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Characterizing Concentration of NO_2 in Indonesia Using Satellite Instrument of GOME 2 MetOp-B

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Indonesia is a country with rapid development of industries, trades, tourism and transportation in recent years. This causes a progressive increase in energy use, and as a result, more emission of pollutants; one of them is nitrogen dioxide (NO_2). NO_2 is a pollutant resulting from the burning of fossil fuels. Based on that fact, air quality monitoring is crucial as part of air quality management. However, air quality monitoring stations in Indonesia are still lacking, and there is only a few that remain active, such as in Jakarta and Surabaya. To overcome this problem, one can use NO_2 information from satellite instruments. The linear correlation analysis based on NO_2 concentration data and totals column data from satellite remote sensing of GOME 2 MetOp-B was conducted to make spatial predictions of NO_2 concentration in Indonesia. It is observed that relationship between NO_2 ground measurements (y) and total column NO_2 (x) follows regression formula $y = 2.10^{-5}x + 0.0002$ with R^2 value of 0.436. This technique demostrates a promising alternative in characterizing and predicting NO_2 concentration in areas where there are no monitoring stations.

Keywords: NO_2, GOME 2 MetOp B, NO_2 Total Column, urban air pollution

1. INTRODUCTION

Indonesia has very rapid development from many sectors. This is evident from the increased use of petroleum energy sources. Data from the US Energy Information Administration[3] showed an increasing petroleum consumption from 2000 to 2014. The increase of the petroleum consumption starts from less than 1.2 million barrels / day to more than 1.6 million barrels / day (Figure 1). Moreover, the vehicle ownership also grows almost exponentially, especially in big cities. The use of fossil fuels, as well as emission from vehicles, is a contributor to air pollution. There are five main pollutants produced; they are SO_2, NO_2, CO, PM_{10}, and Pb, as well as secondary pollutants namely ozone (O_3).[2] Fossil fuels yield higher NO_2 emissions than other[4] pollutants, and it is widely used in Indonesia. NO_2 can damage the ozone layer in the troposphere. NO_2 formation in the stratosphere is caused by photodissociation,

On the other hand, tropospheric NO_2 is formed as a result of industrial activities, motor vehicles and biomass burning.[1]

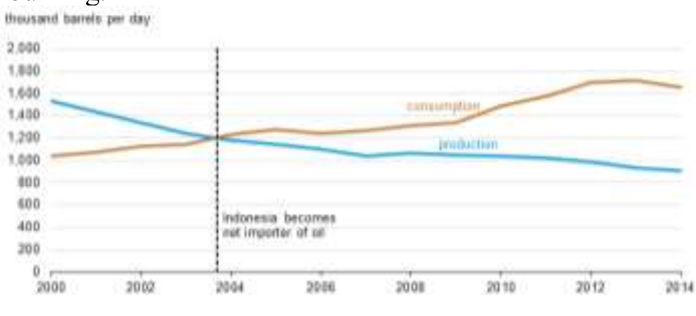

Fig.1. Petroleum consumption and production in Indonesia.[3]

To manage air quality, especially in urban areas, air quality monitoring stations were installed. There are several air quality monitoring stations which are located in major cities, but only a few are still active, such as those in Jakarta and Surabaya.

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The concentration of NO_2 in the air can be seen by trace gases in the atmosphere by satellite remote sensing. GOME 2 MetOp-B satellite is one of the satellites that is able to capture visualization of NO_2 in the atmosphere. The satellite remote sensing data has been processed by the Koninklijk Netherlands Meteorologisch Institute (KNMI) and is displayed in the form of a map that has a value of each pixel.[9] The pixel value is the total column value (10^{15} Molecule/cm^2). Linear correlation of ground measurement NO_2 with satellite GOME remote sensing has been performed in Austria.[5,6]

GOME 2 MetOp-B satellite is one which operates for the purpose of overseeing the density and profiles of ozone and trace gases NO_2, BrO, OCIO, HCHO, SO_2 and H_2O in the atmosphere (Troposphere layer). GOME 2 is an improvement of GOME 1, which was launched in 1995 by ERS-2. Improvements were made, in particular, on the spatial resolution, polarization measurements, and calibrations. GOME 2 was launched in 2012 and has operated from 2013 until today. GOME 2 instrument works on nadir-scanning UV/visible spectrometer with medium resolution. GOME 2 consists of 4 main optical channels with a level of focus up to 1024 pixels for each optics, and also Polarization Measurement Devices (PMDs). The four channels provide continuous wave spectral wavelengths from 240 nm up to 790 nm. PMDs Channel was designed so that similarities in the nature of the optic fourth are guaranteed[10]. Its spatial coverage is 14 orbits per day, whichprovidesglobal coverage in approximately one week.[8]

Table 1. Characteristics GOME 2 MetOp B [7]

Principle	Nadir-scanning UV/VIS grating spectrometer
Wavelength Range	240-790 nm 4 channel
	300-800 nm in 2 polarisation channel (s/p)
Detectors	1024 element Reticon linear diode arrays
Readout time	46,875 ms (complete arrays)
Spectral sampling	0,12-0,21 nm (main channel)
Spectral resolution	FWHM 0,26-0,51 nm (main channel)
Swath width	Default 1920 km
Swath Type	Earth-curvature compensating
Min effective IT	187,5 ms
Spatial resolution	Default 80x40 km^2
Internal Calibration	LED, spectral lamp (PtCrNeAr), White Lamp
Sun diffuser	Quartz quasi-volume
Date Rate	400 kbits/ or 300 MB/orbit

The processed data taken from the www.temis.nl is a publication of the Koninklijk Nederland Meteorologisch Instituut (KNMI) Netherland. That data describes the character of NO_2 concentration in the troposphere. Format of the data is available in the form of ESRI grid format that can be converted into shapefile data and read using any GIS software.

2. MATERIALS AND METHOD

Ground-level NO_2 Data. NO_2 daily data in units of parts per million (ppm) concentrations are obtained from the measurement results of air quality monitoring stations in the city of Surabaya and Jakarta. The data was obtained in the period from 2013- 2015. Both cities have several monitoring points (Table 1). NO_2 concentration in the coordinates that are on the same pixels is averaged in order to get the value of NO_2 concentration in one pixel.

Table 2. Air Quality Monitoring Station Locations

City	Monitoring Point	Location	Coordinate
Surabaya	SUF 1	Taman Prestasi	-7.262016 112.746425
	SUF 2	Perak Timur	-7.223738 112.733968
	SUF 3	Sukomanunggal	-7.248917 112.647734
	SUF 4	Gayungan	-7.333790, 112.707853
	SUF 5	Gebang Putih	-7.290515 112.793565
	SUF 6	Wonorejo	-7.313076 112.785212
	SUF 7	Kebonsari	-7.327922 112.713241
Jakarta	DKI1	Bunderan HI	-6.1949571 106.82306
	DKI2	Kelapa Gading	-6.1604549 106.905461
	DKI3	Jagakarsa	-6.334917 106.823737
	DKI4	Lubang Buaya	-6.2939072 106.903398
	DKI5	Jakarta Timur	-62069444 106.752222
	JAF4	West Jakarta	-6.1683295 106.758849

Satellite GOME 2 MetOp-B NO_2. Data were obtained from the total column NO2 official website, KNMI, which is www.temis.nl. Data published were already in the form of a map with a total column value (10^{15} molecule/cm^2) of NO_2 for each pixel (Figure 2).The monthly total column tropospheric data that was processed by KNMI was the data used. Period of data available were from the year 2013 until today**.** Coordinate points from Table 1 were then input to the NO_2 total column map.

Since the grid resolution of the satellite image is large, we grouped several monitoring stations based on their location on image pixels. The groups for Surabaya are SUF 7, SUF 1, SUF 4; SUF 6, SUF 5; and SUF 3, SUF 2 (Figure 3). The groups of monitoring stations of Jakarta are DKI 3, DKI 4; and DKI 1, DKI2, DKI5 (Figure 4). Total column value for each pixel was taken in accordance with the time period on ground NO_2 measurement data (air quality monitoring stations, AQMS).

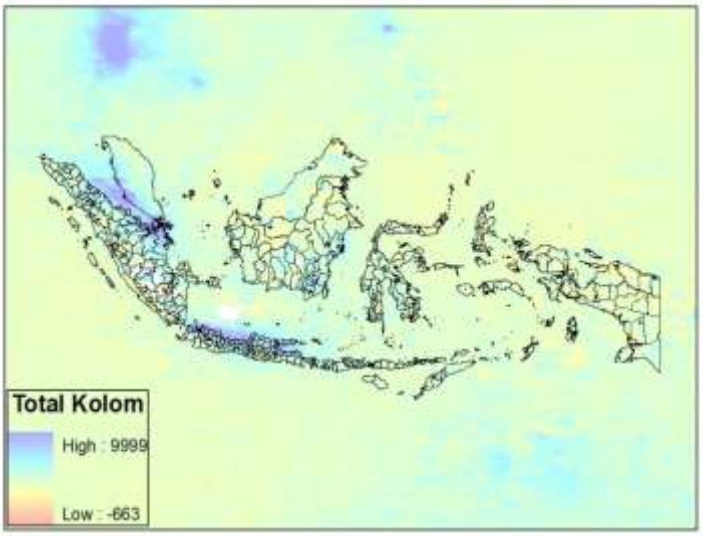

Fig. 2. Map of monthly total column NO_2 in Indonesia, January 2013. [9]

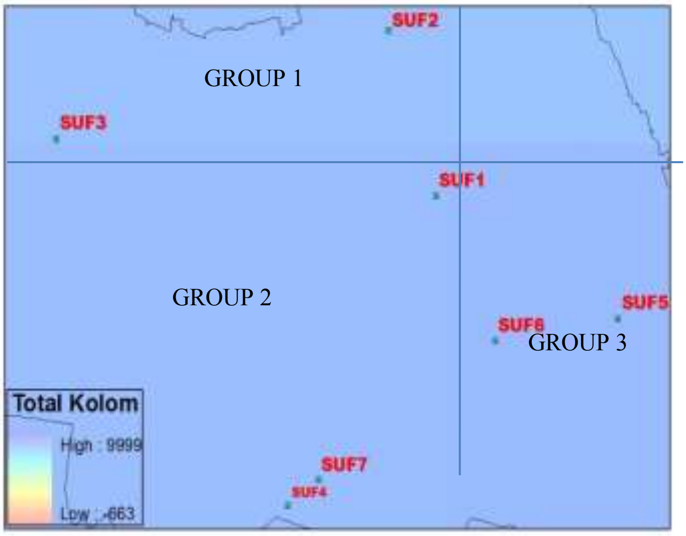

Fig. 3. Overlay coordinates of air quality monitoring stations with total column's map, Surabaya on January 2013.[9]

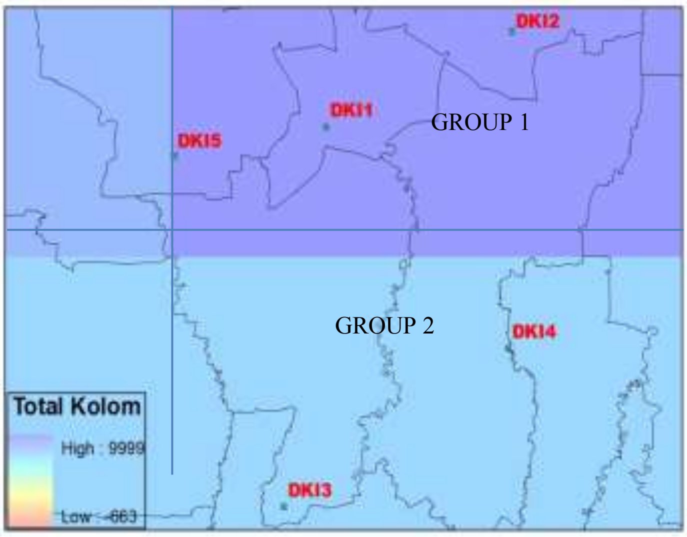

Fig. 4. Overlay coordinates air quality monitoring stations with total column's map, Jakarta, January 2013.[9]

Statistic Model. Linear regression is a statistical method used to find the data relationship between the dependent variable (Y) with the independent variable (X). Regression analysis was used to describe the phenomenon of data or cases under investigation, control objectives, and goals predictions. Regression as a prediction function for the data range of the independent variables regressed.[8] The purpose of linear regression statistical model is to obtain a statistical model that can predict NO_2 concentration with total column value from satellite GOME 2 MetOp-B NO_2. The data used was the total column of satellite GOME 2 MetOp-B remote sensing and data NO_2 concentration measurements of the earth. NO_2 concentration value is represented as the data y and the total column value as the data x.

Model Validation. Validation of a linear regression model was done by entering data to the linear equation from trained data. These data were not used in building a correlation between ground measurement and total column of NO_2. Data were taken randomly, as much as 10% of the total data columns, which were used to establish regression formula.

3. RESULTS AND DISCUSSION

Linear Regression. Data used to establish correlation is shown on Table 4; data for validation has already been taken out. There were 75 monthly mean values of NO_2 that were used for regression analysis. Missing values were observed for some months (~43%), because of data unavailability from ground measurements of NO_2. The missing data was mainly due to sensor disorders of monitoring stations or the data collected possessed error values. Data total column of Satellite GOME 2 MetOp-B remote sensing were nearly all available in every month except in December, which was mostly empty or contained an error. The total amount of data used was 81 records (Table 3).

Table 3. Total number of data used

	Pixel 2 SBY	Group 3 SBY	Group 1 SBY	Group 1 JKT	Group 2 JKT
Amount of data	21	25	5	15	15
Period	2013 to 2015	2013 to 2015	2013	2013 to 2014	2013 to 2014

We use data in Table 4 for correlation analysis using linear regression (Figure 5). Results of linear regression showed R^2 value of 0.436 with a linear equation $y = 2*10^{-5}x + 0.002$. Coefficient of determination, R^2, shows that the ability of the total column NO_2, that explains the variance ground concentration of NO_2, is 43.6%, respectively.

Table 4. Summary of the total column's (10^{15} mol/cm^2) data and NO_2 concentration's data from Air Quality Monitoring System, AQMS (in ppm)

Year	City	Station	Data	Month											
				1	2	3	4	5	6	7	8	9	10	11	12
2013	Surabaya	Group 3	AQMS (ppm)	0.0031	0.0018	0.0018			0.0038	0.0088	0.0033	0.0066			
			Total Column	373	486	373			528	552	316	453			
		Group 1	AQMS (ppm)	0.0035		0.0011	0.0007	0.00002							
			Total Column	363		496	393	345							
		Group 2	AQMS (ppm)	0.0099	0.0114	0.0116	0.0027	0.0081	0.0108	0.0081	0.0030	0.0067	0.0062	0.0085	
			Total Column	385	376	363	320	305	486	412	324	408	303	492	
	Jakarta	Group 1	AQMS (ppm)	0.0168	0.0202	0.0219	0.0208	0.0236	0.0223				0.0254	0.0240	
			Total Column	566	1127	1402	874	905	1044				910	844	
		Group 2	AQMS (ppm)	0.0098	0.0121	0.0124	0.0128	0.0147	0.0142	0.0150	0.0125	0.0132	0.0133	0.0114	
			Total Column	286	1063	1101	689	984	808	730	542	684	809	640	
2014	Surabaya	Group 3	AQMS (ppm)	0.01	0.01	0.01	0.01	0.01	0.01			0.01	0.01	0.01	
			Total Column	252	326	414	521	333	418			415	306	529	
		Group 2	AQMS (ppm)	0.01	0.01	0.02	0.02	0.02	0.02			0.02	0.02	0.02	
			Total Column	481	255	427	571	383	435			448	352	496	
	Jakarta	Group 1	AQMS (ppm)	0.02	0.02	0.03	0.02								
			Total Column	682	793	1118	952								
		Group 2	AQMS (ppm)	0.01	0.02	0.03									
			Total Column	443	1019	1191									
2015	Surabaya	Group 3	AQMS (ppm)	0.0094	0.0111	0.0090	0.0100		0.0046						
			Total Column	320	255	383	369		414						
		Group 2	AQMS (ppm)	0.0032	0.0042	0.0036									
			Total Column	327	384	420									

Validation. The data used to validate the model were selected by pure random sampling. The data selected are Group 1 of Surabaya on February 2013, Group 1 of Jakarta on July, August, and September 2013, Group 2 of Jakarta on April 2014, and Group 2 on April, and June 2015 (Table 5). Validation results showed that the predicted values for Group 1 Jakarta in July, August and September are fairly close to the concentration of NO_2 ground measurements (air quality monitoring station data Jakarta). Group 2 of Jakarta in April 2014 also has predicted value that is relatively close with the station data. However, we noted that the predicted values in Surabaya were quite far from ground measurements of NO_2. One possible reason was that there were many missing daily data of NO_2 during those months in Surabaya, and a result, the monthly mean values are not quite accurate in representing daily data. Missing data was often due to sensor disorders, thus producing many error values after internal validation from the environmnetal agency of Surabaya.

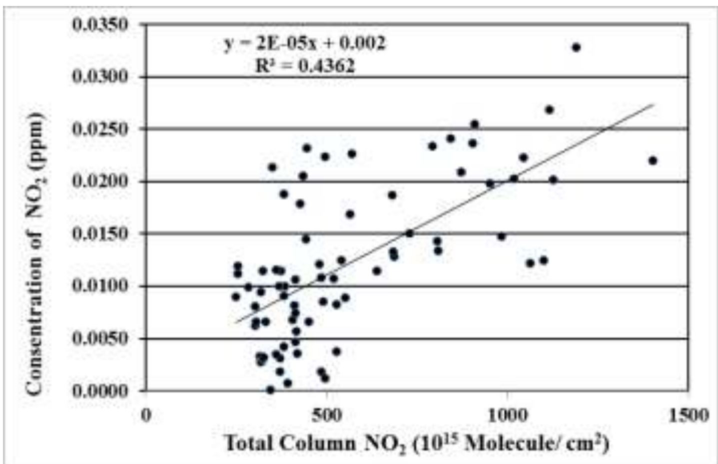

Fig. 5. Regression graph of NO_2 total column and NO_2 concentration.

Table 5. Results of data validation

Year	City	Location	Month	Monthly Mean of NO_2 (y) [ppm]	Total Column (x) (10^{15} molec/cm^2)	Ground measurement NO_2 (ppm)
2013	Surabaya	Group 1	February	0.001	690	0.0158
	Jakarta		July	0.0236	852	0.019
		Group 1	August	0.0187	677	0.0155
			September	0.0232	778	0.0176
2014	Jakarta	Group 2	April	0.0226	843	0.0189
2015	Surabaya	Pixel 2	April	0.0048	398	0.01
			June	0.0084	448	0.011

5. CONCLUSIONS

The present study tries to compare the satellite measurements obtained from GOME 2 MetOp-B of tropospheric NO_2 columns and ground measurements of NO_2 taken from two (2) big cities, Jakarta and Surabaya. The comparison was made by monthly mean values. Despite missing values due to ground monitoring failures, we have compared data side by side with 74 monthly records. The research demonstrates relatively low correlation between satellite observation and ground mesurements of NO_2. The linear equation is $y = 2 * 10^{-5}x + 0,002$ with the accuracy level, represented by R^2, is 0.436. However, research can be further extended to improve the prediction formula, e.g., only to take into account cloud-free images, using daily data on which comparison can be made with a bigger size of data. Despite the weak correlation, the usage of satellite images, upon improvement, shows good potential use in the future especially in characterizing NO_2 patterns over areas that have no monitoring stations, especially for cities in developing countries.

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