The influence of environmental conditions (vegetation, temperature, equator, and elevation) on tropospheric nitrogen dioxide in urban areas in Indonesia

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Abstract. Nitrogen dioxide (NO₂) is one important species in the tropospheric layer that has a contribution towards air quality. In urban areas in Indonesia, urbanization and growing industrial activities have increased rapidly, which may have affected tropospheric NO₂. This study investigates the effect of green spaces and other environmental variables (e.g., temperature, city, distance from the equator) on tropospheric NO₂ in over thirty (30) urban areas in Indonesia between 2007 to 2016. Data on land cover were obtained from Google Earth’s satellite imagery data, tropospheric NO₂ readings came from Metop-A, and information on temperature was obtained from the Terra MODIS satellite. Our results show an annual decrease in green space over 10 years in all urban areas except Surabaya. Multiple linear regression analysis also reveals that a decline in vegetation decreases tropospheric NO₂ significantly. Other influential environmental factors are surface temperature and distance to the equator. Despite a promising model being obtained from this study, adding variables is important to improve the forecasting.

Keywords: Green space, Metop-A, Tropospheric NO₂, Urban area.

1. Introduction

NO₂ is one among many gas pollutants that are emitted largely through combustion processes, such as those in the transportation sector [1]. A large concentration of NO₂ will have a negative impact on health, namely decreased lung function and visibility, and it also inhibits plant growth [2].

The increase in NO₂ concentration has occurred mainly in urban areas. In Indonesia, almost all of the provincial capitals have increased air pollutant concentrations, which is in line with increased urbanization activities. Based on United Nation’s data from 2015, urbanization in Indonesia is predicted to increase by 64% by 2050 and cause dramatic changes in land cover and use [3]. Many facts support vegetated land becoming tighter. This condition indicates that vegetated land as an absorber for various air pollutants is getting smaller, whereas, on the other hand, the number of buildings, industries, and vehicles as sources of emissions keeps increasing [4].

Vegetation has an important role in controlling temperature and air quality, including the amount of NO₂ in the atmosphere. Vegetation has an effect on the climate through two processes: providing canopy shade and evapotranspiration. Canopy shade in the form of leaves and twigs reduces the amount of solar radiation that reaches the area under trees. The amount of sunlight transmitted through the canopy varies
by plant species. Evapotranspiration cools the air by using heat from the air to evaporate water [5]. The mechanism of NO$_2$ processes in plants is divided into three major processes: assimilation into amino acids, accumulation in vacuoles, and re-emission as NOx [6]. Specific types of vegetation have high NO$_2$ absorption capabilities since plant morphology affects NO$_2$ absorption. One influencing factor is stomata size. The larger the size of stomata, the higher the absorption rate [7].

Almost all urban area in Indonesia are losing green space every year. For example, between 2001 and 2014, Jakarta lost as many as 5.1% of its trees while growing by approximately 13% [8]. Further, vegetation in Yogyakarta decreased, on average, by 1% during 2003-2014 [9]. Finally, the decrease in vegetation in Semarang was approximately 0.26% and in Bandung 1.4% in the period 1994-2002 [10]. The dominant factors that dictate urban land cover changes in Indonesia are agricultural activities, industry, and land ripe for development [11].

Studies related to the control of NO$_2$ are not limited to a micro scale, but can also be done on a macro scale because the dispersion of the gas pollutant will be on a large and predominant scale in the atmospheric layer. Therefore, this study aims to investigate how the decreasing trend in green space over thirty (30) large cities in Indonesia has affected tropospheric NO$_2$ concentrations using satellite images.

2. Method

This quantitative research is based on remote sensing data. Satellites used are Google Earth Pro to identify land cover, GOME MetOP-A for tropospheric NO$_2$ concentrations, and Terra MODIS for temperature readings. Data used as variables in this research are proportion of vegetation area (%), tropospheric NO$_2$ concentration (molecules/cm$^2$), urban surface temperature ($^{\circ}$C), elevation, and perpendicular distance of an urban center from the equatorial line (km). We observed thirty (30) capital cities of provinces, which may represent the urban conditions in Indonesia. All data were processed using ArcGIS 10.0, and statistical analysis was conducted using Minitab 16.

2.1. Data Generation for Vegetation Area

Google Earth imagery data is classified based on two classes: non-vegetation and vegetation. The time span of imagery data used is from 2007 to 2016. Magnification of the map was done up to one thousand meters, which is represented by one centimeter on the map. Identification of vegetation was done by digitizing (creating a polygon following the shape of the visual green area), then the area of each polygon was calculated. Once these were summed up, the percentage of green area was obtained.

2.2. Data Generation for Tropospheric NO$_2$

GOME-2 MetOP-A satellite datasets were used in this research, and the images were converted into an ArcGIS format file. Once a visual map appeared in the program for each city, the pixel colors in the legend were adjusted. The value of troposphere NO$_2$ was obtained by averaging values from the pixels that cover each city.

2.3. Data Generation of Urban Surface Temperature

The Terra-MODIS data used was the monthly MOD11C3 product. Based on the Terra MODIS data processing guide, the MOD11C3 product has a 0.02 factor scale used in surface temperature identification algorithms. A unit conversion process by map calculation uses the following formulation:

\[ (^{\circ} \text{Celsius}) = ([\text{LST}_\text{Day}] \times 0.02) -273.15 \]  \hspace{1cm} (1)

Urban surface temperature ($^{\circ}$C) was then calculated by averaging all pixel values until all of the data in the range 2007-2016 was incorporated.
2.4. Data for Distance from the Equator and Elevation

Elevation categories are either low or high hill based on secondary data published by each municipal government agency. In this categorization, an area with an elevation of more than 200 meters above sea level is referred to as a high hill [8][12]. The distance from the city to the equator line was measured perpendicularly.

Statistical analysis was used to obtain the relationship between the above independent variables and tropospheric NO\textsubscript{2}. Regression was done using Minitab 16. It was found that the correlations between variables are small, except for the correlation between temperature and vegetation. As expected, more vegetation reduces the surface temperature (Table 1).

Table 1. Correlations among variables (p-values inside brackets).

|                  | Vegetation (%) | NO\textsubscript{2} (molec/cm\textsuperscript{2}) | Temperature (°C) | High Hill |
|------------------|----------------|-----------------------------------------------|------------------|----------|
| NO\textsubscript{2} (molec/cm\textsuperscript{2}) | -0.036 (0.000) |                                 |                  |          |
| Temperature (°C) | -0.577 (0.000) | 0438 (0.000)                               |                  |          |
| High Hill        | 0.066 (0.000)  | -0.027 (0.106)                              | -0.116 (0.000)   | -0.013 (0.443) |
| Distance from equator (km) | -0.494 (0.000) | 0.261 (0.000)                              | 0.404 (0.000)    |          |

3. Results and Discussion

In this study, the green cover classification does not include vegetation type or density. Over the ten year period (2007 - 2016), the change in each city is different. Overall, green land cover decreased in area. Figure 1 explains that almost all of the 30 provincial capitals in Indonesia experienced a decrease in the area of green land in each year of the study period. The average decrease in green land area in the 30 cities over the given time period was 14.56%. The cities with the highest percentages of green area decline were Mataram (35.7%), Banda Aceh (32.8%), Kupang (26.6%), Pangkal Pinang (25.2%), and Jambi (24.2%).

The decrease in green areas is due to the conversion of land into land for building. This is supported by the increasing number of residents and various activities making the developmental changes in these cities dynamic. The five cities with the lowest percentage of green areas during the last ten years were Jakarta (4%), Yogyakarta (7.7%), Jambi (16.7%), Bandung (21.3%), and Denpasar (34.9%). Cities with the highest percentages of green areas were the capital cities in eastern Indonesia and Kalimantan; the five cities with the highest green areas were Ambon (95.5%), Jayapura (94.5%), Palangkaraya (up to 97%), Samarinda (75.5%), and Palu (84.4%). It should be mentioned that Surabaya is an exception. It increased its percentage of green space between 2012 and 2016 by 4.7%. The overall trend in urban green spaces areas in Indonesia can be seen in Figure 1. For ease visualization of thirty cities, we create three graphs showing overall conditions of all cities.
Figure 1. Trend in Urban Vegetation Areas (%) of thirty cities (displayed in three graphs for clear visual) in Indonesia (a) Banda Aceh, Medan, Bengkulu, Pangkal Pinang, Tanjung Pinang, Pekanbaru, Jambi, Bandar Lampung, Palembang, Padang, (b) Serang, Surabaya, Denpasar, Palangkaraya, Bandung, Yogyakarta, Mataram, Semarang, Jakarta, Kupang, (c) Samarinda, Palu, Manado, Jayapura, Banjarmasin, Kendari, Ternate, Makassar, Gorontalo, Ambon.

The percentage of urban green land area and its fluctuations are influenced by many factors. The density of a city; as controlled by the area, type, and shape of the topography of the urban land surface; population; and development of the city; is one such factor. There are also socio-economic factors that come into play which influence government development policies, such as urban sprawl (uncontrolled urban sprawl), the need for land for agricultural activities, and the growth of new hierarchical centers [11]. Some cities in Java, Bali, Sumatra, and Nusa Tenggara have a tendency to change the area given over to green land through expanded city development, while some cities located in Kalimantan, Sulawesi, and Papua have a tendency to change the extent of green land through urban development and mining activities.

The results of the satellite Metop-A present the tropospheric NO$_2$ concentration on a macro scale well. Over the past ten years, global NO$_2$ gas concentrations in thirty cities in Indonesia have been increasing. Some of the cities with the highest NO$_2$ gas concentrations are Sumatra and Java, while, in the eastern part of Indonesia, concentrations tend to be lower. The five cities with the highest average of NO$_2$ concentrations were Jakarta (826.3), Serang (570.1), Surabaya (384.0), Bandung (299.7), and Tanjung Pinang (298.8). The five cities with the smallest average concentrations of the NO$_2$ gas were
Ternate (32.2), Ambon (32.9), Gorontalo (38.8), Manado (39.0), and Jayapura (39.6). The trends in tropospheric NO$_2$ concentrations are seen clearly in Figure 2.

In 2014, NO$_2$ emissions spiked in almost all the cities. The process of NO$_2$ dispersion in the atmosphere is influenced by meteorological conditions (solar radiation, temperature, wind distribution, and air humidity). However, pollutants from anthropogenic activities are the main cause of increasing NO$_2$ production, especially the transportation sector. Overall conditions for troposphere NO$_2$ concentrations in Indonesia, based on the average value of the 30 cities, point to an increase of 18.49% between 2006 and 2017. Air pollution prevention documents state that nitrogen dioxide in urban NO$_2$ gas loads varies according to time, season, and meteorological conditions. Commonly, NO$_2$ concentrations in urban areas increase in the morning and afternoon due to peak traffic in the morning and photochemical reaction at noon. In addition to being peak times for anthropogenic activity, especially transportation and other fuel usage activities, these are also times of higher solar intensity, leading to increases in NO$_2$ concentrations during these periods [13].

The cities with the highest surface temperature averages were Jakarta (38°C), Yogyakarta (34.9°C), Surabaya (34.4°C), and Makassar (34°C). Some of the cities with the lowest surface temperature averages were Ambon (26.3°C), Ternate (26.9°C), Jayapura (28°C), Manado (28.8°C), and Padang (28.9°C). The trend of surface temperatures from 2006 until 2017 in urban area of Indonesia can be seen in Figure 3.
The urban surface temperatures in the 30 cities during the study period fell in an interval from 25-40 °C. During those ten years, most cities experienced the highest temperatures in 2014 and 2015. The years 2010 and 2011 were most likely to show decreases in temperature. Increasing the surface temperature of the earth impacts many aspects of life. These impacts include increased energy consumption for air conditioning and fans, need for use of motorized vehicles, and hunger due to decreased crop production or crop failure, evaporation which limits the availability of water, and pest and disease attacks.

The magnitude of the effect of vegetation area, urban surface temperature, distance to the equator, and hill category on tropospheric NO\textsubscript{2} were analyzed statistically. The results of the analysis can be seen in Table 2.

| Variable                 | Coef. | F Stat. (P-Value) | R\textsuperscript{2} | VIF |
|--------------------------|-------|------------------|----------------------|-----|
| Constant                 | -441.80 | 0.000            |                      |     |
| Vegetation (%)           | -1.0649 | 0.000            |                      | 1.709|
| Temperature (°C)         | 21.434 | 0.000            | 22%                  | 1.559|
| Distance from equator (km)| 0.03651 | 0.001            |                      | 1.364|
| High Hill                | 13.273 | 0.136            |                      | 1.015|

Based on the VIF values, there is no multicollinearity among the independent variables. Hence, the multiple regression equation can continue on to influence analysis. Table 2 shows that each variable has a different coefficient of influence. The result has a coefficient of determination (Rsquare) of 22%. Based on the Rsquare value, 22% of all variation in tropospheric NO\textsubscript{2} concentrations can be explained by these four variables, while the remaining 78% of the variability may explained by other factors not taken into account in this model.

Due to its nature, NO\textsubscript{2} reacts easily with other components. However, ozone can bind subsequently with NO in the troposphere to form NO\textsubscript{2} once again. These conditions, along with the micro NO\textsubscript{2} conditions on the surface, result in the rapid accumulation of tropospheric NO\textsubscript{2} [14]. The very rapid fluctuations in and reactions of NO\textsubscript{2} changing its stability are supported by the increasing sources of NO\textsubscript{2} on earth, especially industrial and transportation sources.

The regression coefficient of area vegetation is -1.0649. The negative value means that the relationship between vegetation areas and tropospheric NO\textsubscript{2} is inversely proportional, i.e., as vegetation increases, tropospheric NO\textsubscript{2} concentration decreases. These results agree with previous research on both laboratory and macro scales using satellite image databases. An experiment on the reduction of NO\textsubscript{2} gas by various species of plant species yielded the information that Erythrina cristagali and Caliandra sp have the highest absorption capabilities of 68.3 and 41.01 μg/g, respectively [15]. Another review showed that stomata play an important role in air control in the troposphere layer, especially in terms of ozone and NO\textsubscript{x}. In these processes, the surface temperature factor also has an effect, mainly on the dispersion and chemical reactions that occur [16]. In an examination of the absorption of NO\textsubscript{2} using eight types of plants under different environmental conditions, it was found that NO\textsubscript{2} absorption rates by plants are higher in higher temperatures (approximately 30°C) than in lower temperatures (approximately 20°C) [7].

The regression coefficient for surface temperature is 21.343, which means that urban surface temperature has a positive effect on tropospheric NO\textsubscript{2}. The higher the urban surface temperature, the higher the concentration of tropospheric NO\textsubscript{2} gas. The results of this analysis contradict, or are not in accordance with, the basic theoretical relationship established between temperature and concentrations of NO\textsubscript{2} or various other types of gas pollutants. Results from previous research, as mentioned above, indicate that the lowest concentration of NO\textsubscript{2} occurs when the air temperature is high, and the highest
concentration of NO\textsubscript{2} occurs when the air temperature is low. Although contrary to most theories, this study’s result is possible. Jakarta, for instance, has produced results that show that a high temperature indicates high concentrations of pollutants in the air. In urban areas, the disparities between NO\textsubscript{2} conditions during the day and afternoon are larger than they are in rural areas. The main factors driving NO\textsubscript{2} concentrations are, as noted previously, anthropogenic activity on the part of the transportation sector and fuel consumption in industry. The next most influential factor is the difference in air temperature that occurs [17]. It is also known that high ozone concentrations indicate high concentrations of NO\textsubscript{2} gas.

Another study has also explained that, overall, starting from the surface of the earth up to a height of about 17 km, ozone concentration and temperature have a positive correlation such that the lower the concentration of ozone, the lower the temperature. The height of 17 km includes the troposphere layer. At a height of 17-27 km, the positive correlation between the concentration of ozone and temperature persists. Conversely, at a height of 27-40 km, the correlation turns negative, meaning that the higher the temperature, the lower the ozone concentration [18].

Based on elevation, cities are classified as being high or low hill. In this analyze, being at ‘high hill’ in elevation has a positive regression coefficient of 13.273. Hence, the higher elevation of a city means that it is likely that the tropospheric NO\textsubscript{2} is higher too. This condition has a meteorological explanation. A high hill or plain has a low temperature. High temperatures cause the air to release water and become less dense, making the convection of various pollutant gases, including NO\textsubscript{2}, flow upward. This means that NO\textsubscript{2} concentration will be low. On the other hand, low air temperatures cause the surrounding air density to be almost equal to the density of the upper air layer. Therefore, the flow of air convection moves more slowly and causes NO\textsubscript{2} concentrations to be high as it accumulates on the surface [19].

The position of a city, as based on its latitude, which determines its distance to the equator, also affects tropospheric NO\textsubscript{2} concentration. Cities in Indonesia generally have a fairly small distance from the equator in accordance with the position of Indonesia, which is a tropical country. The result of the regression analysis indicates that the distance of a city from the equator positively affects troposphere NO\textsubscript{2} gas concentration with a regression coefficient of 0.03651. According to a 2016 publication which shows that ozone conditions in developing countries, Southeast Asia, in particular, increased its ozone concentrations rapidly during the period 1980-2010 [20]. The mapping of dispersions based on the equator shows that pollutants, especially ozone, have high concentrations in areas with low latitudes (close to equator). If the ozone concentration is high in areas with low latitudes, then NO\textsubscript{2} is low in these areas. A city close to the equator will have a relatively high surface temperature. In high surface temperature conditions, the pollutant concentration, including that of NO\textsubscript{2} gas, tends to be low [21].

4. Conclusion
Urban growth in developing countries, especially in Indonesia, is marked by substantial growth in the number of urban buildings, which is usually followed by a decrease in green space over time. However, this need not be the case if local leaders are aware of the importance of vegetation and increase public green space by adding more vegetation and trees in the city. Among the 30 cities observed in Indonesia, this was the case only in Surabaya, where the green space grew as much as 0.94 % annually between 2012 and 2016.

However, a growth in green space will fail to outweigh massive additions of anthropogenic sources that emit nitrogen dioxide, leading to an increasing trend in tropospheric NO\textsubscript{2} concentration, despite a decreasing trend in surface temperature. The statistical analysis also shows that temperature and elevation affect tropospheric NO\textsubscript{2} concentrations. This result implies that a green space expansion policy should receive attention from local governments and other stakeholders in order to improve air quality not only in the troposphere but also on the surface. Despite the model having quite low accuracy, we have been able to show that using data from satellites and other secondary sources may further improve the model. Therefore, this may be a promising method with which to derive conclusion concerning air quality as well as suggest policy.
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