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ANALYSIS OF URBAN COMFORT LEVEL IN JAVA ISLAND BASED ON AIR TEMPERATURE AND AIR QUALITY IN 2015 – 2019

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ABSTRACT

The island of Java as the center of activity in Indonesia is experiencing uncontrolled urbanization and industrialization. Urbanization and industrialization are sources of air pollution and increases in air temperature, which can increase the risk of health problems for humans and reduce the comfort level of the city. The assessment of the comfort level based on air temperature uses an outdoor thermal comfort (OTC) index, namely universal thermal climate index (UTCI) and physiological equivalent temperature (PET) as well as air quality assessment based on Air Quality Guideline (AQG) criteria. This study focuses on assessing the comfort level of cities in Java based on the relationship between temperature and air quality human health levels in 2015 to 2019, in 10 cities, namely Jakarta, Bandung, Surabaya, Semarang, Tasikmalaya, Malang, Surakarta, Yogyakarta, Cilegon, and Tegal. The technique used is narrative review, recapitulation of secondary data sources from remote sensing and health data. The year 2019 was classified as extreme because there were indications of strong heat stress in 9 cities based on UTCI criteria and there were 3 cities classified as strong heat stress based on PET criteria. The PM2.5 concentration in Malang and Surabaya is at an unsafe level, while the CO concentration is safe based on the AQG. The recapitulation of health data shows an increase in cases of acute respiratory infections (ARI) in Malang, Jakarta, and Tasikmalaya cities which is in line with the trend of data on increasing air temperature and PM2.5 concentrations.
Keywords: *temperature, air quality, health, remote sensing*

INTRODUCTION

The increase of temperature and the decline in the air quality are major problems in cities around the world along with global economic growth. The phenomenon of urbanization is closely related to an increase in population, accompanied by changes in land use that increase the built-up land cover (Liu et al., 2018; Maru and Hidayati, 2016). The increase in built-up land cover will cause urban air temperatures to increase and create an urban heat island (UHI) phenomenon. UHI and heat waves (HW) have been reported to occur in the Asian region such as major cities in India (Guleria and Gupta, 2018), China and South Korea (Nori-Sarma et al., 2019), and several regions in Southeast Asia such as the Malaysian peninsula, the Indochina peninsula, and the island of Java (Li, 2020). Indonesia has the potential to experience HW in the Java Island region because it has a trend of higher temperature increases compared to other large islands (Li, 2020). The big cities in Indonesia with the highest population are concentrated on the island of Java. Java Island is an area that has a function as a center for industrial and economic activities with a massive level of regional development, which triggers a decrease in air quality and other environmental problems. Report on Air Quality Life Index (AQLI) Indonesia (which triggers a decrease in air quality and other environmental problems. Report on Air Quality Life Index (AQLI) Indonesia, which triggers a decrease in air

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quality and other environmental problems. Report on Air Quality Life Index (AQLI) Indonesia (Greenstone and Fan, 2019) air pollution conditions in 1998 - 2016 in Java continued to increase and reduce life expectancy. The UHI phenomenon in cities on the coast of Java Island has an impact on increasing the potential for drought and decreasing the comfort level of the city (Hakim et al., 2018). High temperatures and deteriorating air quality conditions can increase the risk of mortality and morbidity in urban areas (Heaviside et al., 2017; Manisalidis et al., 2020; Rajagopalan et al., 2018).

Temperature conditions and air pollution are very dynamic temporally, monitoring changes in atmospheric conditions are needed quickly and thoroughly to anticipate worse conditions (Zhang et al., 2020; Mudede et al., 2020). Monitoring of air conditions can be carried out by measuring weather stations and using remote sensing imagery. Remote sensing techniques have the advantage of monitoring a wider area of coverage in a relatively short time when compared to static weather stations (Zhang et al., 2020; Davison et al., 2020). Remote sensing imagery presents data on air composition and air temperature spatially and temporally to compare and change the composition of the atmosphere as well as to identify UHI and urban heat hazard phenomena (Chan and Konstantinou, 2020; Tomlinson et al., 2011; Yu et al.,

Air pollution conditions in several cities in the world, including on the island of Java, have the potential to cause health problems and worsen environmental conditions and reduce the comfort level of settlements (Manisalidis et al., 2020; Rajagopalan et al., 2018). However, there has been no research that combines aspects of air quality and city temperature and its relation to public health in Java. Thus, the research is focused on assessing the comfort level of cities in Java based on the relationship between air temperature and air quality human health levels from 2015 to 2019. We obtained several criteria of the urban comfort level from relevant literatures and applied it to the remote sensing data to classify urban comfort level for several cities in Java island.

RESEARCH METHOD

Article Search

Writing a systematic review using the PICO (population, intervention, comparator, and outcome) method to search for scientific articles that are used as references. PICO is a technique for formulating keywords that are relevant to the study theme. Keywords based on PICO are presented in Table 1. Article searches were performed on the Scopus database and Google Scholar platform, yielding 177 articles. In addition to searching for journals, the search for reports on air quality levels and the effects of UHI as well as user book of remote sensing images is done through the Google search engine.

Article Selection Method

Articles that have been collected will be selected based on the level of conformity to the focus of the study and the duplication of the discussion on it. The article selection method was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) systematic review diagram. So that in the article selection process, there were 49 articles that were used to compose the writing.

Secondary Data Processing

The analysis of city comfort in Java is also supported by remote sensing image data extraction. The data used are shown in Table 2. Secondary data processing of remote sensing images aims to determine the value of air temperature and air quality in big cities on Java Island which are classified as megapolitan cities, metropolitan cities, big cities, and medium cities based on the total population of the city. The cities are Jakarta, Surabaya, Semarang, Bandung, Malang, Tasikmalaya, Surakarta, Cilegon, Tegal, and Yogyakarta.

Air temperature information was obtained from the extraction of LST values from Landsat 8 The Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images with a spatial resolution of 100 meters (United States Geological Survey, 2019). The LST value recorded by the thermal sensor is the result of radiant heat from the earth's surface which is the energy of thermal infrared electromagnetic waves (United States Geological Survey, 2019). Air quality information is obtained from various data sources that present specific data on the composition of air quality. The air quality assessment in this study is based on the composition of PM2.5 and CO in the air with a predetermined coverage area. The CO composition was obtained from the Atmospheric InfraRed Sounder (AIRS) image instrument (Tian et al., 2013). AIRS provide monthly average data on the global CO composition spatially and temporally since 2002 (Zou et al., 2019; Zhang et al., 2020). CO data from the AIRS instrument is provided by the National Aeronautics and Space Administration (NASA) Earthdata Worldview platform. AIRS provide monthly mean data on global CO composition and has been widely used in the identification of the spatial and temporal distribution of atmospheric composition globally. The composition of PM2.5 was obtained from the Modern-Era Retrospective Analysis for Research and Application version 2 (MERRA-2) (National Center for Atmospheric Research Staff, 2019) which was obtained through Giovanni's Earth Data platform.

Table 1. Article search keywords

Category	Keywords
Population	*"Urban Comfort" OR "Air Quality" OR "Urban Heat Island" OR "Remote Sensing" OR "Public Health Assessment"*
Intervention	*"Land Surface Temperature" OR "Urban Climate Change" OR "Thermal Comfort" OR "Heat Wave" OR "LULC" OR "Urbanization" OR "Built Up Area" OR "Urban Morphology" OR "Air Pollution" OR "Urban Remote Sensing " OR "Coastal Cities" OR "PM2.5" OR "CO"*
Comparator	*"Rural" OR "Megacities" OR "Urban Population" OR "Urban Size" OR "Urban Form"*
Results	*"Urban Comfort Criteria" OR "Outdoor Thermal Comfort" OR "Universal Temperature Climate Index" OR "Air Quality Guidelines" OR "Indonesia" OR "Java Island"*

RESULTS AND DISCUSSION

City Comfort Criteria Based on Air Temperature

The UHI and HW phenomena are indicators for the criteria for assessing urban comfort that affect health quality (Pan, 2015). UHI is a phenomenon characterized by an increase in urban air temperature compared to the surrounding area, namely rural areas (Rodriguez et al., 2020). Meanwhile, HW is characterized by extreme air temperature levels exceeding a predetermined threshold for a certain period (Li, 2020). UHI and HW are urban microclimate (UMC) phenomena, namely variations in special climatic conditions on a relatively small scale in urban areas that are used to plan cities that prioritize sustainable aspects (Tahbaz, 2018).

One of the sustainable aspects of the city from the UMC element is the comfort level of the city which is assessed based on the OTC index (Kumar and Sharma, 2020). The use of the OTC index is used to define human thermal comfort and determine the level of thermal stress in certain conditions in an area (Blazejczyk et al., 2012). OTC indices that are often used in urban comfort studies are universal thermal climate index (UTCI), physiological equivalent temperature (PET), effective temperature (ET), standard effective temperature (SET), predicted mean vote (PMV) (Elnabawi and Hamza, 2020). The index is built based on a combination of factors such as thermal environmental effects and personal factors such as a sensation of heat, daily activities, and type of clothing (Blazejczyk et al., 2012). The OTC category for each index is represented by the air temperature level. Level criteria the OTC index air temperature for each category is shown in Table 3. The average air temperature value that is included in the comfortable category is in the range of 21.6 °C to 32.0 °C (Canan et al., 2019); 23°C to 31°C (Ndetto and Matzarakis, 2016).

The use of the OTC index continued to develop in the 20th century because it was

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directly related to the increase in global temperature and its impact on human health (Kumar and Sharma, 2020; Milner et al., 2017). Furthermore, a study by Kumar and Sharma (2020) stated that UTCI and PET criteria have a high correlation and are able to map thermal conditions for tropical climates such as Indonesia. Błażejczyk et al. (2013) stated that UTCI is able to describe the temporal variability of thermal conditions better than other OTC indices because it is very sensitive to changes in temperature, solar radiation, wind, and humidity, just like the human body. While PET emphasizes human psychology in responding to a hot environment (Kumar and Sharma., 2020).

Table 2. Remote sensing image data sources (United States Geological Survey, 2019; Tian et al., 2013; National Center for Atmospheric Research Staff, 2019)

Data	Image Type	Data source
Air temperature	Landsat 8 The Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	*Google Earth Engine*
PM2.5	*Modern-Era Retrospective Analysis for Research and Application version*2 (MERRA-2)	*Earth Data Giovanni*
CO	*Atmospheric InfraRed Sounder*(AIRS)	*Earthdata Worldview*

City Comfort Criteria Based on Air Quality

Urban areas as centers of human activity are more susceptible to decreasing air quality due to industrial activities and the mobility of people using motorized vehicles. Polluting gases and solid particles that pollute urban air are caused by incomplete combustion motorized engines (Manisalidis et al., 2020). There is no air quality index that is used explicitly to assess city comfort, but emissions from motorized vehicles and industrialization activities result in a decrease in environmental quality that affects the comfort of a place to live (Environmental Protection Agency, 2014). In addition, in several studies there are several pollution index criteria to assess air quality in urban areas.

Identification of air quality conditions can be known from the air pollution index or also known as the air quality index. There are various types of air pollution indices with different criteria. According to Kanchan et al. (2015) some air pollution indices are less representative for modeling air quality because they do not consider human health factors. Several index criteria can be used to assess air quality in urban areas such as the Air Quality Index, Air Quality Guideline, and the pollution index (Kanchan et al., 2015). The WHO AQG

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Table 3. Air temperature threshold criteria on the OTC index (Blazejczyk et al., 2012; Zare et al., 2020; Nazarian et al., 2017)

Thermal stress	*Index* (oC)			
	UTCI	PET	ET	SET
Extreme cold	< (-40)			
Very high cold	(-40) – (-27)			
High cold	(-27) – (-13)	<4	<1	10 – 14.5
Moderate cold	(-13) – 0	4 – 8	1-9	14.5 – 17.5
Slight cold	0 – 9	8 – 18	9 – 17	<17.5 – 22.2
No thermal stress (comfort)	9 – 26	18 – 23	17 – 21	22.2 – 25.6
Slight heat stress	26 – 32	23 – 35	21 – 23	25.6 – 30
Moderate heat stress	32 – 38	35 – 41	23 – 27	30 – 34.5
High heat stress	38 – 46	>41	>27	34.5 – 37.5
Extreme heat stress	>46			>37.5

criteria are considered more stringent than other measurement standards in defining air quality by considering environmental conditions and adverse impacts on human health (Manisalidis et al., 2020). The WHO AQG assesses an annual time period. Meanwhile, daily dynamic air pollution conditions can be defined using the AQI which has a measurement standard commensurate with the WHO AQG (Manisalidis et al., 2020). The WHO AQG safe threshold criterion for PM2.5 concentration is 20 g/m3 for the average annual measurement and for CO concentration is 30 g/m3 for the 1-hour average measurement (WHO, 2017).

The Relationship of Air Temperature and Air Pollution with Human Health

City comfort criteria based on temperature and air quality were built by considering the impact of health and psychological conditions on humans (Environmental Protection Agency, 2014; Elnabawi and Hamza, 2019; Blazejczyk et al., 2012; WHO, 2017). The phenomenon of UHI, HW, increasing temperature and decreasing air quality greatly affect human health and the quality of the living environment which is contrary to the requirements of a healthy city in accordance with the implementation of the Sustainable Development Goals (SDGs) (Mirzaei et al., 2020; Manisalidis et al., 2020; Tomlinson et al., 2011;Ramirez-Rubioet al., 2019). Extreme temperatures and air pollution in recent years have increased the number of mortality and morbidity caused by serious health problems (Landrigan et al., 2018; Environmental Protection Agency, 2016). Health problems that can be caused by exposure to extreme temperatures, according to WHO (2018) are dehydrating, heat cramps, heat exhaustion, heat stroke and can worsen cardiovascular, respiratory, cerebrovascular, diabetes mellitus, mental health, and kidney disease conditions. Factors of age and poor health affect the level of vulnerability to health problems caused by UHI (Tomlinson et al., 2011). Furthermore, the UHI phenomenon during 1984 - 2017 increased cardiovascular and mortality rates by 28.8% (Huang et al., 2020).

Exposure to air pollution in a short time triggers Chronic Obstructive Pulmonary Disease (COPD), coughing, shortness of breath, wheezing, asthma, other respiratory diseases (Manisalidis et al., 2020). While in the longer term it will cause chronic asthma, pulmonary insufficiency, cardiovascular disease, and death (Manisalidis et al., 2020; De Sario et al., 2013).Environmental Protection Agency (2014) stated that the increase in global morbidity and mortality due to respiratory, lung and kidney diseases was mainly caused by exposure to air pollution. More specifically, air pollution in the form of solids such as PM10 and PM2.5 causes diabetes mellitus, cardiovascular disease, respiratory disease, decreases lung function, and increases the risk of lung disease (Suryadhi et al., 2020; Lu et al., 2015) . Exposure to air pollution such as NO2, CO, CH4, O3, will increase mortality mainly due to respiratory diseases, lung cancer, (Rovira et al., 2020; Environmental Protection Agency, 2014).

Thermal Conditions of Java

Figure 1 presents a spatial-temporal visualization of air temperature conditions on Java Island from 2015 to 2019. Air temperature conditions on Java Island show a significant increasing trend from 2016 - 2019. However, in 2015 the air temperature in Java Island was quite high because it was influenced by the Elucidation phenomenon. Nino occurs due to an increase in sea surface temperature in the central and eastern Pacific Ocean. The graph in Figure 2 presents the level of thermal stress, according to UTCI and PET criteria based on the annual average air temperature trend. Based on the UTCI criteria, cities that experienced more strong heat stress (32oC – 38oC) occurred in 2015, 2018, and 2019. Meanwhile, based on the PET criteria, strong heat stress (35oC - 41oC) occurred in 2015 and 2019. The high temperature in 2015 was influenced by the effect of the El-Nino climate anomaly that occurred in a certain period. Meanwhile, strong heat stress, which occurred in 2018 and 2019 without the influence of extreme climate anomalies. In 2018 there were 5 cities that experienced strong heat stress, according to the UTCI criteria, namely the cities of Jakarta, Yogyakarta, Surakarta, Malang, and Surabaya. Meanwhile, in 2019 there were 9 cities that experienced strong heat stress, according to UTCI criteria, namely Jakarta, Bandung, Tasikmalaya, Tegal, Semarang, Yogyakarta Surakarta, Malang, and Surabaya. According to the Jakarta City PET criteria, Bandung and Surabaya are classified as areas experiencing strong heat stress levels. Cities that are classified as strong heat stress are uncomfortable cities because they can cause uncomfortable heat sensations for humans under normal conditions and affect health problems for the vulnerable human body.

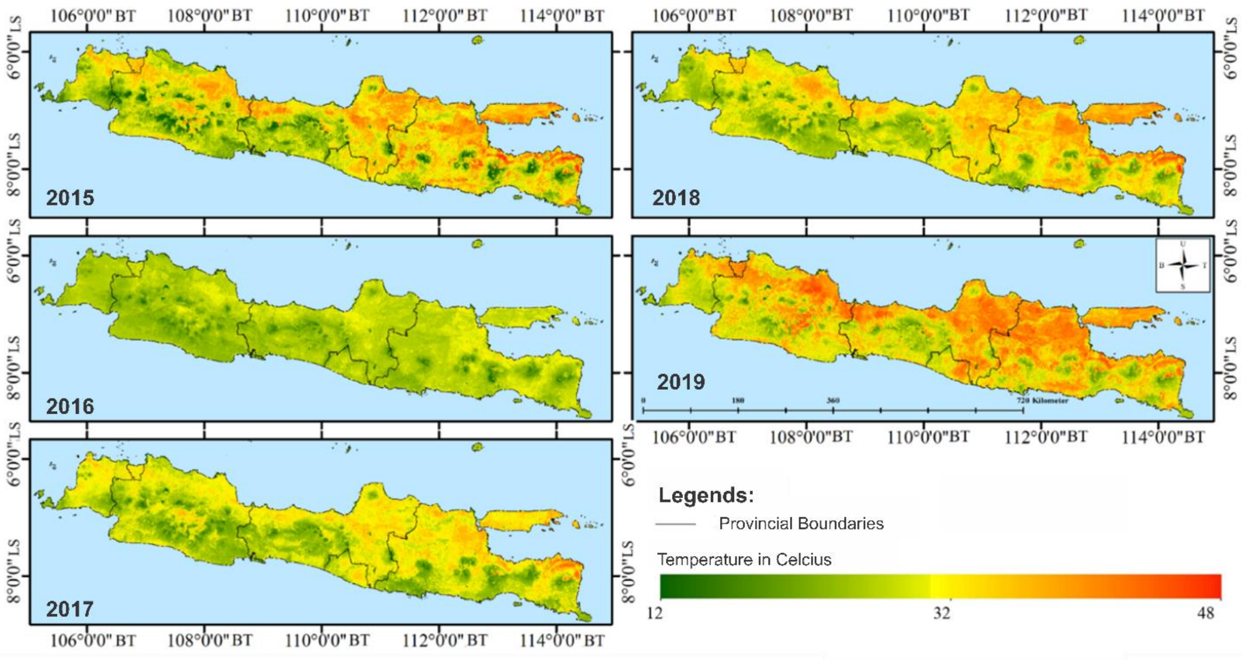


Figure 1. Air temperature distribution map for Java Island in 2015-2019

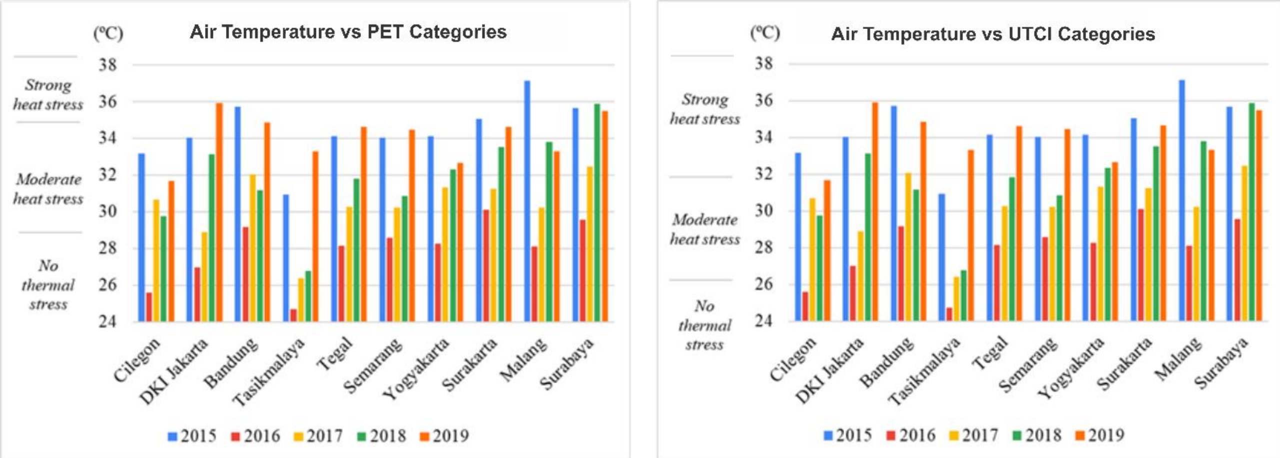
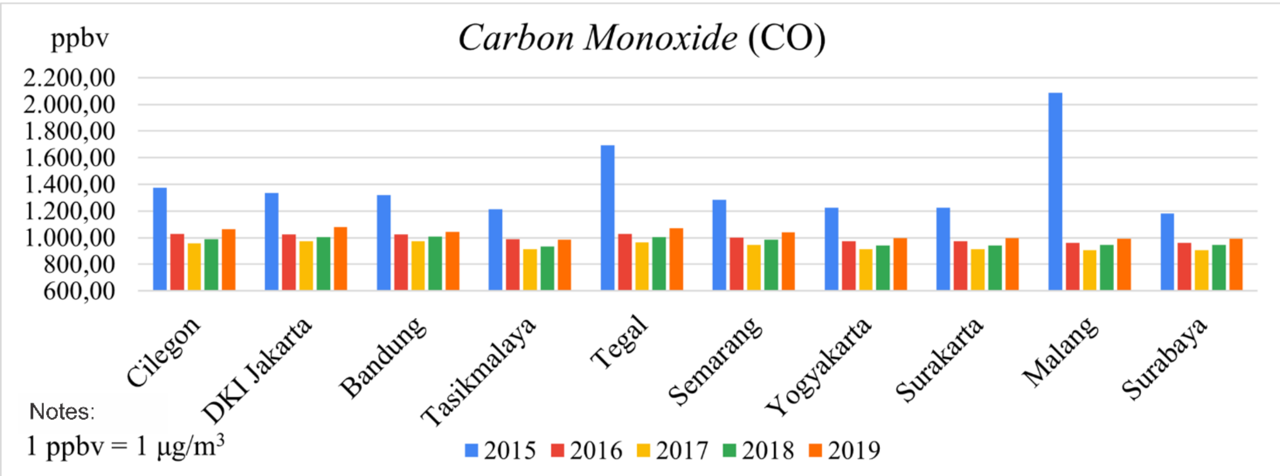
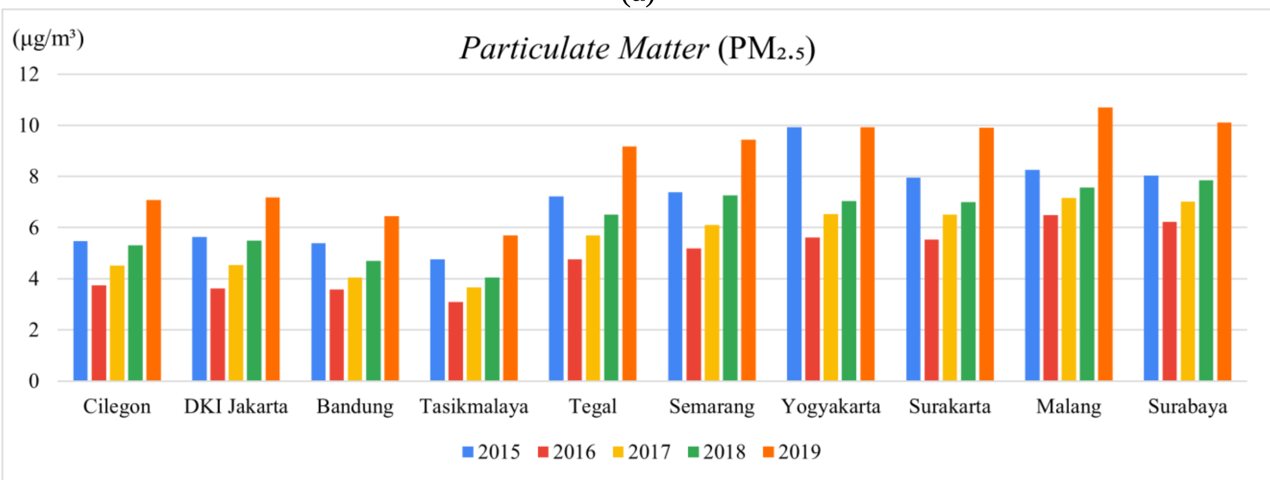


Figure 2. Air temperature and thermal stress in 10 cities in Java in 2015 – 2019



(a)



(b)

Figure 3. a) CO concentrations in 10 cities in Java during 2015-2019, b) PM2.5 concentrations in 10 cities in Java during 2015-2019 (Source: National Center for Atmospheric Research Staff, 2019; NASA, 2017)

Air Quality Conditions in Java

Air quality conditions in Java Island were assessed based on PM2.5 and CO concentrations associated with the use of motorized vehicles and sources of outdoor air pollution (Amaran et al., 2016). The CO concentration tends to fluctuate and the highest concentration occurred in 2015 with Malang City being the city with the highest concentration (Figure 3a). The concentration of PM2.5 continues to increase along with the turn of the year. In 2019 the concentration of

PM2.5 was higher than the previous four years (Figure 3b). Based on the WHO AQG, CO concentrations in 10 cities for the last 5 years are in the safe category. Meanwhile, PM2.5 concentrations in 2019 in Malang and Surabaya showed unsafe levels (10 g/m3) and the cities of Tegal, Surakarta, Semarang and Yogyakarta were close to unsafe levels (9 g/m3).

CONCLUSIONS

The criteria that were used in this study are able to assess the level of thermal stress and the level of air quality in urban areas. City comfort mapping can use the UTCI and AQG WHO criteria to assess the level of thermal stress and the concentration of pollution in the air. Based on the UTCI criteria, there are 9 out of 10 cities classified as strong heat stress and based on PET there are 3 cities classified as strong heat stress in 2019 in Java Island. The PM2.5 concentration assessment is based on the WHO AQG standard that the City of Surabaya and Malang City are cities that are classified as unsafe for both human health and the environment. The cities of Yogyakarta, Surakarta, Semarang, and Tegal are cities that are close to unsafe levels for PM2.5 concentrations. Based on the summary of health data, there is an increase in ARI disease in Tasikmalaya City, Jakarta.

RECOMMENDATIONS

The status of various cities in Java Island will require proper monitoring in the future. In the future, the combination of using remote sensing data and field instrumentation is needed to acquire model detail information at local scale.

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