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The Recent State of Ambient Air Quality in Jakarta

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ABSTRACT

Air pollution has become a growing concern, especially in urban cities with rapidly developing economies, increasing infrastructure and vehicular population, and reduced green spaces. Fossil fuel and transportation are the main source of pollutive particles (e.g., sulfur oxide and nitrous) released into the atmosphere. Once they have entered the atmosphere, these particles create health problems, degrade air quality, and cause acid rain. Seasonal investigations on rainwater chemistry and particulate matter pollution (SPM, PM_{10}, and $PM_{2.5}$) were conducted to understand the recent state of the ambient air quality in Jakarta, Indonesia. The characteristics of $PM_{2.5}$ were also analyzed during Ied Al Fitr in 2016 and 2017. Based on the observational data, the ambient air quality in Jakarta improved during the period of our study (2000–2016). The chemical constituents, i.e., the anion and cation concentrations, in precipitation show decreasing trends starting from 2006. Moreover, the PM_{10} and SPM concentrations also decreased slightly. The causes of these favorable trends are climatic conditions—namely, an increasing trend of rainfall—and policy intervention. Additionally, an assessment during the feast of Ied Al Fitr in 2016 and 2017 indicated a further decrease in $PM_{2.5}$ due to highly reduced inner-city traffic. These events exhibited an extreme reduction of the $PM_{2.5}$ concentration in Jakarta.

Keywords: Jakarta; Air pollution; Rainfall chemistry; Particulate matter.

INTRODUCTION

The changing on the atmosphere's composition in this century has been observed with an increase of the concentration of trace gasses and aerosols (Lazaridis, 2011). Aerosols in the atmosphere experience a physico-chemical processes which will determine their concentration, composition, deposition, removal, and transport.

Airborne particulate matter pollution is an environmental health problem that affects people worldwide, whereas low- and middle-income countries are the most vulnerable to this problem. Airborne particulate matter negatively impacts human health (Jiang *et al.*, 2015; Lelieveld *et al.*, 2015; Powell *et al.*, 2015; Pedersen *et al.*, 2016), degrades visibility (Field *et al.*, 2009; Han *et al.*, 2012; Langridge *et al.*, 2012; Kusumaningtyas and Aldrian, 2016), and affects climate systems (Boucher, 2015). Fine particulate matter ($PM_{2.5}$) is a complex mixture of small particles and liquid droplets with a broad compositional range possibility (Lang *et al.*, 2017). This particulate may have primary and/or secondary sources mainly from burning of biomass, transportation, industrial activities, and wind-blown dust. Black carbon as one of the components of $PM_{2.5}$, is a residue of the incomplete combustion of fossil fuels, biofuels, and biomass. Airborne particulate matter could be removed from the atmosphere through washout process and delivered to the earth's surface called wet deposition (Seinfeld and Pandis, 2006). As the atmosphere is a potent oxidizing medium, acidic species are likely removed from the atmosphere and cause acid rain. Rapid economic growth, emissions and consequently atmospheric concentrations of many pollutants have increased enormously in Indonesia, particularly in big cities. Biomass burning and urban air pollution that occur, consecutively, in several wildfire prone provinces (Kusumaningtyas and Aldrian, 2016; Kusumaningtyas *et al.*, 2016) and big cities in Indonesia are likely worsened in the future. According to World Health Organization (World Health Organization, 2012), the mortality rate attributed to household and ambient air pollution in Indonesia is 85.0 (per 100,000 population), while the Southeast Asia average number is 119.9. Lelieveld *et al.* (2015) in his study mentioned Indonesia as rank top 8 in the global for premature mortality linked to outdoor air pollution in 2010. A big city like Jakarta is the major contributor to the air pollution and greenhouse gases emissions. Over last several decades, Jakarta, as a capital city, has undergone a substantial massive development and urbanization coupled with motorization that leads to an increase in the energy use. The poor and marginalized

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community, in particular, tends to suffer the most from the effects of air quality degradation (Schwela *et al.*, 2007). Overpopulation, expansion of middle class in urban centers in developing countries, and availability of cheaper vehicles contribute to the immense release of particulate matter into the atmosphere. According to Lelieveld *et al.* (2015), Jakarta has 10,400 (22.5 × 106 total population) and 16,400 (26.1 × 106 total population) deaths cases associated with premature mortality related to $PM_{2.5}$ and O_3 in 2010 and 2025, respectively. A study by a Cost-benefit Analysis Fuel Economy together with United Nations Environment Program (UNEP), United States Environmental Protection Agency (USEPA), Ministry of Environment of Indonesia (KLH), and Joint Committee for Leaded Gasoline Phase-Out (KPBB) (2012), in Jakarta, found that 57.8% of people are suffered by diseases/illness which correlates with air pollution and must pay the medical cost with total 38.5 trillion Indonesian Rupiah ($2,852,064,600).

On the other hand, air quality, stratospheric ozone depletion, and climate change are closely related, all with the potential to affect human well-being (EANET, 2014). In addition, for any comprehensive and realistic assessment of the changes in atmospheric composition, it is crucial to have information not only on the concentration of PM but also the chemical constituents of precipitation. The rain chemistry information could imply the history or the source of the air pollution.

To address urban air pollution, there has been a growing concern on the monitoring of acid deposition and particulate matter in the recent years. In Indonesia, however, information on the concentration of fine particles in the ambient air and chemical constituents are still rare. Therefore, assessment on air quality both acid deposition and particulate matter in Jakarta is scarce to find (Martono *et al.*, 2003). To our knowledge, there is no scientific publication to date on the state of ambient air quality in Jakarta for the recent decade.

This will be, however, the first paper on a comprehensive study of chemical constituents on precipitation and particulate matter in the Jakarta Metropolitan Area. The objective of this paper is to review the state of ambient air quality in urban city Jakarta through (1) assessing chemical composition and its trend in rainwater; (2) analyzing particulate matter pollution and its trend by assessing seasonal Suspended Particulate Matter (SPM), PM_{10}, and $PM_{2.5}$; and (3) analyzing a special case study of the impact of human activity on particulate matter during an important feast day in Jakarta. Considering the scarcity of such a study, at the end, the outcome of this paper is expected to establish a scientific foundation for further researches and a better pollution control to policymakers of the Jakarta Metropolitan Area.

METHODS

Profile of Jakarta

The Jakarta city covers an area of approximately 662 square kilometers. Along the northern coast, the landscape is very flat with an average altitude of 7 meters above the mean sea level (Indonesia Statistical Agency, 2017). It is larger than any other municipality in Indonesia with 15,558 people per square kilometer in 2016. Jakarta has a population of 10.3 million in 2016 (Indonesia Statistical Agency, 2017). Many people work in Jakarta live in surrounding suburban areas in the west, east, and south of Jakarta. Together they are called as the Jakarta Metropolitan Area. Jakarta along with its suburban areas, Bodetabek (Bogor, Depok, Tangerang, and Bekasi) further known as Jabodetabek, is the largest urban concentration in Indonesia of about 10% of the total population of the country (Rustiadi *et al.*, 2015) around more than 25 million in 2016. The number of population in Bodetabek in 2016 was 18,500,000. The metropolitan area of Jabodetabek has a total area of 4,384 square kilometers (1,693 sq mi). The city proper has a very high population density of 14,464 people per square kilometer (37,460/sq mi), while the metro area has a density of 4,383 people/sq km (11,353/sq mi) (http://worldpopulationreview.com/world-cities/jakarta-population/, accessed on 10 October 2017). Land conversion tends to increase every year. Many fertile farmlands and other greenery areas are converted to built-up areas (settlement, industries, commercial services and others). From 1995 until 2012, built-up areas in Jabodetabek and urban area in Bogor, Depok, Tangerang, and Bekasi were growing rapidly. Approximately 71% or 152,000 ha of forest have disappeared, the dry land has reduced by 31% or 71,000 ha, whereas the built-up areas have expanded 31-fold or 195,000 ha during 1972–2012 (Rustiadi *et al.*, 2015).

According to Indonesia Statistical Agency (2017), the number of motor vehicles in Jakarta in 2016 was 18.7 million including motorcycles, passenger cars, cargo cars, buses, and trucks. During 1985 to 2012 the number of motor vehicles significantly increased with an increasing rate of 9.3% (Wati and Nasution, 2017). On the other hand, in 2015, industrial activities in Jakarta has consumed a total of more than 20 billion liters of fuel (gasoline and solar). Fuel consumption in Jakarta increases annually along with rapid economic development and urbanization (Indonesia Statistical Agency, 2017). Using the available data, relative acidity contributions each by sulfuric and nitric acids is calculated using below equation to be able to easily understand the contribution of the transportation system or fuels

Acidity contribution (%) by sulfuric acid =

$$\frac{\left[nssSO_4^{2-}\right]}{\left[nssSO_4^{2-}\right]+\left[NO_3^{-}\right]}\times 100 \tag{1}$$

Acidity contribution (%) by nitric acid =

$$\frac{\left[NO_3^{-}\right]}{\left[nssSO_4^{2-}\right]+\left[NO_3^{-}\right]}\times 100 \tag{2}$$

where nss SO_4^{2-} is non sea-salt sulphate.

According to Aldrian and Susanto (2003), the climate of the city is influenced by two monsoons which bring two major seasons, the dry (from May to September) and wet (from November to March) season. During the dry season, the southeasterly (SE) monsoon dominates and brings cold and dry air and a small amount of precipitation, while in the wet season the northwesterly (NW) wind brings warm and wet air resulting in heavy evaporation over the Java Sea (including Jakarta) as a source of precipitation.

Sampling Sites

Air quality monitoring sites for both rainfall chemistry and particulate matter in Jakarta are shown in Fig. 1. Location of sampling sites, type of parameters, and data collection are also presented in Table 1. Rainwater samples have been collected from the Kemayoran site (Central Jakarta) and analyzed for its chemical constituents as well as its pH by the Air Quality Laboratory of BMKG as part of their daily task and function. This activity is part of the World Meteorological Organization (WMO) and EANET station network. Beside rainwater chemistry, PM_{10} measurement also carries out in this site. This site is located in BMKG Headquarter in Central Jakarta with coordinates 6.155°S, 106.846°E. This site has elevation 4 m and surrounded by many building offices.

Suspended Particulate Matter (SPM) samples were collected from 2 locations in Jakarta namely Ancol (North Jakarta) and Glodok (West Jakarta) with coordinates 6.130°S, 106.830°E and 6.150°S, 106.820°E respectively. Those two sites have different characters in which Ancol is a coastal area, while Glodok is located at the center of business district in West Jakarta. These site have long term and complete SPM measurement data compare with 2 other locations (Kemayoran and Bandengan) in Jakarta.

$PM_{2.5}$ concentration data is obtained from the United States Government in Jakarta. They measure $PM_{2.5}$ in 2 locations in Central and South Jakarta as part of AirNow program. This data is publicly available through (https://airnow.gov/index.cfm?action=airnow.global_summary#Indonesia$Jakarta_South). However, we only use data from Central Jakarta since it is closer to BMKG Headquarter (approximately 3 km) which collect rainfall data. This rainfall data, then, will be plotted together with $PM_{2.5}$. Meteorological parameters (wind direction, wind speed, and rainfall) to produce seasonal wind roses in dry and rainy season is obtained from Tanjung Priok Meteorological and Maritime Station with coordinate 6.108°S, 106.881°E. This site is selected since it has complete meteorological data and quite near from SPM sampling sites. Meteorological data during 2013 to 2017 have been used to create the seasonal wind roses.

Data Collection and Analysis

Rainwater is collected by using Automatic Rain Water Sampler (ARWS) and sampling once in a week at 0900 local time in order to analyze its chemical constituents. The following compound was being analyzed such as sulphate, nitrate, chloride, ammonium, sodium, potassium, magnesium, and calcium using an Ion Chromatograph (Dionex 500) referring to WMO guideline on manual for the Global

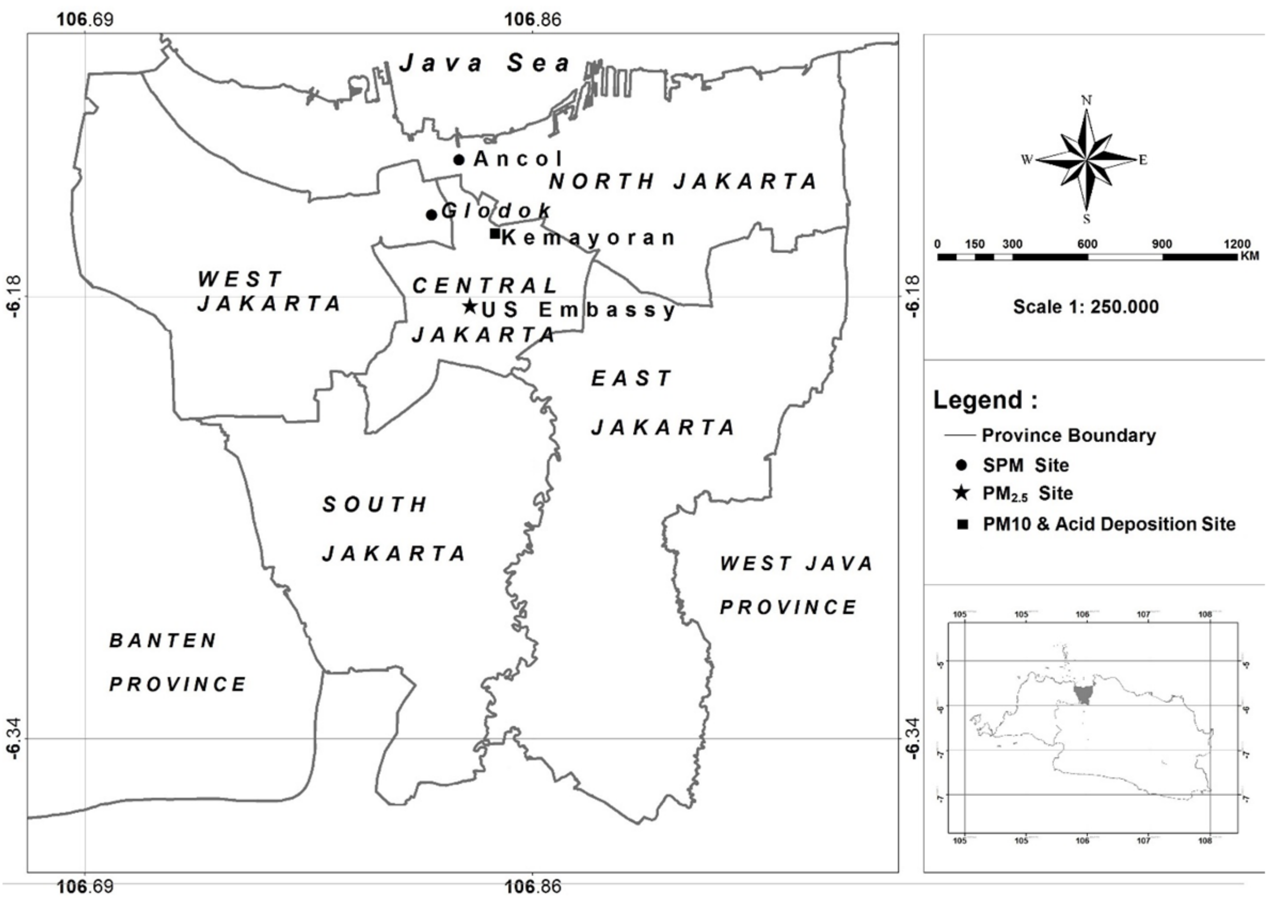

Fig. 1. Map of Jakarta and sampling sites.

Table 1. Location of sampling sites, type of parameters, and data collection.

Location	Parameter	Coordinate	Data Collection
Kemayoran (BMKG Headquarter)	Rainfall chemistry (anion and cation)	6.155°S, 106.846°E	2000 to 2015
	Total Rainfall		2000 to 2015, and during June to July in 2016 and 2017
	PM_{10}		October 2014 to March 2017
Tanjung Priok Meteorological	Number of dry days/month	6.108°S, 106.881°E	October 2014 to March 2017
Station (BMKG)	Meteorological parameters (wind direction, wind speed, rainfall)		2013 to 2017
Ancol (BMKG)	SPM	6.130°S, 106.830°E	1980 to 2016
Glodok (BMKG)	SPM	6.150°S, 106.820°E	1980 to 2016
Central Jakarta (US Embassy)	$PM_{2.5}$	6.183°S, 106.834°E	June to July in 2016 2017

Atmosphere Watch (GAW) precipitation chemistry programme (World Meteorological Organization, 2004). Ion chromatography has been widely used in recent years to analyze cations, as well as anions, in precipitation. Anions and cations in precipitation are separated on an ion exchange column because of their different affinities for the exchange material (World Meteorological Organization, 2004). PM_{10} and $PM_{2.5}$ are measured by using Beta Attenuation Monitoring (BAM) 1020 analyzer.

The sampling of SPM was done using High Volume Sampler referring to American Standard for Testing Material (ASTM) D4096 Application of the High Volume Sample Method for Collection and Mass Determination of Airborne Particulate Matter. High-volume sampler consists of a blower and a filter, and is operated in a standard shelter to collect a 24-h sample. It is sampling a large volume of atmosphere, 1,600–2,400 m^3 (57,000–86,000 ft^3), with high-volume blower, typically at rate of 1.13–1.70 m^3 min^{-1} (40–60 ft^3 min^{-1}). Air is drawn into the sampler and through a quartz filter by means of a blower, so that particulate matter collects on the filter surface (ASTM D4096). The filter is collected once in a week and then is weighed to determine concentration.

In this paper we analyze rainwater ions in Jakarta during period of 2000 to 2015. This data, then, together with pH and annual precipitation are plotted in graphs. Seasonal variation of SPM concentration has been analyzed using monthly data from 1980 to 2016. Temporal variation of PM_{10} in Jakarta is assessed by using monthly average concentration data from October 2014 to March 2017. We also reveal analysis of $PM_{2.5}$ concentration during the celebration of Ied Al Fitr to illustrate the influence of human activity to particulate matter pollution. Daily average concentration of $PM_{2.5}$ during festive event (since D−7 to D+7) in 2016 and 2017 are plotted together with rainfall amount to understand other factor reducing $PM_{2.5}$ in the atmosphere.

RESULTS AND DISCUSSION

Variations of PH and Ionic Constituents of Rainwater

As can be seen from Fig. 2, mean concentrations for the eight ions in rainwater during 2000 to 2016 followed the sequence of $SO_4^{2-} > NO_3^- > Ca^{2+} > NH_4^+ > Cl^- > Mg^{2+} > Na^+ > K^+$. Sulfur and nitric acid are widely known as major causes of acidification. Originated from the coal burning and oil for industrial activities and automobiles, sulfur dioxide, and nitrogen oxides, in existence of rain, will react to form sulfuric acid and nitric acid that are deposited on the earth (Seinfeld and Pandis, 2006). Sulfuric acid is the precursor of acid deposition and plays an important role to decrease pH. A lot of amount of calcium and ammonium were also found in rainwater in Jakarta. Calcium and Magnesium were found mainly from dust (road dust or construction dust) or from mineral dust that came from outside the city. While, human and animal excretions were probably the source of NH_4^+. The use of fertilizers as part of agricultural activities also contributes to the emitting major amount of ammonium, however, this is unlikely occur in

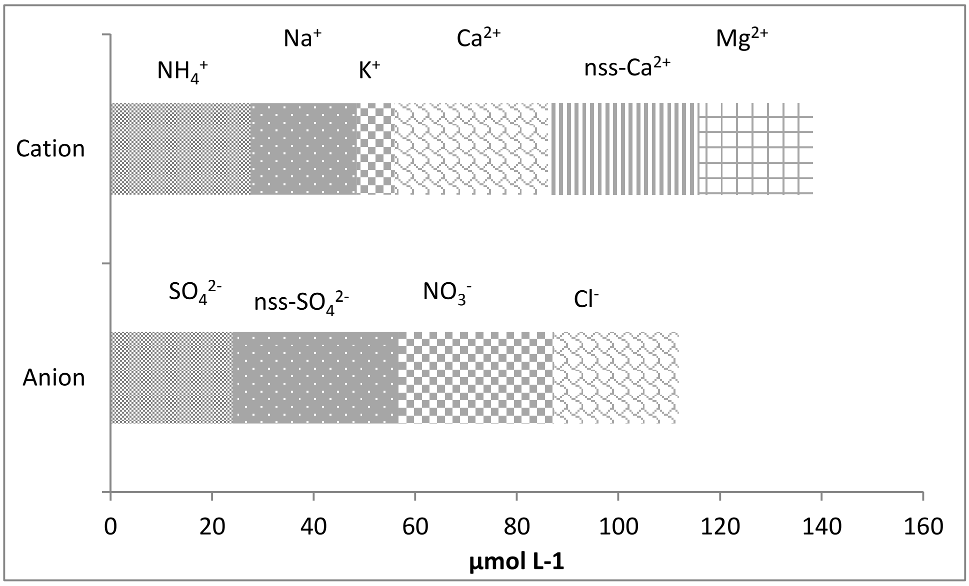

Fig. 2. Concentration of rain water ions in Jakarta during 2000 to 2015.

Jakarta as an urban city. According to Safai *et al.* (2004), in an urban city, emissions from both brick kilns and vehicles could be other sources of ammonium as there are number of brick industries found in Jakarta and Bekasi areas.

Fig. 3 shows the temporal variation of rainfall amount, pH, and concentration of ionic constituents of rainwater in Kemayoran, one of the busiest areas in Central Jakarta during 2000–2015. Annual precipitation amount during 2000 to 2015 from Kemayoran site shows a significant increasing trend ($R^2 = 0.4507$, $\alpha < 0.0000001$). This result is in accordance with Aldrian (2007) and Supari *et al.* (2016), who found an increasing trend of rainfall in Jakarta. Furthermore, Siswanto *et al.* (2015) found that the trend of extreme rainfall event (> 50 mm day^{-1}) in Jakarta increasing over the 1866–2010 period and stronger trend over the period 1961–2010, while the number of days with rainfall has decreased over the 1866–2010 period.

The concentration of anions of Jakarta rainfall showed a similar pattern. All ionic concentrations experienced decreasing trends from 2000 to 2015. However, from 2006 to 2015, the concentration of ion sulfate, nitrate, and chloride are steady with 52.9% of relative acidity contribution from sulfuric acid during period of 2000 to 2015. The decreasing of ionic concentration after 2006 might be a result of policy intervention. In 2007, Governor of Jakarta has issued Regulation No. 141 about Utilization of Gas Fuel for Public Transportation and Local Government Operational Vehicles. This policy is established as a follow up of the previous policy by local government No. 2/2005 about Air Pollution Control. Also in 2007, Governor of Jakarta also issued Regulation No. 103 about Development of Mass Public Transportation through the improvement and development of busway and commuter line (MRT/Mass Rapid Transport). Besides improvement of the system transportation and fuels, other policies introduced by government to improve clean air are replacing traditional stove which using kerosene to gas for cooking, planting trees on city streets, requiring 30% of the total area of the city for green area (Act No. 26, 2007, about spatial planning), introducing green building, etc. In addition to the policy intervention, the decreasing trends of all chemical constituents in rainwater is also influenced by the total amount of rainfall which showed increasing trend.

The annual average pH during same period varied from 4.31 to 5.42 and showed a decreasing trend ($R^2 = 0.1515$), though it is not significant. Normal rain has a pH of about 5.6. Acid rain usually has a pH between 4.2 and 4.4. Average pH values in Jakarta recorded less than 5.6 meaning that the precipitation was slightly acidic (contains high H^+ ion concentration). This is in line with EANET (2011) which assessed average pH values from 2005 to 2009 and revealed that Jakarta experiences acid rain. pH values in Jakarta are more acidic compared with other urban cities in Southeast Asia such as Hanoi, Metro Manila, and Bangkok during the same period. However, it is slightly better compared with Petaling Jaya in Malaysia (EANET, 2011). Distribution of pH values is presented in Fig. 4, where the first quartile is 4.60 and the third quartile is 4.77 with a mean of 4.73 (n = 15). It shows that most of pH ranged from 4.60 to 4.77. Long-range transport of sulfur and nitrogen is possible to other regions. Sulfur and nitrogen could transport to other region and deposited to earth to form acid rain (Seinfeld and Pandis, 2006; EANET, 2015). Long-range transport from the industrialized areas of Jabodetabek may contribute to an anthropogenic sulfur and reactive nitrogen depositions throughout Jakarta city. High deposition in one area could be explained by high emission rates of their precursors around this area or other regions (EANET, 2015). Slightly decrease pH values while the ionic trends also decrease indicates the influence of long-range distribution of regional pollution and not the local pollution.

Particulate Matter Pollution

Seasonal variation of SPM concentration in Ancol (a) and Glodok (b) during 1980 to 2016 is shown in Fig. 5. The

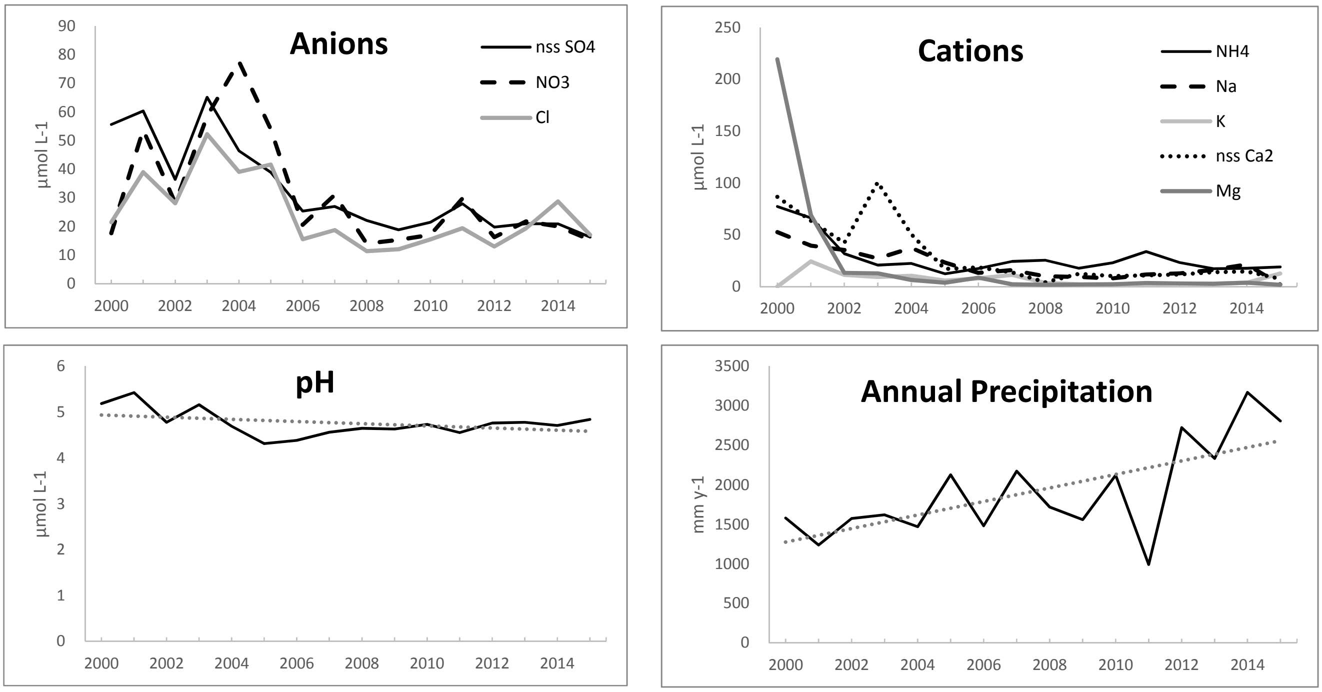

Fig. 3. Temporal variations of rainfall amount, pH, and concentration of anions and cations in rain water in Kemayoran, Jakarta during 2000–2015.

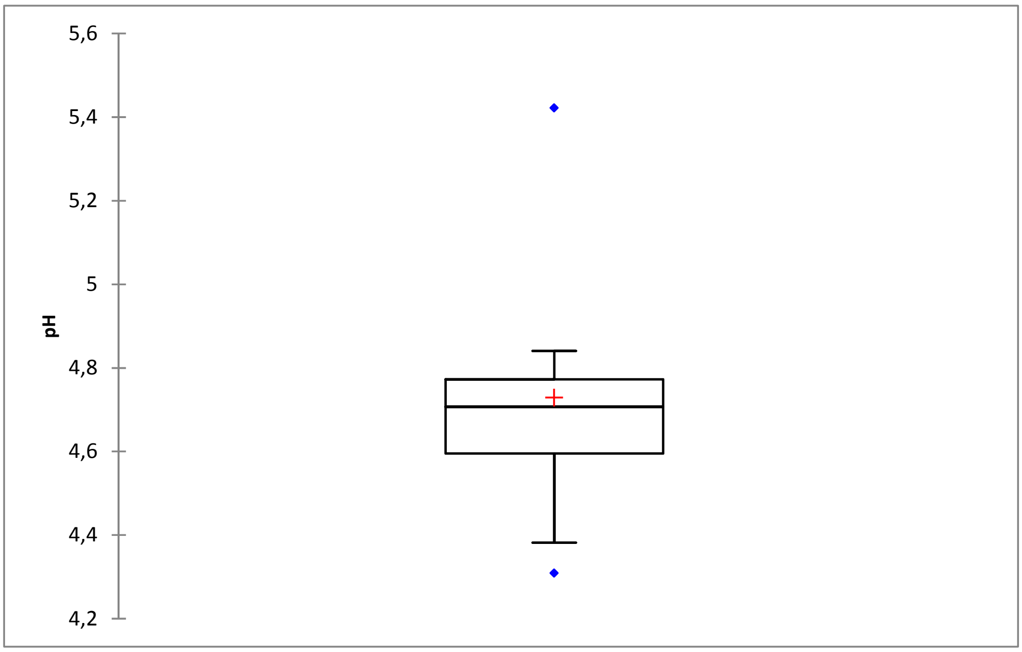

Fig. 4. Box Plot of pH distribution for Kemayoran Jakarta.

average of monthly SPM in Ancol (Fig. 5(a)) shows mostly that SPM concentration is higher in dry season (April–September) than wet season (October–March). Seasonal variation is most reflected in Ancol during El Nino year in 1982, 1983, 1997, and 2015. In the other hand, seasonal pattern does not strongly influence the SPM concentration in Glodok (Fig. 5(b)). In certain years, SPM concentrations appeared higher in wet season than dry season. Transportation and dust (from road and construction) could be the other factors influence the SPM concentrations. As explained previously that this sampling site is located in one of the busiest areas in West Jakarta. The SPM instrument shelter is in the sidewalk of main and busy street in Glodok where financial and business district are centered.

The correlation of SPM concentration in Glodok with the number of dry days per month in Tanjung Priok Meteorological station is 0.18 and is not stronger than in Ancol ($r = 0.35$) significantly with $\alpha < 0.05$. The significant

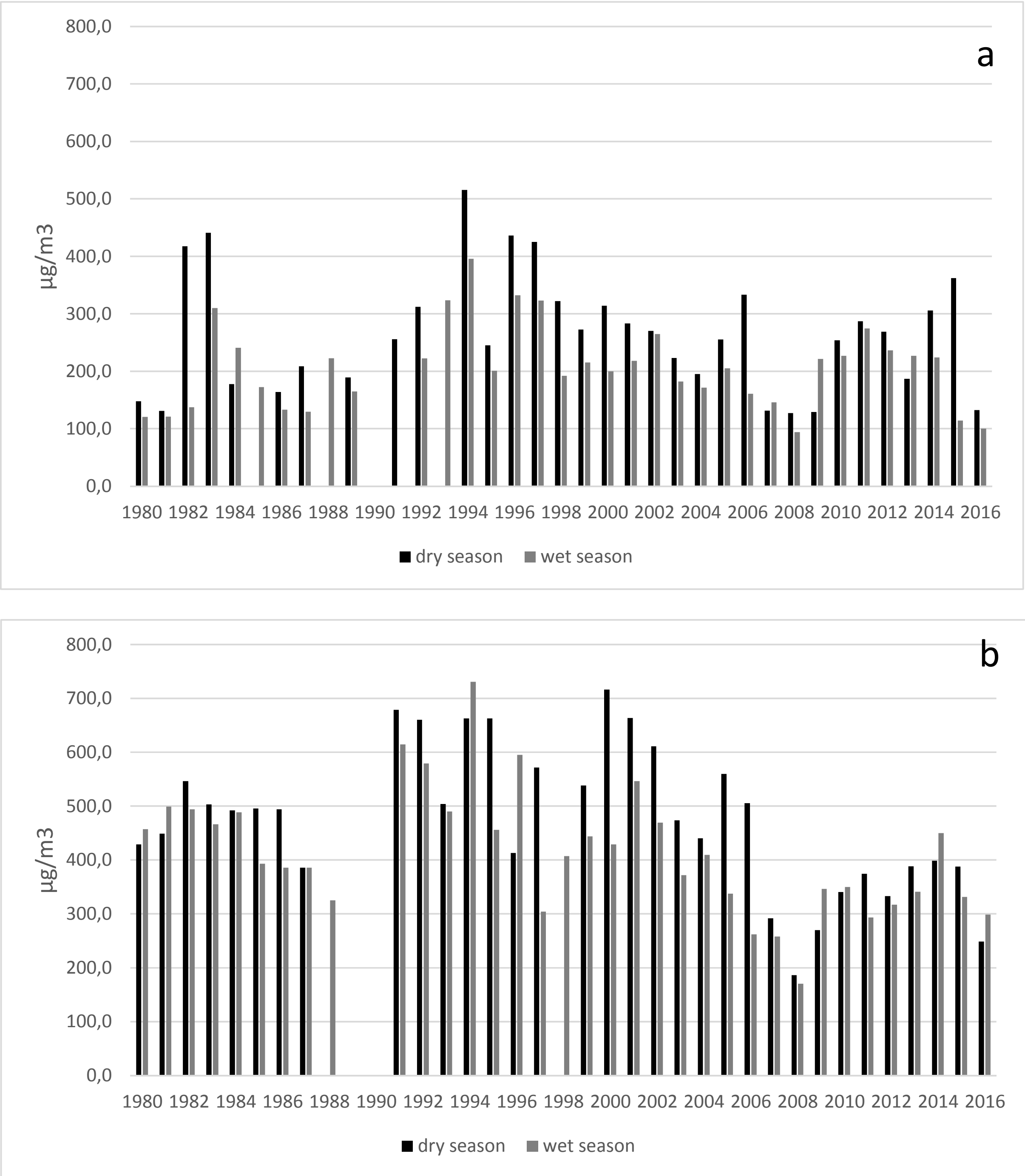

Fig. 5. Seasonal variation of SPM concentration in (a) Ancol (North Jakarta) and (b) Glodok (West Jakarta).

positive correlation also indicates the concentration of SPM is influenced by the occurrences of rainfall. Naturally, rainfall will remove pollutants from the atmosphere through washout or wet deposition processes, therefore, decrease the concentration of SPM in ambient air. This fact is also in line with findings in previous studies (Tian *et al.*, 2015; Dotse *et al.*, 2016) which showed rainfall as one of meteorology variables that influence the dispersion, transformation, and removal of atmospheric pollutants from the atmosphere. Several statistical studies also confirmed that PM influenced temporal changes (typical diurnal, weekly, seasonal, and annual cycles) in meteorological parameters (Choi *et al.*, 2008; Sfetsos and Vlachogiannis, 2010; Lee *at al.*, 2011; Mamtimin and Meixner, 2011; Unal *et al.*, 2011; Han *et al.*, 2012; Tian *et al.*, 2014).

Fig. 6 illustrates the monthly mean SPM concentrations in Ancol and Glodok during 1980–2016. The variation of monthly mean of SPM showed that the highest concentration occurred on June in Glodok with the value of 512 µg m^{-3} and on September in Ancol with the value of 298 µg m^{-3}. Meanwhile, the lowest is in February in both of sites with the value of 390 µg m^{-3} and 171 µg m^{-3}, respectively, in

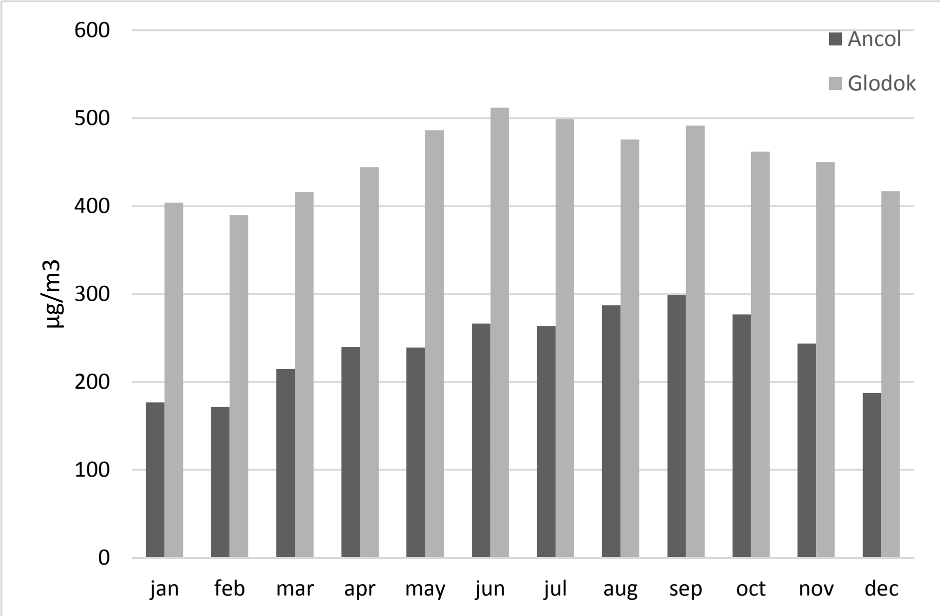

Fig. 6. The monthly mean SPM concentrations during 1980–2016.

Glodok and Ancol. SPM concentration in Glodok appeared a much higher than that in Ancol. Glodok is recognized as a central business district and one of the busiest areas in West Jakarta, while Ancol is characterized as a coastal area and does not have many building offices surrounding it. This site, however, lies beneath the busiest Jakarta highway corridor. During the monitoring period, SPM concentration in both sites has exceeded the threshold set by Indonesia Ministry of Environment for SPM is 230 µg m^{-3} (24-h average) and 90 µg m^{-3} (1-year average) except in Glodok during the rainy season.

According to its seasonal variability, SPM concentration is higher in the dry season (April–September) than in the rainy season (October–March) as seen in Fig. 6. This result is similar to that of Juneng *et al.* (2009), who found that particulate matter in Peninsular Malaysia exhibited a remarkable seasonal variation with maximum values from May to September (dry season) associated with southwesterly winds. Meanwhile, the minimum concentrations were found during the rainy season from December to March (Abas *et al.*, 2004). According to Kanniah *et al.*, (2016), and Inouye and Azman (1986), the washout effects of heavy rainfall and absences of strong ground-based inversion are the main causes for the low concentrations of atmospheric particles during the rainy season.

The distributions of wind direction and speed over the dry season and rainy season are shown in Figs. 7(a) and 7(b). The wind rose shows wind blowing in all directions in the dry season but dominant in the northeast quadrant with approximately 32.5% with weak prevailing winds in the southeast direction of 19% and west direction 5%. High SPM values during the dry season period were associated with the southeast monsoon months, while in the rainy season, the wind rose as can be seen in Fig. 7(b) blows dominantly in the northwest quadrant approximately 21.5% and west direction 18% and weak winds from all direction.

The concentration of PM_{10} recorded in Kemayoran (Central Jakarta) during October 2014 to March 2017 is presented in Fig. 8(a). The average concentration ranged from 38.30 µg m^{-3} to 112.92 µg m^{-3}. Lowest concentration occurred during February 2017 and highest in September 2015. This concentration is still below the threshold set by Indonesia Ministry of Environment for PM_{10}, which is 150 µg m^{-3} (24-h average) (PP No. 41, 2007). However, some of them are exceeded the World Health Organization (WHO) air quality guidelines for PM_{10} which is 50 µg m^{-3} for 24-h average (WHO, 2006). The concentration of PM_{10} and number of dry days per month is given in Fig. 8(b). Similar with SPM, PM_{10} and number of dry days per month showed positive correlation 0.52 indicated that increasing of PM_{10} is accompanied by the increase of a number of dry days. During the investigation period, monthly mean of highest concentration occurred on September (during the dry season) and lowest concentration on December.

Variations of $PM_{2.5}$ during the Ied Al Fitr Feast Day

An investigation on $PM_{2.5}$ characteristic has been done during a special event of Ied Al Fitr in 2016 and 2017. Ied Al Fitr is the most important day in the Islamic calendar and celebrated by 84% of Muslim people in Indonesia. The Ied Al Fitr is the biggest holiday in the country and is celebrated officially in two days. However, most of the business activities including offices and services are closed for the whole week. The Ied Al Fitr for 2016 and 2017 was on 6 July and 25 June, respectively. Holiday started from D−2 to D+3. During Ied Al Fitr holiday, most of the people living in urban areas like Jakarta leave the city and travel to their places of origin or hometowns in different cities and islands. During the Ied Al Fitr holiday, consequently, Jakarta experienced fresher air. The concentration of $PM_{2.5}$ during the feast event in 2016–2017 in Jakarta is summarized

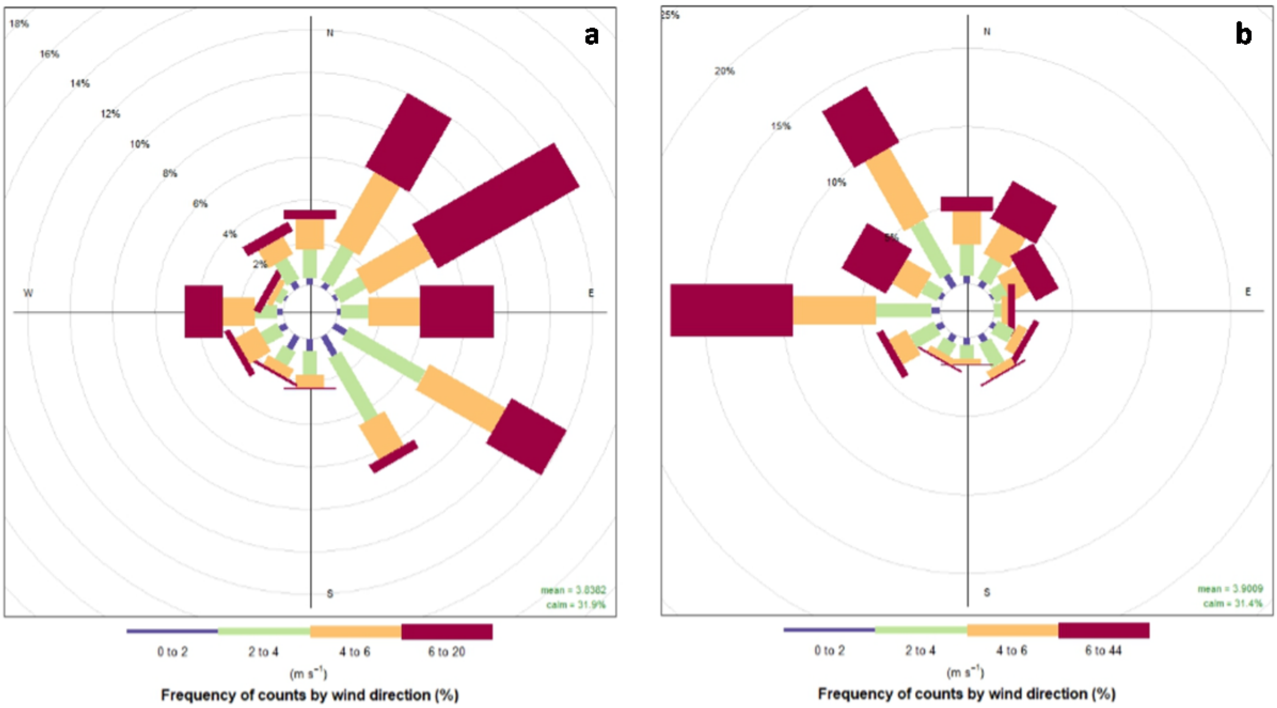

Fig. 7. Seasonal wind rose (a) from April to September and (b) from October to March during 2013 to 2017.

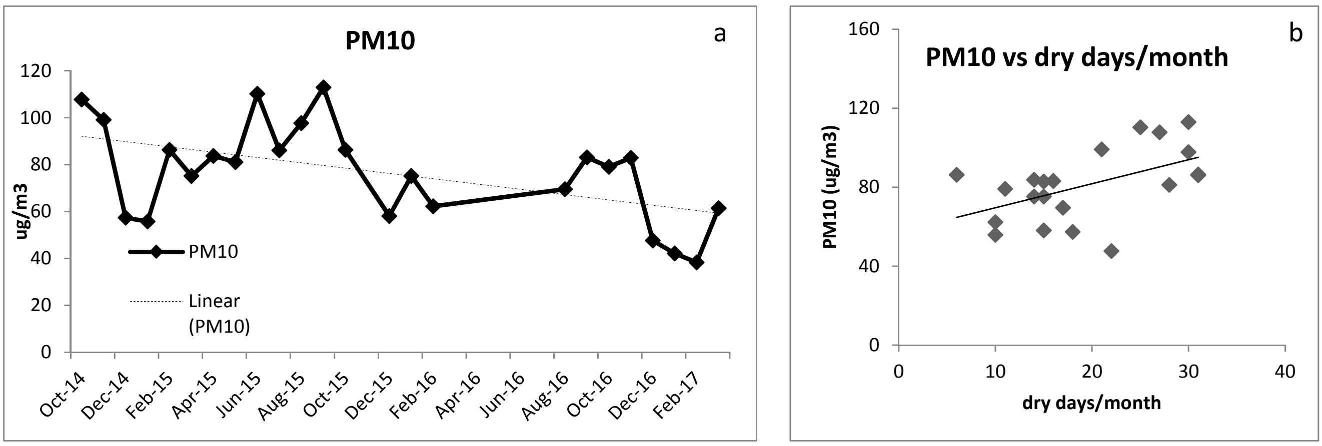

Fig. 8. Temporal variation of PM_{10} monthly average concentration in Kemayoran, Jakarta during (a) October 2014 to March 2017 and (b) PM_{10} concentration versus number of dry days/month.

in Fig. 9. The number of concentration shall represent one day before the measurement. We only showed investigation during D−7 to D+7. The average daily $PM_{2.5}$ concentration in 2016 and 2017 feast events ranged from 36.41 µg m^{-3} to 65.92 µg m^{-3} and from 3.66 µg m^{-3} to 59.16 µg m^{-3} respectively.

Based on 2-week observations, on both feast events in 2016 and 2017, the most daily reduction of $PM_{2.5}$ concentration occurred during the Ied Al Fitr feast day (from D−1 to D). Both in 2016 and 2017 during the D-Day (with or without rain), concentration of $PM_{2.5}$ reduced compared than before and after D-Day. On the day of Ied Al Fitr 2016 and 2017, there were reductions of the $PM_{2.5}$ concentration of 15.5 and 28.7 µg m^{-3} from the previous day, respectively. Concentration of $PM_{2.5}$ during D-Day in 2017 experienced a lot of reduction due to rainfall while in 2016 the reduction was obvious when there was no rain at all. However, further observation of future similar events is needed to have better statistics.

Besides rainfall, human activities through transportation, business, and industrial activities contribute to the reduction of $PM_{2.5}$ concentration. Most of the $PM_{2.5}$ concentration reductions are attributed to the reduction of a number of vehicles remain in Jakarta city during the Ied Al Fitr feast day. There are three main gateways to Jakarta that connect the city to the east, south, and west, which are namely, consecutively, the Cikarang Utama toll gate, the Cibubur toll gate, and the Cikupa toll gate. The Cikarang Utama toll road is the main highway that connects Jakarta with many cities east of Jakarta in West, Central, and East Java

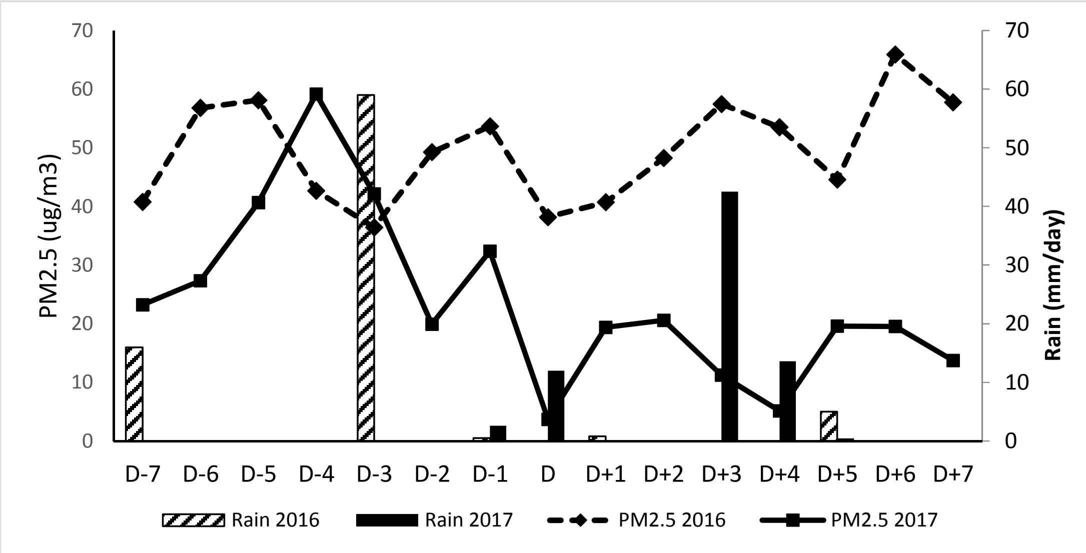

Fig. 9. $PM_{2.5}$ concentration before, during, and after celebration of Ied Al Fitr in Jakarta in 2016 and 2017.

provinces. According to PT Jasa Marga, a company which operates toll roads in Indonesia, as reported by an online news (http://www.aktual.com/ini-total-jumlah-kendaraan-pada-arus-mudik-dan-balik-lebaran-2017, accessed on 2 October 2017) that 919,114 and 922,215 vehicles were passing the Cikarang Utama toll gate and leaving Jakarta to the east in 2016 and 2017, respectively. In addition, 814,779 and 877,864 vehicles were reported to leave Jakarta to the south through the Cibubur Utama toll gate in 2016 and 2017, respectively. PT Jasa Marga also monitored the number of vehicles entered Jakarta after the holiday season (D+1 to D+10). In 2016 and 2017, more than 1 million vehicles entered Jakarta through the Cikarang Utama toll gate during D+1 to D+10. In Cibubur Utama toll gate, 734,879 and 714,525 vehicles were recorded entering Jakarta in 2016 and 2017 respectively, while 453,259 and 455,703 vehicles were passing through the Cikupa toll gate to enter Jakarta from the west.

General Discussion

In the atmosphere, particles like sulfur dioxide and nitrous oxide could react with rainfall to form sulfate and nitrate that can cause acidification. Particles like SO_2 and NO_2 could also affect heavy haze (Quinn and Bates, 2003; Wu *et al.*, 2005; Che *et al.*, 2007; Tie *et al.*, 2009; Liu *et al.*, 2013), photochemical smog (Ma *et al.*, 2002; Wang and Kwok, 2003) and transported to other region (Qu *et al.*, 2016). Reducing aerosols or particulate matter emissions could reduce air pollution and acid deposition (EANET, 2014). Sulfate and nitrate were found as dominant ions in rainwater in Jakarta. Based on observation, sulfate and nitrate experienced decreasing trends during 2006 to 2016. Decreasing trends were also observed in SPM and PM_{10} concentrations. Management and improvement of a transportation system and limitation or restriction of fossil fuel could reduce the emissions of sulfur oxide and nitrogen oxide and improve air quality. Decreasing of annual $PM_{2.5}$, PM_{10}, SO_2, and NO_2 concentrations also studied by Lang *et al.* (2017) in Beijing during 2000 to 2015 as a result of implementation of air pollution control measures, including the controlling of industry, motor vehicle, coal combustion, and fugitive dust pollution.

CONCLUSIONS

During the investigative period of this study, the chemical constituents, i.e., the anion and cation concentrations, in precipitation showed decreasing trends from 2006 onward. Moreover, the PM_{10} and SPM concentration decreased slightly. However, the pH of the rainfall also exhibited a decreasing trend, which signals deteriorating air quality. We conclude that the local ambient air quality during this period of study improved, as shown by the anion and cation concentrations, while the regional air quality worsened.

The causes of the favorable local trends were an increasing trend of rainfall, and policy intervention. The decreasing trend of ions with the rainfall was also associated with the increase in the amount of precipitation. The removal of SPM, PM_{10}, and $PM_{2.5}$ is influenced by meteorological factors, such as wind speed, wind direction, and rainfall. The implementation of a Governor Regulation on public transportation, including the use of gas fuel, also contributed to the improvement in air quality. Nonetheless, an assessment of the particulate matter pollution indicates that the SPM concentrations in 2 locations in the busiest business district of Jakarta, which experiences heavy traffic daily, still exceed the guideline set by the Ministry of Environment. Additionally, an assessment during the feast of Ied Al Fitr in 2016 and 2017 indicated a further decrease in $PM_{2.5}$ due to highly reduced inner-city traffic. These events exhibited an extreme reduction of the $PM_{2.5}$ concentration in Jakarta.

The findings of this study are confined to locations where observed data are available, i.e., central and northern Jakarta. Further extension of the observational network is expected in order to study the ambient air quality of the Jakarta Metropolitan Area.

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