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 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.

Figure 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 ($R = 0.4507$, $\alpha < 0.0000001$). 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 a 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, and 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= 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 (EANET, 2015; Seinfeld and Pandis, 2006). 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 average of monthly SPM in Ancol **(Fig. 5a**) shows mostly that SPM concentration is higher in dry season (April to September) than wet season (October to 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. 5b**). 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 whereas 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 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 (Dotse *et al.*, 2016; Tian *et al*., 2015) 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; Han *et al.*, 2012; Lee *at al.*, 2011; Mamtimin and Meixner, 2011; Sfetsos and Vlachogiannis, 2010; Tian *et al.*, 2014; Unal *et al.,* 2011).

Figure 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 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, lays 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 the Peninsula 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 **Fig. 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 fest event in 2016-2017 in Jakarta is summarized 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 two-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 a 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 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 (Che *et al.*, 2007; Quinn and Bates, 2003; Tie *et al.,* 2009; Wu *et al*., 2005; 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 nthe controlling of industry, motor vehicle, coal combustion and fugitive dust pollution.

CONCLUSIONS

During the investigation period in this study, chemical constituents, i.e. anion and cation concentration, in precipitation show decreasing trends starting from 2006 onward. Moreover, the trend of PM_{10} and SPM concentration was also decreased slightly. On the contrary, the pH of rainfall chemistry shows decreasing trend, which signals a worsening air quality. We conclude that the local ambient air quality during the period of study was improved as shown in the anion and cation concentration trend, while the regional contribution to the local ambient air quality show a worsening situation.

The causes of the local favorable trends are a climatic condition, which is an increasing trend of rainfall and the policy intervention. The decreasing trend of ions with rainfall also associated with the increasing of rainfall amount in the same period. Removal of SPM, PM_{10}, and $PM_{2.5}$ are influenced by meteorological factors such as wind speed, wind direction, and rainfall. The second cause of the trends is the implementation of Governor Regulation in Public transportation and the use of gas fuel for public transportation. Nonetheless, an assessment of particulate matter pollution indicated that SPM concentration in 2 locations in Jakarta are still high and exceeded the guideline set by Ministry of Environment amid their locations in the busiest business district of Jakarta with heavy daily traffic load. In addition, an assessment during feast event of Ied Al Fitr in 2016 and 2017 showed a further reduction of $PM_{2.5}$ due to much reduction of the inner-city traffic. The case of Ied Al Fitr day exhibits an extreme reduction or extreme low case for $PM_{2.5}$ concentration in Jakarta city.

The finding of this study is confined to locations where observed data are available, i.e. central and north Jakarta. Further extension of observation network is expected to study the comprehensive Jakarta Metropolitan Area ambient air quality status.

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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) Total Rainfall PM_{10}	6.155 ^{0}S, 106.846 ^{0}E	2000 to 2015 2000 to 2015, and during June to July in 2016 and 2017 October 2014 to March 2017
Tanjung Priok Meteorological Station (BMKG)	Number of dry days/month Meteorlogical parameters (wind direction, wind speed, rainfall)	6.108 ^{0}S, 106.881 ^{0}E	October 2014 to March 2017 2013 to 2017
Ancol (BMKG)	SPM	6.130 ^{0}S, 106.830 ^{0}E	1980 to 2016
Glodok (BMKG)	SPM	6.150 ^{0}S, 106.820 ^{0}E	1980 to 2016
Central Jakarta (US Embassy)	$PM_{2.5}$	6.183 ^{0}S, 106.834 ^{0}E	June to July in 2016 2017

Figure Captions

Fig. 1. Map of Jakarta and sampling sites

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

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

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

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

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

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

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

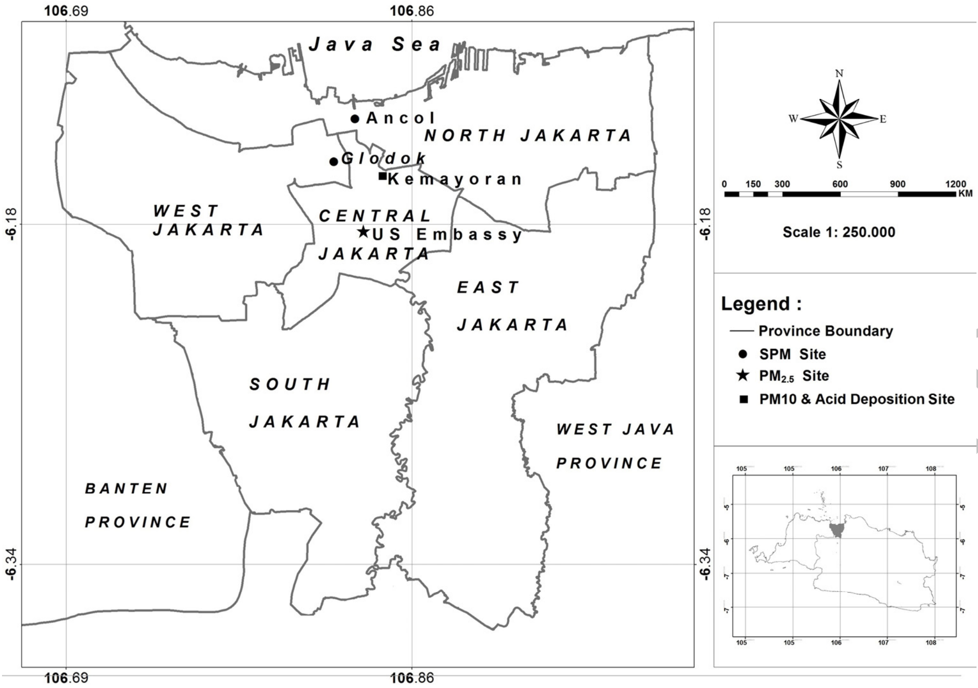

Fig. 1. Map of Jakarta and sampling sites

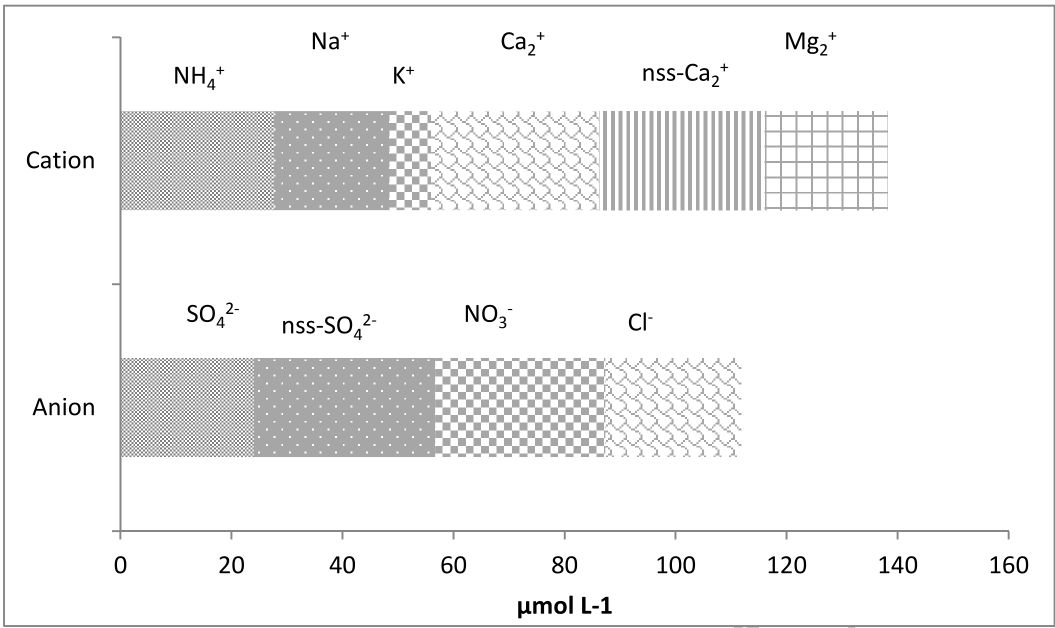

Fig. 2. Concentration of rain water ions in Jakarta during 2000 to 2015

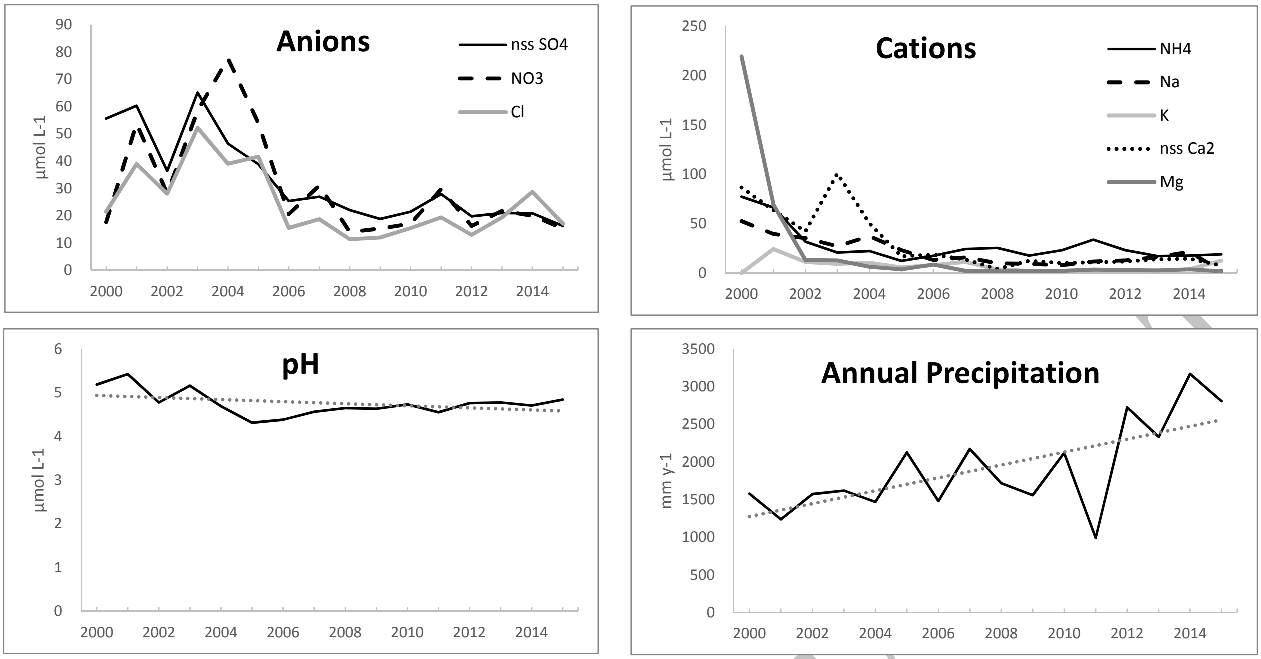

Fig. 3. Temporal variations of rainfall amount, pH, and concentration of anions and cations in rain water in Kemayoran, Jakarta during 2000-2015

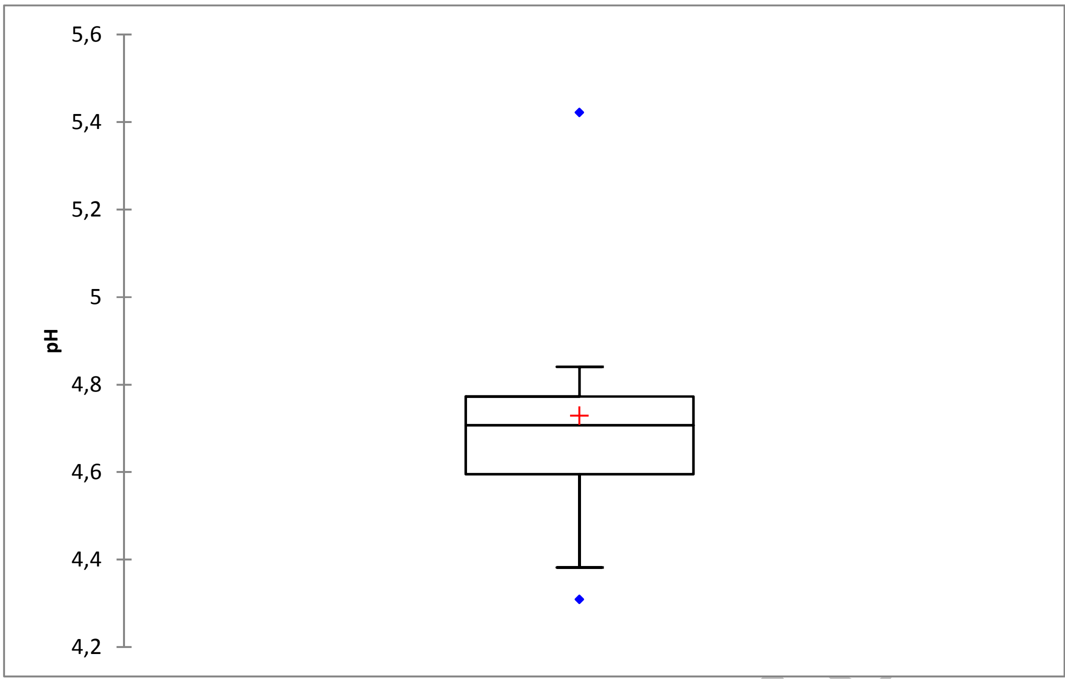

Fig. 4. Box Plot of pH distribution for Kemayoran Jakarta

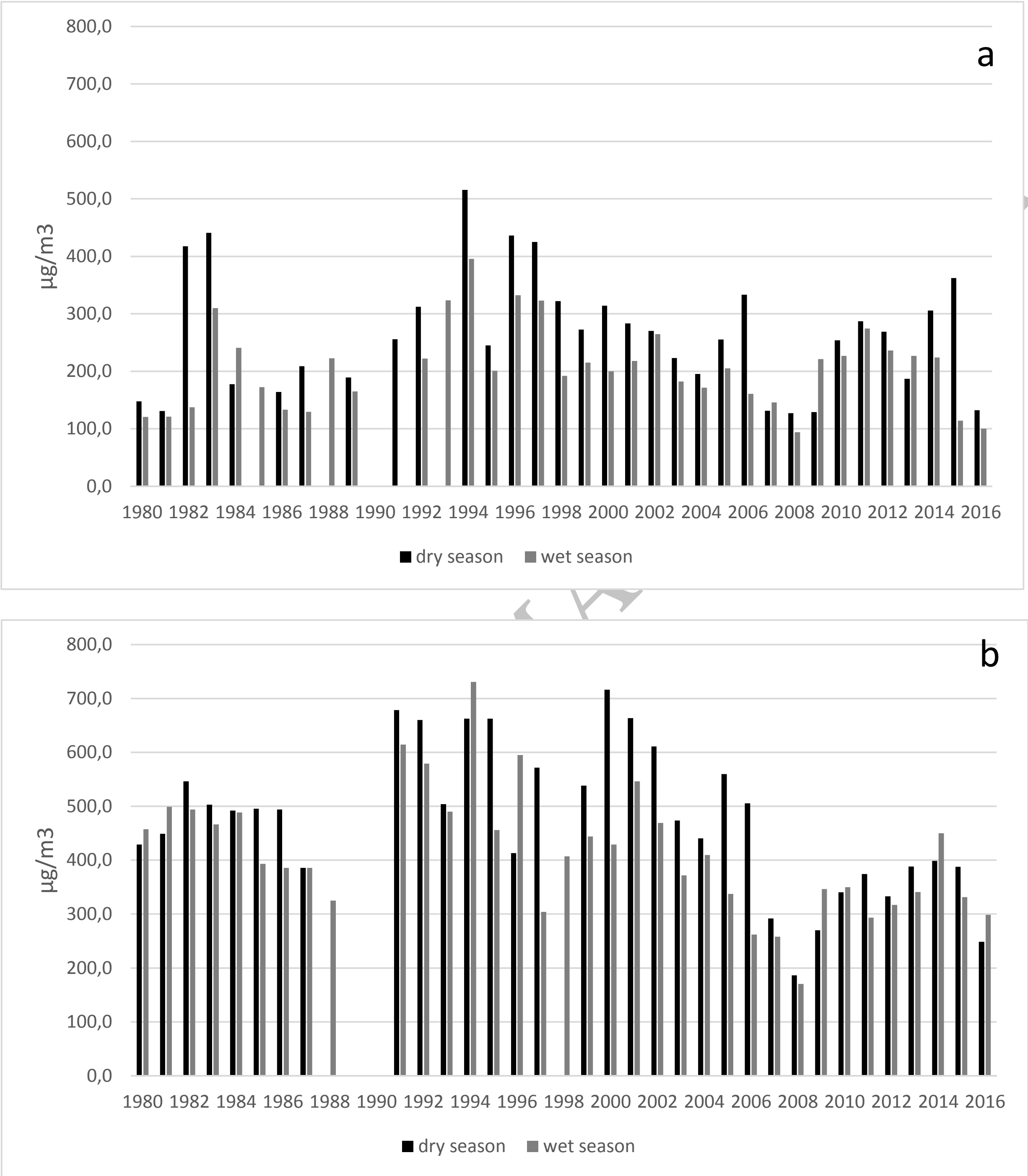

Fig. 5. Seasonal variation of SPM concentration in Ancol (North Jakarta) (a) and Glodok (West Jakarta) (b)

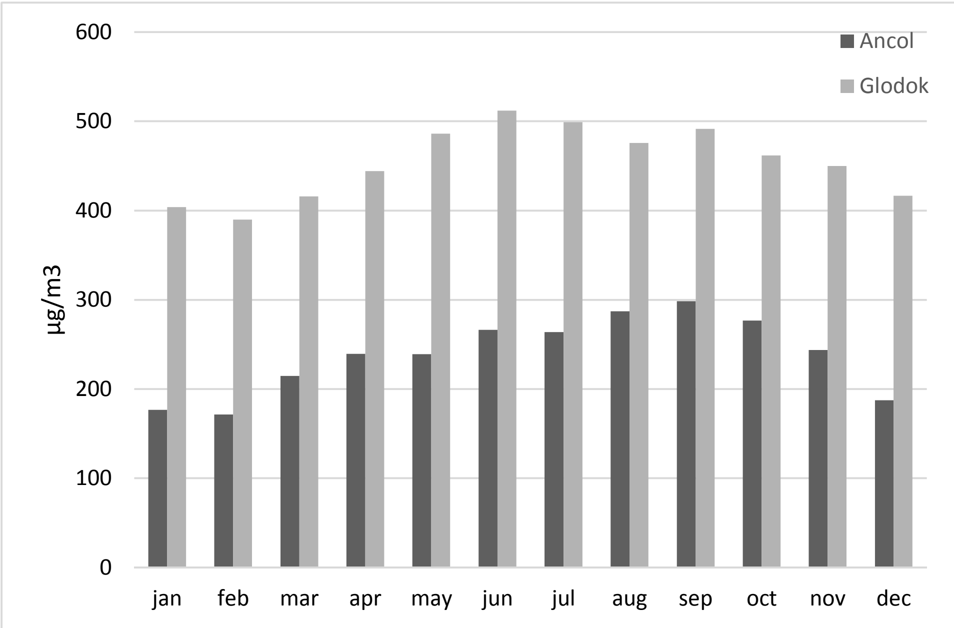

Fig. 6. The monthly mean SPM concentrations during 1980 – 2016

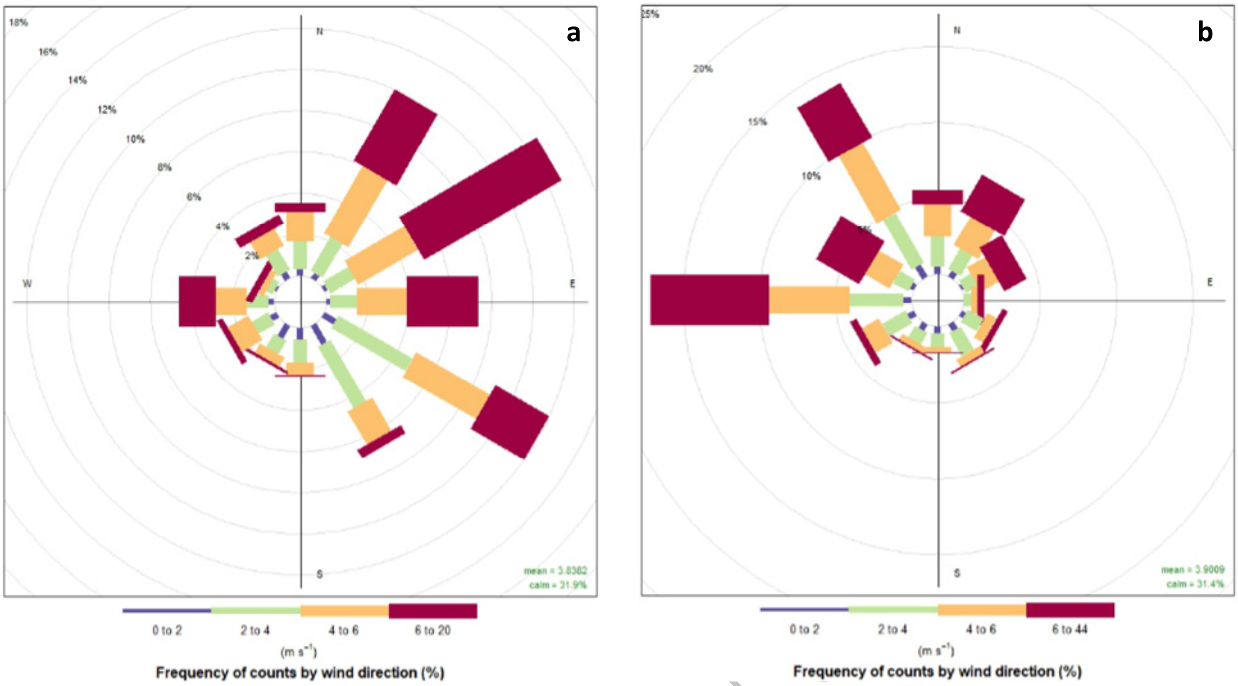

Fig. 7. Seasonal wind rose from April to September (a) and from October to March during 2013 to 2017 (b)

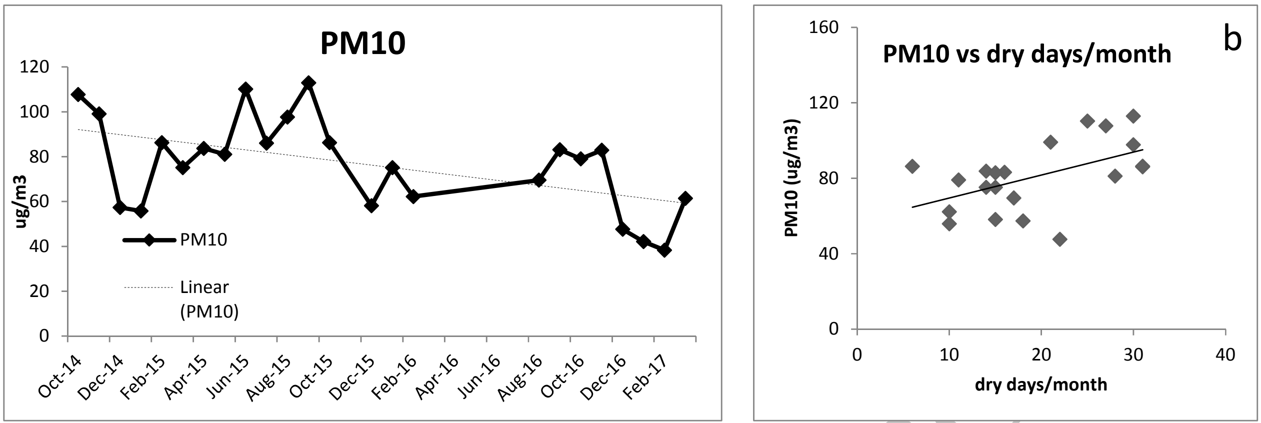

Fig. 8. Temporal variation of PM_{10} monthly average concentration in Kemayoran, Jakarta during October 2014 to March 2017 (a) and PM_{10} concentration versus number of dry days/month (b)

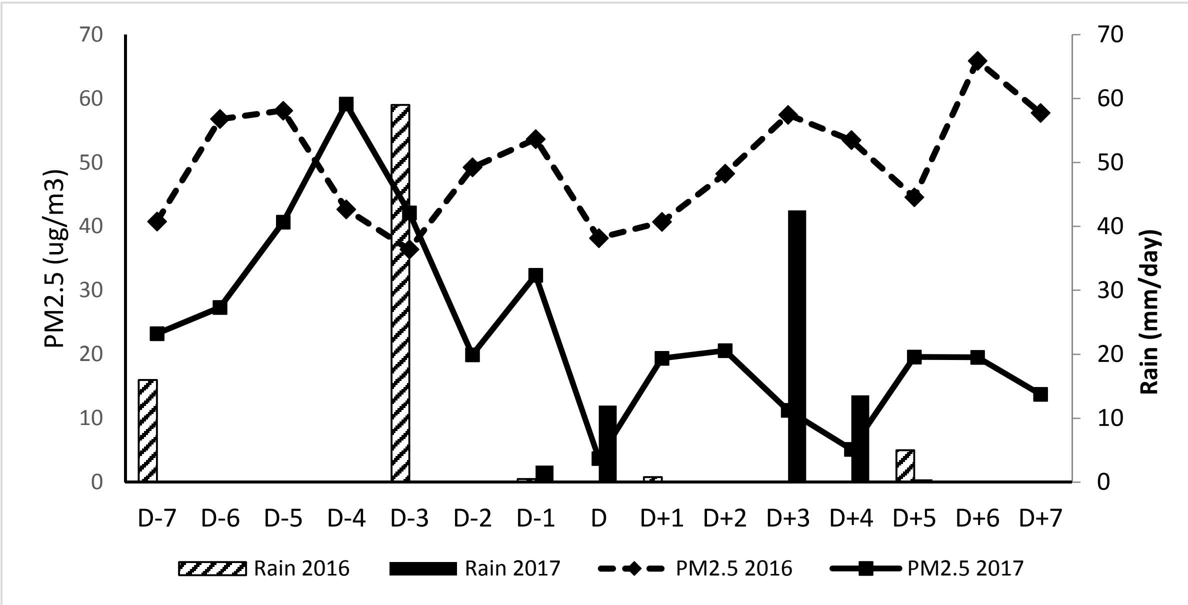

Fig. 9. $PM_{2.5}$ concentration before, during, and after celebration of Ied Al Fitr in Jakarta in 2016 and 2017