Investigating ozone changes in Jakarta Greater Area from ground observation and satellite measurement: Trend, meteorological influences, and formation regimes

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Abstract

Jakarta Greater Area, a vast urban agglomeration, is undergoing rapid economic development accompanied by a vast population, land-use change expansion, and increased energy demand for transportation and industrial activities, resulting in air pollution. The concentration of pollutants increases including ozone in Jakarta urban area and Bogor rural. Formed as a product of photochemical reactions from volatile organic compounds (VOCs) and nitrogen oxides (NOx), O_3 exerts an adverse impact on the environment and human health. Quantifying the O_3 changes, its attribution, and the formation sensitivity help to understand the O_3 characteristics in the area and also to provide insight for appropriate control strategy. In this study, we present the interannual trends of O_3 in the dry season (April to November) in five sites in Jakarta urban city (2010-2018) and one site in Bogor rural (2017-2019). We developed Multi Linear Regression (MLR) to quantify the influence of meteorology on ozone concentration, and finally, investigate ozone formation sensitivity using formaldehyde nitrogen ratio (FNR) from the measurement of Ozone Monitoring Instrument (OMI). The maximum daily 8-h average (MDA8) O_3 exhibited an increasing trend in all sites except central and east Jakarta. Mann-Kendall and Theil-Sen analysis suggests that the significant increase occurred in West Jakarta with 10.2 μg m-3 year-1. All sites in Jakarta have exceeded World Health Organization Air Quality Guideline (WHO AQG) for MDA8 O3 with a percentage above 55% during dry season days. Ozone sensitivity was toward NOx-limited regime with a higher ratio in Bogor suggesting more reduction of NOx emissions would be a suitable approach for decreasing tropospheric O_3 concentration.

Introduction

- Surface ozone is produced from photochemical reactions among VOCs and NOx with sunlight
- Affects human health and vegetation; contributes to global warming
- **Meteorological parameters** and changes in **VOCs and NOx** could alter the surface O3 concentration
- O3 formation is a non-linear process concerning the precursors (NOx and VOCs)
- Ozone formation sensitivity analysis using ratio from OMI measurement could help to understand the relationship between ozone formation and its precursors
- essential and critical to establishing effective ozone abatement efforts
- Jakarta Greater Area (JGA) is a vast urban agglomeration comprising Jakarta province and Bogor
- the O3 levels in Jakarta were high and exceeded the national ambient air quality standard, however lack of continuous measurement and research

Methodology

Study Area

- Jakarta (Bogor) population is 10 (6) million as of 2021, with a total area of 664 km2 (200 km2)
- Jakarta sites represent central, north, south, east, and west
- Bogor site is located in rural area and up on the hill

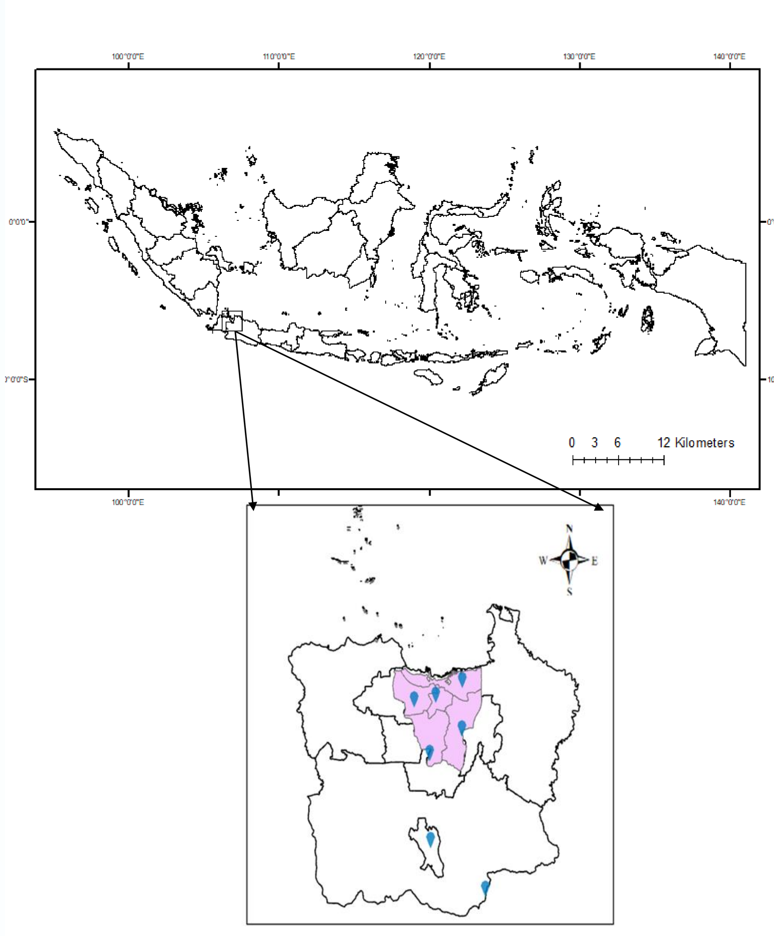

Figure 1. Map of study area

Table 1. Air quality and meteorological data used in this study

Station	Lat/long	Parameter	Elevation (m)	First date	Last date
DKI 1: Bundaran HI (Central Jakarta)	-6.194, 106.823	O3 (hourly)	3	Jan 2010	Dec 2015
DKI 2: Kelapa Gading (North Jakarta)	-6.153, 106.910	O3 (hourly)	5	Jan 2014	Dec 2018
DKI 3: Jagakarsa (South Jakarta)	-6.356, 106.803	O3 (hourly)	71	Jan 2011	Dec 2018
DKI 4: Lubang Buaya (East Jakarta)	-6.288, 106.909	O3 (hourly)	27	Jan 2011	Dec 2018
DKI 5: Kebon Jeruk (West Jakarta)	-6.207, 106.752	O3 (hourly)	6	Jan 2013	Dec 2018
CBR BGR: BMKG Cibeureum (South Bogor)	-6.735, 106.986	• O3 (hourly) • maximum temperature (Tmax) • rainfall (RRR) • wind speed mean (WS_MEAN) • relative humidity (RH) • maximum wind direction (WD_MAX)	920	Jan 2017	Dec 2019
Kemayoran Meteorological Station (Central Jakarta)	-6.155, 106.840	• maximum temperature (Tmax) • rainfall (RRR) • wind speed mean (WS_MEAN) • relative humidity (RH) • maximum wind direction (WD_MAX)	4	Jan 2013	Dec 2018
Tanjung Priok Meteorological Maritime Station (North Jakarta)	-6.107, 106.880		3		
Soekarno Hatta Meteorological Station (West Jakarta)	6.120, 106.650		11		

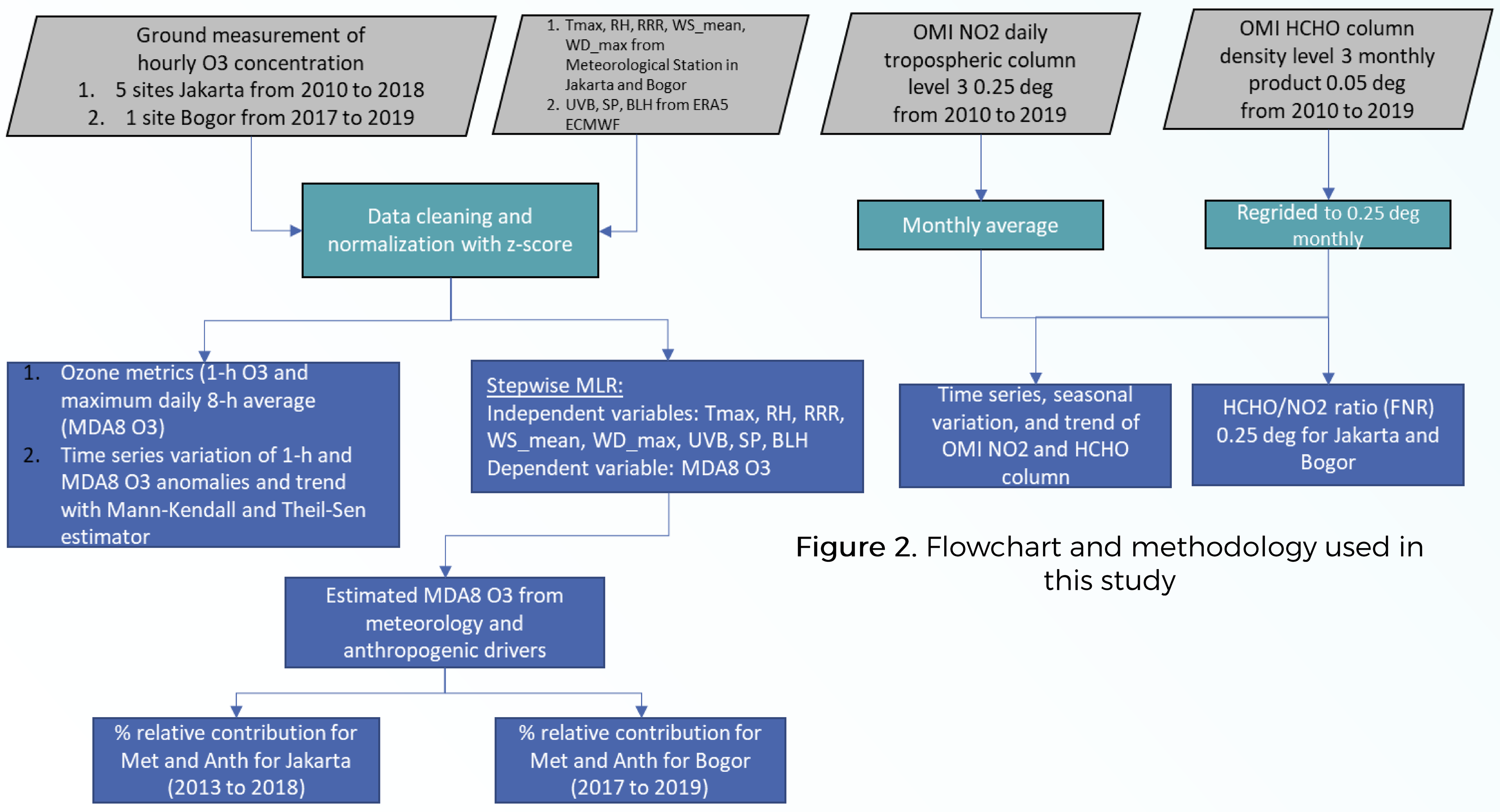

Figure 2. Flowchart and methodology used in this study

Results

Monthly anomalies of MDA8 show an insignificant upward trend at DKI2, DKI3, DKI5, and CBR-BGR, while a downward trend occurred at DKI1 and DKI4 during the dry period. A remarkable increasing trend was at DKI5 with an annual increase of 10.2 μg m-3 year-1 followed by DKI2 and DKI3 which were 4.8 μg m-3 year-1, and 1.3 μg m-3 year-1, respectively. On the other side, MDA8 O3 at DKI1 and DKI4 have decreased by about 5.2 μg m-3 year-1 and 2.7 μg m-3 year-1, consecutively (Fig. 2)..

The internannual of O_3 changes at Jakarta sites was influenced by meteorology and anthropogenic components with 22 % and 77 %, respectively. Meanwhile, meteorological (49 %) and anthropogenic (51 %) factors contributed proportionally to O3 variability at Bogor site.

FNR in Jakarta was higher compared to other urban cities in the world such as LA, New York (FNR<1) (Duncan et al., 2020), North China Plain (FNR<2.3) (Wang et al., 2021), Mexico city (FNR<1) (Santiago et al., 2021). Ozone regime threshold varies regionally. The results in Jakarta indicated NOx reduction would be suitable to decrease O_3, however, further research should be conducted.

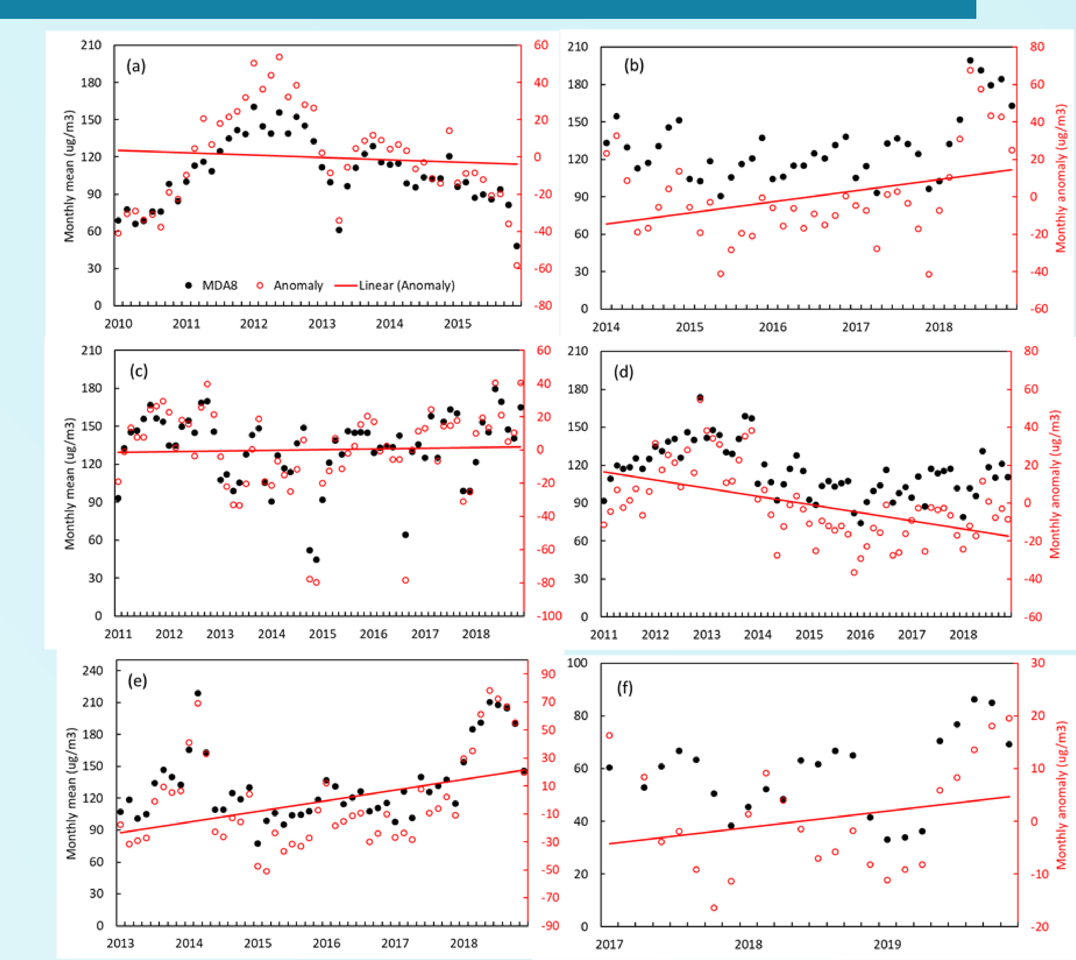

Figure 3. Time series of the average (black dots, left axis) and anomaly (red circle, right axis) of the monthly mean of ozone maximum daily 8-hour average (MDA8) during dry season (April to November) in (a) central, (b) north, (c) south, (d) east, (e) west Jakarta, and (f) Bogor, respectively. Solid line: linear fitted curve.

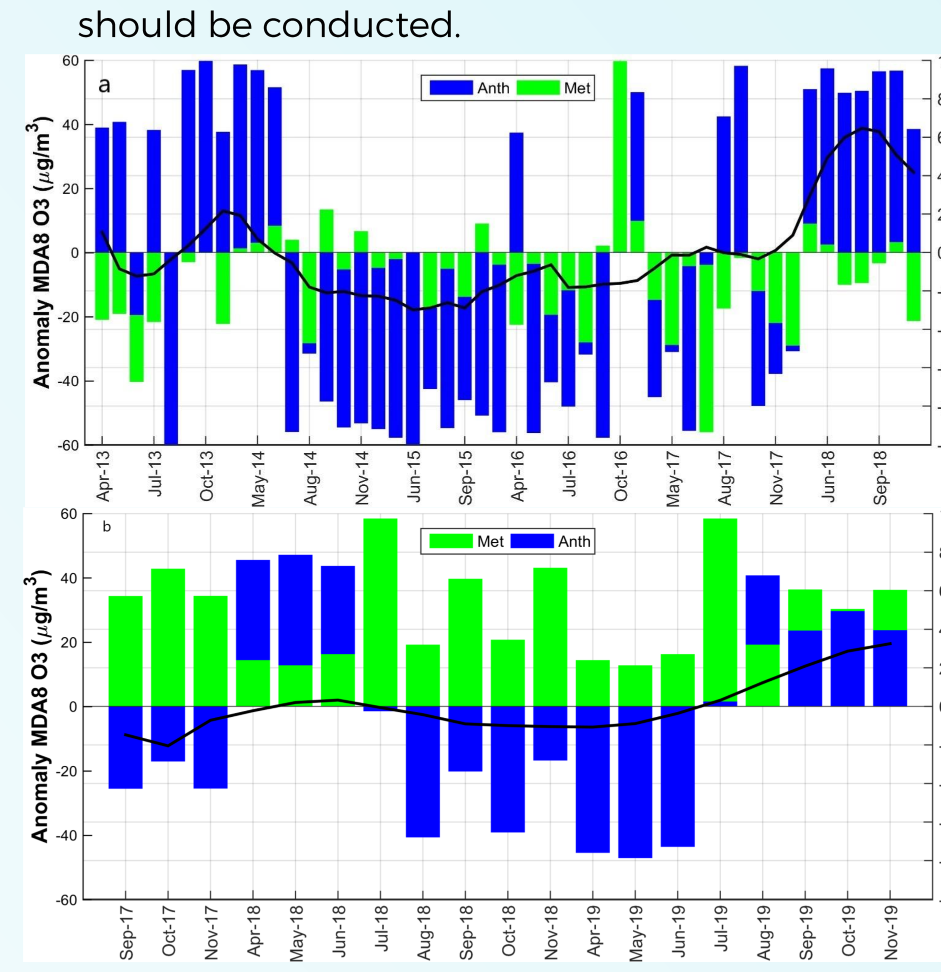

Figure 4. Contribution of meteorology to O3 variation at Jakarta sites (a), and Bogor site (b) during dry period

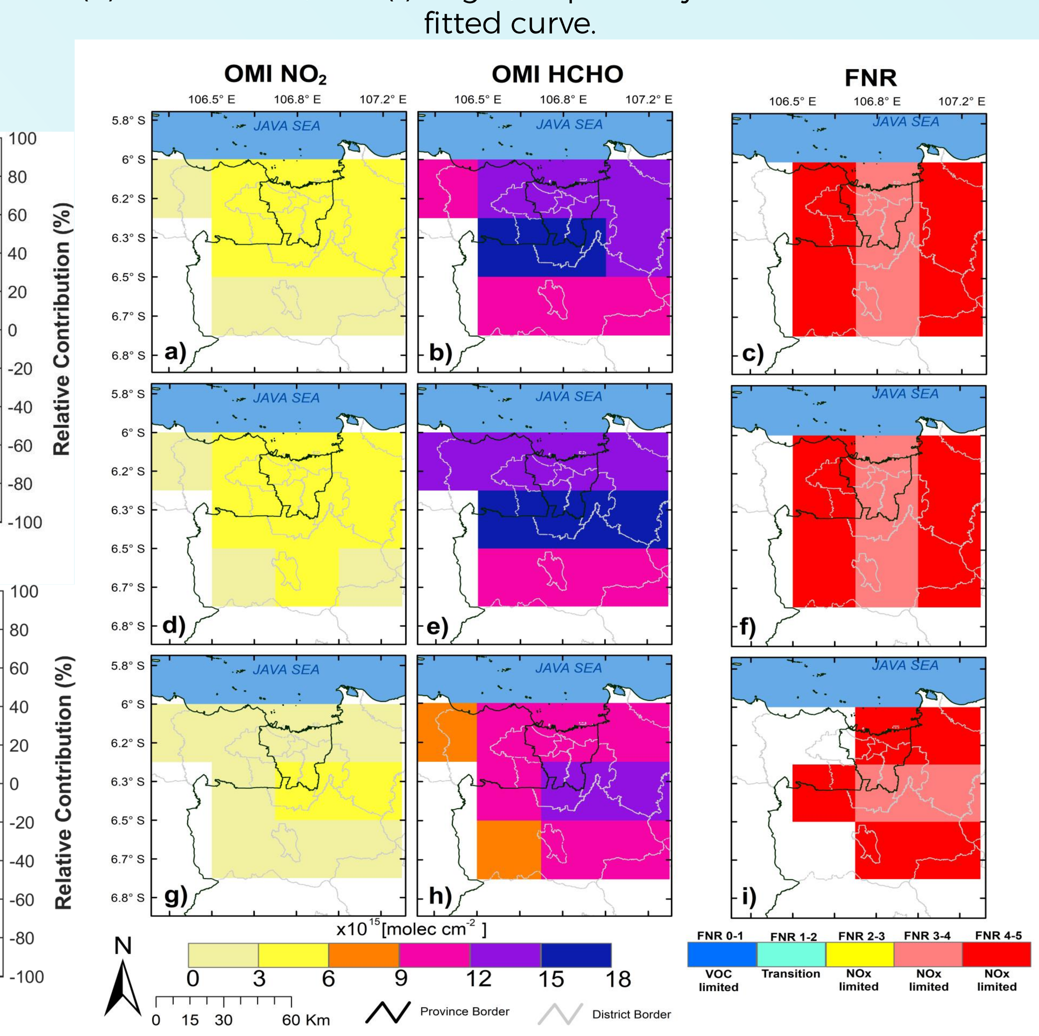

Figure 5. Map of the average of (a) OMI NO2 tropospheric column, (b) OMI HCHO vertical column, and (c) Ozone sensitivity regime classification from 2009-2019 for all seasons; (d), (e), and (f) for dry seasons; and (g), (h), and (i) for wet season.

Conclusion

1. Five Jakarta sites have high 1-h O3 concentration and exceeded NAAQS threshold (> 150 μg m-3) with highest percentage in the downwind areas in west (39 %) and south (34 %) Jakarta. Meanwhile, only 0.1 % have exceeded the standard at Bogor site. A remarkable upward trend was in the west Jakarta with annual increase of 10.2 μg m-3 year-1 followed by north and south Jakarta which were 4.8 μg m-3 year-1, and 1.3 μg m-3 year-1, respectively. Meanwhile, Bogor also increased by about 3.6 μg m-3 year-1 indicating enhanced precursors for O3 production.
2. Meteorology contributed 22 % and anthropogenic 77 % to the internannual O3 changes in Jakarta. UVB, WS_mean, T_max, and RH contributed significantly. Meanwhile, meteorological and anthropogenic components contributed 49 % and 51 % at Bogor site, respectively. UVB, BLH, T_max, and SP provided significant contribution.
3. Ten-year average of FNR from 2010 to 2019 shows lower value for Jakarta (FNR= 3.73) compared to Bogor (FNR= 4.37) and demonstrates upward tendency toward NOx-limited regime. Further research using modelling and observation could be conducted to justify our FNR findings and derive suitable thresholds for Jakarta.

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