Characterizing NO$_2$ in Indonesia Using Satellite Ozone Monitoring Instruments

Trio Bagoes Darmawan, Arie Dipareza Syafei
Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia

Email: dipareza@enviro.its.ac.id

Abstract. Indonesia suffers from high annual vehicle ownership growth, resulting in worsening urban air quality. Nitrogen dioxide (NO$_2$) is one of the combustion products of vehicles which needs to be monitored. Unfortunately, few cities have air quality monitoring stations, thus there is an immediate need to tackle this issue. One way to do so is by utilizing remote sensing via satellite. In this study, we utilized a satellite OMI (Ozone Monitoring Instrument) to read patterns in gaseous NO$_2$ concentrations. This work was assisted by a Geographical Information System (GIS) program, which used the results from the satellite to create images. Data validation was conducted by comparing the results from the satellite images in the form of color pixels with the results obtained from monitoring stations in Jakarta and Surabaya via linear regression. The results showed a weak correlation. Further research should introduce additional variables to improve accuracy.

1. Introduction
Air pollution is one of the major factors contributing to the decline in air quality in urban areas [1]. In an urban environment, the spatial and temporal variabilities in Nitrogen dioxide (NO$_2$) concentrations are high due to the short lifetime of the troposphere [2]. Growth in the number of vehicles, especially in urban areas, results in an increased amount of exhaust, mainly NO$_2$. Hence, NO$_2$ concentrations are indicative of the quality of ambient air. Once the concentration exceeds the threshold value, it affects human health directly or indirectly through an increase in the concentration of ozone[3] since NO$_2$ acts as a catalyst in the formation of ozone [4].

For better urban air quality management, local governments should monitor ambient air quality. Therefore, the presence of air quality monitoring stations is crucial. However, due to the cost of a station, only large cities can afford such a system, leaving more than 80% of the cities in Indonesia without monitoring stations. Hence, there is a lack of data with which to evaluate ambient levels. In order to combat this problem, it is necessary to find an alternative means of providing information on the air quality in those cities without monitoring stations. One such method is to utilize remote sensing of air quality. Remote sensing from various spacecraft and aerial sensors provides a large amount of data on the Earth's surface for detecting and monitoring changes on the Earth's surface [5].

Remote Sensing Imagery produced by satellites can determine the distributions of gasses and aerosols, and there is currently global coverage of tropospheric NO2 [6]. The two satellite of Ozone Monitoring Instruments (OMIs) products available for reading NO$_2$ concentrations are the NASA
standard product (SP) [7,8] and the Dutch OMI NO2 product (DOMINO) [9], which are both available in their second version (SP2 and DOMINO-2).

A satellite OMI is used to obtain an inversion algorithm from which to calculate the amounts of NO2, SO2, HCHO, BrO and OCIO in the ozone column. The use of satellite OMIs has been growing rapidly for the analysis of data around the world since they use a programming language that is both functional and generally suitable for scientific programming [10]. OMI uses spectrometer images with data coverage on a daily basis to determine the air quality at the Earth's surface [11]. An OMI is one of the four instruments on NASA's EOS-Aura satellite, launched on 15 July 2004 [12]. In particular, the OMI on this satellite uses images from the troposphere to measure NO2 by means of Vertical Column Density (VCD) [11]. This technique is also used by other satellites, namely, SCHIAMACY and GOME.

The modeled emissions data was taken from monitoring stations in Jakarta and Surabaya in Indonesia. In this study, we used the Dutch OMI NO2 (DOMINO) satellite as secondary data for the NO2 column in these urban areas. The column data from the satellite images was extracted using a GIS program, then validated with data from the air quality monitoring stations every month in the period 2012 to 2015. In this paper, we attempt to evaluate the correlation between tropospheric NO2 and ground measurements.

2. Data and Method

Correlation between tropospheric NO2 and ground measurements was evaluated using simple linear regression. Data from OMI is explained in Subsection and NO2 from ground measurements is explained in subsection 2.2.

2.1. OMI NO2 Column Data (DOMINO-2)

An OMI is one of four instruments on NASA's EOS-Aura satellite [12]. The OMI was built by Dutch Space and TNO TPD in the Netherlands in cooperation with the Finnish VTT and Patria Advanced Solutions Ltd. The Royal Netherlands Meteorological Institute (KNMI) is the Principal Investigator Institute, while the overall responsibility for OMI missions lies with the Netherlands for Aerospace Programs (NIVR) with the participation of the Finnish Meteorological Institute (FMI). The OMI-equipped satellites measure solar radiation in the visible part of the spectral range between 270 and 500 nm using two telescopes with a spectral resolution of 0.5 nm.

Tropospheric NO2 data was extracted from OMI images. Since it is raster image, one pixel corresponds to single unit of NO2 in molecule/cm2. Since only Surabaya and Jakarta that have air quality monitoring station, we concentrate on obtaining images that cover the two cities. We selected image pixels where the monitoring stations reside (figure 1 and figure 2).

2.2. Monitoring Station Data

Data were obtained from monitoring stations in the two major cities of Surabaya and Jakarta. There are seven monitoring stations in the city of Surabaya, i.e., SUF1, SUF2, SUF3, SUF4, SUF5, SUF6 and SUF7. In the city of Jakarta, there are six monitoring stations, i.e., DKI2, DKI3, DKI4, DKI5 and JAF4. Information on these stations, along with their location coordinates, can be seen in table 1.

Trio Bagoes Darmawan, Arie Dipareza Syafei
Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia
Table 1. Coordinates and Locations of the Monitoring Stations.

| Cities   | Monitoring Point | Location  | Coordinates (x, y) | Coordinates |
|----------|------------------|-----------|--------------------|-------------|
| Surabaya | SUF 1            | Taman Prestasi | -7.262016, 112.746425 | 112° 44' 47.130" E and 7° 15' 43.258" S |
|          | SUF 2            | Perak Timur  | -7.223738, 112.733968 | 112° 44' 2.285" E and 7° 13' 25.457" S |
|          | SUF 3            | Sukomanunggal | -7.248917, 112.647734 | 112° 38' 51.842" E and 7° 14' 56.101" S |
|          | SUF 4            | Gayungan    | -7.333790, 112.707853 | 112° 42' 28.271" E and 7° 20' 1.644" S |
|          | SUF 5            | Gebang Putih | -7.290515, 112.793565 | 112° 47' 36.834" E and 7° 17' 25.854" S |
|          | SUF 6            | Wonorejo    | -7.327922, 112.713241 | 112° 42' 47.668" E and 7° 18' 47.074" S |
|          | SUF 7            | Kebon Sari  | -6.1949571, 106.82306 | 106° 49' 23.016" E and 6° 21' 8.464" S |
| Jakarta  | DKI1             | Bunderan HI | -6.1604549, 106.90546 | 106° 54' 19.660" E and 6° 20' 5.701" S |
|          | DKI2             | Kelapa Gading | -6.334917, 106.823737 | 106° 49' 25.453" E and 6° 9' 37.638" S |
|          | DKI3             | Jagakarsa   | -6.2939072, 106.90339 | 106° 54' 12.233" E and 6° 17' 38.066" S |
|          | DKI4             | Lubang Buaya | -6.2069444, 106.75222 | 106° 45' 7.999" E and 6° 12' 25.000" S |
|          | DKI5             | East Jakarta | -6.1683295, 106.75884 | 106° 45' 31.856" E and 6° 10' 5.986" S |
|          | JAF4             | West Jakarta | -7.262016, 112.746425 | 112° 44' 47.130" E and 7° 15' 43.258" S |

From all seven stations in Surabaya, there were only five monitoring stations in Surabaya with sufficient data of reading NO₂ from 2012 to 2015. The SUF2 monitoring station could not read the NO₂ concentrations in 2014. Further, the SUF5 monitoring station could only read the NO₂ concentrations for 3 months in early 2014. Hence, the NO₂ gas concentration data from SUF2 and SUF5 were not used in the analysis. All six monitoring stations in Jakarta were functional in 2014. Summary data for the NO₂ concentrations at any point in the cities of Surabaya and Jakarta can be seen in Table 2. The data in this table is the data are average monthly concentrations which have been processed from daily data.

Table 2. Monitoring Station Data.

| Period   | SUF 1 | SUF 3 | SUF 4 | SUF 6 | SUF 7 | DKI1 | DKI2 | DKI3 | DKI4 | DKI 5 | JAF4 |
|----------|-------|-------|-------|-------|-------|------|------|------|------|-------|------|
| January  | 0.00248 | -     | -     | -     | -     | 0.01746 | 0.01748 | 0.00633 | 0.01206 | -     | 0.00481 |
| February | 0.00268 | 0.03886 | -     | -     | -     | 0.01896 | 0.02148 | 0.01132 | 0.02003 | -     | 0.00260 |
| March    | 0.00656 | 0.04434 | 0.00795 | -     | -     | 0.01493 | 0.01730 | 0.00715 | 0.01389 | -     | 0.00918 |
| April    | 0.00613 | 0.04580 | 0.00498 | -     | -     | 0.02997 | 0.02178 | 0.01420 | 0.01853 | -     | 0.01948 |
| May      | 0.00434 | 0.04520 | 0.00210 | -     | -     | 0.03042 | 0.02096 | 0.01488 | 0.01958 | -     | 0.02183 |
| June     | 0.00724 | -     | -     | -     | -     | 0.02984 | 0.01957 | 0.01605 | 0.01878 | -     | 0.02166 |
### Table 2. Monitoring Station Data.

| Period      | Concentration (ppm) | Jakarta | Surabaya | SUF 1 | SUF 3 | SUF 4 | SUF 6 | SUF 7 | DKI1 | DKI2 | DKI3 | DKI4 | DKI 5 | JAF4 |
|-------------|---------------------|---------|----------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|
|             |                     |         |          |       |       |       |       |       |       |      |      |      |      |      |      |
| **2013**    |                     |         |          |       |       |       |       |       |       |      |      |      |      |      |      |
| March       | 0.00177             | 0.00113 | 0.01155  | 0.02706| 0.02288| 0.00950| 0.01538 | 0.01589| -     |      |      |      |      |      |      |
| April       | 0.00072             | 0.00972 | 0.00274  | 0.02490| 0.02025| 0.01100| 0.01459 | 0.01730| -     |      |      |      |      |      |      |
| May         | 0.00002             |         | 0.00806  | 0.02929| 0.02242| 0.01256| 0.01692 | 0.01899| -     |      |      |      |      |      |      |
| June        | -                   | 0.00376 | 0.01081  | 0.02744| 0.02167| 0.01207| 0.01642 | 0.01770| -     |      |      |      |      |      |      |
| July        | -                   | 0.00883 | 0.00809  | 0.02905| 0.02098| 0.01307| 0.01692 | 0.02067| -     |      |      |      |      |      |      |
| August      | -                   | 0.00327 | 0.00303  | 0.02327| 0.01686| 0.01110| 0.01385 | 0.01587| -     |      |      |      |      |      |      |
| September   | -                   | 0.00657 | 0.00674  | 0.03036| 0.02253| 0.01108| 0.01540 | 0.01664| -     |      |      |      |      |      |      |
| October     | -                   |         | 0.00618  | 0.03188| 0.02657| 0.01186| 0.01479 | 0.01777| -     |      |      |      |      |      |      |
| November    | -                   | 0.00847 |         | 0.02762| 0.02770| 0.01005| 0.01280 | 0.01676| -     |      |      |      |      |      |      |
| December    | -                   | -       | -        | 0.02422| 0.02413| 0.00870| 0.01107 | 0.01141| -     |      |      |      |      |      |      |
| **2014**    |                     |         |          |       |       |       |       |       |       |      |      |      |      |      |      |
| January     | -                   | -       | -        | 0.00895| 0.01210| 0.02323| 0.02053 | 0.00547| 0.00899| 0.01237| -     |      |      |      |      |
| February    | -                   | -       | -        | 0.01142| 0.01184| 0.02787| 0.02576| 0.00862| 0.01163| 0.01634| -     |      |      |      |      |
| March       | -                   | -       | -        | 0.01060| 0.01787| 0.03319| 0.02858| 0.01299| 0.01978| 0.01832| -     |      |      |      |      |
| April       | -                   | -       | -        | 0.01067| 0.02263| 0.02440| 0.02281| 0.00899| 0.01357| 0.01227| -     |      |      |      |      |
| May         | -                   | -       | -        | 0.00660| 0.01879| -      | -      | -      | -      | -     |      |      |      |      |      |
| June        | -                   | -       | -        | 0.00556| 0.02045| -      | -      | -      | -      | -     |      |      |      |      |      |
| July        | -                   | -       | -        | 0.00534| 0.01797| -      | -      | -      | -      | -     |      |      |      |      |      |
| August      | -                   | -       | -        | 0.00592| 0.01942| -      | -      | -      | -      | -     |      |      |      |      |      |
| September   | -                   | -       | -        | 0.00736| 0.02312| -      | -      | -      | -      | -     |      |      |      |      |      |
| October     | -                   | -       | -        | 0.00656| 0.02128| -      | -      | -      | -      | -     |      |      |      |      |      |
| November    | -                   | -       | -        | 0.00824| 0.02230| -      | -      | -      | -      | -     |      |      |      |      |      |
| December    | -                   | -       | -        | 0.01135| 0.01175| -      | -      | -      | -      | -     |      |      |      |      |      |
| **2015**    |                     |         |          |       |       |       |       |       |       |      |      |      |      |      |      |
| January     | -                   | -       | -        | 0.00965| 0.00311| -      | -      | -      | -      | -     |      |      |      |      |      |
| February    | -                   | -       | -        | 0.01113| 0.00423| -      | -      | -      | -      | -     |      |      |      |      |      |
| March       | -                   | -       | -        | 0.00905| 0.00365| -      | -      | -      | -      | -     |      |      |      |      |      |
| April       | -                   | -       | -        | 0.00998| 0.00476| -      | -      | -      | -      | -     |      |      |      |      |      |
| May         | -                   | -       | -        | 0.00509| 0.00536| -      | -      | -      | -      | -     |      |      |      |      |      |
| June        | -                   | -       | -        | 0.00462| 0.00842| -      | -      | -      | -      | -     |      |      |      |      |      |

**Note:**
- *SUF 2, 5 not functioning properly*
- *SUF 1, 3, 4 not functioning properly starting in 2013*
- *DKI 5 not functioning properly starting in 2012*
- *DKI 1,2,3,4,5 not functioning properly starting in 2014*

### 3. Results and Discussion

In this study, we investigated the correlation between the value of the tropospheric NO₂ column and the value of the air quality provided by the monitoring stations via a linear regression model. The location determination is based on the monitoring stations points in the cities of Surabaya and Jakarta.
On the OMI satellite imagery, the locations of the monitoring stations in the city of Surabaya are covered by three pixels points. In Jakarta, the monitoring stations are covered by five pixels. The locations of the monitoring stations in Jakarta and Surabaya are detailed in figure 1 and figure 2, respectively.

![Figure 1](image1.png)

**Figure 1.** Overlay of the monitoring stations in Jakarta with the OMI satellite image. This figure is from November 2013. Each dark blue box corresponds to one pixel.

![Figure 2](image2.png)

**Figure 2.** Overlay of the monitoring stations in Surabaya with the OMI satellite image. This figure is from November 2013. Each dark blue box corresponds to one pixel. Only three pixels were used for comparison due to data availability from those stations.

The data from the monitoring station groups per pixel were averaged and became data per pixel. The data per pixel from the monitoring stations (see table 2) and the satellite OMI were then compiled. Recapitulation produced 192 pairs of data. Summary data from the monitoring stations and satellite based on the pixels can be seen in table 3.

| Period            | Pixel A          | Pixel B          | Pixel C          |
|-------------------|------------------|------------------|------------------|
|                   | (SUF 3 and SUF 6) | (SUF 1, SUF 4 and SUF 7) | (SUF5)          |
| SPKU Satellite    | SPKU Satellite   | SPKU Satellite   | SPKU Satellite   |

Table 3. Summary pixel data from the monitoring stations and satellite OMI in Surabaya.
| Year | Month     | (ppm) | $(10^{15} \text{ mol/cm}^2)$ | (ppm) | $(10^{15} \text{ mol/cm}^2)$ |
|------|-----------|-------|-----------------------------|-------|-----------------------------|
| 2012 | JANUARY   |       | 0.00248                     | 187   | -                           |
|      | FEBRUARY  | 0.03889 | 298                          | 0.00268 | 153                          |
|      | MARCH     | 0.04437 | 300                          | 0.00726 | 324                          |
|      | APRIL     | 0.04583 | 338                          | 0.00556 | 236                          | 0.00079 | 225 |
|      | MAY       | 0.04523 | 436                          | 0.00322 | 292                          | 0.00001 | 282 |
|      | JUNE      | -      | 0.00724                      | 295   | -                           |
|      | JULY      | -      | 0.00856                      | 321   | 0.00036                      | 190 |
|      | AUGUST    | -      | 0.00507                      | 249   | -                           |
|      | SEPTEMBER | -      | 0.00718                      | 303   | -                           |
|      | OCTOBER   | -      | 0.00451                      | 320   | -                           |
|      | NOVEMBER  | 0.01277 | 366                          | 0.00411 | 360                          |
|      | DECEMBER  | 0.01493 | 259                          | 0.00873 | 365                          |
| 2013 | JANUARY   | 0.006701 | 243                          | 0.003125 | 227                          |
|      | FEBRUARY  | 0.006186 | 392                          | 0.000916 | 312                          |
|      | MARCH     | 0.006346 | 457                          | 0.000886 | 366                          |
|      | APRIL     | 0.001728 | 200                          | 0.003766 | 334                          |
|      | MAY       | 0.004042 | 283                          | 0.008834 | 286                          |
|      | JUNE      | 0.010815 | 450                          | 0.003271 | 197                          |
|      | JULY      | 0.008099 | 401                          | 0.006571 | 306                          |
|      | AUGUST    | 0.003032 | 228                          | -     | -                           |
|      | SEPTEMBER | 0.006747 | 388                          | -     | -                           |
|      | OCTOBER   | 0.006186 | 423                          | -     | -                           |
|      | NOVEMBER  | 0.008473 | 359                          | -     | -                           |
|      | DECEMBER  | 0.003125 | 227                          | -     | -                           |
| 2014 | JANUARY   | 0.008969 | 191                          | 0.012097 | 194                          |
|      | FEBRUARY  | 0.011427 | 314                          | 0.01185 | 282                          |
|      | MARCH     | 0.01061 | 411                          | 0.017884 | 386                          |
|      | APRIL     | 0.010678 | 432                          | 0.022647 | 221                          |
|      | MAY       | 0.006602 | 259                          | 0.018803 | 221                          |
|      | JUNE      | 0.005661 | 218                          | 0.020462 | 168                          |
|      | JULY      | 0.005341 | 236                          | 0.017982 | 205                          |
|      | AUGUST    | 0.005919 | 272                          | 0.019434 | 254                          |
|      | SEPTEMBER | 0.007363 | 271                          | 0.023137 | 243                          |
|      | OCTOBER   | 0.006564 | 362                          | 0.021296 | 291                          |
|      | NOVEMBER  | 0.008249 | 413                          | 0.022313 | 312                          |
|      | DECEMBER  | 0.011362 | 455                          | 0.011757 | 233                          |
| 2015 | JANUARY   | 0.00944 | 206                          | 0.00319 | 201                          |
|      | FEBRUARY  | 0.01114 | 306                          | 0.00423 | 356                          |
Table 3. Summary pixel data from the monitoring stations and satellite OMI in Surabaya.

| Period  | Pixel A (SUF 3 and SUF 6) | Pixel B (SUF 1, SUF 4 and SUF 7) | Pixel C (SUF 5) |
|---------|---------------------------|---------------------------------|----------------|
|         | SPKU (ppm)                | Satellite (10^15 mol/cm²)       | SPKU (ppm)     | Satellite (10^15 mol/cm²) | SPKU (ppm) | Satellite (10^15 mol/cm²) |
| MARCH   | 0.00902                   | 386                              | 0.00357       | 584                        | -          | -                         |
| APRIL   | 0.00998                   | 692                              | 0.00476       | 404                        | -          | -                         |
| MAY     | 0.00511                   | 222                              | 0.00551       | 196                        | -          | -                         |
| JUNE    | 0.00462                   | 294                              | 0.00842       | 245                        | -          | -                         |

*) There is an empty data in Pixel A, B, C this is indeed the absence of data at a monitoring station malfunction

Table 4. Summary pixel data from the monitoring stations and satellite OMI in Jakarta.

| Period  | Pixel D (DKI1 and JAF4) | Pixel E (DKI2) | Pixel F (DKI3) | Pixel G (DKI4) | Pixel H (DKI5) |
|---------|-------------------------|----------------|----------------|----------------|----------------|
|         | SPKU (pixel value)      | Satellite (pixel value) | SPKU (pixel value) | Satellite (pixel value) | SPKU (pixel value) | Satellite (pixel value) | SPKU (pixel value) | Satellite (pixel value) |
| 2012    |                         |                 |                 |                 |                 |                |
| JANUARY | 0.01114                 | 622             | 0.017488       | 469             | 0.006335       | 121             | 0.012068       | 324             | -               |
| FEBRUARY| 0.010789                | 622             | 0.021493       | 464             | 0.011329       | 570             | 0.028046       | 623             | -               |
| MARCH   | 0.012063                | 279             | 0.017312       | 334             | 0.007159       | 313             | 0.013898       | 354             | -               |
| APRIL   | 0.02474                 | 464             | 0.021796       | 393             | 0.014211       | 380             | 0.018541       | 389             | -               |
| MAY     | 0.026144                | 501             | 0.020971       | 508             | 0.014887       | 495             | 0.019589       | 509             | -               |
| JUNE    | 0.025772                | 705             | 0.019583       | 502             | 0.016062       | 547             | 0.018796       | 516             | -               |
| JULY    | 0.029008                | 798             | 0.02496        | 679             | 0.015185       | 603             | 0.022017       | 603             | -               |
| AUGUST  | 0.024006                | 689             | 0.018264       | 437             | 0.012435       | 625             | 0.016030       | 465             | -               |
| SEPTEMBER | 0.027306            | 628             | 0.020668       | 689             | 0.014089       | 636             | 0.021689       | 626             | -               |
| OCTOBER | 0.026607                | 621             | 0.022189       | 483             | 0.012946       | 692             | 0.018312       | 522             | -               |
| NOVEMBER| 0.034741                | 354             | 0.029375       | 251             | 0.013031       | 439             | 0.022163       | 211             | -               |
| DECEMBER| 0.019285                | 288             | 0.020413       | 457             | 0.008877       | 234             | 0.015318       | 214             | -               |
| 2013    |                         |                 |                 |                 |                 |                |
| JANUARY | 0.020096                | 266             | 0.017788       | 412             | 0.009023       | 259             | 0.012815       | 430             | 0.011941        |
| FEBRUARY| 0.025087                | 429             | 0.021284       | 533             | 0.009504       | 427             | 0.015249       | 498             | 0.014139        |
| MARCH   | 0.027074                | 405             | 0.022892       | 403             | 0.011009       | 354             | 0.015359       | 373             | 0.015903        |
| APRIL   | 0.024911                | 489             | 0.020265       | 564             | 0.012566       | 666             | 0.014601       | 430             | 0.017311        |
| MAY     | 0.029307                | 873             | 0.022436       | 782             | 0.012082       | 404             | 0.016193       | 566             | 0.018998        |
| JUNE    | 0.027453                | 505             | 0.021681       | 441             | 0.013076       | 324             | 0.016434       | 397             | 0.017709        |
| JULY    | 0.029067                | 403             | 0.020992       | 395             | 0.011103       | 496             | 0.016927       | 307             | 0.020677        |
| AUGUST  | 0.023283                | 473             | 0.016876       | 398             | 0.011086       | 857             | 0.013862       | 452             | 0.015877        |
| SEPTEMBER | 0.030377            | 757             | 0.022546       | 694             | 0.011865       | 461             | 0.015413       | 703             | 0.016646        |
| OCTOBER | 0.031898                | 531             | 0.026587       | 512             | 0.010057       | 387             | 0.014801       | 501             | 0.017786        |
| NOVEMBER| 0.027641                | 590             | 0.027715       | 547             | 0.008705       | 167             | 0.012805       | 431             | 0.016774        |
| DECEMBER| 0.024232                | 386             | 0.024143       | 434             | 0.011074       | 246             | 0.011414       | 393             | -               |
| 2014    |                         |                 |                 |                 |                 |                |
| JANUARY | 0.017734                | 311             | 0.020539       | 283             | 0.005473       | 255             | 0.008998       | 255             | -               |
| FEBRUARY| 0.022112                | 243             | 0.025774       | 250             | 0.008629       | 293             | 0.011639       | 420             | -               |

7
Table 4. Summary pixel data from the monitoring stations and satellite OMI in Jakarta.

| Period | Pixel D (DKI1 and JAF4) | Pixel E (DKI2) | Pixel F (DKI3) | Pixel G (DKI4) | Pixel H (DKI5) |
|--------|-------------------------|----------------|----------------|----------------|----------------|
|        | SPKU Satellite (pixel value) | SPKU Satellite (pixel value) | SPKU Satellite (pixel value) | SPKU Satellite (pixel value) | SPKU Satellite (pixel value) |
| MARCH  | 0.025932 695 0.0286718 0.013002812 0.019792790 | - | - | - | - |
| APRIL  | 0.018262436 0.022826486 0.008994297 0.013582265 | - | - | - | - |

* There is missing data in Pixels E, F, G, H due to monitoring station malfunction

* In 2015, only at a monitoring station Surabaya and only until the month of May, whereas data exists for the Jakarta monitoring stations until April 2014

Figure 3 shows the trends for the air quality monitoring stations so that the patterns in the air quality in the cities of Surabaya and Jakarta from 2012 to 2015 can be seen. In Figure 3 it can be seen that the trend in the average air quality for all monitoring stations capturing NO2 values was negative between November until January. This pattern appears repeatedly each year from 2012 to 2015 due to the rainy season from November until January. Further, the concentrations of NO2 in Surabaya and Jakarta did not differ significantly, perhaps because the two cities both have a large number of vehicles. For example, if we compare the monitoring station SUF6 with DKI3, the difference between the two is not significant.

Figure 3. Trends in air quality in Jakarta and Surabaya City.

The data in Tables 3 and 4 is fed into the regression model assuming that ‘x’ represents the total NO2 data column (1015 mol/ cm²) from the satellite OMI and ‘y’ is the average concentration of NO2 (ppm) from the monitoring stations. Figure 4 shows that the correlation between tropospheric NO2 and NO2 at ground level is weak, as indicated by a low R2. The large disparity may be due to the dynamics within atmospheric layers since the NO2 concentration at ground level was taken at 5m above the ground, whereas the tropospheric NO2 concentration is based on the total amount of NO2 in a column of up to 10 km in height.
Figure 4. Linear regression model for the concentration of NO$_2$ measured by monitoring stations and satellite OMI, obtained from the linear regression equation $y = 2E-05x + 0.005$, with $R^2 = 0.2452$.

4. Conclusions

This paper examines the correlation between tropospheric NO$_2$ concentrations obtained from OMI with ground measurements taken from two large cities, Surabaya and Jakarta. Regression analysis reveals a weak correlation between the two types of measurements, as indicated by the low coefficient of determination. This result is probably due to the changing dynamics between ground-level measurements and measurements taken in an atmospheric column. In order to improve accuracy and make image analysis useful in predicting ground level concentrations, future research could be expanded to examine additional variables such as meteorological aspects and topographical items.

References

[1] Colls J 2002 Air Pollution ed (London: Spon Press)
[2] Kuhlman G, Lam Y F, Cheung H M, Hartl A, Fung J C H, Chan P W and Wenig M O 2014 Development of A Custom OMI NO$_2$ Data Product for Evaluating Biases in A Regional Chemistry Transport Model Atmos. Chem. Phys 15 5627–5644
[3] Godowitch J M, Gilliland A B, Draxler R R, And Rao S T 2008 Modeling Assessment Of Point Source NO$_x$ Emission Reductions on Ozone Air Quality in The Eastern United States, Atmos. Environ., 42, 87–100
[4] Knowlton K, Rosenthal J E, Hogrefe C, Lynn B, Gaffin S, Goldberg R, Rosenzweig C, Civerolo K, Ku J Y, Kinney P L. 2004 Assessing Ozone-Related Health Impacts Under A Changing Climate Environ. Health Perspect, 112, 1557-1563
[5] Curlander J, Kober, W 1992 Rule Based System for Thematic Classification in SAR Imagery Proc. IGARSS (New York: IEEE Press) pp. 854-856
[6] Akimoto H 2003 Global air quality and pollution Science 302(5651): 1716-1719
[7] Bucsela E J, Celarier E A, Wenig M O, Gleason J F, Veekind J P, Boersma K F, And Brinksma E J 2006 Algorithm for NO$_2$ Vertical Column Retreival from The Ozone Monitoring Instrument IEEE. T. Geosci, Remote Sens 44
[8] Bucsela E J, Krotko N A, Celarier E A, Lamsal L N, Gleason J F and Pickering K E 2013 A New Stratospheric and Tropospheric NO$_2$ Retrieval Algorithm for Nadir-Viewing Satellite
Instruments Applications To OMI, Atmos. Meas. Tech, 6 2607-2626

[9] Boersma K F, Eskes H J, Veefkind J P, Brinksma E J, Van Der A R, Sneep M, Van Den Oord G H, Levelt P F, Stammes P, Gleason J, And Bucsela E J 2007 Near-Real Time Retrieval of Tropospheric NO₂ from OMI, Atmos Chem. Phys 7 2103-2118

[10] Boersma K F, Eskes H J, Dirksen R J et al 2011 An Improved Tropospheric NO₂ Column Retrieval Algorithm For the Ozone Monitoring Instrument Atmos Meas Tech 4:1905–1928

[11] Boersma K F, Eskes H J, Brinksma E J 2004 Error Analysis for Tropospheric NO₂ Retrieval from Space J. Geophys. Res 109 (D4)

[12] Schoeberl, M R, Et Al 2006 Overview of The EOS Aura Mission IEEE Trans, Geosci, Remote Sens., 44(5), 1066-1074