Evaluation of urban pollution and bio-climate using total suspended particles and discomfort index in Jakarta City

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Abstract. Urban expansion has effects on urban environment problems such as air quality and human discomfort as the impact of urban heat island (UHI). This study attempted to evaluate the climatology of the Total Suspended Particles (TSP) as one of urban pollutants and Discomfort Index (DI) in Jakarta City using data from 1982 to 2014. The aims were to examine the urban pollution and its relation to bio-climate index and climate condition as this can have major implications for urban development. The result showed that the trend of monthly TSP data in Kemayoran not significantly increased, however the frequency of TSP that more than ambient air quality standard/AAQS value which was 230 ppm has been increasing since 2003. Seasonally, the occurrences of TSP more than AAQS value in dry season were higher than rainy season. The climatology of DI was showed significantly increasing, meaning that the thermal discomfort of Jakarta as well has been increasing. One of the factors that cause the increasing of DI was the decreasing area of urban green space which represented the existence of city trees. The relationship between TSP and DI was weaker compared to climatic parameters such as temperature, humidity, rainfall and number of dry days.

1. Introduction
Suspended particulate matter (SPM) is air pollutants that have the most impact on human health and are associated with PM concentrations in the air which adverse health [1]. Historically, the measurement of SPM has concentrated on total particulate suspension (TSP) without preference of size selection. TSP is the fraction sampled using high-volume samplers, approximately particle diameters <50-100 μm. Other particulate matters are usually restricted to particles with aerodynamic diameters 1 μm (PM₁), 2.5 μm (PM₂.₅) and 10 μm (PM₁₀).

Jakarta as a capital city of Indonesia is a big metropolitan with massive development and urbanization. Jakarta has increased fast in motor vehicles use that leads to an increase in the energy use. The number of motor vehicles during 1985 to 2012 significantly increased with the rate of 9.3% [2]. Jakarta is the most polluted city in Indonesia in term of TSP compared to other Asian Cities [3]. It was estimated that 35% of TSP contribution from fuel combustion (including domestic cooking), 30% from transportation sources, 15% from industrial processes, 12% from other sources (including construction and dust), and 8% from solid-waste disposal (including municipal incinerators and open burning) [4]. Some studies and monitoring TSP in some sites of Jakarta have been conducted with different methods [5, 6, 7].

TSP considerably influenced respiratory health and associated with lung function parameters, respiratory symptoms, and mortality [8]. In Mexico, the increasing of dying risk was 6% for every 100 mg/m³ increase in TSP parameter, where it proved the damage of high concentration of particles to
mortality and morbidity [9]. The chemical reaction between the TSP with a smaller size could affect the chemical properties of gases in the atmosphere that influence on climate and human health [10]. The case study in Jordan, temperatures showed significant positive relation with TSP, while relative humidity showed significant inverse relation and wind showed very weak relation [11]. TSP is also a factor in raising the temperature in an area therefore causing discomfort for the human.

The main factor of human discomfort is a component of thermal environmental conditions that included in several indices, which require air temperature, relative humidity and wind speed in the empirical calculation [12, 13, 14]. One of the most known of bio-climate index is Discomfort Index (DI) proposed by Thom in 1959 which calculation based on the temperature and relative humidity. DI reflects the contribution proportion between air temperature and relative humidity on human thermal comfort [15]. Study about the relations between DI as the UHI effect with air quality in the city centre in Greece showed that a strong relationship between discomfort and poor air quality occurred in the summer. The poor air quality and the unfavourable comfort for the most of the population in the city centre conditions during summer season were related to the stronger UHI effect [16].

This paper studied about the climatology of the TSP and DI in Jakarta City. The aims were to examine the urban pollution and its relation to bio-climate index as the effect of UHI and also with climate condition. The relation between DI with the area of urban green space in Jakarta were also evaluated to study the effect of trees on bio-climate in general term.

2. Data and methods

Data employed in this study were monthly TSP data at Kemayoran meteorology station and climate parameter daily data such as temperature, relative humidity and rainfall in 5 meteorology station sites in Jakarta from 1982 to 2014. The five stations were: Kemayoran, Tanjung Priok, Halim, Cengkareng and Pondok Betung as seen on figure 1 with red dot. The TSP data was derived from measurements with Gravimetric method, which the datas were analyzed by comparing the TSP to DI and climatic parameters such as temperature, humidity, rainfall and number of dry days at Kemayoran station. The area of urban green space data of Jakarta in 2013 was used to represent the area of trees to compare with the average of DI. The urban green space area data was from previous study [17] obtained from the Government of Jakarta, Department of Parks and Cemetery.

![Figure 1. Jakarta map and position of station sites (red dot).](image)

DI is one of bioclimatic indices for describing the level of personal thermal sensation due to climatic condition of urban area [16, 18, 19, 20]. In order to evaluate the comfort conditions in outdoor
spaces, generally DI offers information which valuable and accurate for comfort and energy purposes. The Thom’s DI was calculated using the formula as in equation (1).

\[
\text{DI} = T - 0.55 \left(1 - 0.01 \text{RH}\right) \left(T - 14.5\right)
\]

Where: T: Air temperature in Celsius degree and RH: Relative humidity in percent (%). DI classification is determined according to table 1 [21] with a modification which based on the psychological adaption comfort in the tropical climate in Malaysia [22].

**Table 1.** Discomfort index classification [21] with [22] modification.

| Discomfort Index (°C) | Interpretation of DI                           |
|-----------------------|-----------------------------------------------|
| DI < 21               | No discomfort                                 |
| 21 ≤ DI < 24          | under 50% population feels discomfort         |
| 24 ≤ DI < 27          | Over 50% population feels discomfort          |
| 27 ≤ DI < 30          | Most of population suffers discomfort          |
| DI > 30               | Discomfort                                    |

3. Result and discussion

3.1 Total suspended particle

The historical data of monthly TSP during 1982 to 2014 in Kemayoran meteorology station was presented in figure 2. The figure shows that there was no significant change from TSP historical data. However, the occurrences of TSP exceeded the ambient air quality standard (AAQS) value tended to more increasing since 2003, the AAQS value was 230 μgram m⁻³ (24 h average) which were set by Indonesian Government [23]. The TSP ranged from 46 to 572 μgram m⁻³ while the average of monthly TSP was 175 μgram m⁻³ and the standard deviation was 69 μgram m⁻³. The occurrences of TSP exceeding AAQS during 1982 to 2014 was 17.5% of the dataset.

The result from previous study using TSP data from 1986 to 1995 in eastern part of Jakarta (Rawasari and Pulogadung) showed that the TSP ranged from 168 to 270 μgram m⁻³ in Pulogadung and 142-239 μgram m⁻³ in Rawasari while TSP that exceeded the threshold value was in Pulogadung with the variation of 14-46% [6]. The level of TSP were 257.3 μgram m⁻³ in 1978-1981 [24], TSP in Glodok (West Jakarta) was 390 - 512 μgram m⁻³ and Ancol (North Jakarta) ranged between 171-298 μgram m⁻³ during 1980-2016 [25] so that the variability of TSP from the last 3 decades until recently has not shown any significant changes. The TSP sampling at 33 locations in Jakarta and suburban areas (Bogor, Depok, Tangerang and Bekasi) showed that the percentage of the qualified sample for TSP contamination is 12.12% at the edge of the roadway and 75.76% at 120 meters from the roadway [7].
The climate in Jakarta City is influenced by two monsoons namely southeast (from May to September) and northwest (from November to March) which bring two major seasons, the dry and wet season [26]. According to the seasonal variability, mean TSP concentration was mostly higher in the dry season than in the wet season as seen in figure 3. The TSP in Ancol and Glodok during 1980 to 2016 was also mostly higher in dry season than wet season [25]. The occurrences of TSP exceeding AAQS value in Kemayoran station during dry season from 1982 to 2014 were 31, while in the wet season were 18. The previous study said that rainfall is one of the factors of low pollutant particles in the rainy season in India due to the washing process of pollutants by rain [27]. One of the major mechanisms for removing aerosol from the atmosphere is from wet deposition with precipitation [28]. The ambient distribution of air pollution and air quality level are affected by seasonality in meteorological variables [29, 30].

3.2. Discomfort Index

The variability of monthly DI was presented in figure 4 (a) and the trend of annual DI as seen on figure 4 in Kemayoran (b), Halim (c), Cengkareng (d), Tanjung Priok (e) and Pondok Betung (f). Based on the figure 4, monthly DI in Jakarta ranged from 25.2°C to 26.8°C with an average of 25.9°C. The pattern of monthly DI had two peaks, the highest occurred in May and the second peak is in November, while the lowest occurred in February and July. The data used in DI analysis was throughout 1985-2012 period for uniformity in all sites. The trend analysis of annual DI for 5 sites around Jakarta showed an increasing tendency with R² from 0.5 – 0.75. This indicated the thermal discomfort sensation of people increased because of temperature increase in Jakarta. Over the past century (1866-2010) the annual average of temperature in Jakarta has increased by 1.6°C which exceed the rising of global average temperature. The increase of maximum daily temperature was stronger than the increase of average and minimum temperature, where the increasing minimum temperature has been strengthened over the past 50 years [31]. The effect of urban heat island on the urban environment and human discomfort level have gotten worse because of the rapid urbanization in the tropics and climate change due to global warming [32, 33].

The frequency of mean daily discomfort sensation at Jakarta according to interpretation category in table 1 were presented in figure 5. The figure showed that the category “Over 50% population feels discomfort “is the most frequently happen during January to December which ranged from 84% - 96%. The second category was “Most of population suffers discomfort “which ranged from 2% to 15%. The category “under 50% population feels discomfort “ ranged from 0% -2%, while the category “No Discomfort” and “Discomfort” are 0%. The highest frequency occurrences of category “Most of population suffers discomfort “happen on May in all sites, while the lowest discomfort sensation happens on July-August.
Figure 4. The variability of monthly DI (a) and trend of annual DI in Kemayoran (b), Halim (c), Cengkareng (d), Tanjung Priok (e) and Pondok Betung (f) Jakarta.
Figure 5. The frequency of mean daily DI in Kemayoran (a), Halim (b), Cengkareng (c), Tanjung Priok (d) and Pondok Betung (e) Jakarta.

3.3. The relation between TSP with DI and climate variables

Figure 6 shows the relationship between TSP with DI in term of the monthly average (a) and monthly time series (b) in Kemayoran station. The relationship between discomfort sensation and TSP in term of monthly average (figure 6a) did not show any clear relation. The highest number of people who felt the discomfort was on May when there was also an increase in TSP concentration. However, the
highest TSP concentration was at the same time as the lowest number of people who endured discomfort sensation on July. In term of monthly time series as seen on figure 6b, the DI showed a rising trend and more intense since 2003, when the frequency of TSP exceeding AAQS was more increasing. However, previous study about investigation of the recent state of ambient air quality in Jakarta using rainwater chemistry and particulate matter pollution (TSP in Ancol and Glodok, PM\textsubscript{10} and PM\textsubscript{2.5}) showed decreasing trends and the result said there was an improvement of local ambient air quality in Jakarta [25].

![Figure 6](image)

**Figure 6.** Plotting of TSP and DI monthly average (a) and monthly time series (b) in Kemayoran station.

**Table 2.** Coefficient correlation between TSP with DI and climate parameters in Kemayoran station.

| Time scale | TSP vs T | TSP vs DI | TSP vs RH | TSP vs NDD | TSP vs RR |
|------------|----------|-----------|-----------|------------|-----------|
| Monthly    | 0.24*    | 0.12*     | -0.30*    | 0.38*      | -0.27*    |
| Dry season | 0.15*    | 0.00      | -0.29*    | 0.39*      | -0.30*    |
| Wet season | 0.37*    | 0.31*     | -0.34*    | 0.40*      | -0.21*    |
| Annual     | 0.19     | 0.16      | -0.18     | 0.45*      | -0.06     |

Where T: Temperature, RH: Relative Humidity, NDD: Number of dry days, RR: Rainfall
*) significant with $\alpha$ 5%

Correlation analyses between TSP with DI and climate parameters were conducted to quantify the relationship between bio-climate and climate variables with air pollution. The correlation coefficient between TSP with DI and climate variables such as temperature (T), relative humidity (RH), rainfall
(RR) and the number of dry days (NDD) was statistically analysed and the results were presented in table 2. The number of dry days is the accumulation of dry days in a month. From this table it was noted that the monthly TSP showed a significant positive correlation with monthly DI, T and NDD, while significantly negative correlation occurs between monthly TSP with monthly RH and RR during 1982–2014. According to seasonal variability, the correlation between TSP with DI and climate variables were higher in the wet season than dry season. While for annual correlation, only correlation TSP with NDD which significant.

The highest correlation to TSP is between TSP with NDD then followed by RH, RR, T and DI. The result showed that the occurrences of precipitation affect the concentration of TSP. The lesser the occurrences of rainfall, the higher the concentration of TSP. Previous study in India found precipitation and wind speed had the highest correlation with TSP [27]. Precipitation reduced particulate levels in the atmosphere compared to other climatic parameters. When it rains, the soil became moist restricting the possibility of soil derived particles being released [34]. The result study in Turkey found higher TSP concentrations were strongly related to colder temperatures, lower wind speed, higher pressure system and weakly lower precipitation and higher relative humidity [35].

3.4. Comparison between DI with urban green spaces area in Jakarta

Urban green space (RTH) is a type of land use which open space areas for parks, green spaces, lane or clumped areas where plants purposely planted or grows by nature. The government of Jakarta has adopted the Indonesia regulation number 26/2007 concerning spatial planning that obligate the provision of urban green space at minimum 30% which 20% of it for public urban green space [36]. However, the public urban green space in Jakarta only reached 9 - 10% compared to its area [37] which still need more extension. Ecologically urban green space can reduce the level of air pollution and increase the amount of ground water content, given the existing trees are able to store water [17].

![Figure 7. Comparison between DI and Urban green space area in Jakarta](image)

The relation between trees and bio-climate found that city trees improve the microclimate which reduce DI [38] and have positive effect on the thermal environment and air quality [39]. The indoor and outdoor thermal comfort were affected by the tree shading, the shaded building by tree generally is more comfortable than the unshaded building especially during the daytime [40].

The average of DI (1985-2012) was compared with the area of urban green space of Jakarta (2013) according to district as seen on Figure 7. The DI of Pondok Betung station represented the South Jakarta district, Kemayoran station represented The Central Jakarta, Soekarno Hatta Cengkareng station represented the West Jakarta, Halim Perdana kusuma station represented the East Jakarta and Tanjung Priok station represented the North Jakarta (figure 1). The figure 7 showed that
the higher average of DI located in North Jakarta district where the area of urban green space was the lowest (453 ha). However, the lowest average of DI was in East Jakarta while the area of urban green space was not the highest (551 ha). The highest area of urban green space in 2013 was 624 hectares (ha) located in the South Jakarta district.

Previous study said that the urban green space area in Jakarta using Landsat data satellite decreased by 57.5% with data period of 31 years from 1982 to 2013 or the rate of declining was about 1.8% per year [41]. Comparison between urban green space areas in 2007 and 2013 of Jakarta using NDVI (Normalized Difference Vegetation Index) calculation of Landsat data found that the urban green space area in 2007 reached 29% while in 2013 only 9% left of the whole Jakarta area [42]. Study about the relation between temperature and urban green space area in Jakarta showed that the decreasing of urban green space area for 50% would rise the temperature of 1.42°C [43]. The decrease of municipal trees presented by the reducing area of urban green space was one of the reasons which causes the rising of DI values that lead to the declining of thermal comfort.

4. Conclusion & suggestion
Urban pollution in term of TSP in Jakarta using Kemayoran station data from 1982 to 2014 showed no significant changes, however the occurrences of TSP exceeding the AAQS value tended to increase more. The effect of UHI in Jakarta was more perceived by the increase of DI along with climate change due to global warming. In term of monthly time series, the DI denoted a rising trend and more intense since 2003, when the frequency of TSP exceeding AAQS has been increasing. The result in this study indicated the higher concentration of TSP related to the higher of number of dry days, temperature and DI and the lower of relative humidity and rainfall. The relation of TSP with discomfort thermal sensation was weaker than climate variables. There was influence of city trees existence to the rising of DI differential from the decreasing of urban green space area in Jakarta from year to year. Jakarta government policy, regarding the improvement area for municipal trees, highly recommended to improve the urban comfort level and reduce urban air pollution.

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