Spatial distribution of PM$_{10}$ derived from Landsat 8 imagery in Bandung, Indonesia

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Abstract. Air pollutant of PM$_{10}$ concentration over Bandung City was estimated based on satellite imagery. The imagery was acquired by Landsat -8 on 22$^{nd}$ May 2019. The methodology implementation were started with pre-processing includes geometric correction, radiometric calibration to converted of digital number into surface reflectance values to estimated PM$_{10}$ concentration. For calculated the algorithm of PM$_{10}$ need the coefficient aerosol optical depth (AOD) was using from AERONET. The results showed that the estimation of PM$_{10}$ distribution through satellite imagery in Bandung in the year of 2019 in average 36.18 $\mu$g/m$^3$. According to Air Pollution Standard Index from that average Bandung city is still in healthy category of PM$_{10}$ concentration. The calculated data on PM$_{10}$ were also compared with ground measurements of PM$_{10}$ data estimated from different locations of Bandung for validation and a linear relationship was established between them having a moderate positive relationship with the correlation coefficient value of 0.6187.

1. Introduction

Air pollution in big cities has become the main concern, the government and various NGOs (Non-Governmental Organizations) are trying to control the problem of air pollution. Air pollution is divided into two, include particles and gases [1]. One of the major cities in Indonesia is the city of Bandung. The problem of air pollution in Bandung causes a decrease in air quality which can cause disruption of human health and environmental life.

PM$_{10}$ (Particulate Matter 10) is an air particle that is less than 10 μm and very dangerous because it can penetrate through the deepest parts of the lungs and heart system which will cause health problems [2]. The daily threshold value of the average concentration of PM$_{10}$ fine particles in Indonesia is 150 $\mu$g/m$^3$ listed in the Appendix to Government Regulation No. 41/1999 concerning national ambient air quality standards. Air pollutants can be measured from the central air pollution monitoring station with various types of instruments. But these instruments are quite expensive and the number of air pollution measuring stations is limited in each region. The limited number of air pollutant observer stations causes uneven distribution of data, so the air pollution cannot be mapped properly [1].

Studies on PM concentrations are usually based on spatial data and temporal data series measured at the location of air pollution monitoring stations in cities and rural areas [3]. Field observation measurements require high costs for installation and maintenance and the data collected is only effective in small spaces with coverage around the observer station. Thus, measurements at the observer station cannot provide detailed spatial distribution of pollutant particulate matter (PM) over large areas [4].
Measurement of pollutants over large areas can be done by using satellites which are one of the remote sensing instruments. Remote sensing techniques are widely used for environmental pollutant applications such as air pollution [5]. Several studies have shown that satellite data may be useful in uncovering the implications of global climate and environmental air pollution [6]. Satellite data can aid in the detection, tracking, and understanding of pollutant transport by providing observations over large area [1]. In this study, spatial distribution has been estimated for PM10 over Bandung City. Reflectance values in the visible bands (Red, Green, Blue) and Near-Infrared band measured by the satellite landsat8 OLI to derive the PM10 concentration. The algorithm of PM10 utilizes a modified of AOD value based on AERONET (Aerosol Robotic Network).

2. Method

2.1. Study Area
The location of this research is in Bandung, West Java Province which is one of the third largest cities in Indonesia [7]. Bandung City consists of 30 Subdistricts with a land area of 167.67 km\textsuperscript{2}. Bandung is located at 107º36’E longitude and 6º55’ S latitude (Figure 1).

![Figure 1. Study area of Bandung City](image)

2.2. Data
The data used in this study was Landsat 8 Multispectral of Bandung acquired in the year of 2019. In addition to satellite images, topographic maps also used in this study as complimentary data.
Table 1. Specification of Landsat [8]

| Spectral Band                  | Wavelength (µm) | Spectral Resolution (m) |
|-------------------------------|-----------------|-------------------------|
| Coastal Aerosol               | 0.43 – 0.345    | 30                      |
| Blue                          | 0.45 – 0.51     | 30                      |
| Green                         | 0.53 – 0.59     | 30                      |
| Red                           | 0.64 – 0.67     | 30                      |
| Near Infrared (Nir)           | 0.85 – 0.88     | 30                      |
| Shot Wavelength Infrared (SWIR) 1 | 1.57 – 1.67 | 30                      |
| Shot Wavelength Infrared (SWIR) 2 | 2.11 – 2.29 | 30                      |
| Panchromatic (PAN)            | 0.50 – 0.68     | 15                      |
| Cirrus                        | 1.36 – 1.38     | 30                      |
| Thermal Infrared (TIR) 1      | 10.60 – 11.19   | 100                     |
| Thermal Infrared (TIR) 2      | 11.50 – 12.51   | 100                     |

2.3. Pre-Processing

- Geometric Correction
To remove geometric distortion that causes a mismatch between object imagery position and object actual position, it is necessary to have a geometric correction. It establishes the pixel position of imagery to the actual position. In this study, geometric correction is carried out by the image to image method where Landsat-8 become the base/reference to determine GCP on Landsat which will be corrected geometrically.

- Conversion to TOA Radiance
The first thing to do is to convert the digital number on Landsat 8 becomes spectral radiance by using the following equation [9].

\[ L_\lambda = M \times L_{Qcal} + A_{L} \] (1)
Conversion to TOA Reflectance

The following equation is used to convert DN values to TOA reflectance as follows [9]:

\[
\rho_{\lambda}' = M_{\rho}Q_{\text{cal}} + A_{\rho}
\]  

(2)

Where:
- \(\rho_{\lambda}'\) = TOA planetary reflectance.
- \(M_{\rho}\) = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number).
- \(A_{\rho}\) = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number).
- \(Q_{\text{cal}}\) = Quantized and calibrated standard product pixel values (DN).

2.4. PM10 Estimation

The calculation of PM10 with satellite Imagery is used in the following formula [1, 10, 11, 12].

\[
\text{PM10} = a_0 R_{\lambda 1} + a_1 R_{\lambda 2} + a_2 R_{\lambda 3} + a_3 R_{\lambda 4} \ldots
\]  

(3)

Where \(R_{\lambda i}\) is the atmospheric reflectance (i = 1, 2 and 3 corresponding to wavelength for satellite), and \(a_j\) is the algorithm coefficient (j = 0, 1 and 2) are empirically determined.

The atmospheric reflectance was then related to the PM10 using the value of AOD was obtained from AERONET. The reflectance values used are the reflectance values of the red, green, and blue (RGB) bands and near-infrared band. Where PM10 is equal to PM10 concentration in (μg/m³), \(R_{\lambda 1}\), \(R_{\lambda 2}\), \(R_{\lambda 3}\), and \(R_{\lambda 4}\) are equal to the atmospheric reflectance/path radiance in blue, green, red, and near-infrared band [12].

3. Result and Discussion

3.1. Spatial Distribution of PM10

The PM10 algorithm consists of reflectance values of red, green, blue, and near-infrared bands, and AOD parameters obtained from AERONET. The AOD parameter used is obtained simultaneously with the image acquisition date. PM10 distribution map Bandung divided into five classes. For the range of PM10 values classified by following the range of values set by the Head of Environmental Impact Management Agency No. 107 of 1997 based on the Air Pollution Standards Index, including the categories of good, moderate, unhealthy, very unhealthy, and dangerous. The range of PM10 values and PM10 colour level classification based on ISPU (Air Pollution Standard Index) can be seen in the table 2.
Table 2. PM10 range value based on Air Pollution Standards Index [13]

| PM$_{10}$ (µg/m³) | Colour | Class of Classification |
|-------------------|--------|------------------------|
| 0 – 50            | Green  | Good                   |
| 51 – 100          | Blue   | Moderate               |
| 101 – 199         | Yellow | Unhealthy              |
| 200 – 300         | Red    | Very Unhealthy         |
| >300              | Black  | Dangerous              |

According to Air Pollution Standards Index [13] in table 2 the healthy class of PM10 has a range of 0-50 µg/m³ shown as green, the moderate class has a range of values of 51-100 µg/m³ as blue, the unhealthy class has a range of 101-199 µg/m³ as yellow, the very unhealthy class has a range of 200-300 µg/m³ as red and dangerous classes have values above 300 µg/m³ as black. Following distribution of PM10 based on Landsat satellite image processing in 2019 can be seen in Figure 3.

Figure 3. Spatial distribution of PM10 in Bandung City

Based on the Figure 3, the healthy classes range from 0 – 50 µg/m³ are found in almost all over Bandung with the average PM10 concentration in the city of Bandung in May 2019 derived from Landsat imagery is 36.18 µg/m³, the minimum value of PM10 is 1.5 µg/m³, and there are only a few unhealthy class spots and there are no very unhealthy and dangerous classes with the maximum value is 299 µg/m³. Which means Bandung relatively is in healthy category from the danger of PM10.
3.2. Validation with PM10 ground measurements

After getting the results of PM10 processing, an analysis was carried out to determine the relationship between PM10 concentration values of Landsat images and PM10 values from field measurements. Both PM10 concentration values were analyzed for their relationship using linear regression.

Based on the results of particulate matter (PM10) obtained from image processing, there are differences in the concentration values at some points against the results of particulate matter (PM10) from field measurements. PM10 results from Landsat images are relatively small with an average of 22.8 µg / m³, different from field measurements which show a large enough value with an average of 95.42 µg / m³. The results of PM10 concentration values from ground measurements and PM10 concentration results based on Landsat satellite imagery can be seen in figure 4.

![Figure 4. Ground measurements validation of PM10.](image)

![Figure 5. Linear Regression of PM10 from Landsat Imagery and PM10 from Field Measurement](image)
The validation of PM10 based on Landsat-8 between the data of PM10 ground measurements using linear regression relationship above (Figure 5), the equation model is \( y = 0.7614x + 3.0349 \), which \( x \) is PM10 ground measurements data and \( y \) is PM10 based on Landsat-8 imagery with the coefficient of determination value is 0.6187, this means that the relationship between PM10 from the results of ground measurements and Landsat-8 processing is 61.87% having a moderate positive relationship.

4. Conclusions

Based on the spatial distribution of PM10 concentration values, this can be concluded that PM10 air pollutants in Bandung are still in the healthy category based on Air Pollution Standard Index which is included in five classes with with the average PM10 concentration based on Landsat-8 imagery is 36.18 \( \mu g/m^3 \), the minimum value is 1.5 \( \mu g/m^3 \), and the maximum value is 299 \( \mu g/m^3 \). Data validation is also performed which has determination coefficient value is 0.6187 this means the data of PM10 based on Landsat-8 imagery between the data of PM10 ground measurements having a moderate positive relationship.

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