Main Sources of Air Pollution in DKI Jakarta

Technical Brief

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Overview

Air pollution caused 4.9 million premature deaths globally in 2017, with ambient fine particulate matter ($PM_{2.5}$) pollution accounting for 3 millions of those deaths.[1] $PM_{2.5}$ formation varies considerably across different emission sources, geographical region and seasons, making it a challenging pollutant to characterize and regulate for adequate public health protection.

An effective air quality management starts with knowing the leading sources of pollution in the city. Information on what share of air pollution problem is attributable to different sources (e.g., traffic) allows effective clean air actions to be prioritized.[2] Generally, this involves identifying leading sources of air pollution using two complementary approaches: 1) the source-based (or bottom-up) approach that uses emission inventory of sources and meteorological data to simulate source contributions to ambient pollution concentration; and 2) the receptor-based (or top-down) approach that collects ambient air filter samples at air quality monitoring sites (i.e., receptor), analyzes the chemical composition in the samples, and matches the chemical profiles with those of emissions from different fuel types.[2] This approach is complementary to and can be used to identify potential discrepancies with findings from the source-based approach.

Despite the fact the annual average $PM_{2.5}$ concentrations in Jakarta are routinely four to five times the World Health Organization (WHO) health-based Air Quality Guidelines (10 µg/m^3 for annual $PM_{2.5}$ average)[3], reliable and recent information on leading sources of air pollution is scarce. Over the past decades, three ad-hoc air pollution emission inventories for Jakarta were compiled[4–6]; only two included an inventory for $PM_{2.5}$.[5,6] Similarly, results of the only receptor-based source apportionment study for Jakarta, published in 2008, are quite dated now, and likely biased, as the study estimated the contributing $PM_{2.5}$ sources near a roadside monitor in the city.[7] To address this major evidence gap, Vital Strategies worked with the Bandung Institute of Technology (*Institut Teknologi Bandung* or ITB) to expand an ongoing receptor-based source apportionment study in progress to better assess the contributing sources of ambient $PM_{2.5}$ level in two seasons at three urban locations around Jakarta.

References

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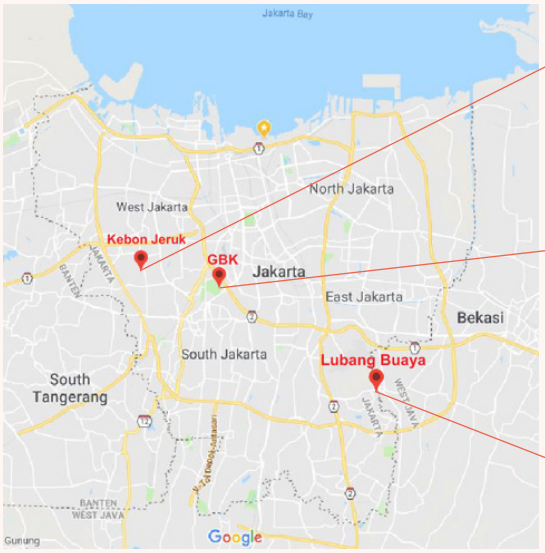
Approach

In order to understand the $PM_{2.5}$ chemical content (composition) and subsequently its leading sources across Jakarta, ITB collected 24-hour filter samples of $PM_{2.5}$ at three urban background sampling sites that were interspersed in different districts of Jakarta: Gelora Bung Karno (GBK), Kebon Jeruk and Lubang Buaya (Figure 1). These sites were selected based on land use, topography, weather (e.g. wind pattern) and other considerations to capture potential variation in air pollution sources, and were co-located with government-owned air quality monitoring stations at the provincial and national level (Figure 1). Monitoring at two of the three sites (i.e., Kebun Jeruk and Lubang Buaya sites) were an expansion of activities set up by ITB previously under the Toyota Clean Air Program (TCAP) project.

Figure 1



West residential site (1 km away from intercity road to Banten, co-located with provincial environmental agency monitor – DKI-5)

Wet: 12 samples; **Dry:** 10 samples

Central mixed site (located in an open field besides a stadium and next to major road, and co-located with national Ministry of Environment and Forestry monitor)

Wet: 32* samples; **Dry:** 9 samples
* Samples collected with financial support from TCAP.

East mixed site (located in a park next to small road, co-located with provincial environmental agency monitor – DKI-4)

Wet: 9 samples; **Dry:** 16† samples
† Additional samples were collected due to sample contamination

There were two sampling periods: one wet season (October 2018 to March 2019) and one dry season (July to September 2019). Sampling was generally conducted on a daily basis for on average 10 days, on both weekdays and weekends in order to capture all emission source patterns throughout the week (e.g., less traffic on the weekend), with the exception of rainy days when no sampling was conducted.

On each sampling day, two Air Mini Volume samplers equipped with a 47mm Teflon filter and a 47 mm Quartz filter, respectively, were used simultaneously to collect $PM_{2.5}$ samples. Meteorological parameters such as temperature, humidity, wind speed and wind direction were also measured simultaneously using anemometer, barometer, compass and sling psychrometer, respectively. Sample collection at the three sampling sites was staggered due to limited equipment availability.

Chemical species characterization

All $PM_{2.5}$ samples collected were stored in the refrigerator before chemical composition analysis. The mass concentration of $PM_{2.5}$ was measured by the reference gravimetric method, that is, by weighing filters before and after sampling.

To enable leading sources of pollution to be identified, filter samples were sent to local and international laboratories, where specific chemical components were detected. Specifically, black carbon (BC), 11 metal elements, and five ions were speciated from Teflon filters; whereas organic carbon (OC) and elemental carbon (EC) were speciated from Quartz filters. The 11 metal elements identified were sodium (Na), aluminum (Al), silicon (Si), sulfur (S), chlorine (Cl), potassium (K), calcium (Ca), titanium (Ti), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn) and lead (Pb). Five ions identified were sodium ion (Na^+), chloride ion (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), and ammonium ion (NH_4^+). Five ions speciated were sodium ion (Na^+), chloride ion (Cl^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), and ammonium ion (NH_4^+). Different instruments were used to determine the concentrations of $PM_{2.5}$ chemical composition (Table 1); these results will be reported elsewhere.

Table 1. Sample Analytic Instruments

Parameter	Instrument
$PM_{2.5}$	Gravimetric
BC	EEL Smoke Stain Reflectometer Model 43D
Metal element	XRF
Ions	Ion chromatography
EC, OC	Thermal-optical transmittance

Source apportionment analysis

A statistical method that takes information on key chemical components and source profiles was then used to scientifically estimate the relative contribution of leading emission sources to ambient $PM_{2.5}$ mass. In this study, the U.S. Environmental Protection Agency's Chemical Mass Balance (CMB), version 8.2 (https://www3.epa.gov/scram001/receptor_cmb.htm), was applied. At least 11 known source profiles (unique chemical signature) were used as input data, along with measurements of $PM_{2.5}$ chemical composition. Details on CMB modeling have been described previously.[8] All filter measurements from the same sampling site were combined and analyzed in one CMB model, resulting in three models developed for the three sites.

References

8. U.S. EPA (Environmental Protection Agency). *Chemical Mass Balance User Manual*.; 2004. https://www3.epa.gov/ttn/scram/models/receptor/EPA-CMB82Manual.pdf.

Six to nine factors were evaluated using goodness-of-fit parameters (i.e., chi-square value and reconstructed mass) to assess how well the model fits the input composition data, and optimum number of sources, which can be estimated with scientific certainty, was subsequently determined.

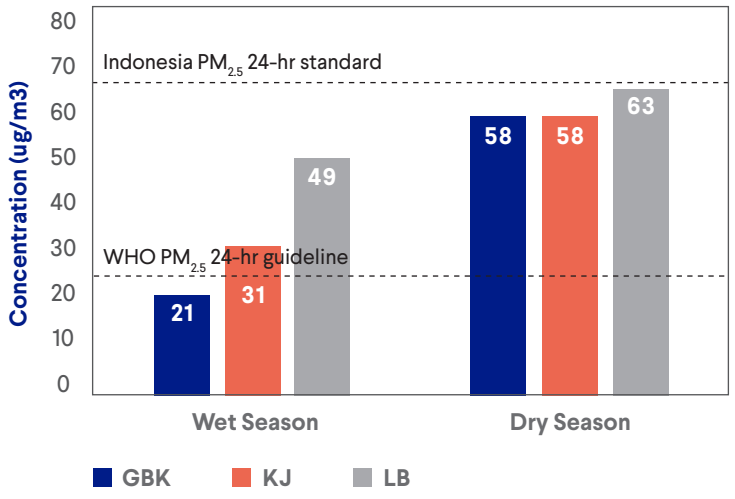
Results

Findings will inform policymakers on the leading sources of air pollution in the city, and also identify potential consistencies and discrepancies with findings from earlier emission inventory results.

Air Pollution Levels in Jakarta

The average daily $PM_{2.5}$ concentrations over the entire sampling period range from 39 µg/m³ in central Jakarta (GBK) to 56 µg/m³ in west of Jakarta (Lubang Buaya); all of which exceeded the WHO's Air Quality Guideline of 25 µg/m³ for 24-hour $PM_{2.5}$ average, though the Indonesian National Ambient Air Quality Standard based on Government Regulation Number 41. year 1999 is 65 µg/m³ (24-hour average). In general, daily $PM_{2.5}$ levels were higher in the dry season than the wet season, but the variability in pollution levels across the city was greater in the wet season than the dry season (Figure 2), possibly due to more influence of transported $PM_{2.5}$ during the dry season. The prevailing wind for the wet season came from West and Southwest of Jakarta, whereas that for the dry season was from East and Northeast of Jakarta.

Figure 2. Average daily $PM_{2.5}$ concentrations in Jakarta



Of the $PM_{2.5}$ chemical components speciated, OC generally accounted for nearly 40% of $PM_{2.5}$ mass across the city, except for central Jakarta where OC only took up 25% (Table 2). EC was another major component of $PM_{2.5}$ (7% to 13%). In central Jakarta (GBK), assorted ions, comprising of Cl^-, NO_3^-, SO_4^{2-} and others, took up the largest percentage (30%) of $PM_{2.5}$ mass, and assorted metals, comprising of S, Pb, Zn and other, also accounted for 21% of $PM_{2.5}$.

Table 2 Average daily $PM_{2.5}$ mass concentration and its chemical composition by sampling sites.

	GBK	Kebon Jeruk	Lubang Buaya
$PM_{2.5}$ mass	39 µg/m³	41 µg/m³	56 µg/m³
OC	25%	38%	37%
EC	7%	13%	8%
BC*	9%*	9%*	8%*
Ions	30%	17%	11%
Cl^-	7%	2%	1%
NO_3^-	7%	5%	4%
SO_4^{2-}	7%	4%	3%
Others^	10%	6%	3%
Metals	21%	18%	15%
S	9%	6%	6%
Pb	2%	4%	1%
Zn	2%	2%	1%
Others#	8%	6%	7%

*Since BC and EC were used interchangeably, BC was not counted towards total $PM_{2.5}$ mass in the presence of EC.

^ Other ions include Na^+ and NH_4^+.

Other metals include Al, As, Br, Ca, Cl, Co, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Si, Ti.

The sum of $PM_{2.5}$ chemical composition concentration was about 68% to 91% of the measured concentration of $PM_{2.5}$ mass, depending on the sampling sites and seasons (data not shown). In general, the higher the percentage, the better the source apportionment results at depicting the actual emission sources.

Main Sources of Air Pollution in Jakarta

Overall, six to seven factors were identified from each sampling site, with known source profiles obtained from literature or references (Table 3). The leading primary sources of ambient $PM_{2.5}$ pollution in Jakarta were vehicle exhaust (32%–57%), non-vehicular emissions (17%–46% including those with natural origins such as sea salt), and secondary formation of particles (1%–16%; secondary aerosols) (Figure 3).

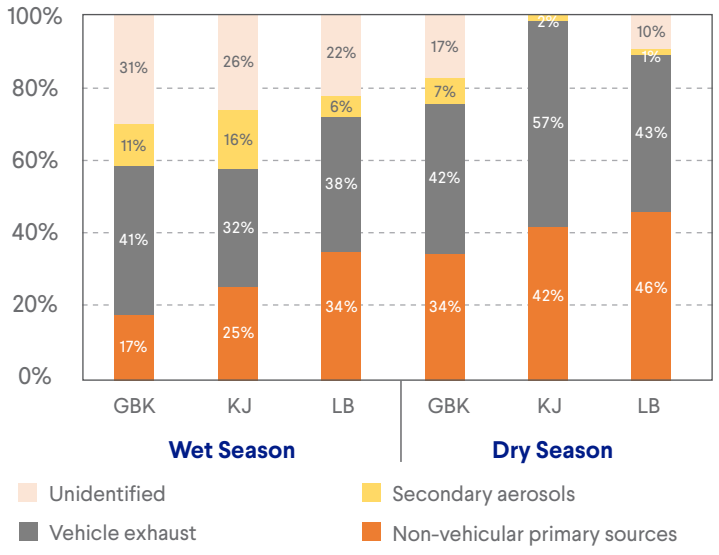
Table 3 $PM_{2.5}$ chemical "trace" components associated with each emission source.

Source	Trace components
Vehicle exhaust	
Gasoline vehicles	OC, Zn, Ni
Diesel vehicles	OC, EC, Zn
Paved road dust	Fe
Construction activities	S, Al, Si, EC
Soil	Al, Si, Ti
Opening burning	OC
Secondary aerosol[i]	NO_3^-, SO_4^{2-}
Coal combustion	Al, Ca, Mn, Cu
Sea salt[ii]	Na, Cl, Na^+
Diesel generator	Fe, Ni, Cu
Residential LPG	EC, NO_3^-

i Secondary inorganic aerosols (e.g., ammonium nitrate or sulfate) are formed when precursor gaseous pollutants (e.g., sulfur oxides and nitrogen oxides) undergo chemical reactions within the atmosphere. On the other hand, primary pollutants occur as a result of direct emissions from an air pollution source.

ii Sea salts, a natural marine emission, are formed due to wind action at the ocean surface.

Figure 3. Source contribution (in %) to ambient $PM_{2.5}$ concentrations in Jakarta



Figures 4 and 5 show the percentage contribution of vehicular and non-vehicular sources in Jakarta. For vehicle exhaust, gasoline vehicles accounted for more than half of the vehicular emissions across the city with the exception of Lubang Buaya site during the dry season (Figure 4). However, it is unclear how much of these came from on-road vehicles and how much from off-road emissions (e.g., construction equipment). For non-vehicular primary sources, coal combustion, (non-combustion) activities and open burning were the leading anthropogenic pollution sources, whereas resuspended soil and sea salt were the major natural sources identified.

Figure 4. Vehicular emission contribution (%) to ambient $PM_{2.5}$ concentrations in Jakarta

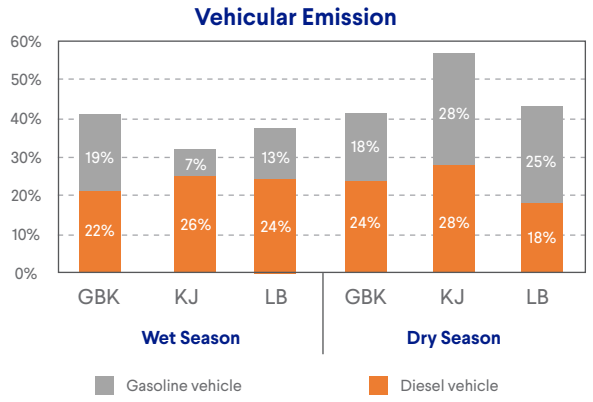
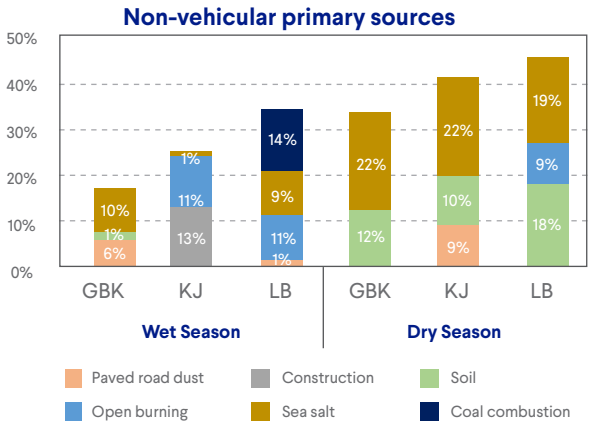


Figure 5. Non-vehicular primary source contribution (%) to ambient $PM_{2.5}$ concentrations in Jakarta



The contribution of leading sources to ambient $PM_{2.5}$ concentration varied across seasons and by location, which may be explained by variation in local activities, or regional sources of pollution, depending on weather conditions (e.g., upwind emission from adjacent cities).

During the wet season, exhaust from gasoline and diesel vehicles was a leading source of air pollution, contributing to 32% to 41% of ambient particulate level across the city. In central Jakarta (GBK), secondary aerosols, sea salt and paved road dust accounted for 11%, 10% and 6%, respectively. In west (Kebon Jeruk) and east Jakarta (Lubang Buaya), open burning of biomass or other fuels was another major source of ambient $PM_{2.5}$ levels (11%), following by secondary aerosols and sea salt. Construction activities also contributed 13% of $PM_{2.5}$ level in Kebon Jeruk[iii]; whereas coal combustion (14%) was observed to be the second leading source in Lubang Buaya after vehicle exhaust. Secondary aerosols accounted for 6–16% of ambient $PM_{2.5}$ level, and source of 22% to 31% of $PM_{2.5}$ mass remained unidentifiable in the wet season.

iii A sensitivity analysis using Positive Matrix Factorization (PMF) model on the 32 samples collected at Kebon Jeruk site during the wet season (under the TCAP project) found that contributions from vehicle exhaust, sea salt, open burning, construction activities, and secondary aerosol were generally in agreement with those from the CMB model. In addition, PMF also identified coal combustion mixed with aged sea salt as anofther contributing source.

Unlike the wet season, pollution sources in the dry season were fairly uniform across the city, with vehicle exhaust, sea salt, resuspended soil being the leading sources. Contribution from exhaust from gasoline and diesel vehicles across the city was higher in the dry season (42%–57%) than in the wet season (Figure 4). Sea salt was another major source of ambient $PM_{2.5}$ level, contributing 19% to 22%, followed by resuspended soil particles (10%–18%). In west Jakarta (Kebon Jeruk), paved road dust (9%) was also found to contribute to $PM_{2.5}$ level. Open burning (9%) remains a major source of polluted air in east Jakarta (Lubang Buaya). Secondary aerosols accounted for 1–7% of ambient $PM_{2.5}$ level. Overall, there was <1% to 17% of $PM_{2.5}$ mass with unidentified origins in the dry season.

Discussion

This is the first study to examine contributing sources to ambient $PM_{2.5}$ level in multiple locations with different land use mix across Jakarta. We found vehicle exhaust, coal combustion, open burning, construction, road dust, resuspended soil particles and sea salt to be significant sources of ambient particulate pollution in Jakarta.

This study cannot pinpoint the exact place of emission of these pollution sources, nor can it determine the relative contributions from local and regional sources. Knowledge on the emission activities and locations of point- and area-sources around the sampling sites and neighborhood area (e.g., Greater Jakarta) may shed light on the potential emission sources. For instance, open burning identified during wet season at Kebon Jeruk site may be indicative of biomass burning in a large area of paddy fields to the west of the sampling site. Secondary aerosols (e.g., ammonium sulfate and ammonium nitrate) represent mainly long-range, transboundary contribution to ambient $PM_{2.5}$ pollution, and can be controlled by addressing regional emissions of their precursor gaseous pollutants (i.e., sulfur oxides and nitrogen oxides). Similarly, the identification of coal combustion and secondary aerosols may be indicative of emission from coal-fired power plant (CFPP), given that 80% of coal consumption in Indonesia is for electricity generation, and coal-burning is the main emission source of sulfur oxides.[9] Although there is no CFPP located within Jakarta's city boundary, there are clusters of CFPP units east (~20km) and west (~55km) of Jakarta. Given that Indonesia plans to construct more CFPPs within 100km of Jakarta, their contribution to ambient $PM_{2.5}$ pollution in Jakarta will increase over time. Another possible origin of coal combustion may be textile factories that may consume coal, though the amount of coal consumed remains unknown.

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This receptor-based source apportionment study suggests that there are many leading sources of ambient $PM_{2.5}$ pollution in and around Jakarta, and that comprehensive air pollution control measures are needed to tackle these leading sources in order to improve air quality in the city. Results from this study should be interpreted with caution given the small sample size, and limited data on scarcity in known source profiles for CMB analysis. Future research might include source-based approach that encompasses emission inventory and modeling analysis for the Greater Jakarta Area, as well as receptor-based approach with more specific marker types (e.g. molecular markers that could more effectively identify sources like coal) and the use of larger datasets.

Acknowledgements

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For further details, including policy recommendations, visit www.vitalstrategies.org/source-apportionment-report.