representing the allocation of mixture and DKI 5 (Kebon Jeruk). These five observation points observed the concentrations of pollutants NO_2, PM_{10}, and O_3.

In this section, we will investigate whether the pollutant concentrations of NO_2, PM_{10}, and O_3 are also influenced by the increase in air temperature compared to the surrounding area temperature or the so called Urban Heat Island phenomenon. Observation time taken on August 25, 2013 and August 31, 2015, and compared between the two condition in this research.

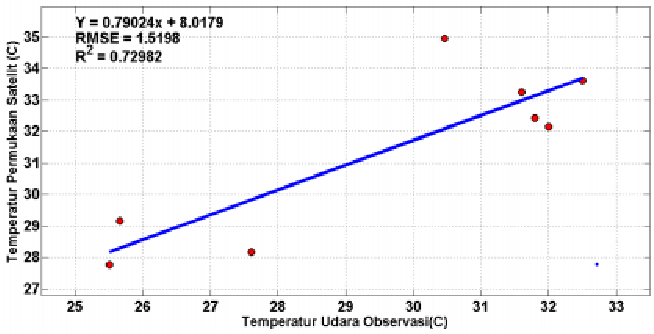
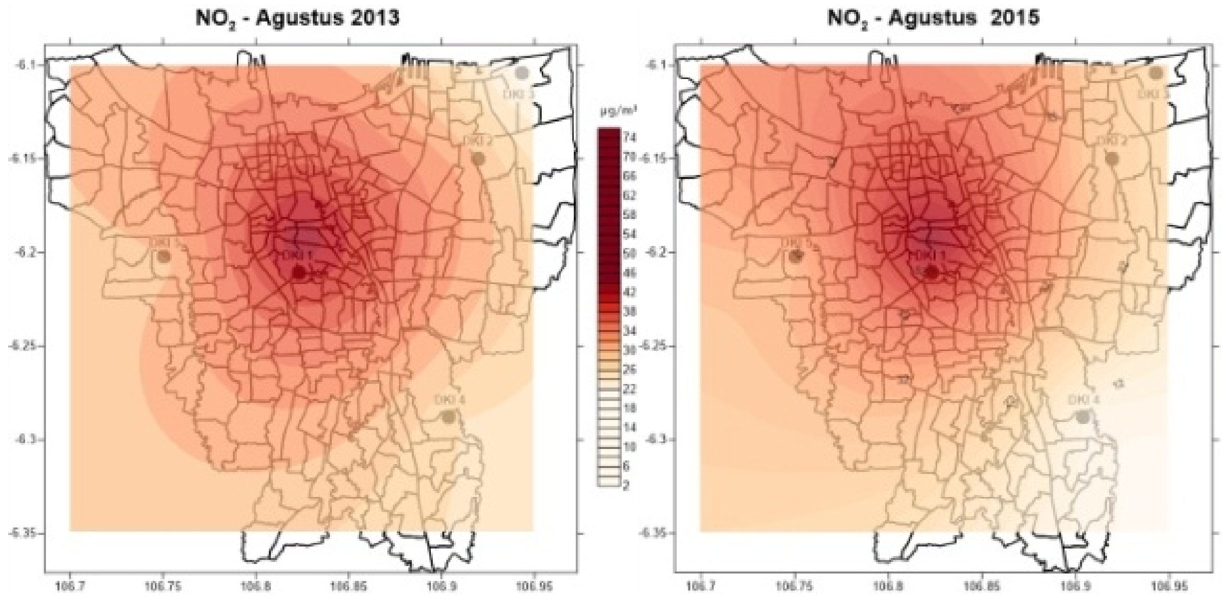


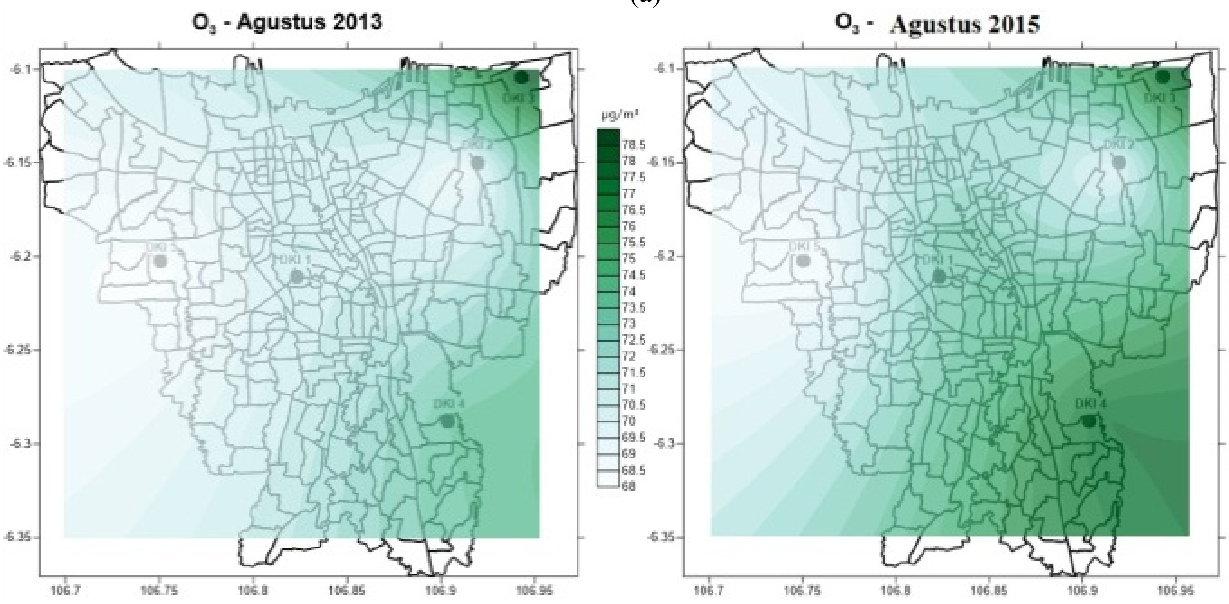
Fig. 5 Verify surface temperature with air temperature

In **Fig. 6**, there is a picture (a) which gives us an idea of the spread of NO_2 pollutant s in the observation areas in 2013 and 2015. From the **Figure 6a**, we can see that the largest pollutants of NO_2 pollutants are in the region DKI 1, which in this region represents the roadside area, namely in the area of Bundaran HI. The maximum concentration in 2013 and 2015 is 74 $\mu g/m^3$ and spread to the surrounding area. High concentrations in the area of DKI 1 (Bundaran HI) can be due to transport factors that are chosen to represent this area as the observation area for roadside. With respect to average temperatures, in the pollutant area at Bundaran HI, it has a temperature of 32°C in 2013 and 35°C in 2015. Source of pollution in Jakarta is still a lot, especially from roadside or vehicle. While **Fig. 6b** gives us an illustration of the pollutant of O_3 in the observation areas in 2013 and 2015. From **Fig. 6b**, we can see that the largest pollutants of O_3 are located in DKI 3, where in this region representing settlement area, that is in the area of Jagakarsa. Maximum concentration in 2013 is 78.5 $\mu g/m^3$ and 2015 is 83 $\mu g/m^3$ and spread to the surrounding area. High concentration in the area of DKI 3 (Jagakarsa) could be due to the settlement factor built in DKI Jakarta which was chosen to represent the observation area for the settlement. With respect to average temperatures, in the area of pollutant observed in the Jagakarsa region, has a temperature of 35°C in 2013 and 38°C in 2015. O_3 pollutants are secondary pollutants resulting from other pollutant reaction reactions generated from residential area activities, such as the use of Air Conditioner (AC), garbage, and sanitary activities (MCK).

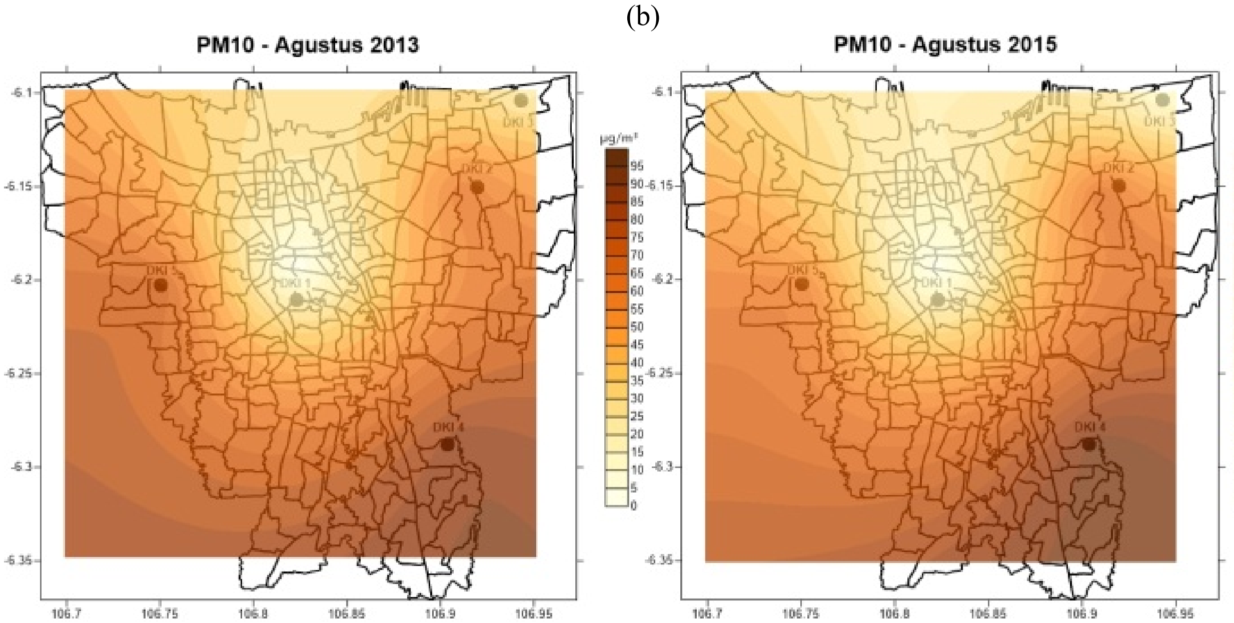
Finally, the picture (c) gives us an idea of the distribution of pollutant PM_{10} in observation areas in 2013 and 2015. From **Fig. 6c**, we can see that the largest pollutant PM_{10} is in DKI 4, This region represents a mixed area of transport, industry and residential areas, namely Lubang Buaya. Maximum concentration in 2013 is 95 $\mu g/m^3$ and 2015 is 115 $\mu g/m^3$ and spread to the surrounding area. High concentration in the area of DKI 4 (Lubang Buaya) can be caused by factors mostly in this region that is a region with mixed buildings between industries, settlements, and the presence of transportation in the Region of DKI Jakarta which was chosen to represent the observation area. With respect to average temperatures, in the area of pollutant pollutants observed in the Jagakarsa region, has a temperature of 34°C in 2013 and 38°C in 2015. When viewed from its size, particulate particulates are very easily generated from sources of pollutants and migrate so that the distribution is easier in the supporting areas. The ISPU varies, depending on region and climate. For example in certain areas where it is raining, while in other areas it is dry, the pollution level of the area where there is rain may be lower. The worst areas of air quality in Jakarta are due to industry and transportation. This is because the use of coal for industry is still widely found in the North and East Jakarta.



(a)



(b)



(c)

Fig. 6 Map of dispersion of pollutant concentrations in DKI Jakarta in 2013 and 2015 for pollutants (a) NO_2, (b) O_3, and (c) PM_{10}

Temperature Humdity Index of Jakarta

The Temperature Humidity Index and its calculations are used to see the implications of increasing the intensity of the Urban Heat Island towards the comfort level in Jakarta and its surroundings. To see the change of the comfort level in Jakarta temporarily, used trendline in four meteorological observation stations located in different locations, namely Soekarno Hatta Meteorological Station, Kemayoran Meteorology Station, Tanjung Priok Meteorology Station, and Pondok Betung Meteorology Station. The data processing mechanism of the four stations is averaged and processed to find the price of the comfort index of DKI Jakarta area. **Figure 7** shows the trendline of Temperature Humidity Index in August of 2013 and 2015 in 4 observation stations.

To see changes from the comfort level in Jakarta temporally, used trendline in 4 observation stations that have been averaged.

Trendline of the Temperature Humidity Index at four observation stations in August showed an increase in 2013 to 2015. The reason for the August selection to test the comfort index in Jakarta was the difference in average temperature in August which had the highest average temperature difference between months others in 2013 and 2015.

This increase in the Temperature Humidity Index may result in reduced comfort levels in Jakarta as it indicates an increasingly heated condition due to rising temperatures in the DKI Jakarta area due to land cover that is beginning to change from vegetation to residential or industrial areas and others. Trend increase in 2015 has a higher rate of increase than in 2013. This can be because the temperature of DKI Jakarta in 2015 has a tendency higher than in 2013. In addition, the DKI Jakarta area has a vegetation or Green Open Space the longer the less.

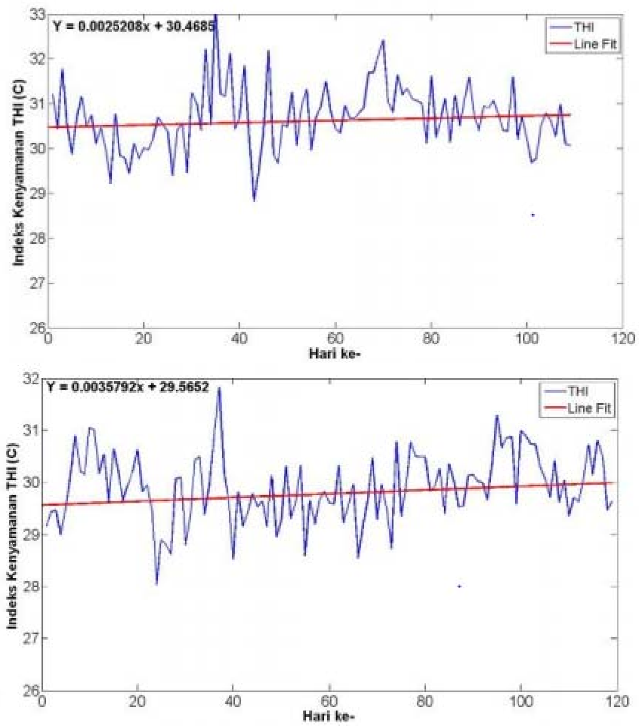


Fig. 7 Trendline of Temperature Humidity Index on August 25, 2013 (left) and August 31, 2015 (right)

CONCLUSION

The most significant land cover change is the change of land cover and vacant land into a residential area. UHI is relatively higher in industry and residence compared to temperatures in vegetation and water areas. It is characterized by a significant increase of observed surface temperatures, higher in residence and industrial estates than in vegetation and waterbody areas. There is an increase in the intensity of the Urban Heat Island in areas experiencing land cover changes from vacant land and vegetation to settlements. Areas that did not experience significant land cover changes did not increase the intensity of Urban Heat Island.

The effect of UHI on the spread of air pollutant concentration in Jakarta Capital Region is significant to NO_2, O_3, and PM_{10} pollutants at the time of the research which the authors specify and in the area of observation appropriate to their territory (eg roadside, industrial, residential or mixed area) in DKI Jakarta. There is a decrease in the level of comfort in areas experiencing significant land cover changes, especially in urban areas (urban). This is caused by the amount of land cover, where the more to the city center, the less the amount of vegetation covering the land of DKI Jakarta.

REFERENCES

Belgaman, H. A. (2006): *Studi Pulau Panas Perkotaan Dan Kaitannya Dengan Temperatur Udara Menggunakan Citra Satelit Landsat 7 ETM+; Sudi Kasus DKI Jakarta dan Sekitarnya,* Tugas Akhir Program Sarjana, Institut Teknologi Bandung, 25-29.

Data from the DKI Jakarta Meteorological Observation Year 2011-2016 is the result of observational data from the Jakarta Meteorology, Climatology and Geophysics Agency (BMKG), daily data obtained through the internet site: http://dataonline.bmkg.go.id/ home. Downloaded on March 15, 2017.

Feizizadeh, B. & Blaschke, T. (2013): Examining Urban Heat Island Relations to Land Use and Air Pollution: Multiple Endmember Spectral Mixture Analysis for Thermal Remote Sensing, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **6,** 661 – 667.

Hart, M. A. & Sailor, D. J. (2008): Quantifying the influence of land-use and surface characteristics on spatial variability in the Urban Heat Island, *Theoretical and applied climatology*, **95 (3-4)**, 397-406.

Kim, Y. & Baik, J. (2005): Spatial and Temporal Structure of the Urban Heat Island in Seoul. J. Appl. Meteor., **44**, 591–605.

Kurnia, R., Effendy, S. & Tursilowati, L. (2010): *Identifikasi Kenyamanan Termal Bangunan (Studi Kasus: Ruang Kuliah Kampus IPB Baranangsiang dan Darmaga bogor), Jurnal* Agromet Indonesia, **24**, 14 – 22.

Land Cover, Topography, and Surface Temperature Data of DKI Jakarta Year 2013-2016 (spatial) is the result of Landsat 8 OLI satellite imagery data from the United States Geological Survey

(USGS), data via the internet: https: //landsat.usgs .gov / landsat-data-access. Downloaded on July 17, 2017.

Novianti, S. & Driejana. (2010): *Pengaruh Karakteristik Faktor Emisi terhadap Estimasi Beban Emisi Oksida Nitrogen (NOx) dari sektor transportasi (studi kasus: Wilayah Karees, Bandung). Jurnal* Teknik Lingkungan, **16**, 185 - 198.

Sarrat, C., Lemonsu, A., Masson, V. & Guedalia, D. (2006): Impact of Urban Heat Island on Regional Atmospheric Pollution, *Journal of Atmospheric Environment.,* **40**, 1743–1758.

Tursilowati, L. (2007): *Pengaruh Perkembangan Pembangunan Daerah Urban pada Perubahan Iklim dan Lingkungan di Semarang,* Jurnal Lingkungan Tropis, **12**, 233-241.

Voogt, J.A. & Oke, T.R. (2003): Complete Urban Surface Temperatures, *Journal of Applied Meteorology,* **36**, 1117–1132.

World Health Organization. (2006): Air Quality Guidelines: Global Update 2005 (Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide), *Copyright of World Health Organization 2006*. ISBN 92 890 2192 6, 217 – 415.