Spatiotemporal trend of particulate matter (PM$_{10}$) concentration on cement industries in Klapanunggal and Citeureup Sub-districts

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Abstract. Increasing demand of cement has affected to environment destruction. PM$_{10}$ pollution that emitted by cement industries in Klapanunggal and Citeureup Sub-districts have affected the health of workers and the people around the industrial site in long-term period. This research discusses the identification on variation of PM$_{10}$ pollution concentration that emitted by cement industries in Klapanunggal and Citeureup Sub-districts spatiotemporally. The method we used in estimating concentrated PM$_{10}$ was by applying aerosol optical thickness (AOT) algorithm on Landsat 7 ETM+ and Landsat 8 OLI within 16 years (2002-2018) period of time. The results show that PM$_{10}$ concentration in Klapanunggal and Citeureup were fluctuated within those 16 years. High concentrated PM$_{10}$ were tended to agglomerate in cement processing plant, cement-based industrial plant (where cement is used as raw material), and limestone mining which have meaning of causing bad impact to environment sustainability and increase the risk in morbidity and mortality.

1. Introduction

The need of cement in Indonesia has increased significantly while its sales rate was expected to grow 4.9% from the previous year to be 73 million ton in 2019 followed by the acceleration of national infrastructures development [1,2]. Unfortunately, the increase in cement production would bring threats to environment sustainability [3]. In general, the bad impacts of cement production were caused by exploitation of water and raw material (limestone), noises, water pollution, and air pollution [4]. Air pollution from cement production activities is need to be aware of, considering its effect in abiotic depletion, global warming, acidification and marine ecotoxicity [5].

Air pollution which produced by cement production processing (kiln system, grinding, handing operations, etc.) are formed in chemical compounds (TOC, VOC, PCDDs-PCDFs) and particulate
matter [3–6]. High concentrated Particulate Matter (particularly) with less than 10µm size has already been identified as a matter that affects respiratory problems and increase in morbidity (aggravation of asthma and respiratory symptoms) and mortality (cardiovascular diseases, respiratory diseases and lung cancer) in long term [7–9].

Klapanunggal and Citeureup Sub-districts become one of the industrial centers of integrated limestone as raw materials on Java Island. However, these industrial locations are currently close to community settlements. Given the increasing trend of cement demand in Indonesia and the dangers of PM$_{10}$ produced by the cement industry, this study aims to identify variation of PM$_{10}$ pollution concentration emitted by the cement industry in Klapanunggal and Citeureup Sub-districts spatiotemporally which may define the effect to public health.

2. Materials and methods

2.1 Research area

Klapanunggal and Citeureup are located in the central area of Bogor Regency, West Java Province (figure 1). Both sub-districts are tended to be suburban area on the west side and gradually become rural area on the east side. The land use of Klapanunggal and Citeureup suburban area are consist of community settlement and industrial activities. Cement processing industry and cement-based industry (ceramic, concrete, etc.) are dominating industrial activities in both sub-districts. The existence of those industries are supported by the presence of Klapanunggal Limestone Formation which classified in tertiary aged and about ±66.67 Km$^2$ wide [10]. This formation outspread in Gunung Putri, Klapanunggal, and Jonggol Sub-districts.

![Figure 1. Research area](image)

2.2 Materials

In this research, five Landsat 7 ETM+ and four Landsat 8 OLI imageries within a period of time 16 years (2002-2018) are used to observe spatiotemporal trend of PM$_{10}$ concentration. The imageries are downloaded in United States Geological Survey official website (earthexplorer.usgs.gov.us) in path/row 122/065. Landsat 7 ETM+ imagery consists of eight spectral bands (band 1-7 with 30m spatial resolution; band 8 with 15m spatial resolution) [11], meanwhile Landsat 8 OLI imagery consists of nine spectral bands (band 1-7 and 9 with 30m spatial resolution; band 8 with 15m spatial resolution) [12]. Visible color bands (RGB) in Landsat 7 ETM+ (band 1, 2, and 3) and Landsat 8 OLI (band 2, 3, and 4) imageries in Klapanunggal and Citeureup Sub-districts area are used in estimating PM$_{10}$ concentration.
Three Landsat 7 ETM+ and two Landsat 8 OLI imageries which utilized in this research have less than 10% cloud coverage (table 1).

### Table 1. Landsat satellite imageries used

| Satellite Imageries | Date of Acquisition | Sun Elevation | Sun Azimuth |
|---------------------|---------------------|---------------|-------------|
| Landsat 7 ETM+      | 29th March 2002     | 53.10         | 54.12       |
| Landsat 7 ETM+      | 9th September 2004  | 57.40         | 68.34       |
| Landsat 7 ETM+      | 27th June 2006      | 46.72         | 44.15       |
| Landsat 7 ETM+      | 18th July 2008      | 47.56         | 47.65       |
| Landsat 7 ETM+      | 22nd June 2010      | 47.31         | 43.20       |
| Landsat 8 OLI       | 30th August 2012    | 56.66         | 61.55       |
| Landsat 8 OLI       | 13th September 2014 | 60.93         | 68.42       |
| Landsat 8 OLI       | 30th June 2016      | 42.13         | 48.51       |
| Landsat 8 OLI       | 6th July 2018       | 48.52         | 43.04       |

2.3 Methods

2.3.1 Pre-Processing Image. Landsat 7 ETM+ have failed censor (Scan-Line Corrector) since 31st May 2003 permanently which result in 22% of data loss and the imagery scene of acquisition result was appeared striped [13]. Therefore, before taken to radiometric calibration, Landsat 7 ETM+ imageries which acquire in 2004, 2006, 2008 and 2010 have to be repaired. The fixation was made by applying corrective reinforcement and bias to pixel values of SLC-off images that can be generated from the average and standard data deviation [14]. This can be done using the extension plug-in of "Gapfill" in ENVI 5.2. The next step, radiometric calibration is carried out with conversion of sensor DN to top of atmosphere (TOA) reflectance as in equation (1) and continued with sun angle correction as in equation (2) [15]. The work flow of the research is showed on Figure 2.

\[
\rho' = M\rho \ast Q_{cal} + A\rho
\]  
(1)

\[
\rho = \rho' / \cos(\theta_{SZ}) = \rho' / \sin(\theta_{SE})
\]  
(2)
Where,
\[ \rho_{\lambda} = \text{TOA planetary reflectance}; \]
\[ \rho'_{\lambda} = \text{TOA planetary reflectance (without correction for solar angle)}; \]
\[ M_{\rho} = \text{Band-specific multiplicative rescaling factor from the metadata}; \]
\[ A_{\rho} = \text{Band-specific additive rescaling factor from the metadata}; \]
\[ Q_{\text{cal}} = \text{Quantized and calibrated standard product pixel values (DN)}; \]
\[ \theta_{\text{SE}} = \text{Local sun elevation angle}; \]
\[ \theta_{\text{SZ}} = \text{Local solar zenith angle and } \theta_{\text{SZ}} = 90^\circ - \theta_{\text{SE}} \]

2.3.2 Processing Image. The relationship between PM\textsubscript{10} and AOT is derived for a single homogeneous atmospheric layer containing spherical aerosol particles. Hence, it can be expected that the particulate matter concentration correlates better with AOT directly [16]. Using the algorithm of AOT for a single band or wavelength (\(\lambda\)) is simplified as in equation (3):

\[ AOT(\lambda) = a_0 R(\lambda) \]  \hspace{1cm} (3)

Or can be rewritten into three bands equation as mentioned below:

\[ AOT(\lambda) = a_0 R_{\lambda 1} + a_0 R_{\lambda 2} + a_0 R_{\lambda 3} \]  \hspace{1cm} (4)

Where,
\[ R_{\lambda i} = \text{atmospheric reflectance (i = 1, 2 and 3 corresponding to the wavelength band of the satellite)}; \]
\[ a_j = \text{algorithm coefficient (j = 0, 1 and 2) which are empirically determined.} \]

AOT Algorithm that used in this research is AOT Algorithm model of Othman, Zubir, Jafri, & San (2010). This AOT algorithm was chosen by considering the R coefficient value as \(> 0.8\) and the utilization of Landsat 7 ETM+ and Landsat 8 OLI imageries which accommodated visible bands for AOT algorithm as in equation (5) [17].

\[ PM_{10} = 396 R_{\lambda 1} + 253 R_{\lambda 2} - 194 R_{\lambda 3} \]  \hspace{1cm} (5)

Where,
\[ R_{\lambda 1} = \text{Blue band (Band 1 on Landsat 7 and Band 2 on Landsat 8)}; \]
\[ R_{\lambda 2} = \text{Green band (Band 2 on Landsat 7 and Band 3 on Landsat 8)}; \]
\[ R_{\lambda 3} = \text{Red band (Band 3 on Landsat 7 and Band 4 on Landsat 8).} \]
3. Result and discussion

AOT algorithm from Othman, Zubir, Jafri, & San (2010) are succeeded to identify variation of PM$_{10}$ concentration spatiotemporally in Kalapanunggal and Citeureup Sub-districts within 16 years (2002-2018) period of time. According to data on figure 3, high concentrated PM$_{10}$ in Klapanunggal and Citeureup are agglomerated around cement processing plant, cement-based industrial plant, non-cement based plant, limestone mining area, and along the roadway.

Based on its sources, PM$_{10}$ that spread out along the roadway mostly come from vehicles’ emission, PM$_{10}$ in plant site mostly come from raw material processing emission, and PM$_{10}$ around mining area come from limestone exploitation on the surface [18–21]. Among those PM$_{10}$ sources, in Klapanunggal and Citeureup Sub-districts, cement processing plant, cement-based industrial plant, and mining area are contributing in PM$_{10}$ emission significantly, see figure 3.

Based on figure 4, during the year of 2002 to 2018, PM$_{10}$ concentration in Klapanunggal and Citeureup have been fluctuated on minimum, average, and maximum values. Specifically, the maximum values of PM$_{10}$ concentration in both sub-districts are tended to increase within 16 years. This fact is indicating the gradual increase of PM$_{10}$ concentration that emitted by mining activities, cement processing industries, and cement-based industries.
Variation of spatial distribution of PM$_{10}$ concentration are inseparable from wind direction and speed factor. The influence of these two factors is shown in diffusion phenomenon of PM$_{10}$ concentration in 2008 and 2014 from the area of cement processing plant and cement-based industrial plant to residential areas around the plant sites (figure 3) [22]. PM$_{10}$ that diffused from those areas are needed to be aware of as it potentially causes harm for public health.

Based on the PM$_{10}$ threshold classification with short-term exposure condition that adopted from the Air Quality Guide of World Health Organization (AQG-WHO), PM$_{10}$ concentration in Klapanunggal and Citeureup Sub-districts tend to be dominated by concentrations in the range of 50-75µg/m$^3$. Specifically, the area of cement processing plant, cement-based industrial plant, and mining area are the place where high concentrated PM$_{10}$ agglomerated and they concentrated in the range of 75-100µg/m$^3$, 100-150µg/m$^3$, and above 150µg/m$^3$ (figure 5). In this kind of condition, the people in Klapanunggal and Citeureup are still at the lowest level of death case, cardiopulmonary, and lung cancer due to PM$_{10}$ exposure in the short-term period [23]. However, the area around cement processing plant, cement-based industrial plant, and mining area may have higher probability of death case, cardiopulmonary and lung cancer due to exposure of PM$_{10}$ in the short-term period at 2.5%–5%. This condition is dangerous for people who live around those areas.
4. Conclusions
High concentrated PM$_{10}$ in Klapanunggal and Citeureup Sub-districts for 16 years (2002-2018) were identified agglomerating around the emission source areas – cement processing plants, cement-based industrial plants, and limestone mining areas. During the year of 2002 to 2018, PM$_{10}$ in both sub-districts were fluctuated and showed increasing trend of maximum values which indicated a significant rise in high concentrated PM$_{10}$. This condition has increased the probability in morbidity (aggravation of asthma and respiratory symptoms) and mortality (death, cardiopulmonary, and lung cancer) for the people living around cement processing plants and cement-based industrial plants.

5. References
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