

UNDERSTANDING THE SOURCES OF AIR POLLUTION AND THE INFLUENCE OF WEATHER AND CLIMATE ON INDONESIA'S AIR QUALITY



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BADAN RISET DAN INOVASI NASIONAL**



4 September 2026

National Awareness Workshop



Current and Future Perspective on Air Pollution Research

Atmospheric research is conducted for two major reasons

1. Earth Science Viewpoint:

Basic science approach to obtain fundamental physical and chemical understanding of the atmospheric system

- ✓ Begins because of the need to understand weather phenomena
- ✓ Focused on the whole atmosphere from troposphere to thermosphere
- ✓ Looking at quantitative and qualitative variations over space and geological time
- ✓ **Not focused on anthropogenic activities** per se

2. Air Pollution Viewpoint:

Applied science to understand the atmospheric system sufficiently well that it can be manipulated so as to change atmospheric concentrations over time.

- ✓ Begins by perception that there are problems breathing, seeing, and feeling poorly
- ✓ Focused primarily on the troposphere with an interest in stratospheric ozone and UV transmission
- ✓ Looking at quantitative and qualitative variations over space and recent time
- ✓ **Focused on anthropogenic activities**



ATMOSPHERIC SCIENCE

- The 1952 London Fog Episode encouraged the composition of the atmosphere to become a major focus of study
- Primary interest for atmospheric science was weather prediction, but difficult to do since mathematical models could not be built and tested and observations were scattered and of varying quality, frequency, and spatial resolution.
- The advent of extensive air travel required standardization and cooperation.
- Advent of computers (even primitive ones) meant models could begin to be built, and data could be more effectively analyzed.
- Satellite observations opened vast new perspectives on weather phenomena, particularly major and potentially catastrophic events (hurricanes, typhoons, cyclones, tornadoes, large-scale blizzards, etc.)
- Even with all of the current technology, forecasts are only around 60% correct on a global basis so there is a push for more understanding of the physics of the atmosphere.
- Climate change is another whole field of study that includes the atmosphere as the major driver, but relies on atmospheric science to provide additional inputs to the global climate models and to provide the measurements of critical radiation forcing species (GHG and particles).
- Our interests are in air pollution and related human and environmental health issues and thus, this will end the discussion of atmospheric science.

Air Pollution Research

Just as weather drove the start of atmospheric science, air pollution effects on health and quality of life drove the beginnings of air pollution studies.

Recognition of Air Pollution Disasters

- December 1930. Meuse Valley, Belgium. 63 deaths in an industrialized river valley
- October 1948. Donora, PA. 20 deaths, 6000 become sick in a 4.5-day inversion
- December 1952. London. The largest and most obvious of all modern air pollution events. But multiple episodes continued in 50s and 60s.
- November 1962. NYC, London, Europe



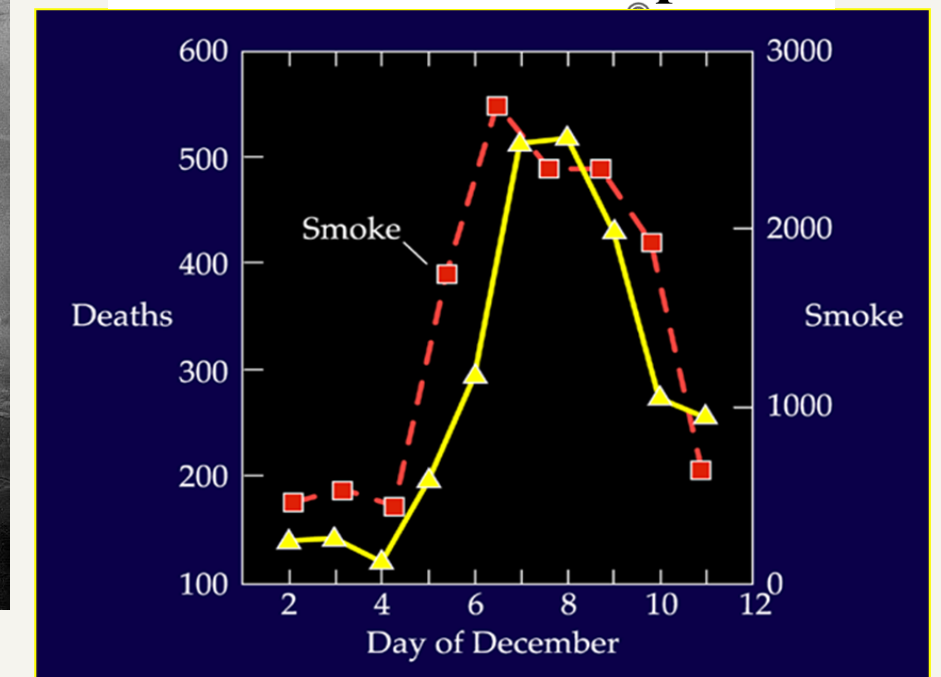
“Those who cannot remember the past are condemned to repeat it”

Claude Monet in London in the 1890s



Pittsburgh in 1930s

The 1952 London Episode



Many cases, still not recognizing that economic development without pollution control dooms many citizens to disease, death, and a poor quality of life.

Current Status in Indonesia

- Recognition of air quality and other environmental issues in Indonesia
- Signs of improvement in terms of better fuel quality and better-quality vehicles (getting to at least Euro 4 standards)
- Movement to reduce dependence on coal combustion for electricity
- The economic decision to move from exporting raw materials to exporting value-added products. However, the processing of the materials should be done cleanly
- People moving to higher degrees and deeper understanding

?

- Will the increased wealth in part support more research and researchers to explore the local aspects of specific pollution problems?
- How can Indonesia reach out into Southeast Asia, and collaborate to bring the region to a higher standard of living with related improved environmental quality?

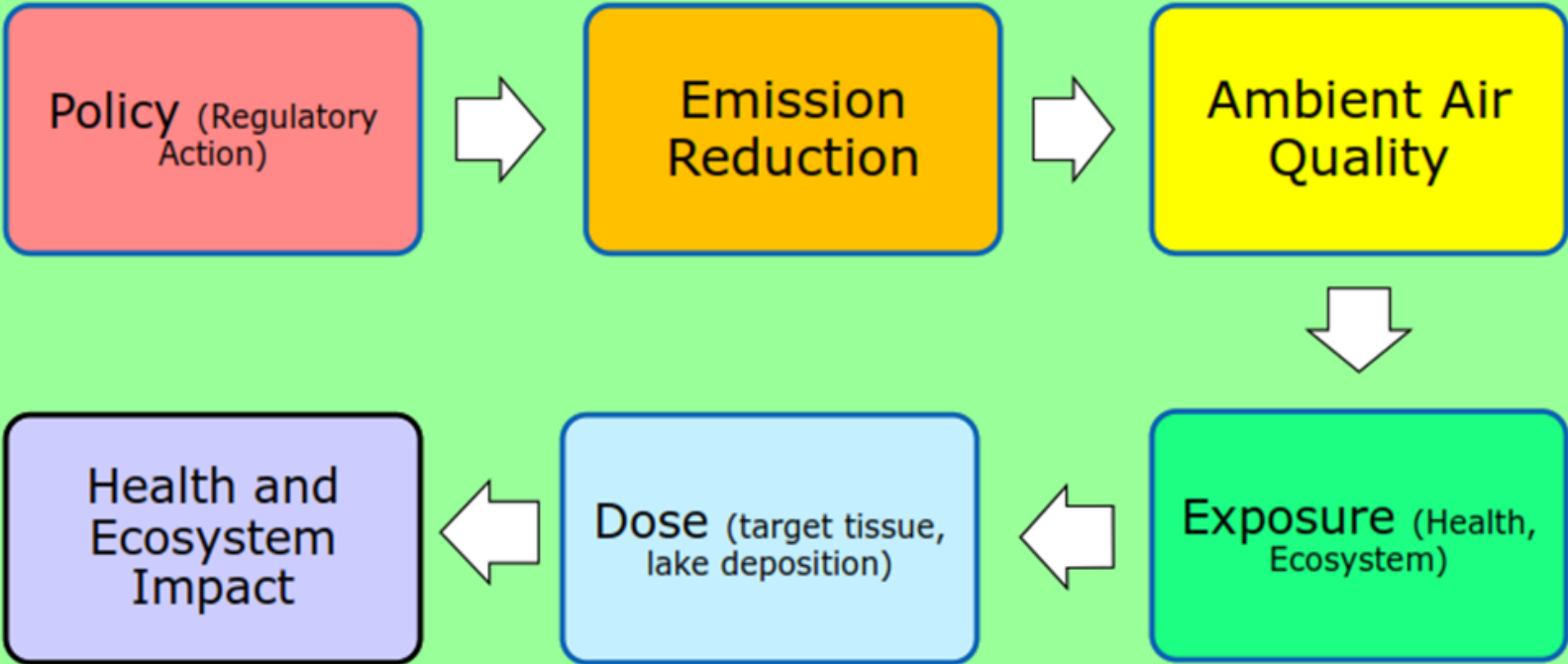
We need the global and local knowledge and the willingness to do what we can with what we have when we can to make things better



A Paradigm Shift in Air Quality Control Planning

PERATURAN MENTERI LINGKUNGAN HIDUP/
BADAN PENGENDALIAN LINGKUNGAN HIDUP
REPUBLIK INDONESIA
NOMOR 5 TAHUN 2026

Accountability must be measured at various stages to demonstrate pollution control effectiveness



NRC, 2004; Bell et al., 2010, *Environ. Sci. Technol.*

Transformation of Air Quality Management

Paradigma Lama: Daftar Kegiatan Administratif	Paradigma Baru: Clean Air Action Plan Berbasis Sains
✗ Persepsi asuntif atau sekadar rutinitas tahunan.	✓ Inventaris emisi spesifik & Source Apportionment.
✗ Diukur dari jumlah kegiatan atau output administratif.	✓ Diukur dari penurunan tonase emisi & konsentrasi polutan di udara.
✗ Kebijakan seragam dan dipukul rata di seluruh wilayah.	✓ Intervensi spesifik berdasarkan Kelas WPPMU & Rencana Tata Ruang.
✗ Daftar keinginan (<i>wishlist</i>) tanpa skala prioritas yang jelas.	✓ Diuji melalui pemodelan skenario & analisis efektivitas biaya.

The entire program is valid only if the targeted pollutants and the projected reductions can be specified.

SOURCE APPORTIONMENT



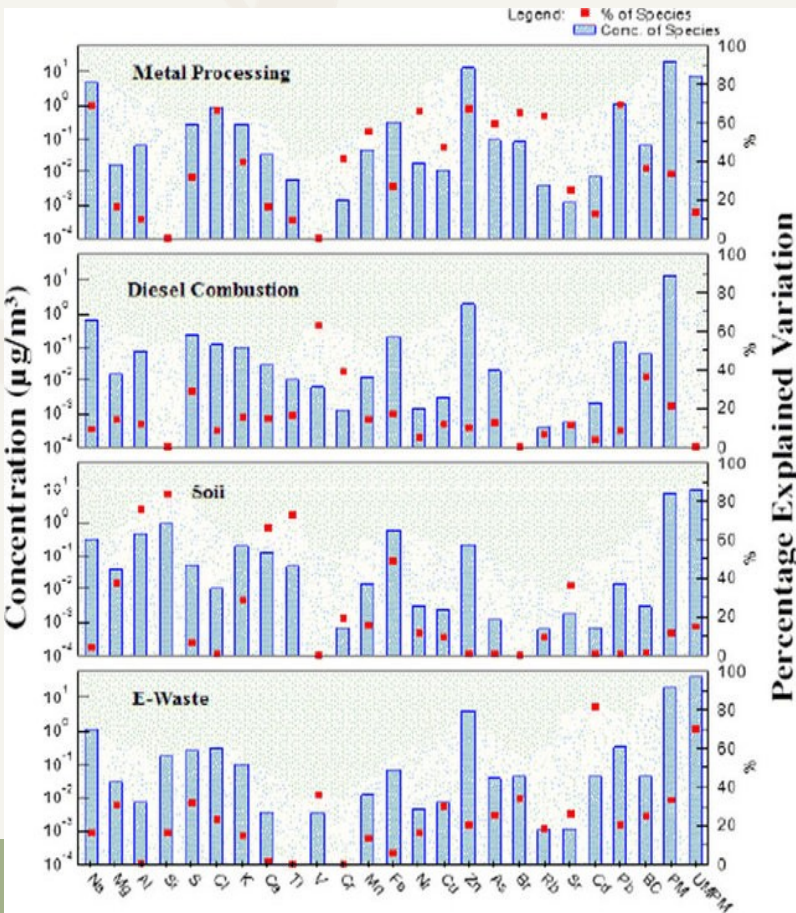
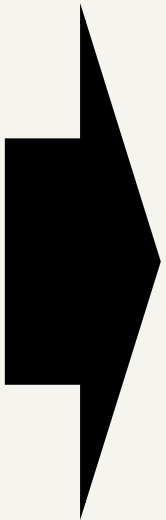
How do we reduce the pollution in the city?



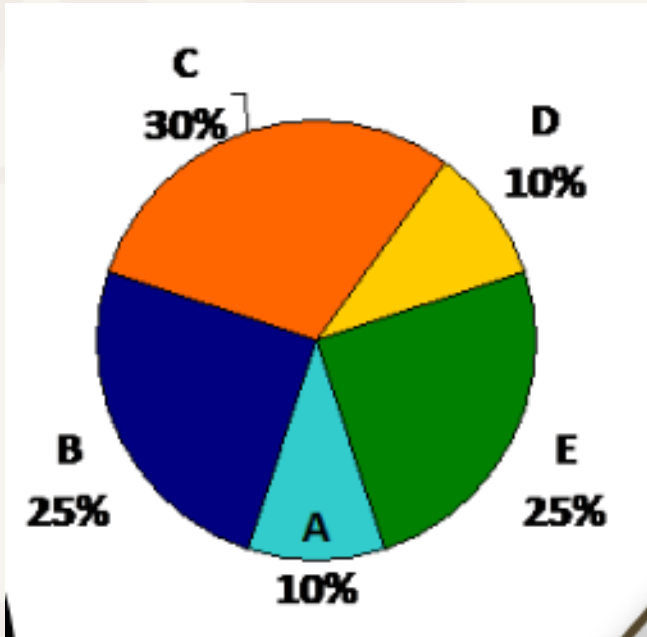
Conducting Source Apportionment, which will tell us

1 what the sources of pollution are

2 how much each source contributes to total pollution



Source Profile

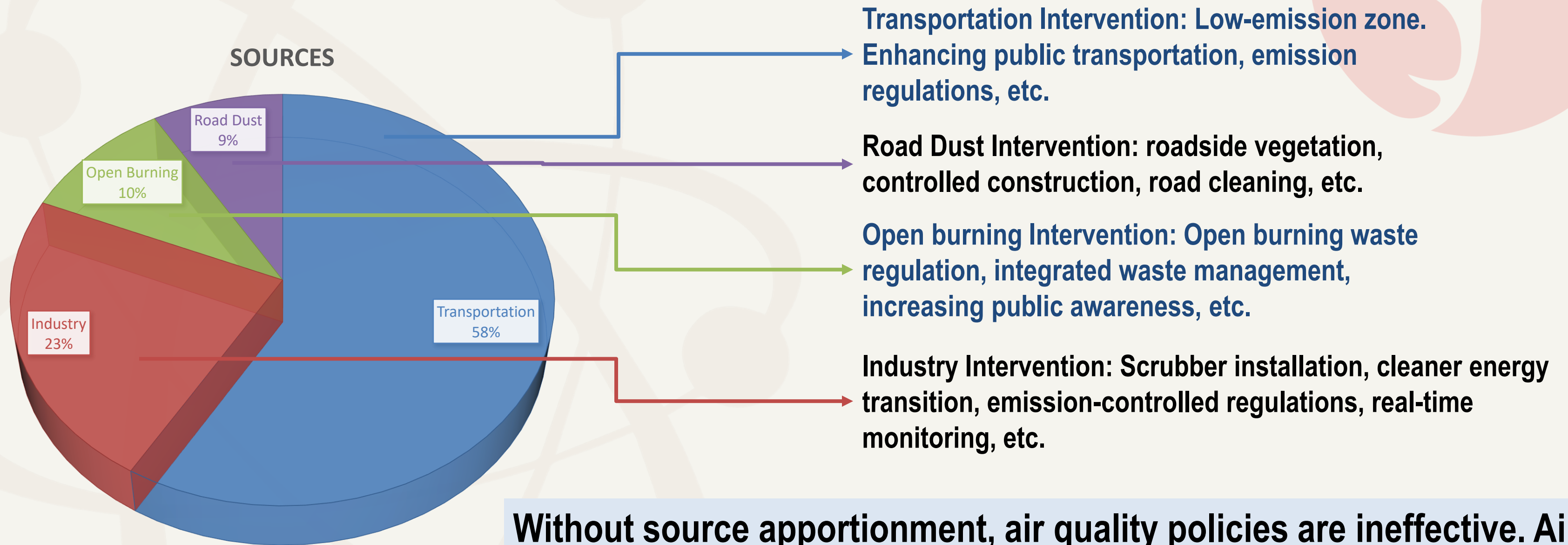


Source Contribution

The SA Results will scientifically determine these contributions. Eliminating the tendency to overemphasize certain sources or underemphasize or ignore others

WHY IS POLLUTION SOURCE IDENTIFICATION IMPORTANT?

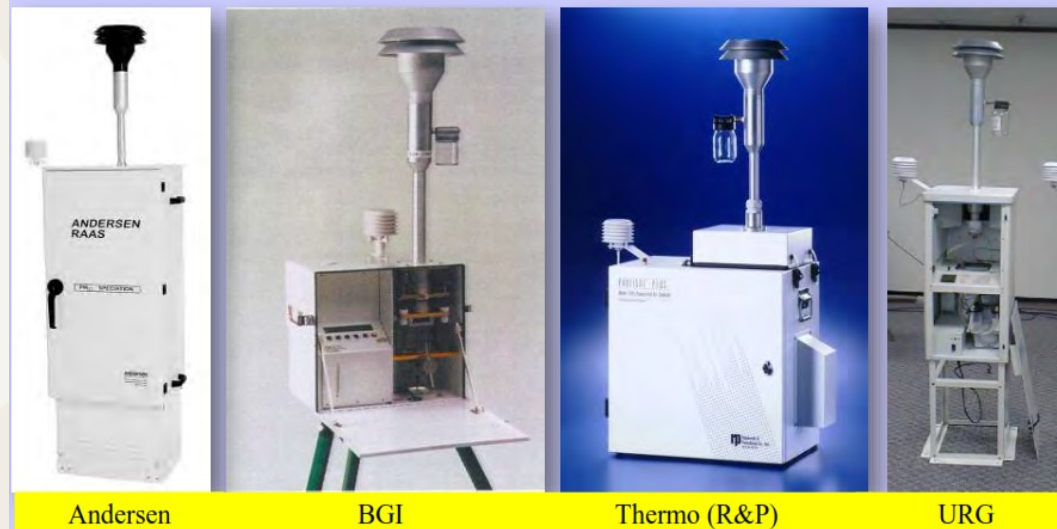
Source Apportionment → Targeting the root problem for designing effective management plan



Without source apportionment, air quality policies are ineffective. Air pollution control planning must explicitly link direct interventions to the dominant sources of pollution in the region

Air Sampling Methods

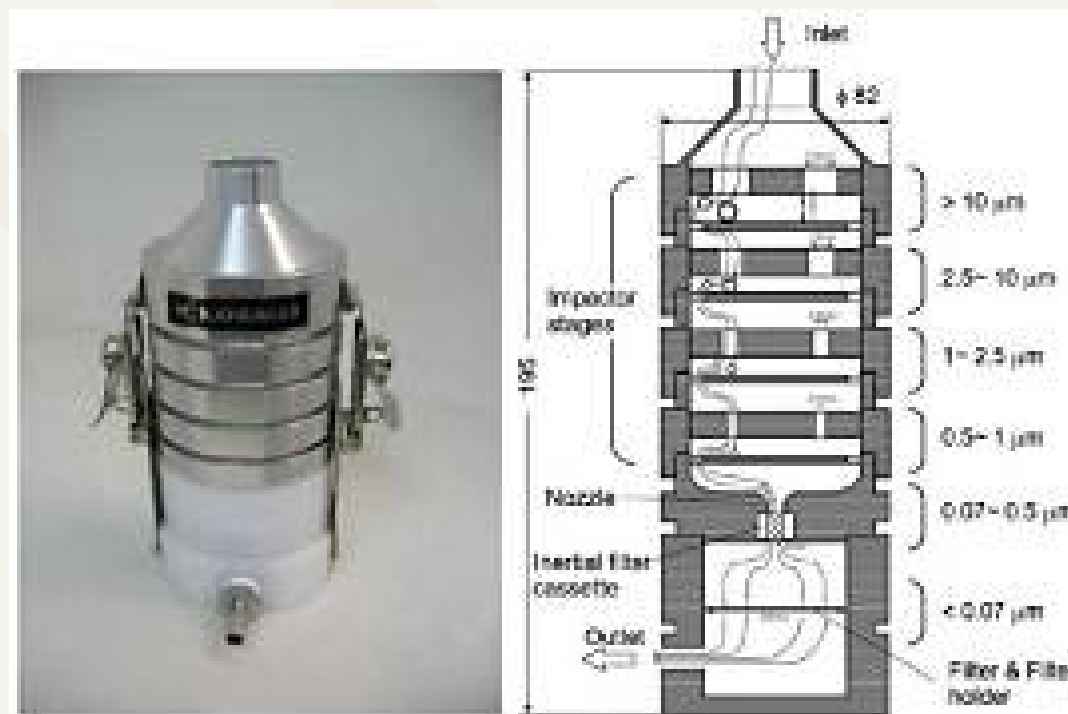
FRM* compliance data can be used to track long-term trends and evaluate effectiveness of control strategies



*Federal Reference Method (PM_{2.5}) **FRM Methods for PM_{2.5}**



SuperSASS® multi-filter



Ambient nano sampler, PM₁₀ to PM_{0.1}



Low-Cost Sensor (LCS)

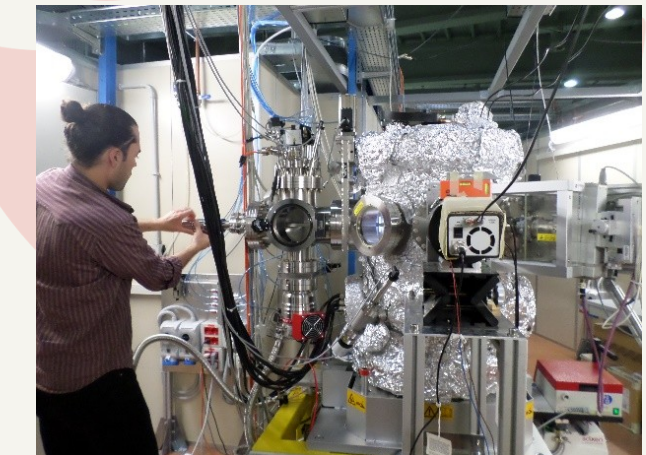
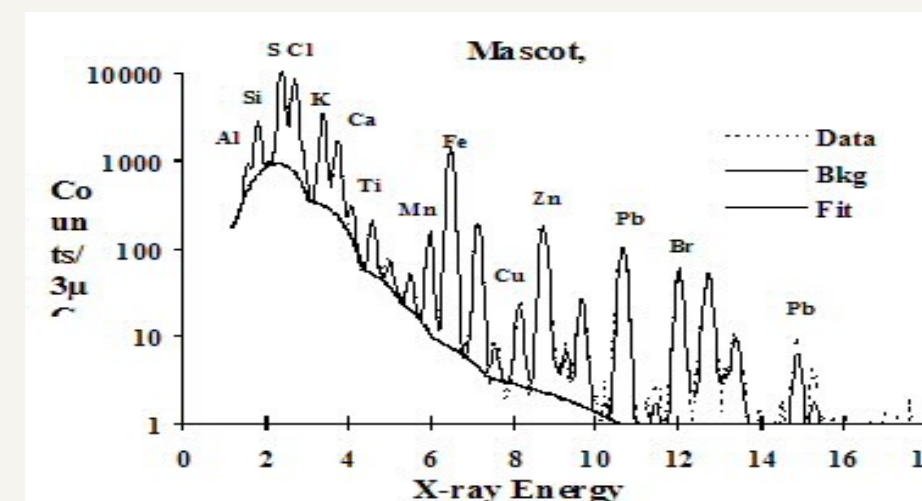
ADVANCED TECHNOLOGY FOR CHARACTERIZATION FOR APM

Advantages

- Simultaneous, multi-elements
- Nondestructive, selective, and sensitive
- Small/Light amount of sample
- Effective (time-consuming)



NAA and XRF



Synchrotron, Elettra - Italy

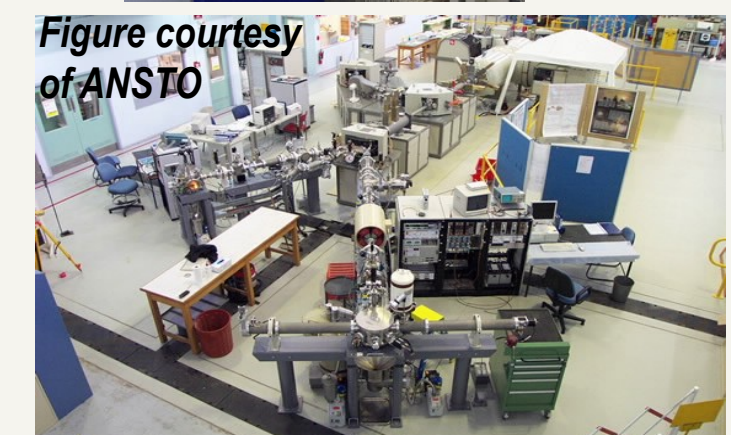
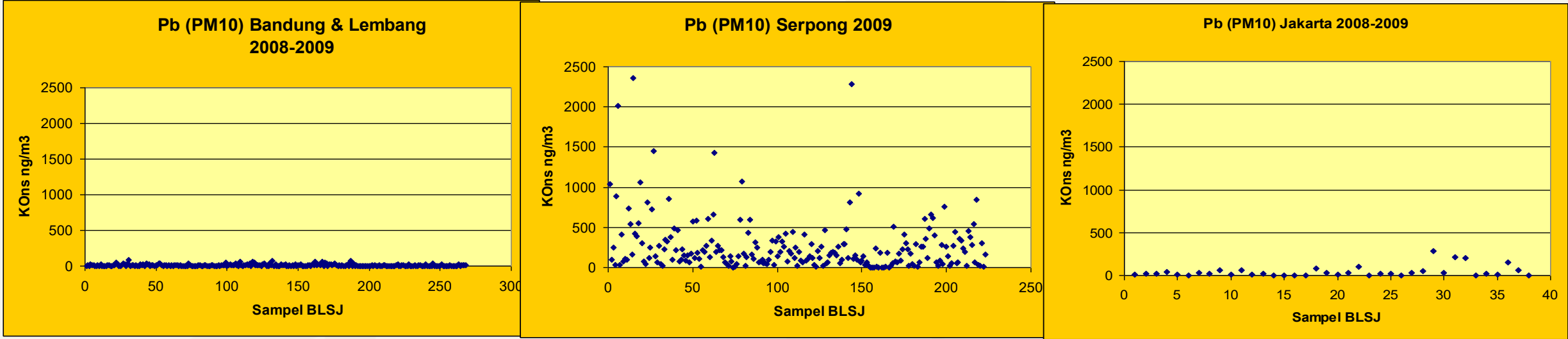


Figure courtesy of ANSTO

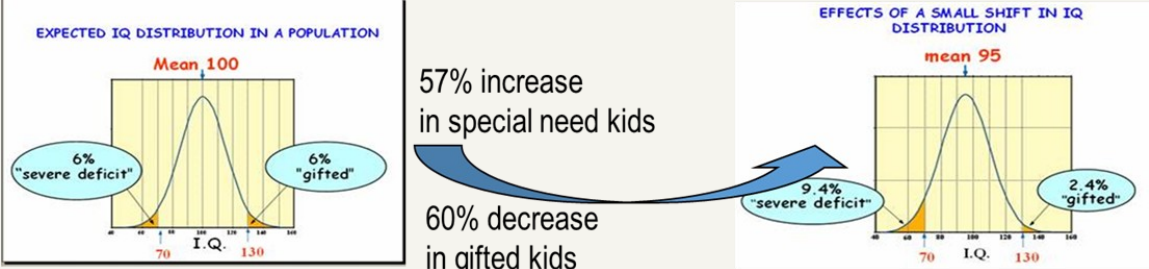
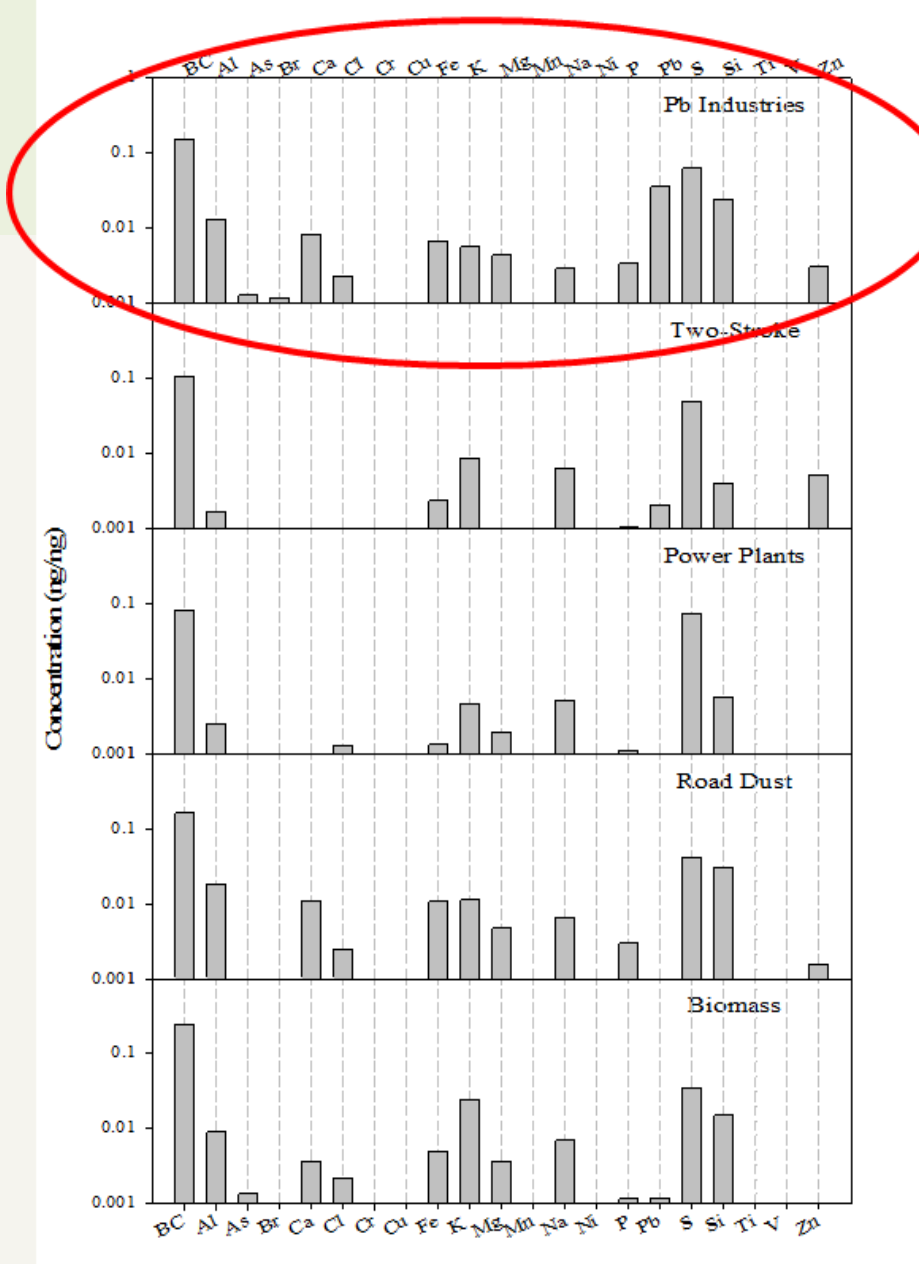
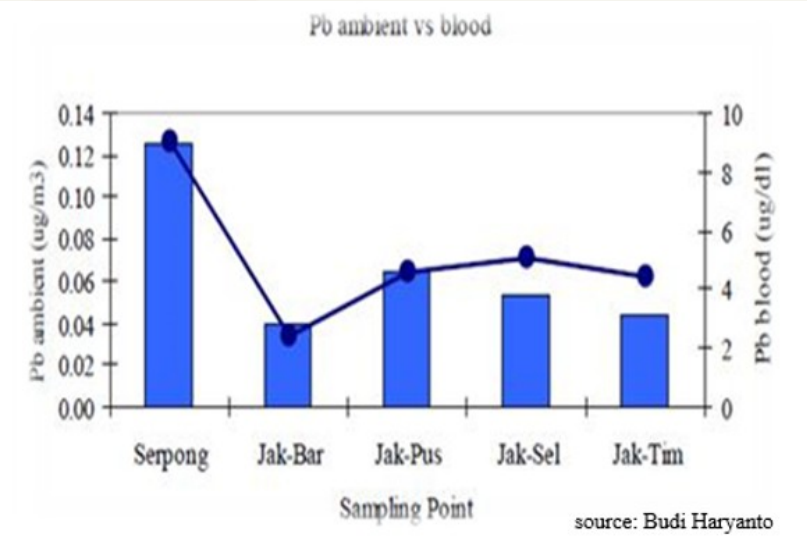
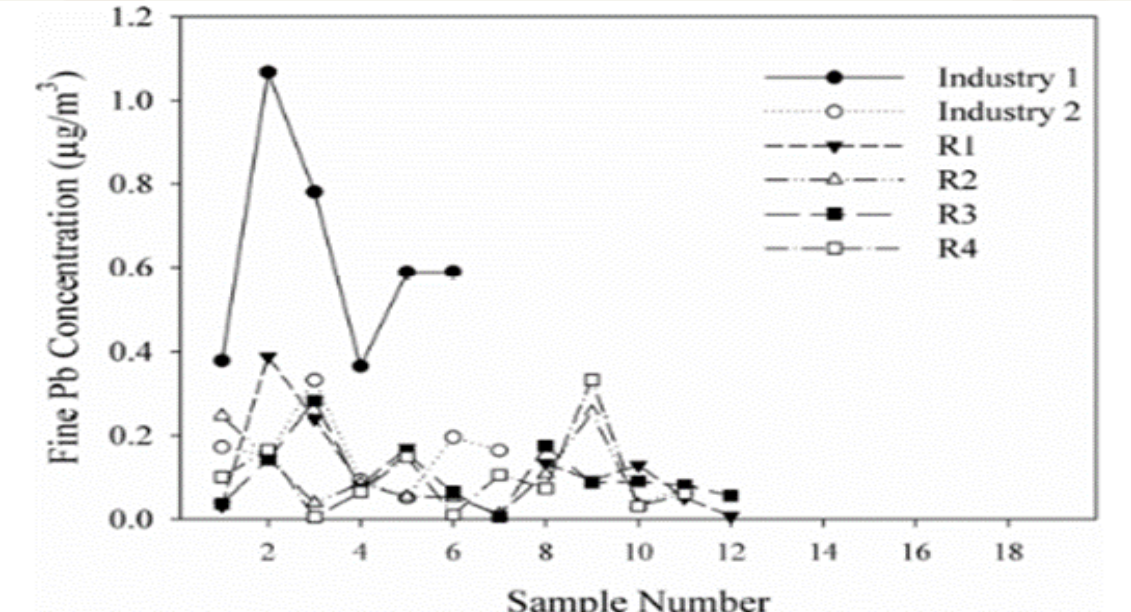
Ion Beam Analysis

SOURCE IDENTIFICATION OF HEAVY METAL IN PM_{2.5}

Case Study: Lead Pollution in Serpong, South Tangerang



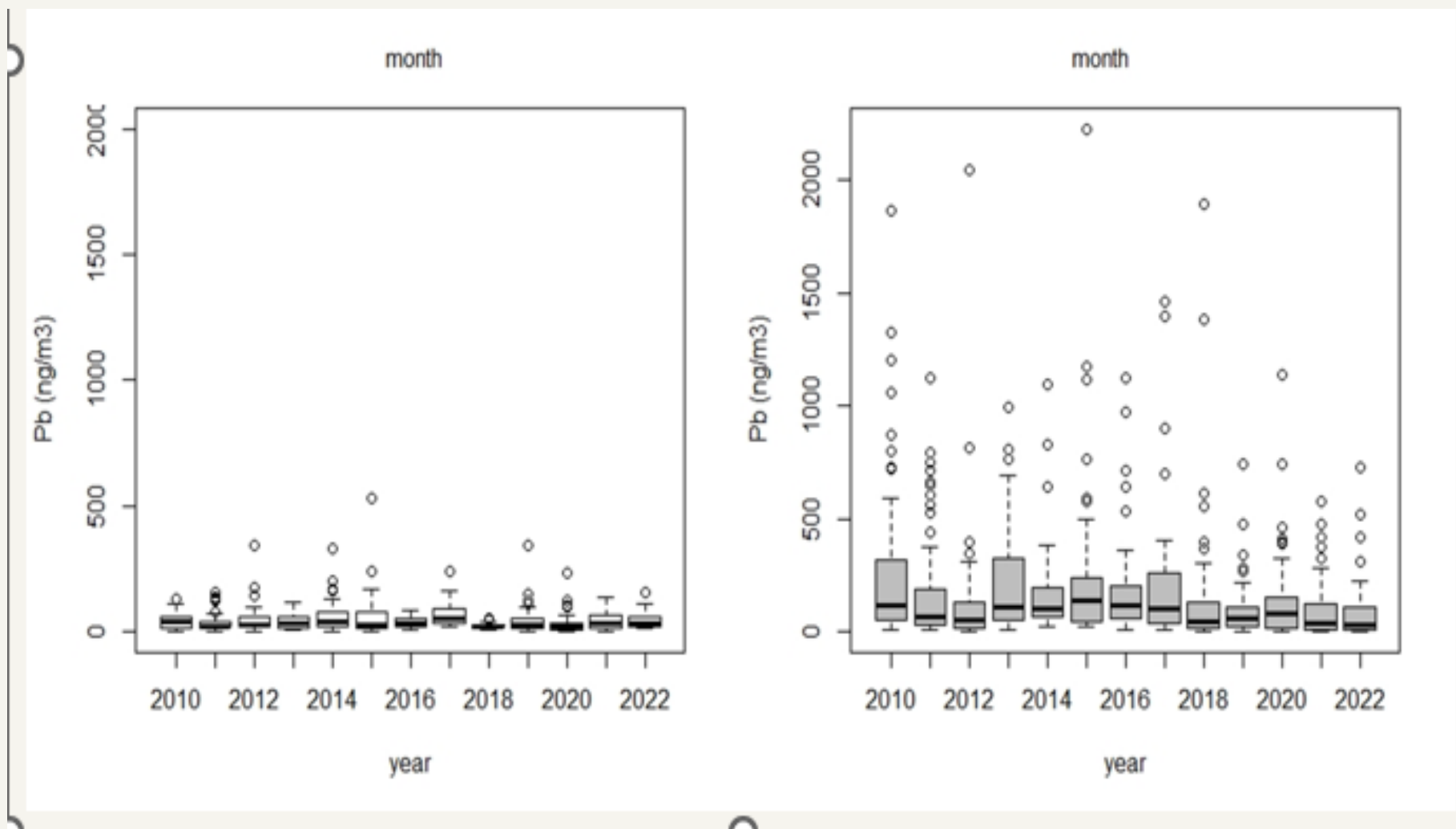
Comparison in pre study by BATAN Bandung – EMC MoE in 2008-2009, showed higher Pb concentration in Serpong was hundred times than in Bandung or Jakarta



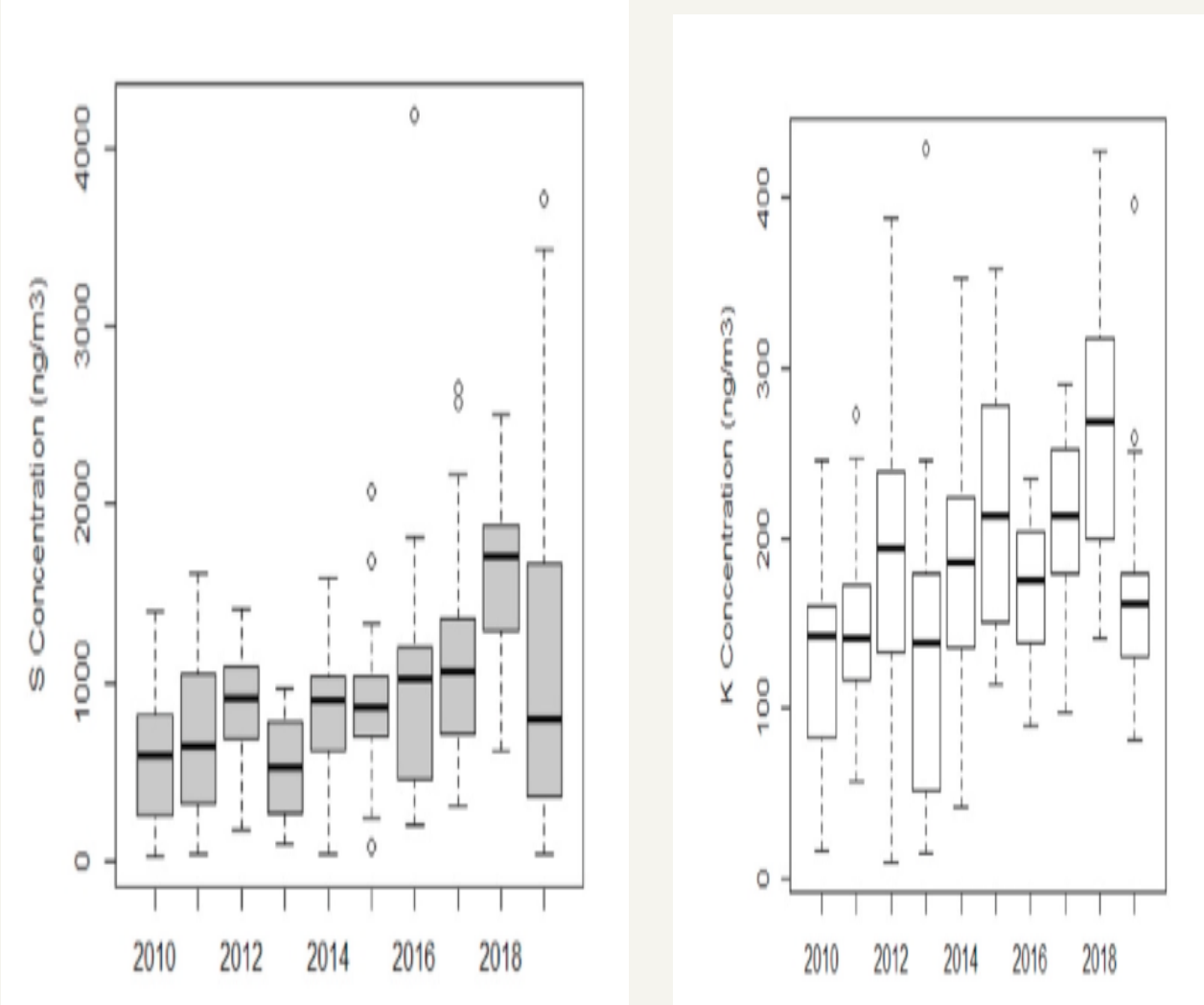
The high concentrations of lead were primarily associated with a lead battery recycling and lead bar production facility. Santoso, et al., APR 2 (2011)



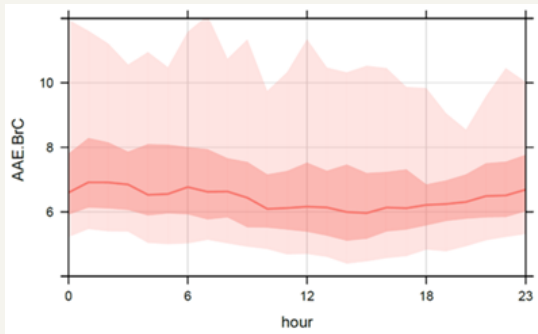
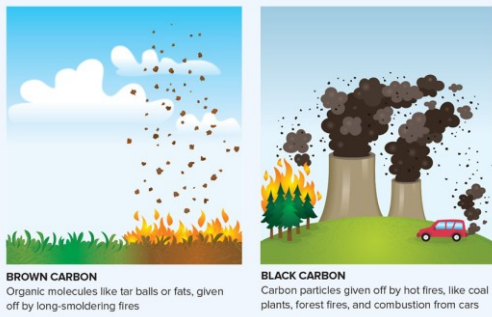
Long-Term Monitoring of APM in Jakarta



The concentrations of heavy metals in PM2.5 for Jakarta and Serpong are very different.

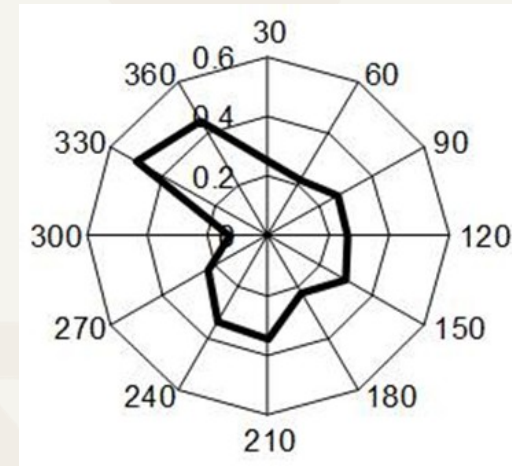
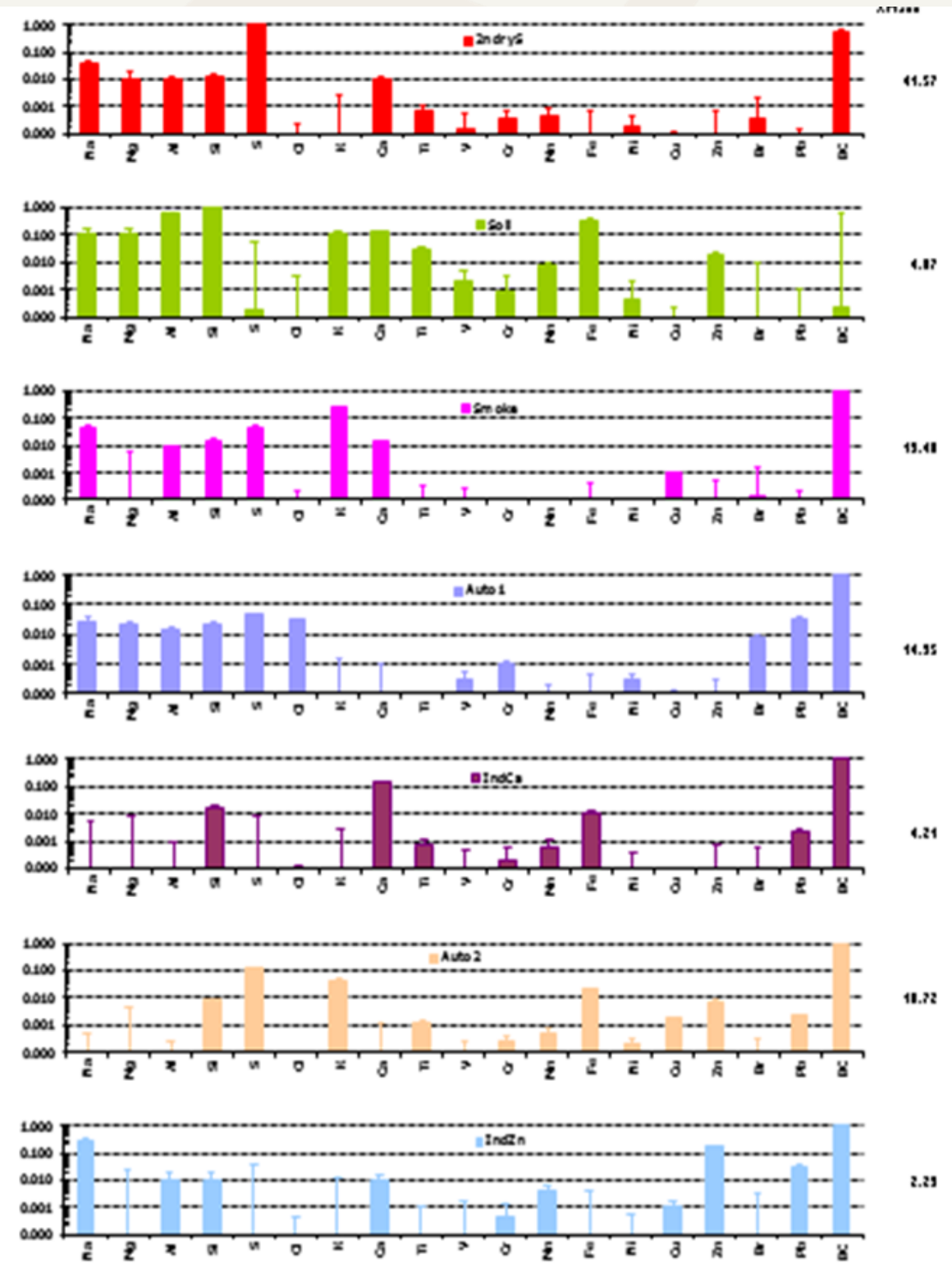


The concentration of S and K in PM2.5 in Jakarta shows an increasing trend from year to year.

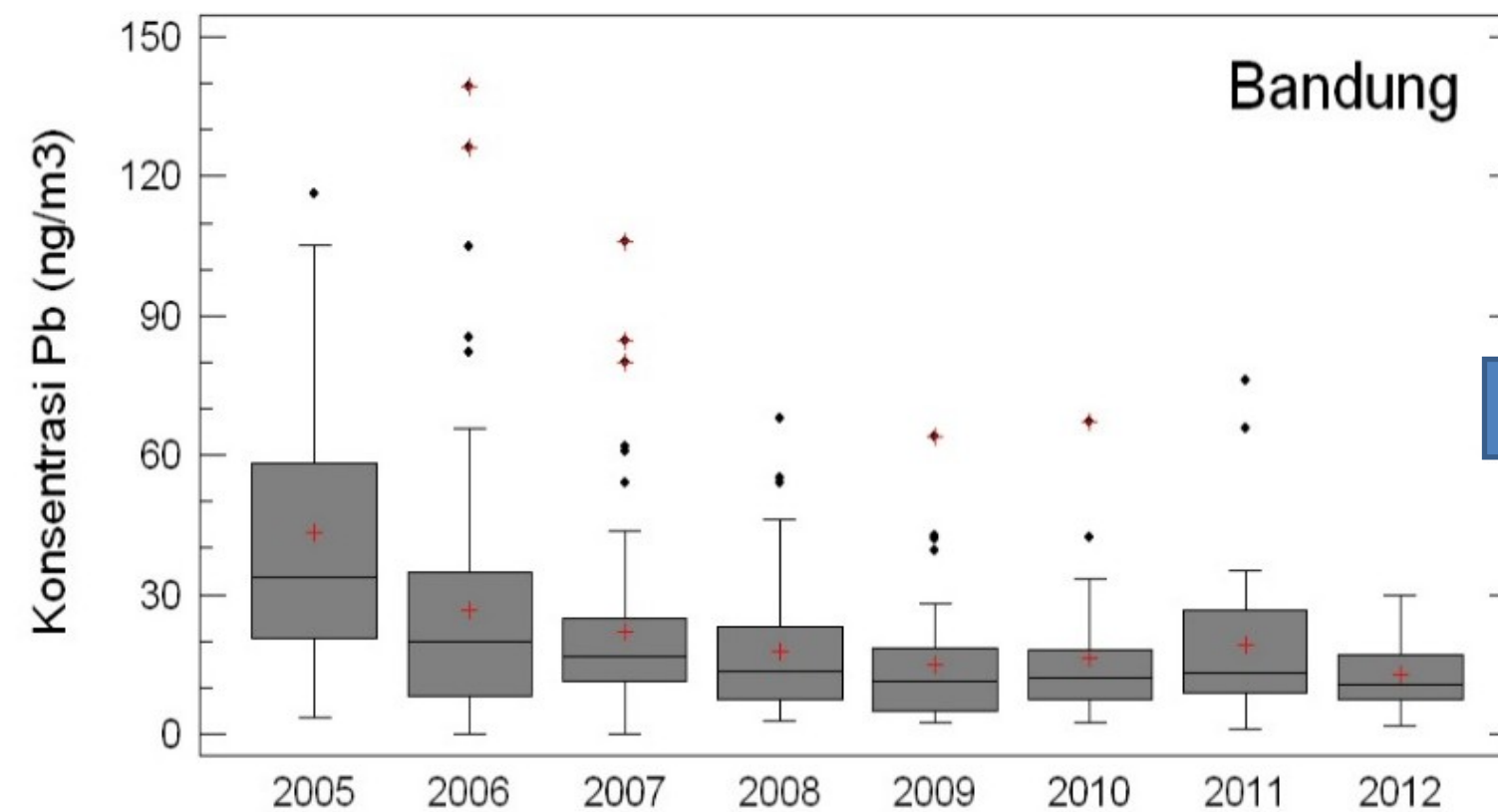
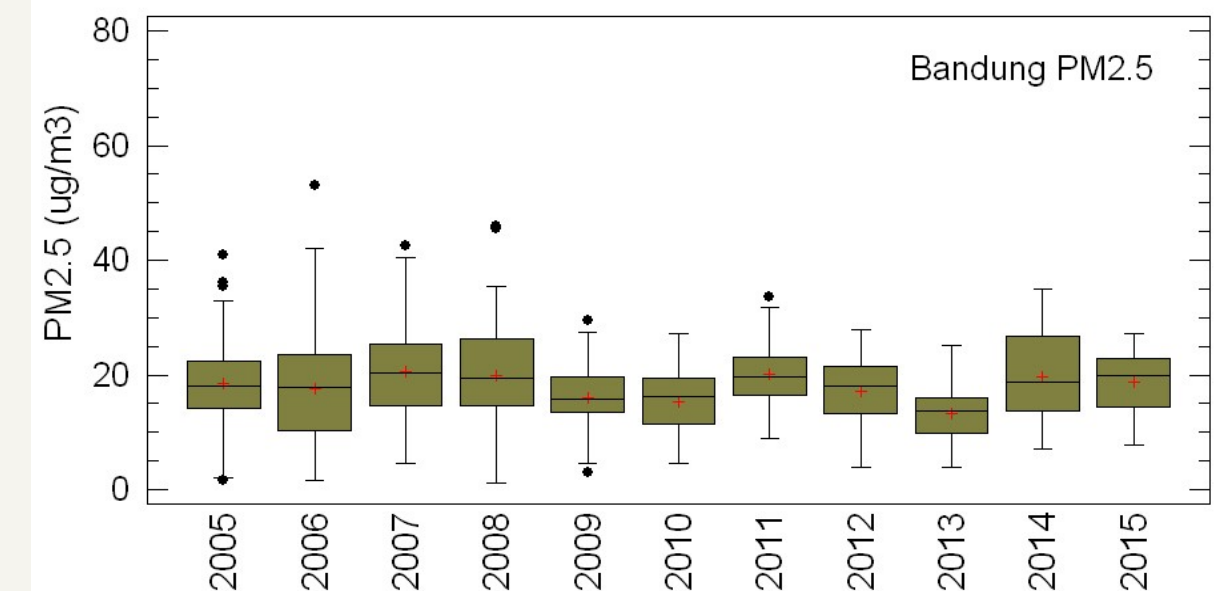


MONITORING AND SOURCE IDENTIFICATION OF PM_{2.5}

Case Study: Long-Term Monitoring of APM in Bandung West Java for Policy's Evaluation



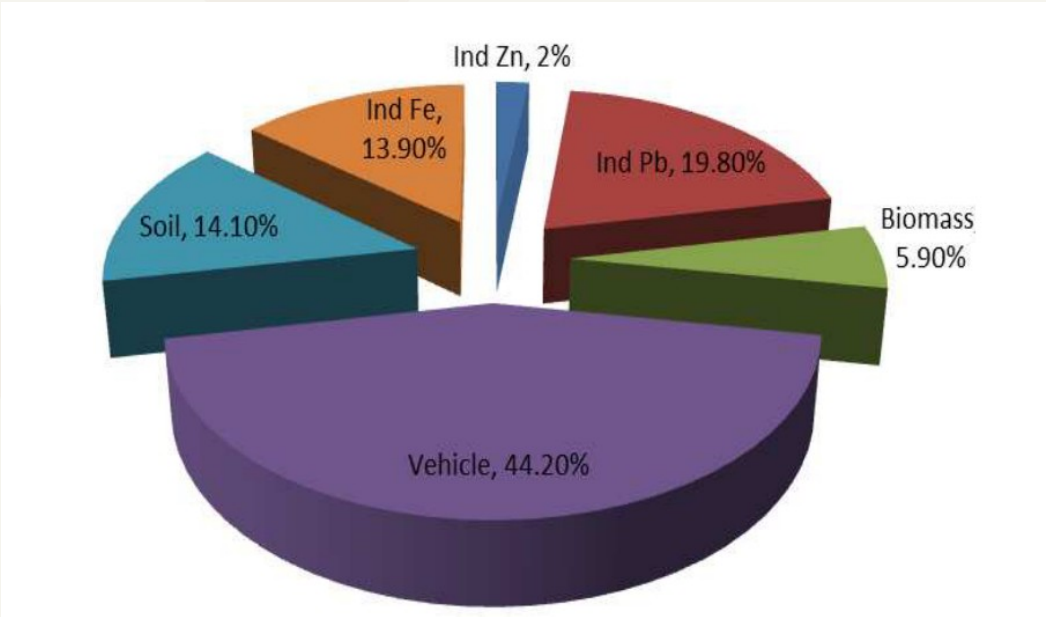
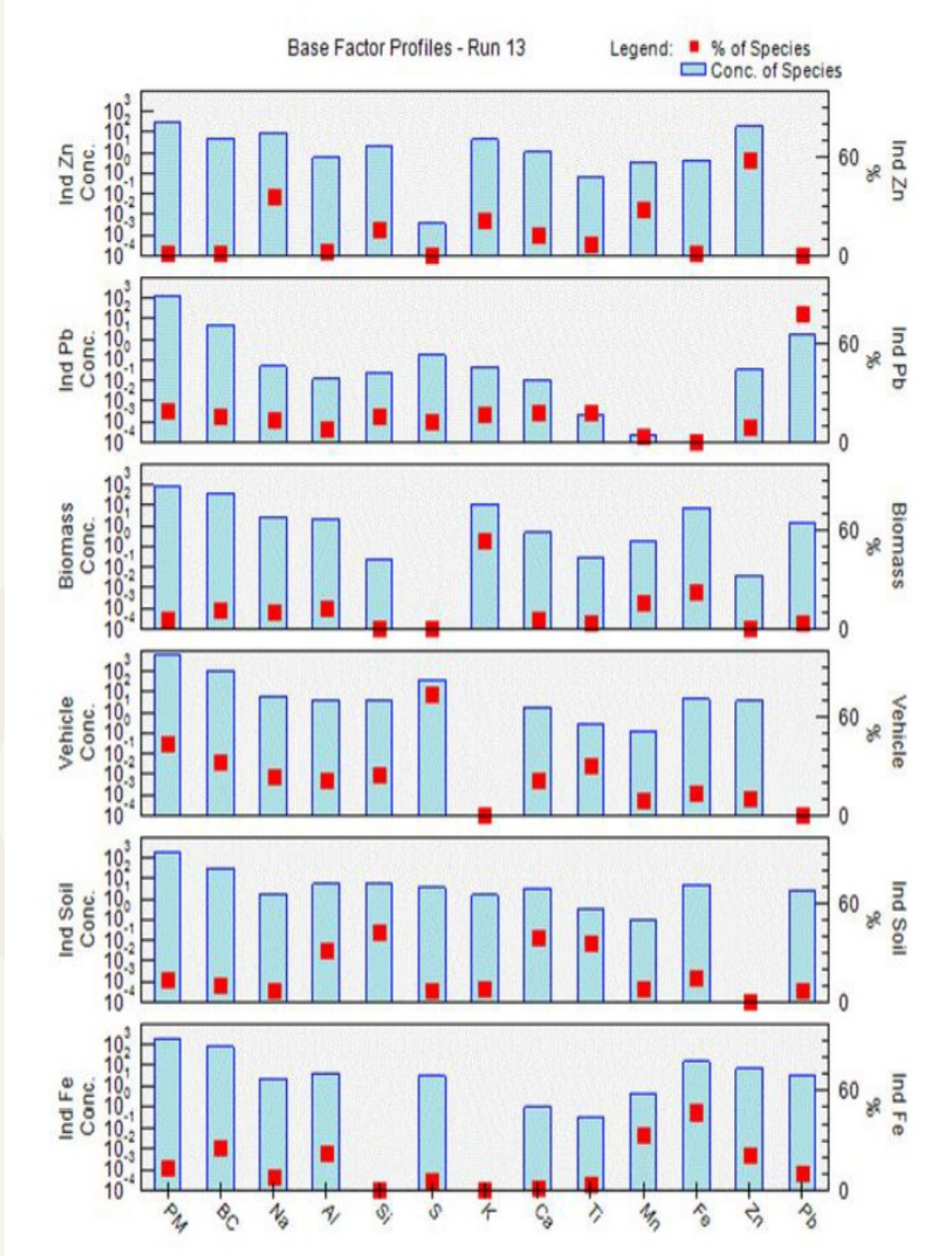
Wind rose and source identification of pollutant in Bandung (7 factors)



After the implementation of the unleaded gasoline program, the Pb concentration in PM_{2.5} decreased significantly. NATs can be used for evaluation of the effectiveness of the Government Regulation on Unleaded Gasoline Programs

SOURCE APPORTIONMENT OF PM_{2.5}

Case Study: Source Apportionment and Chemical Composition in Surabaya

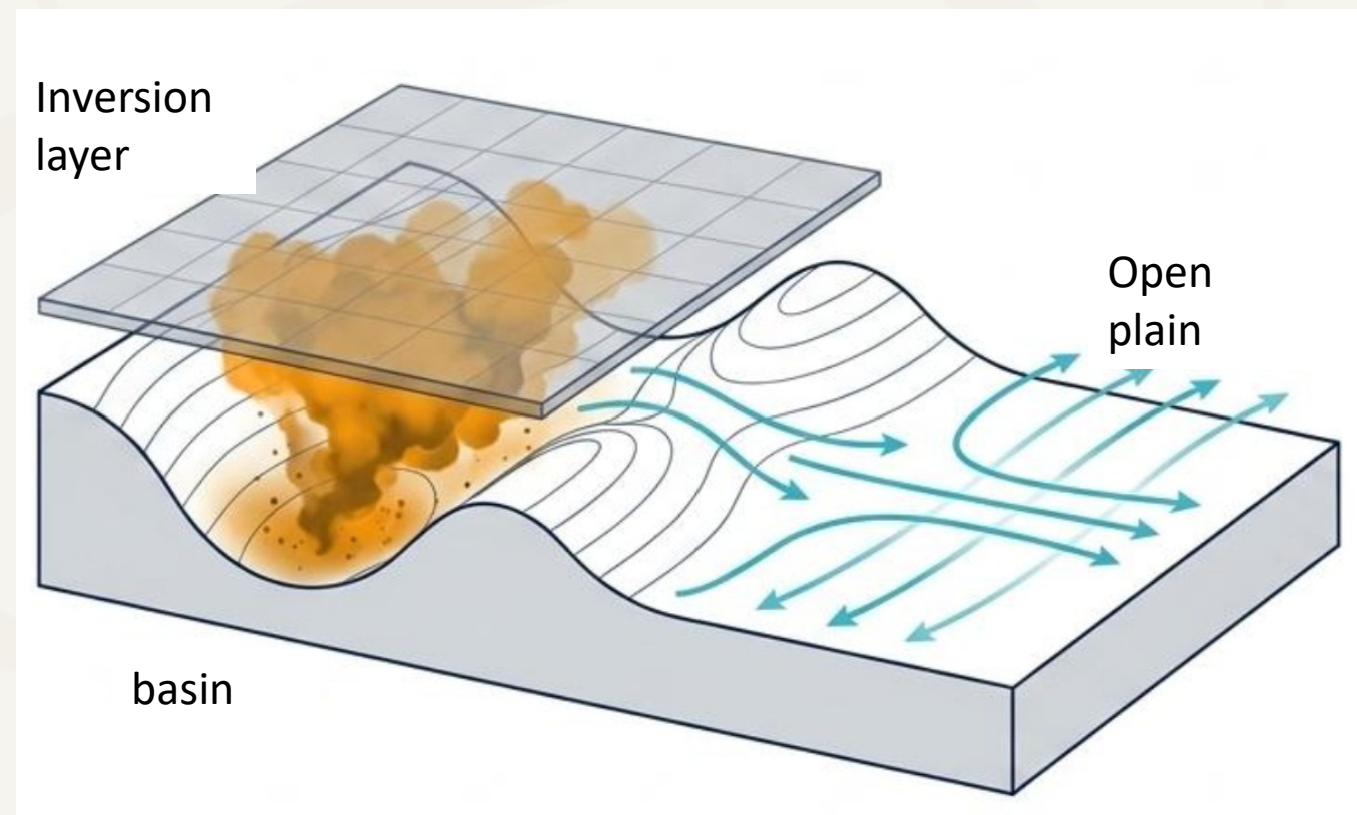


Source Apportionment resulting 6 sources of PM_{2.5} in Surabaya with the biggest contributor is vehicle/transportation, followed by metal industries, soil, and biomass burning

Every region has its own characteristics of pollution related with the anthropogenic activities in the region and in their surrounding area. Source apportionment gives us representative information related to the pollution sources and their level of contribution, which allows us to design an effective management plan or policies of air pollution

GEOGRAPHICAL FACTOR

Air pollution is not just a problem that exists in a vacuum; it's closely intertwined with the geographical features of an area. Geography plays a pivotal role in determining how pollutants disperse, settle, and accumulate in the atmosphere. In essence, the landscape shapes the way air pollution behaves, influencing health outcomes and environmental quality.



The topography of an area, its natural and physical features, is crucial when it comes to air pollution dispersion.

- Valleys often trap inversions and pollutants, while flat plains allow for greater air mixing and cleansing.
- For instance, a bowl-shaped valley can lead to poor air quality, especially where there are high emissions from vehicles or industries.
- Open landscapes might encourage wind currents to carry away pollutants, dispersing them across wider areas.

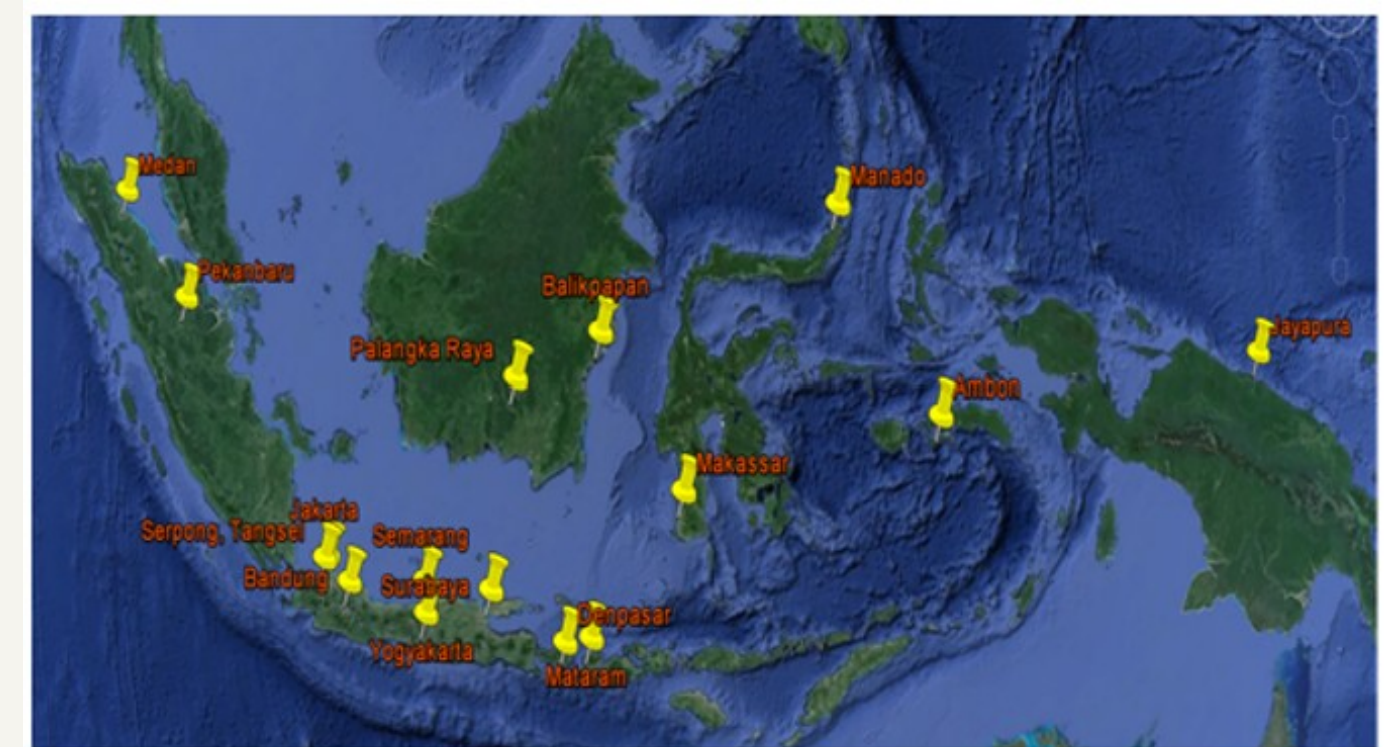
GEOGRAPHICAL FACTOR

Proximity to Pollution Sources

Geography determines proximity to pollution sources, impacting local air quality. Urban centers, often positioned near major transportation routes, tend to have elevated pollution levels simply due to their locations. The vast populations and heavy industrial activities generate immense amounts of pollutants that can significantly degrade air quality. On the other hand, more rural areas with fewer nearby pollution sources can often boast much cleaner air.

SAMPLING SITES IN INDONESIA

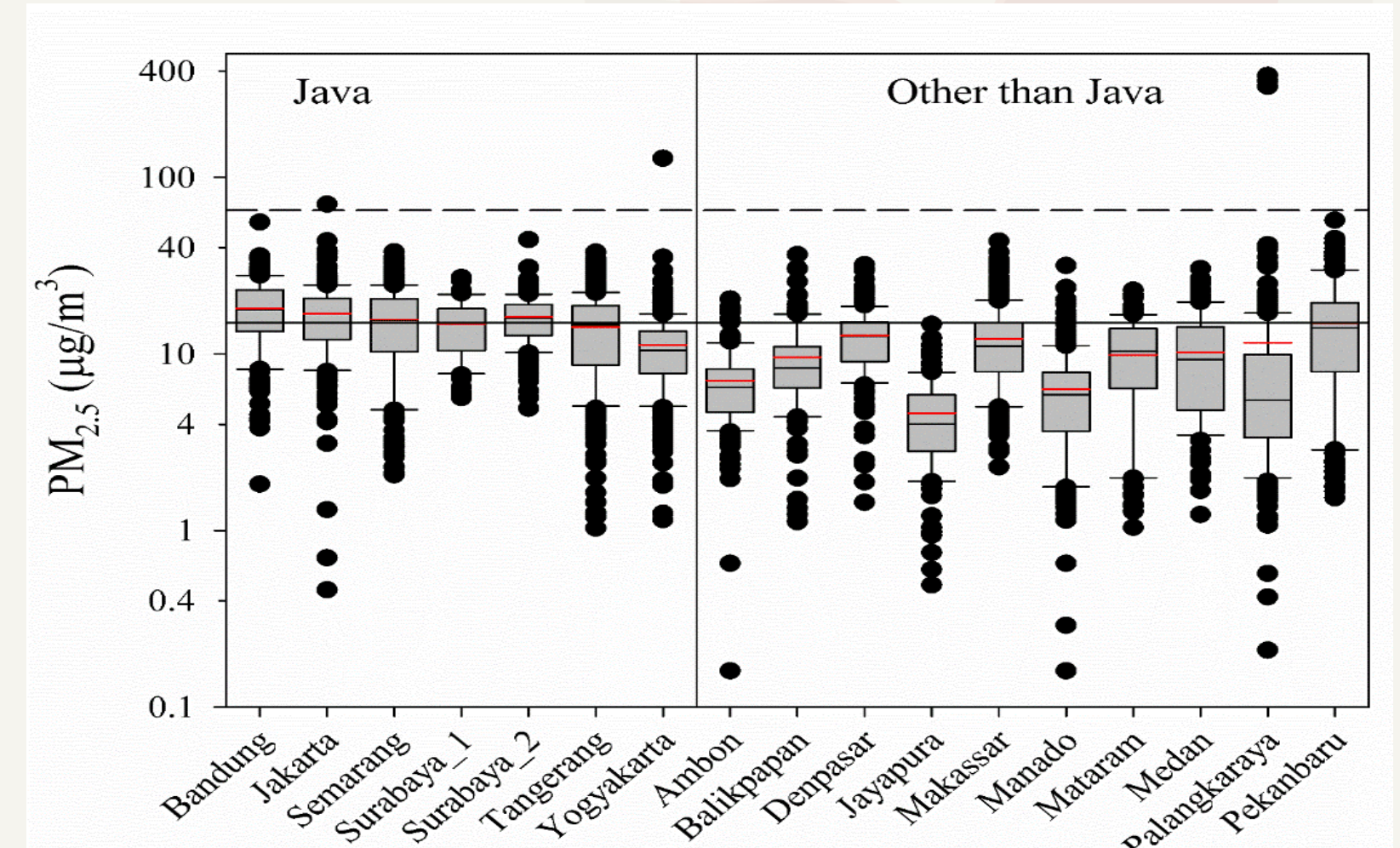
- The APM samples were collected in **17 sites covering 16 provinces**
 - ✓ **Java:** Jakarta, Tangerang, Bandung, Semarang, Yogyakarta, Surabaya
 - ✓ **Bali:** Denpasar
 - ✓ **Nusa Tenggara Barat:** Lombok
 - ✓ **Sumatra:** Pekanbaru, Medan
 - ✓ **Borneo:** Palangka Raya, Balikpapan
 - ✓ **Sulawesi:** Makassar, Manado
 - ✓ **Maluku:** Ambon
 - ✓ **Papua:** Jayapura



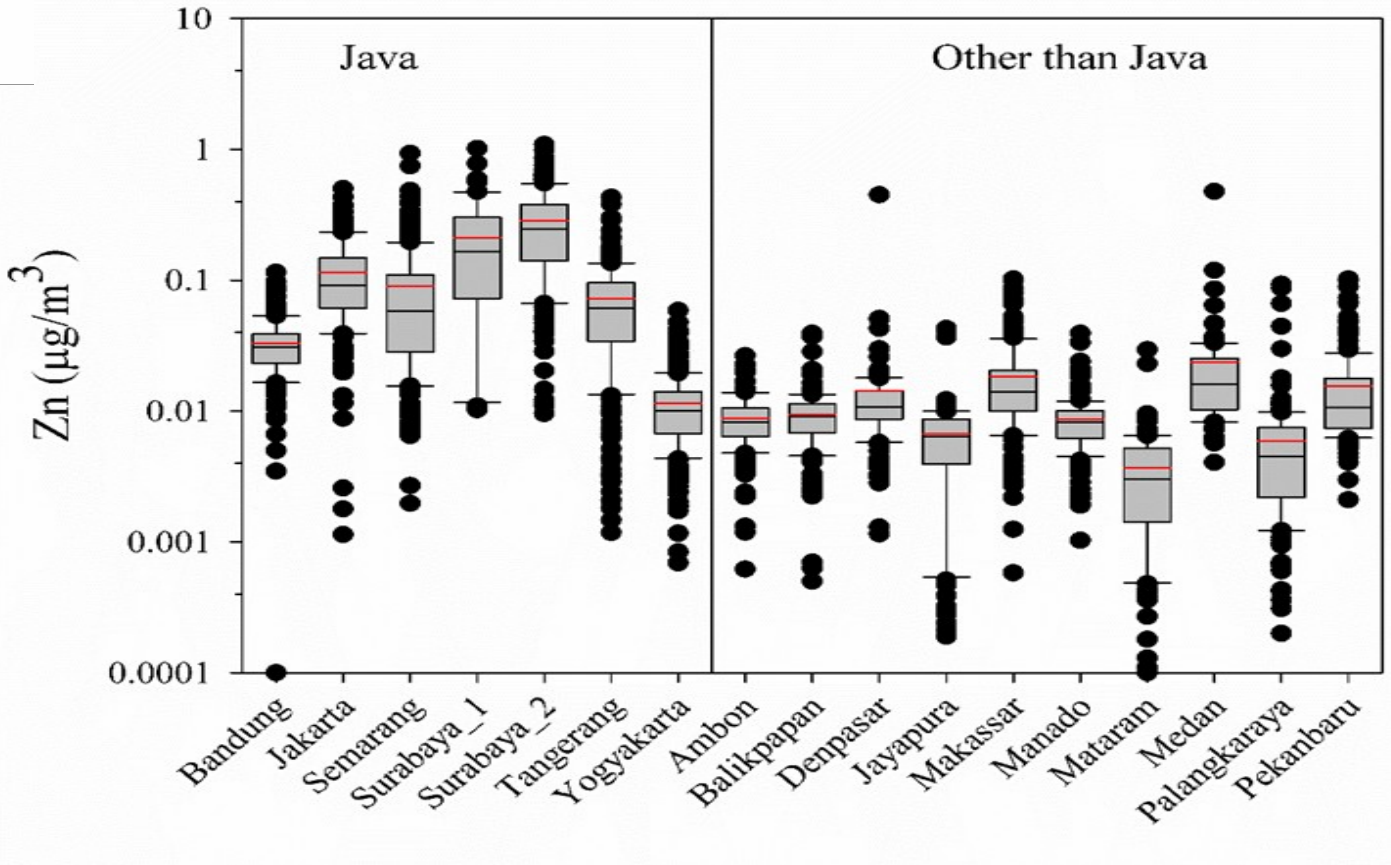
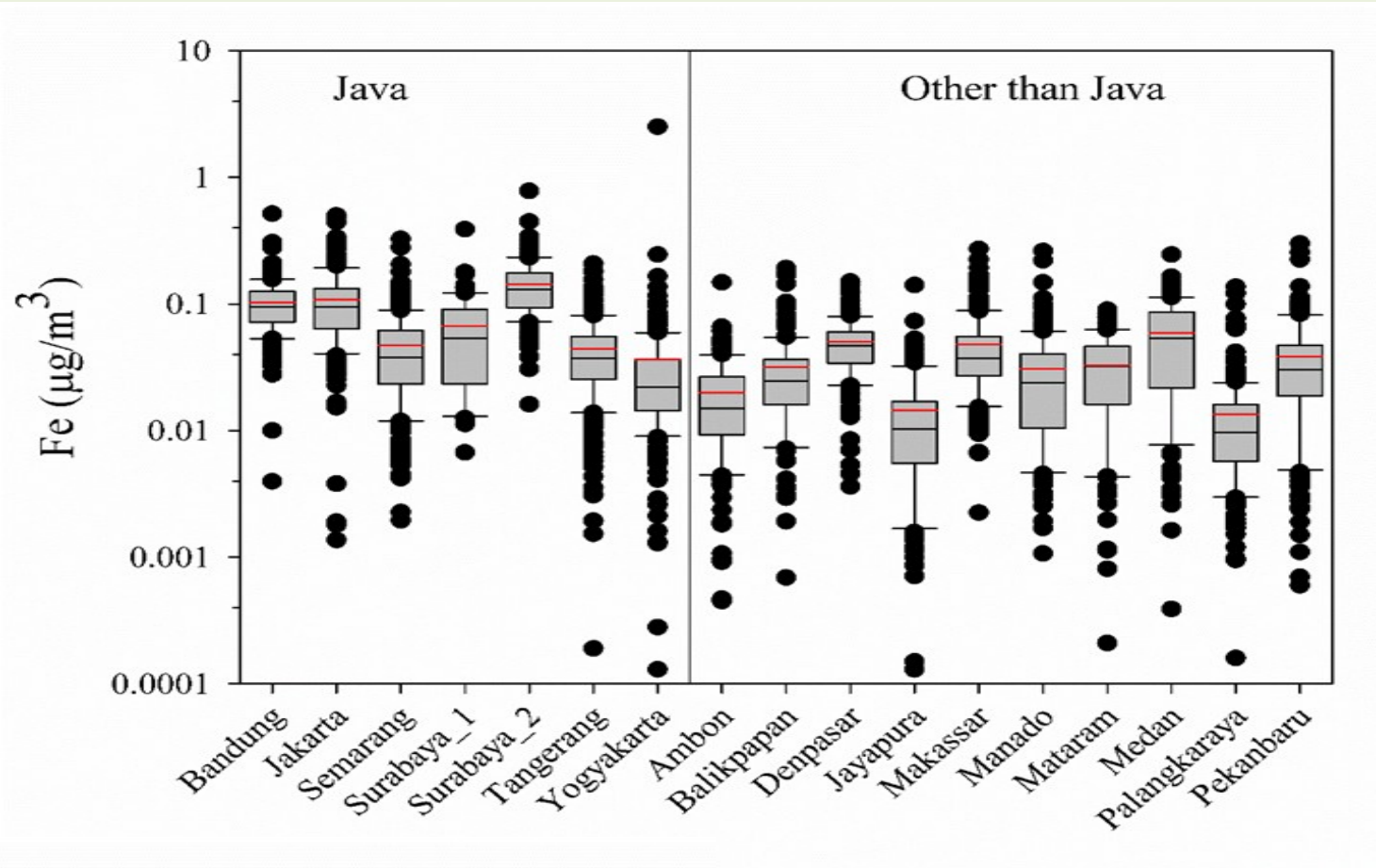
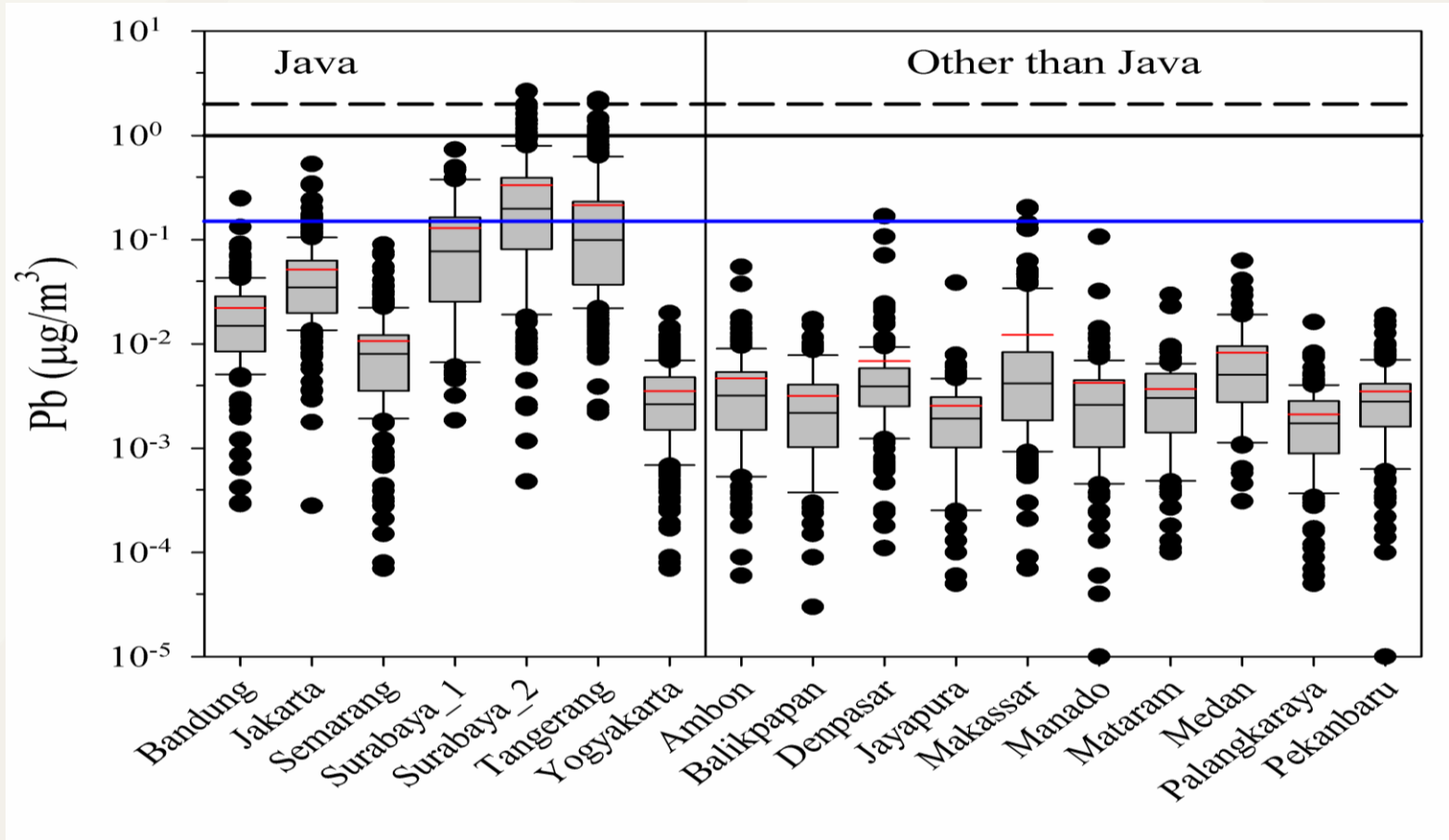
Air Pollutants distribution in 17 sites in Indonesia



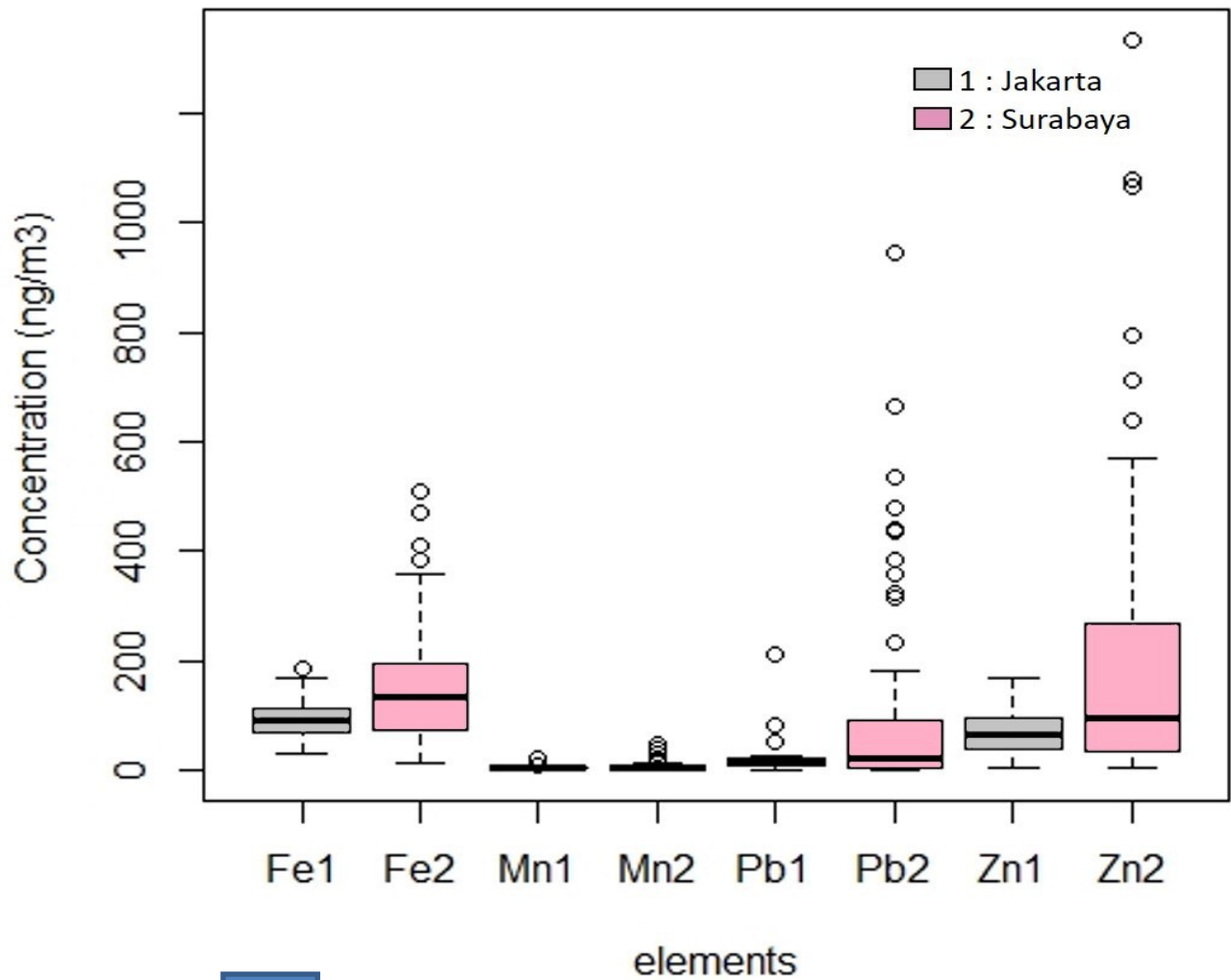
- $PM_{2.5}$ concentrations on Java sites generally exceeded the air quality standards
- The density of the cities and the amount of industrial estate in Java Island are led to the higher concentration of $PM_{2.5}$ compare with the cities outside Java
- Volcanic eruptions and forest fires produced locally high $PM_{2.5}$ concentrations



Air Pollutants distribution in 17 sites in Indonesia



Monitoring of APM in Jakarta and Surabaya



The concentration of heavy metals in the Jakarta PM and the Surabaya PM is significantly different, even though both cities are located on the coast

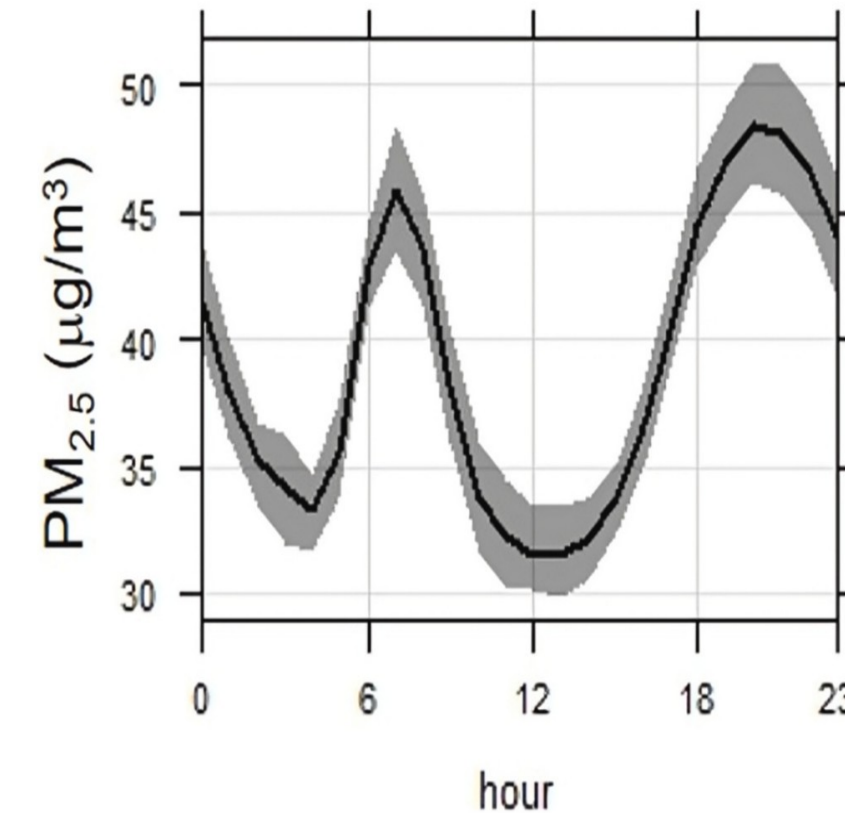
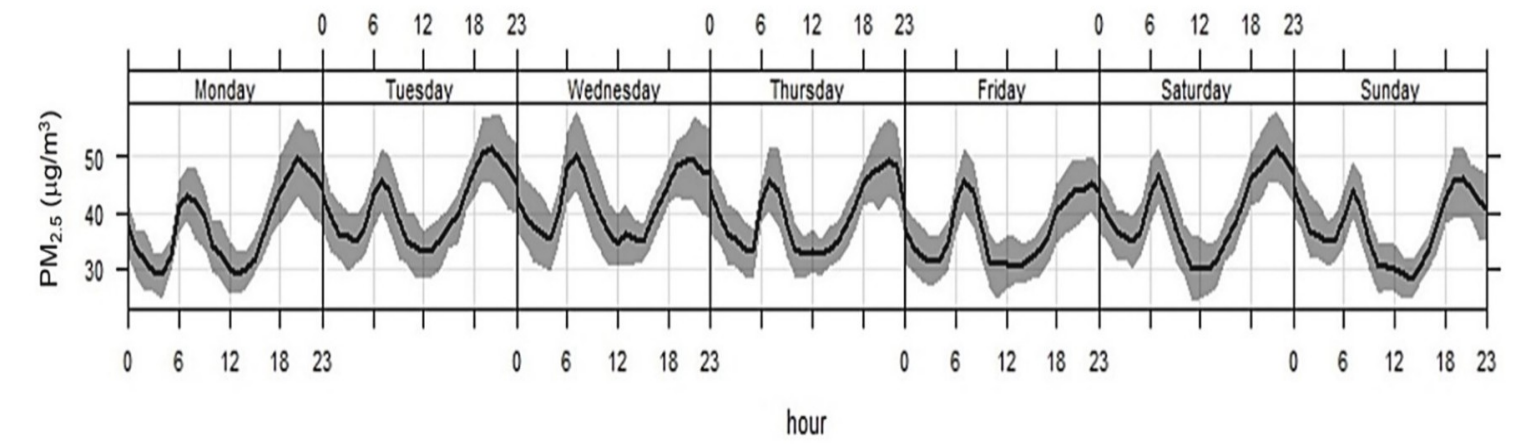
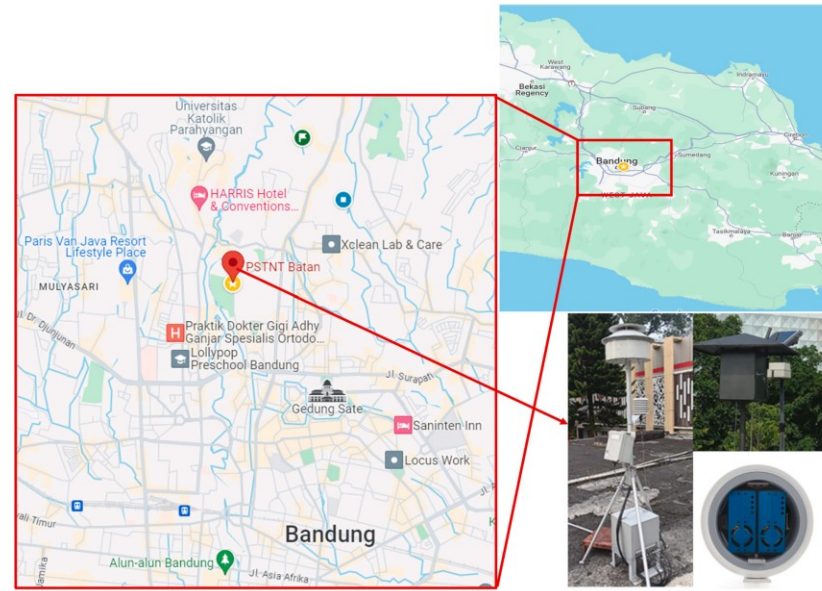
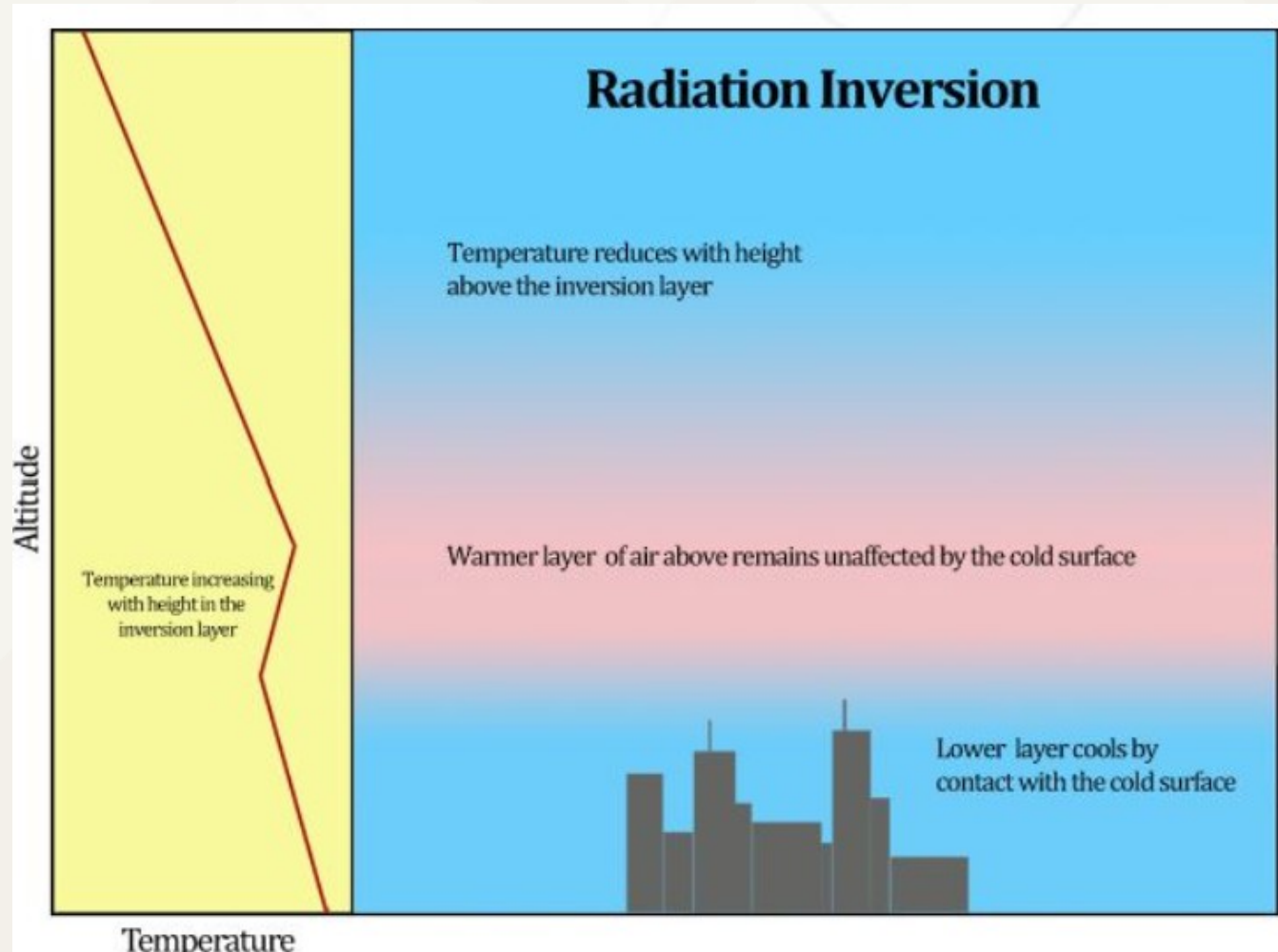


Indonesia has banned the use of leaded petrol since July 2006

Every region has its own characteristics of pollution related with the anthropogenic activities in the region and in their surrounding area.

METEOROLOGICAL FACTOR

Planetary Boundary Layer Height



Kurniawati et al. Kuwait Journal of Science 52 (2025)

The diurnal pattern a bimodal pattern with increasing peaks occurring in the morning and evening.

- The morning peak indicating increased activity during the morning rush hour as people commute to school and work and mainly influenced by vehicular emissions
- The evening peak was influenced by the decreases in boundary layer height and wind speed in the afternoon, along with the increased source activity during the afternoon rush hour. The diurnal concentration being high at night suggests that the air pollutants may accumulate overnight due to the low temperature and stagnant conditions

METEOROLOGICAL FACTOR

Wind speed and Wind Direction

Case study: Industrial estate in Waru, Sidoarjo, East Java



Air pollutants will be dispersed along with the wind. The meteorological data are needed for forecasting/ modeling the dispersion of air pollutant. While as in receptor site, the data of wind speed and wind direction are useful to estimating the pollution source and to conforming the source identification results.

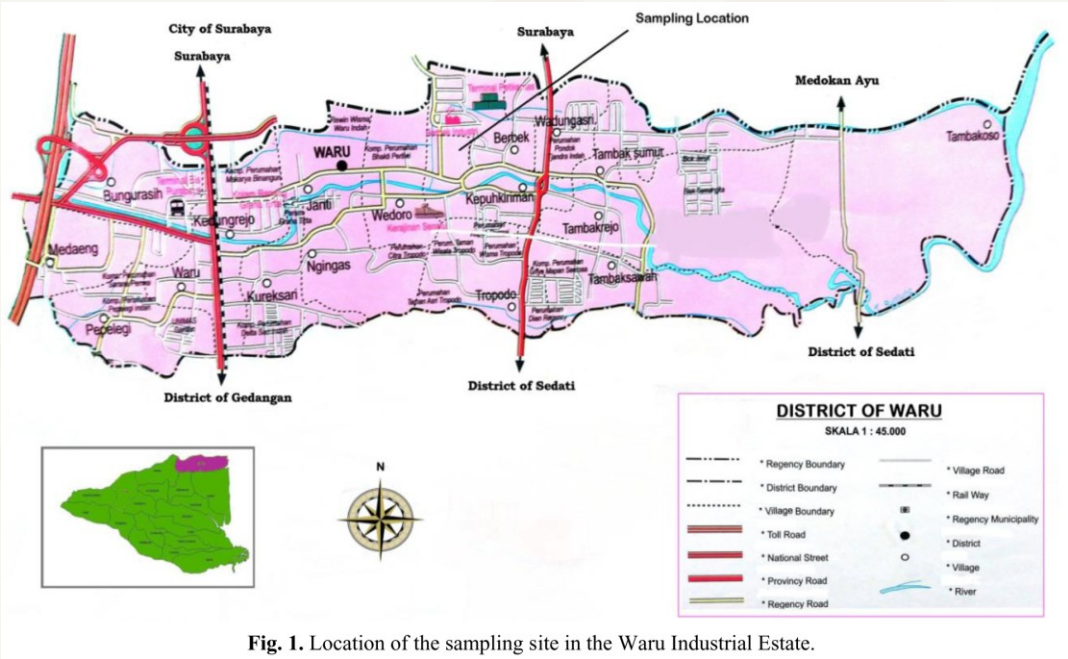
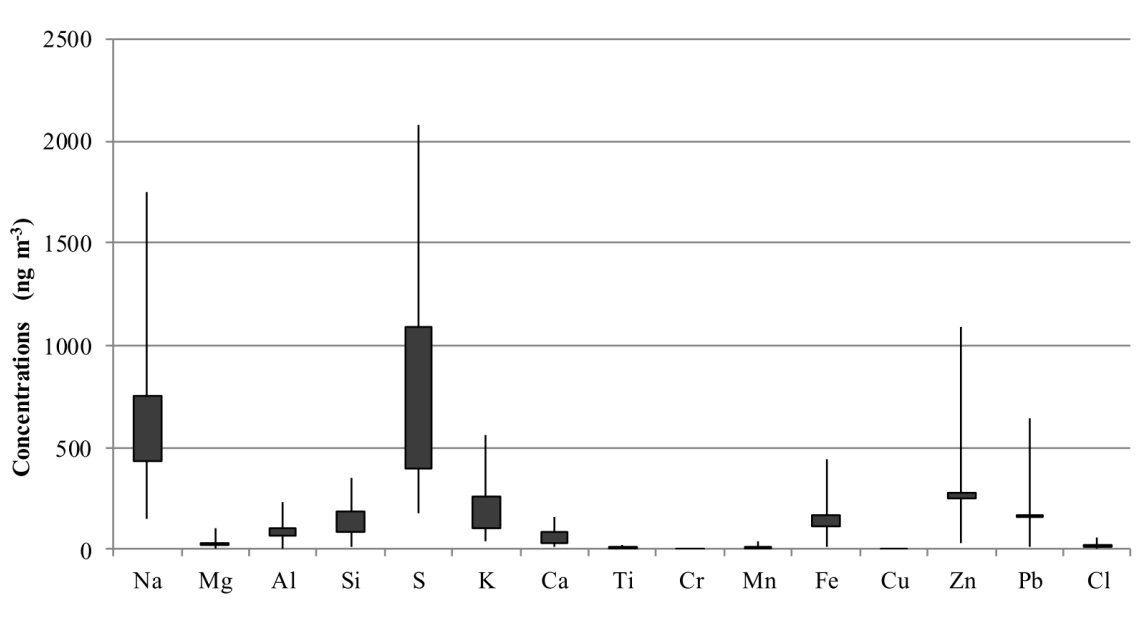


Fig. 1. Location of the sampling site in the Waru Industrial Estate.

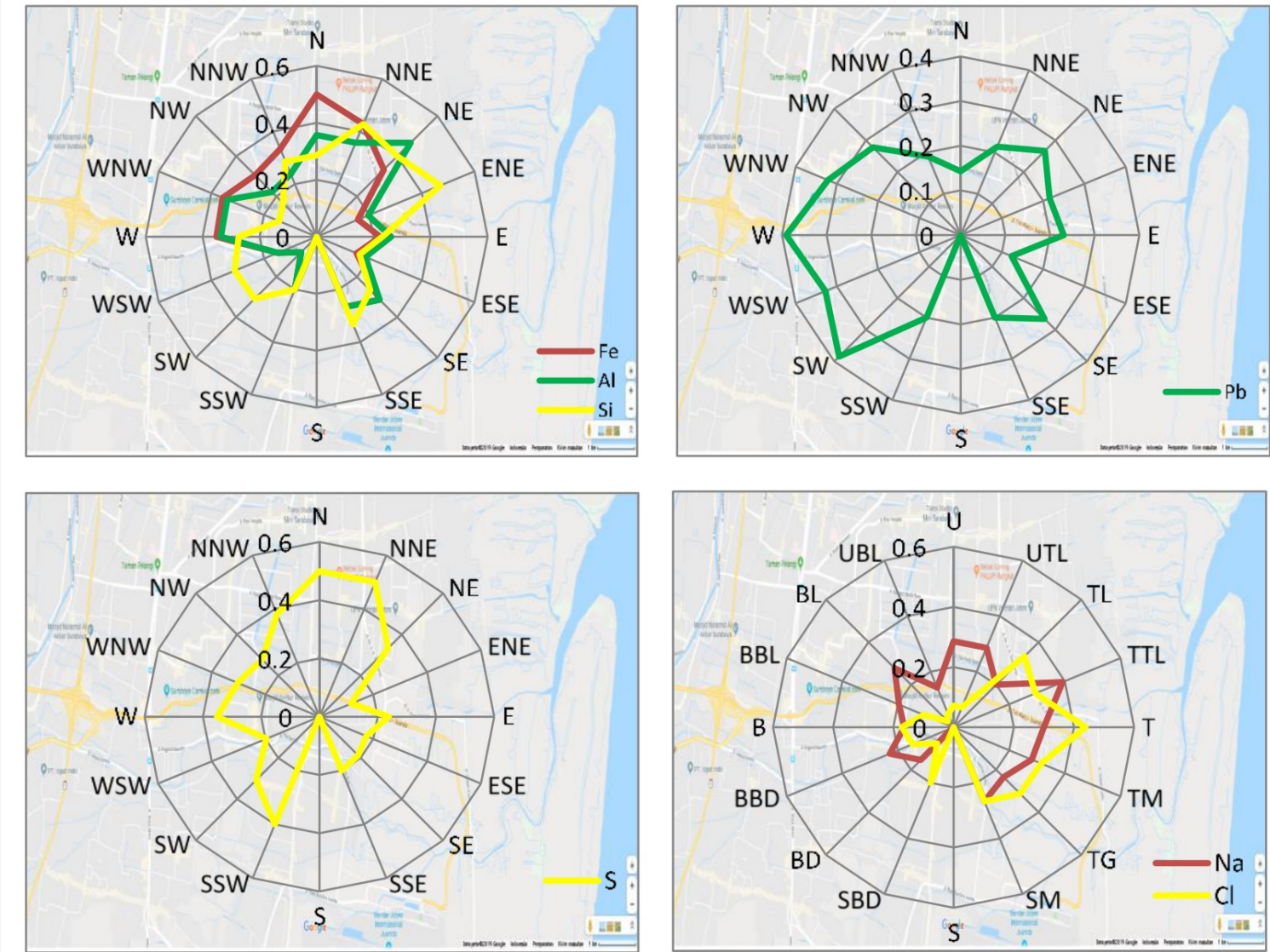


Fig. 5. CPF plot for the estimated location of the source of pollutants.

METEOROLOGICAL FACTOR

Wind speed and Wind Direction

Source Identification of PM_{2.5} in East Java Indonesia

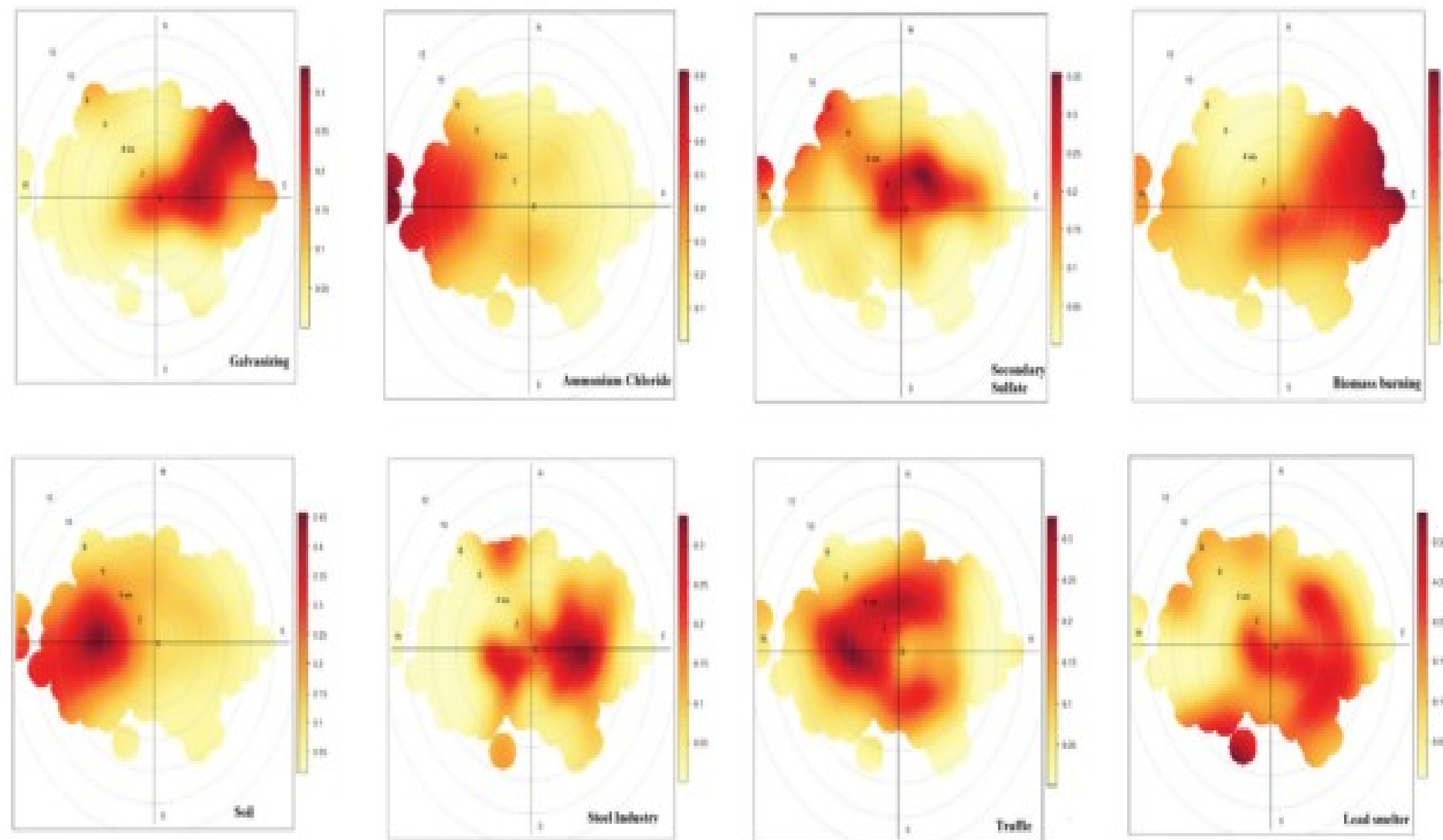


Figure 6. The plot of CBPF for each profile of pollutant sources in Surabaya 2021–2022.

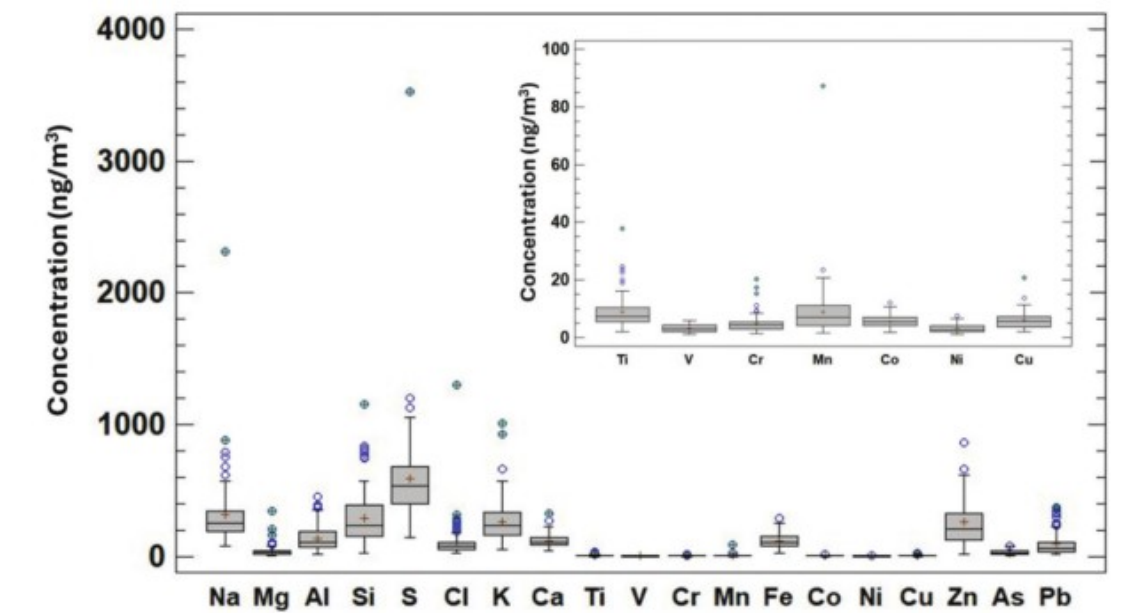


Figure 4. Whisker plot of elemental concentrations of PM_{2.5} in Surabaya 2021–2022.

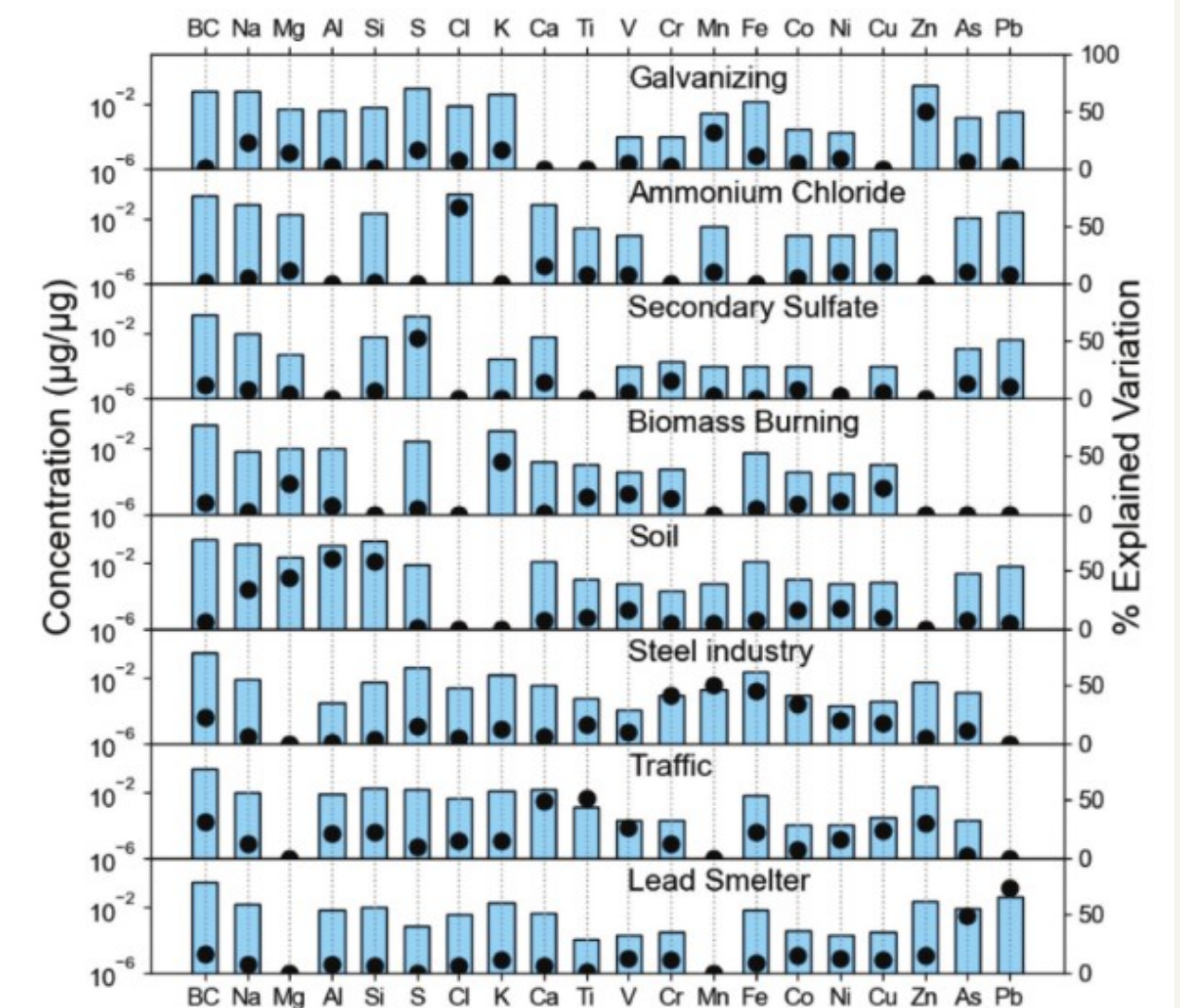
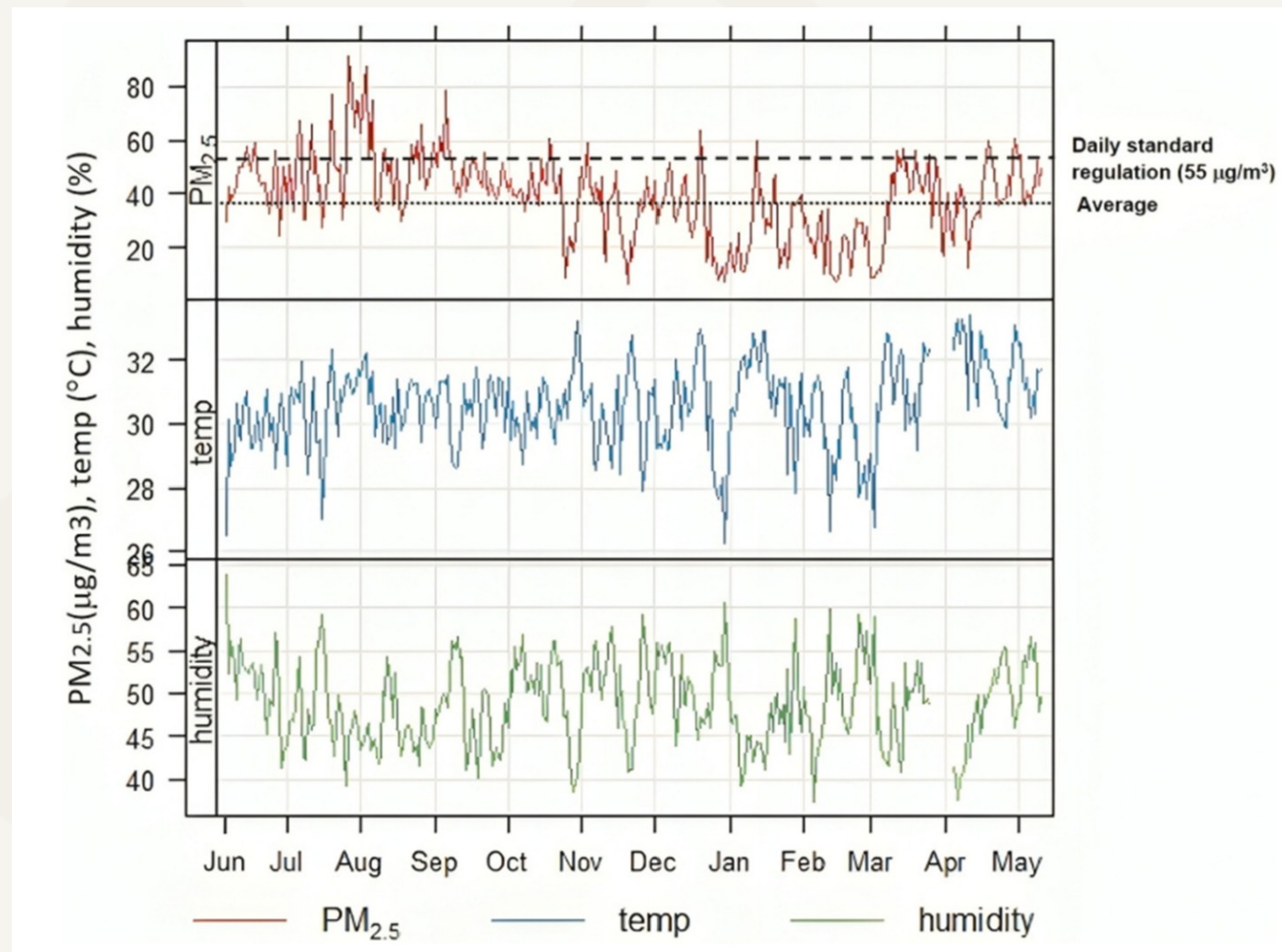


Figure 5. Source profiles of PMF for PM_{2.5} at Surabaya 2021–2022.

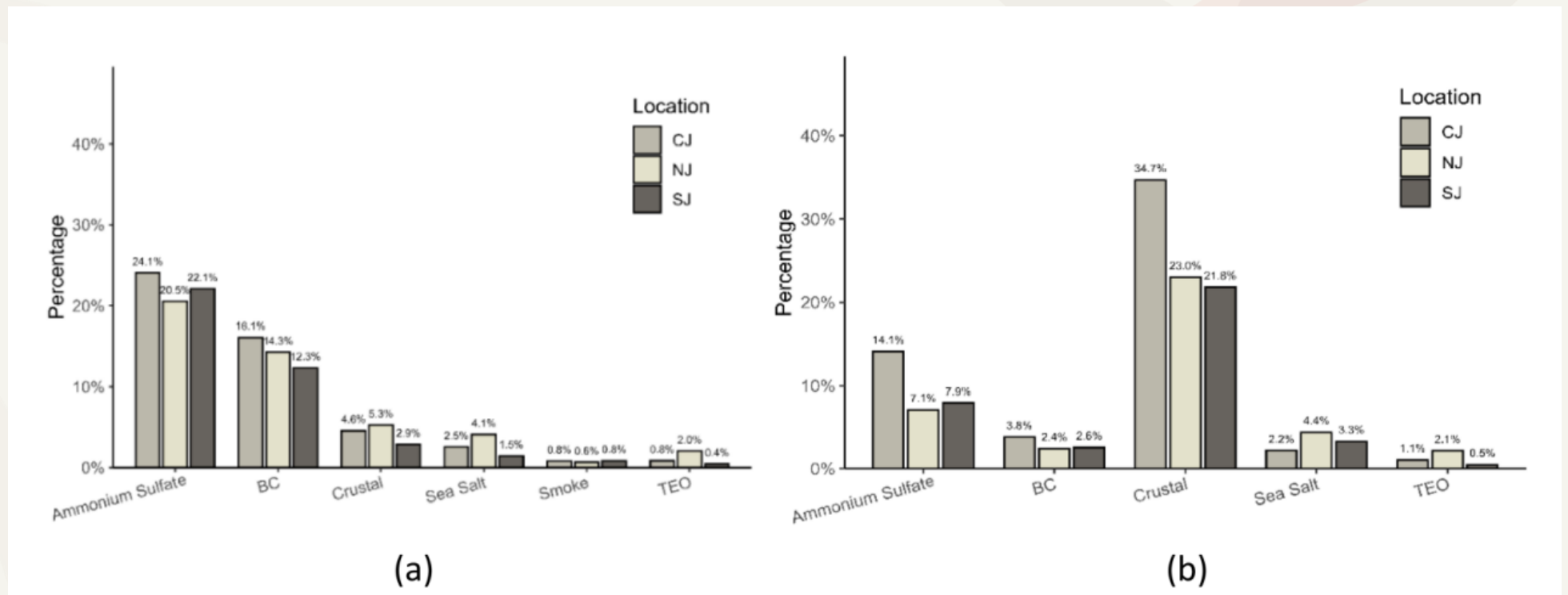
METEOROLOGICAL FACTOR

Temperature and Relative Humidity



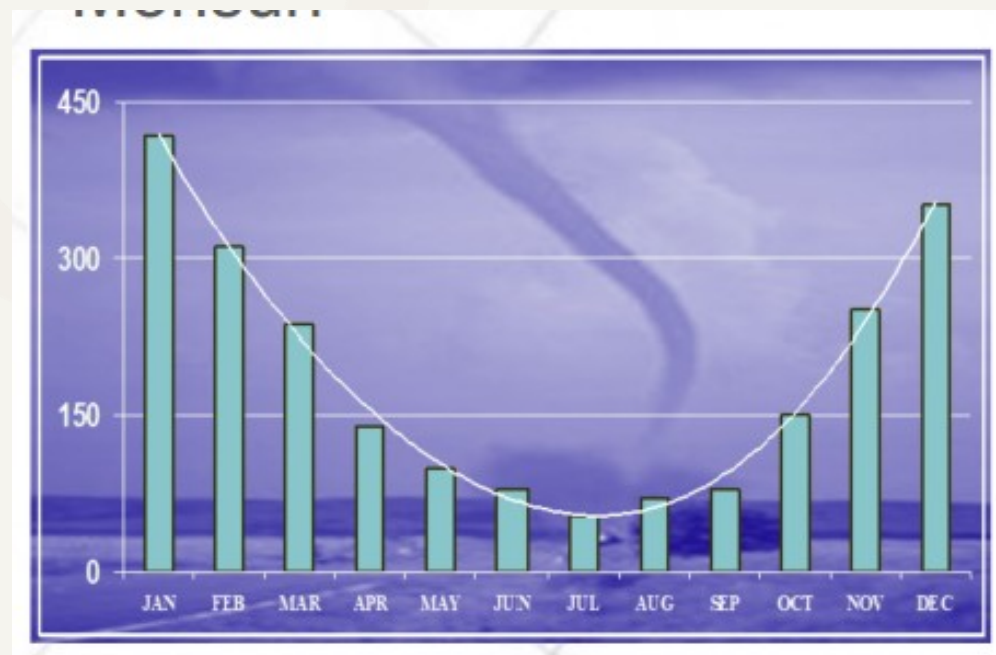
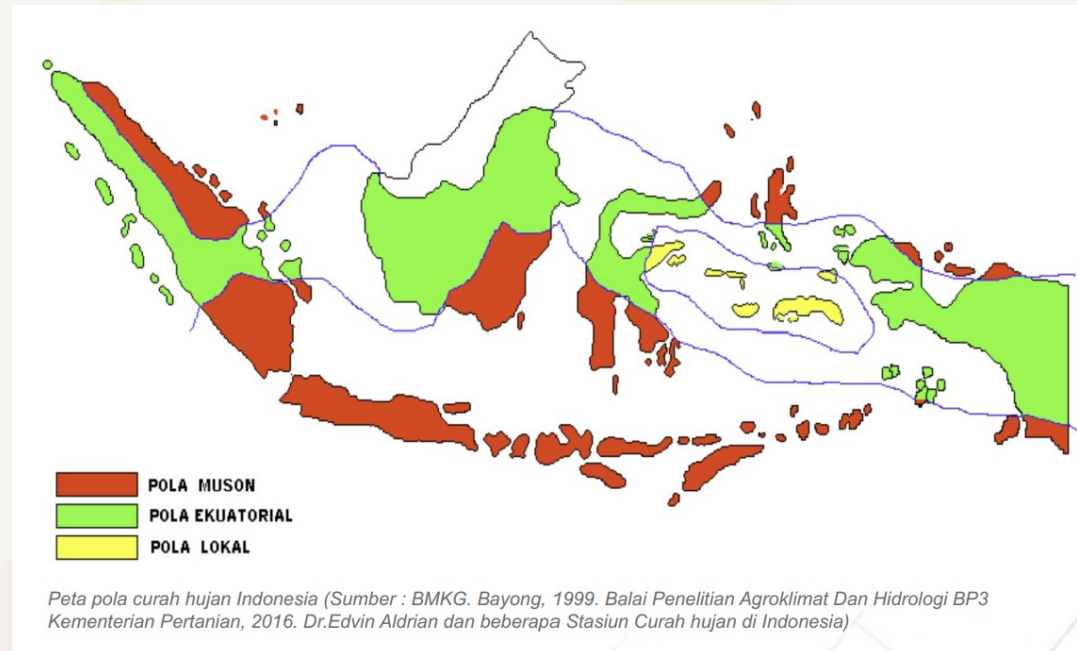
Temperatur and RH gives positive and negative correlation to PM_{2.5} respectively

High humidity in Indonesia tend to form secondary aerosol through chemical transformation. Therefore, Secondary aerosols; secondary sulfate and/or secondary nitrate most likely to be one of air pollution source identified in Indonesia.



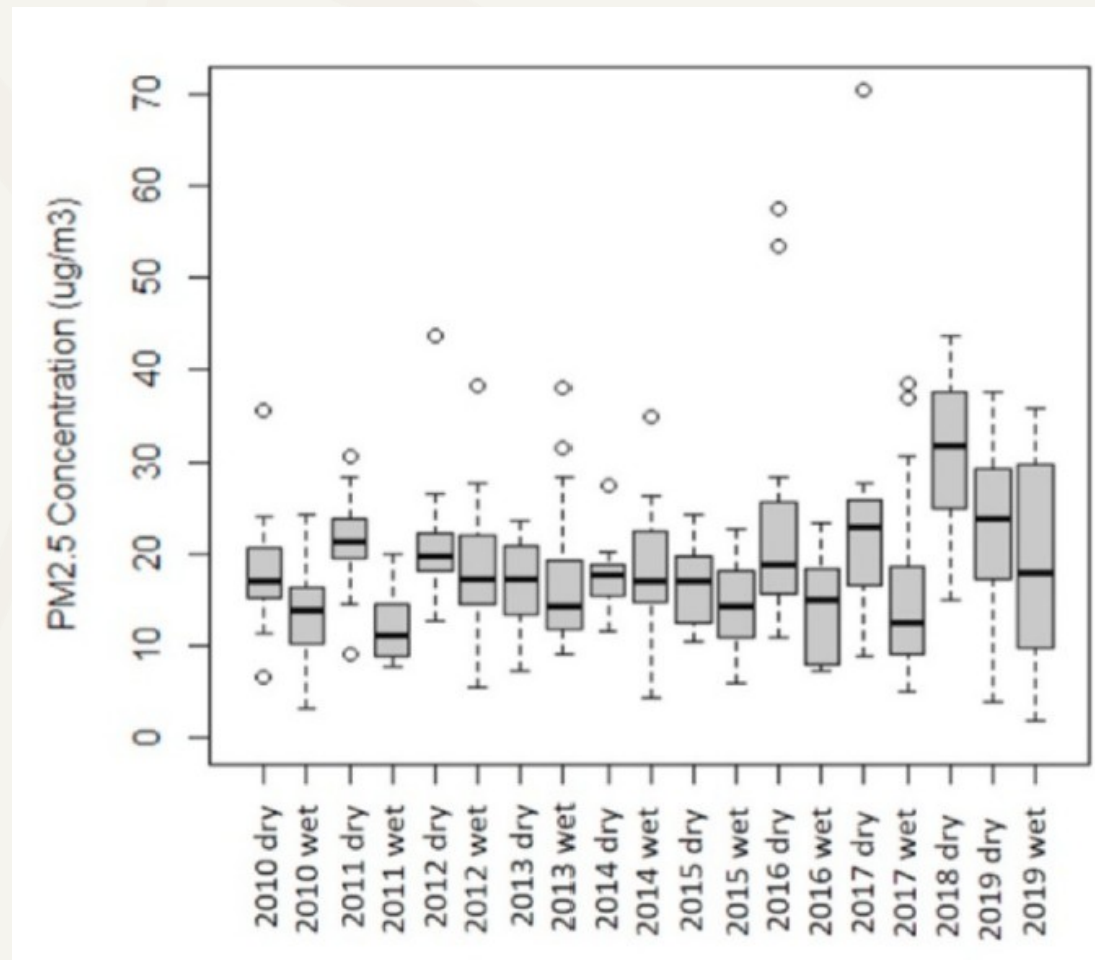
METEOROLOGICAL FACTOR

Seasonal Variations

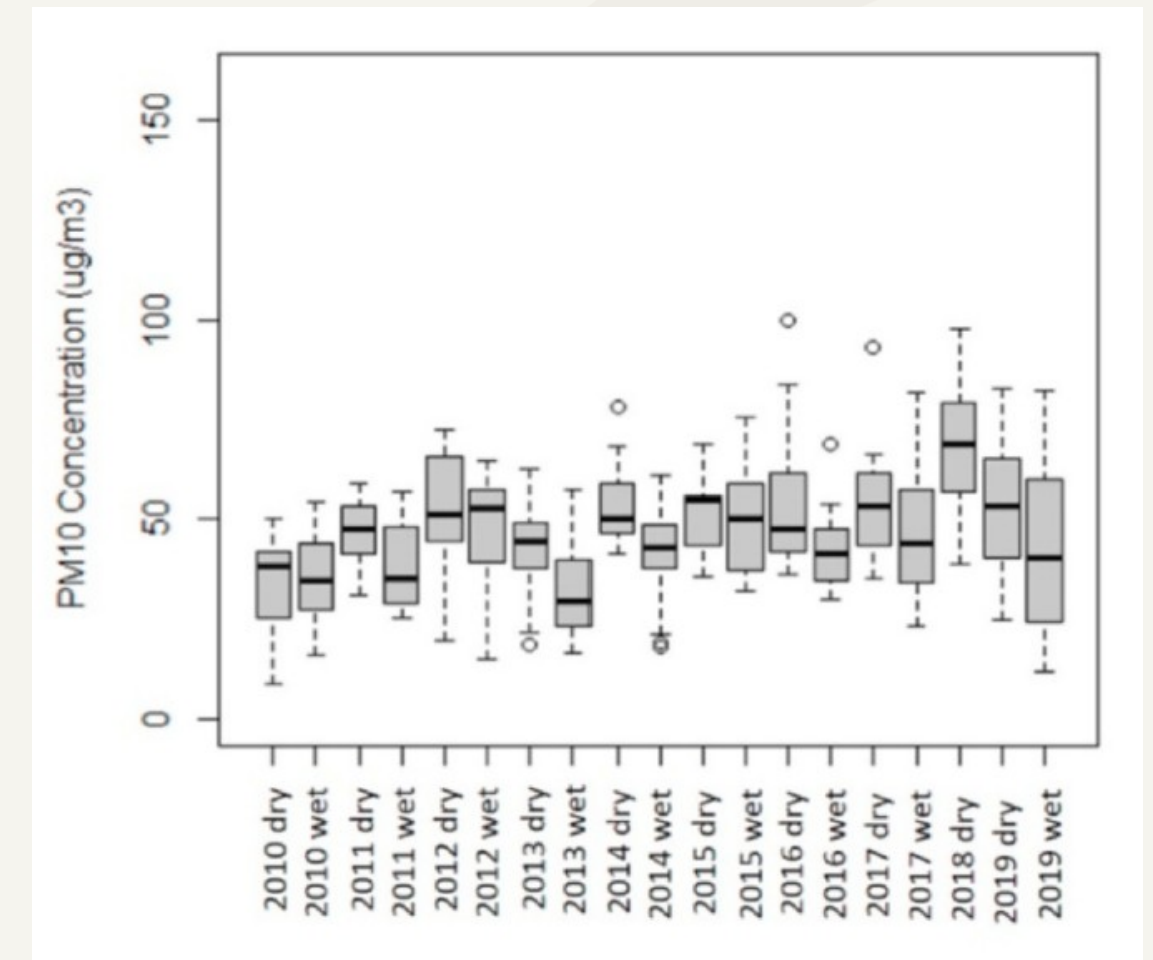


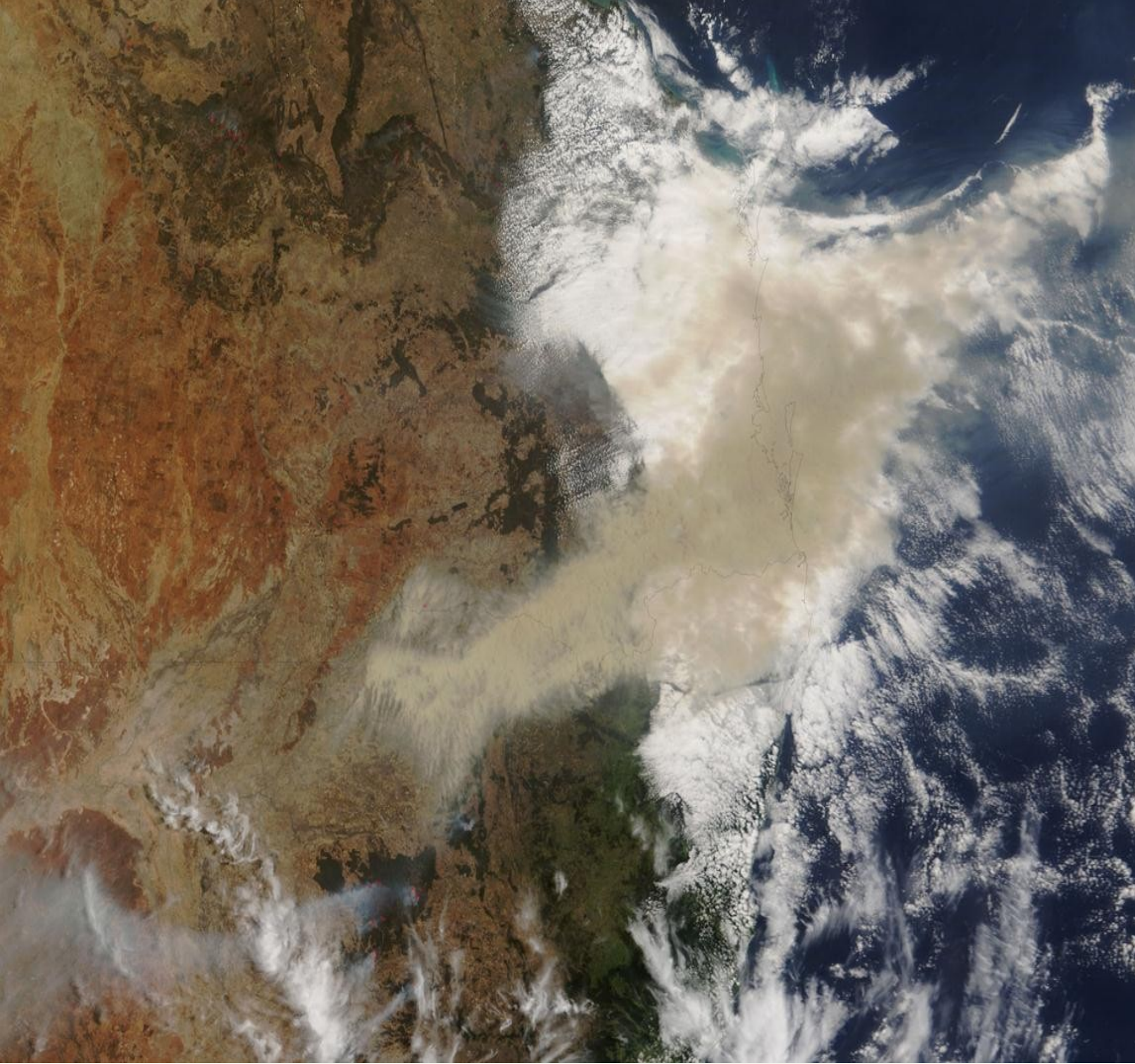
Monsoon Rainfall pattern

The air in Jakarta and other cities on the island of Java tends to be clean during the West Monsoon (rainy season) due to atmospheric cleansing by rain (wet deposition). Conversely, pollution spikes sharply during the East Monsoon (dry season) because of dry air and weaker winds.

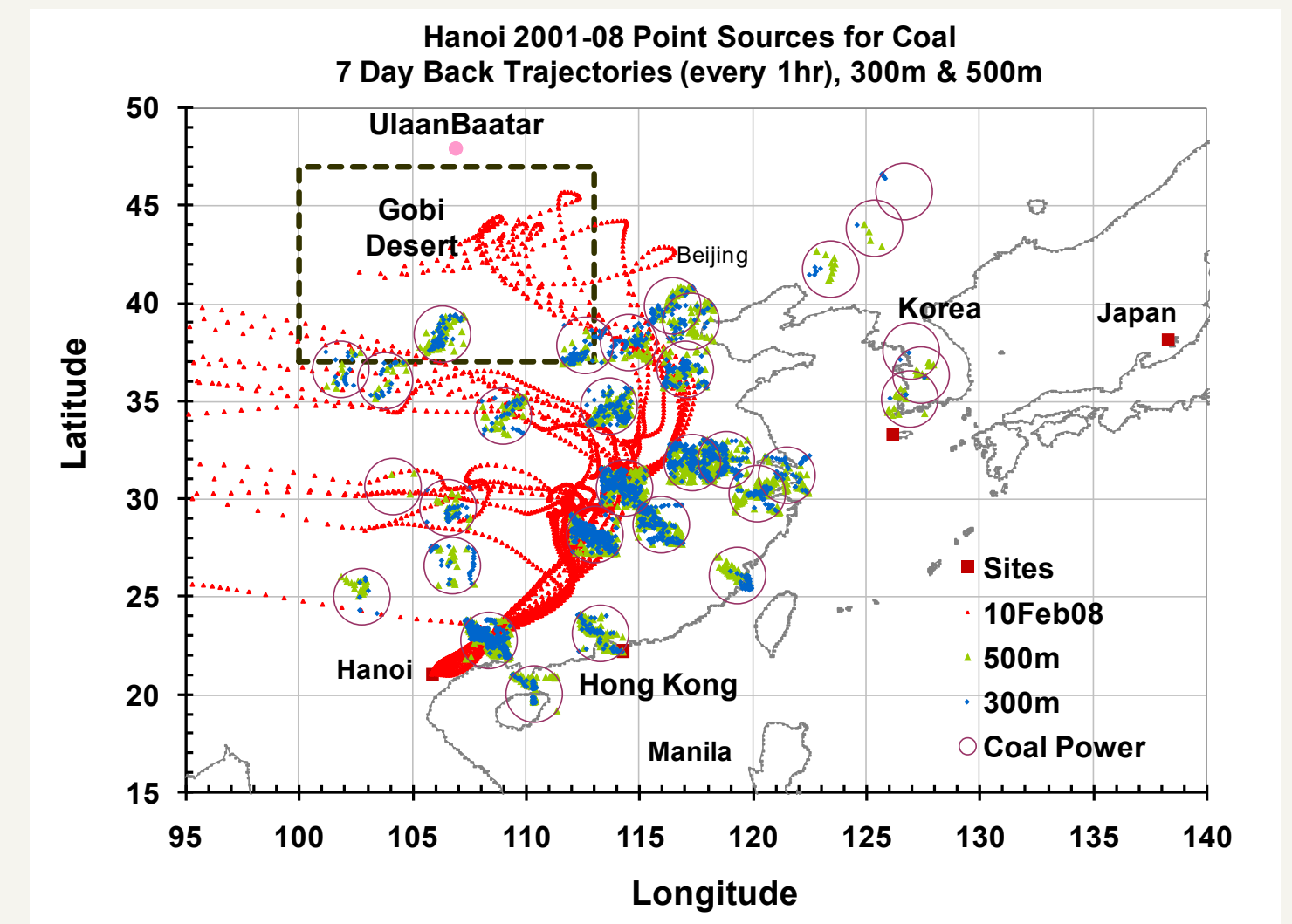


Seasonal variations of PM2.5 in Jakarta

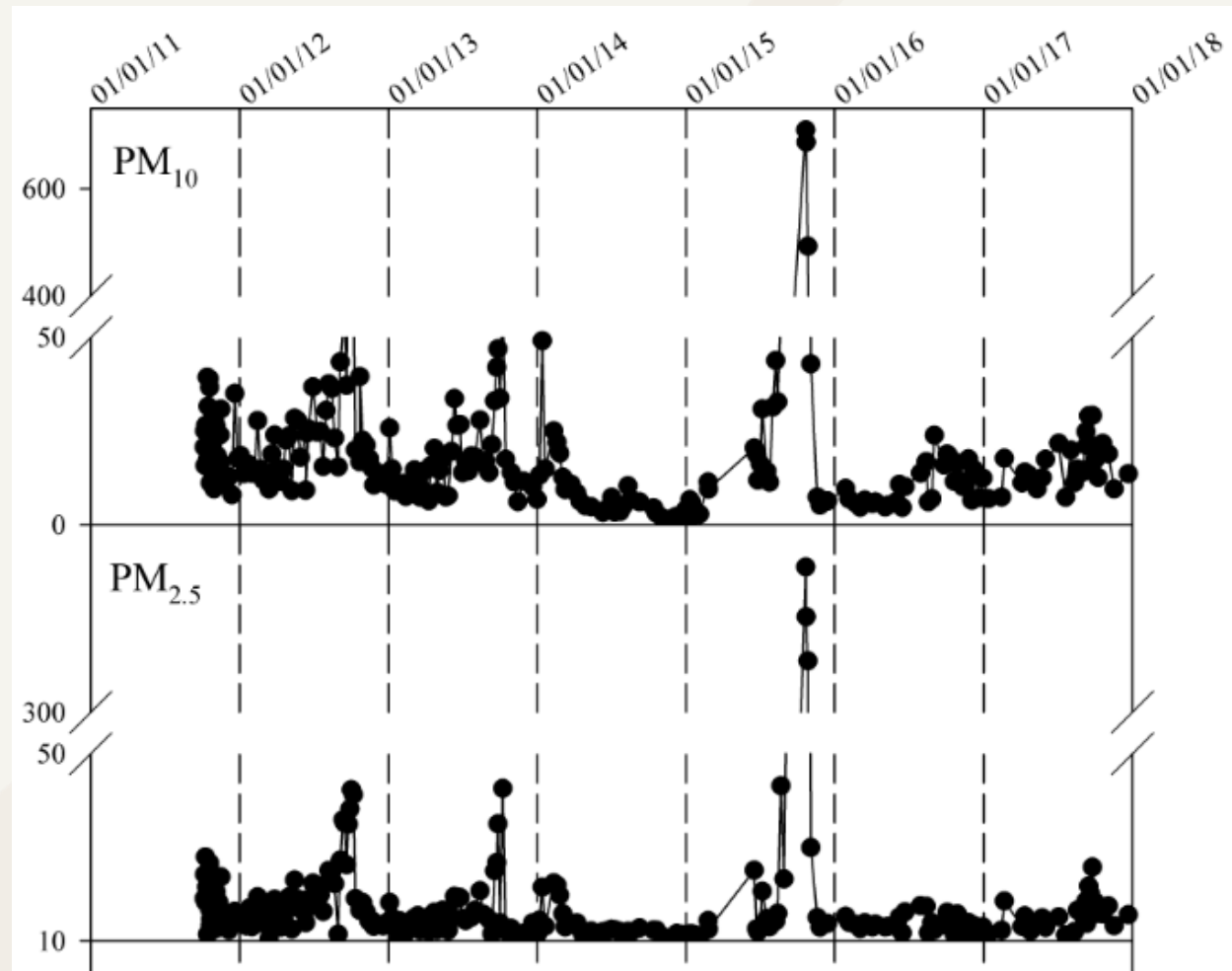




TRANSBOUNDARY POLLUTION

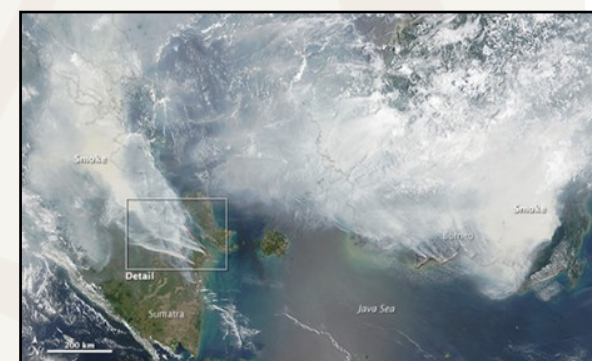
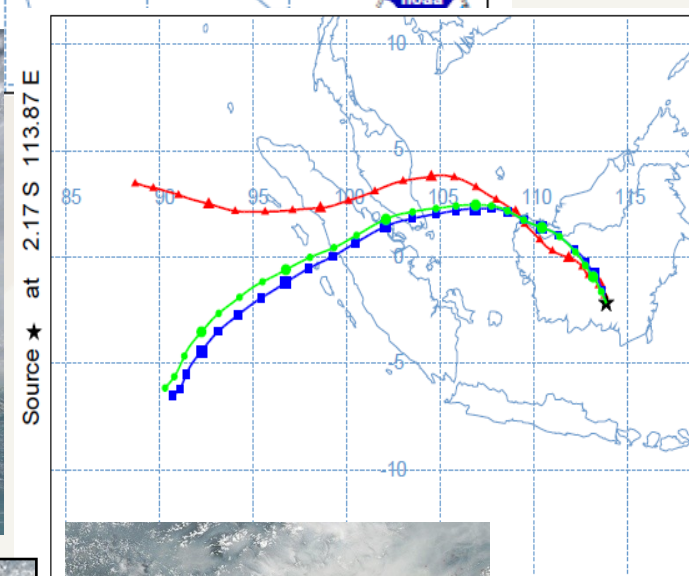
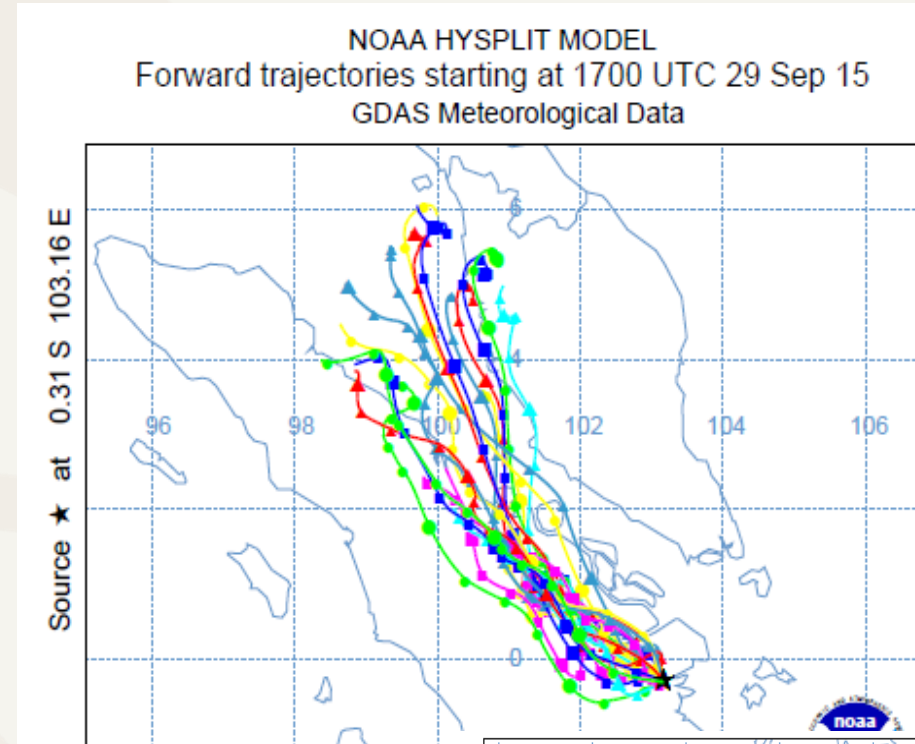


SMOKE FROM PEAT/FOREST FIRES

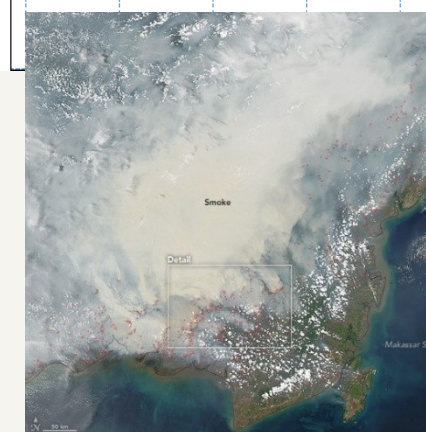


Time series of PM_{2.5} and PM₁₀ in Palangka Raya

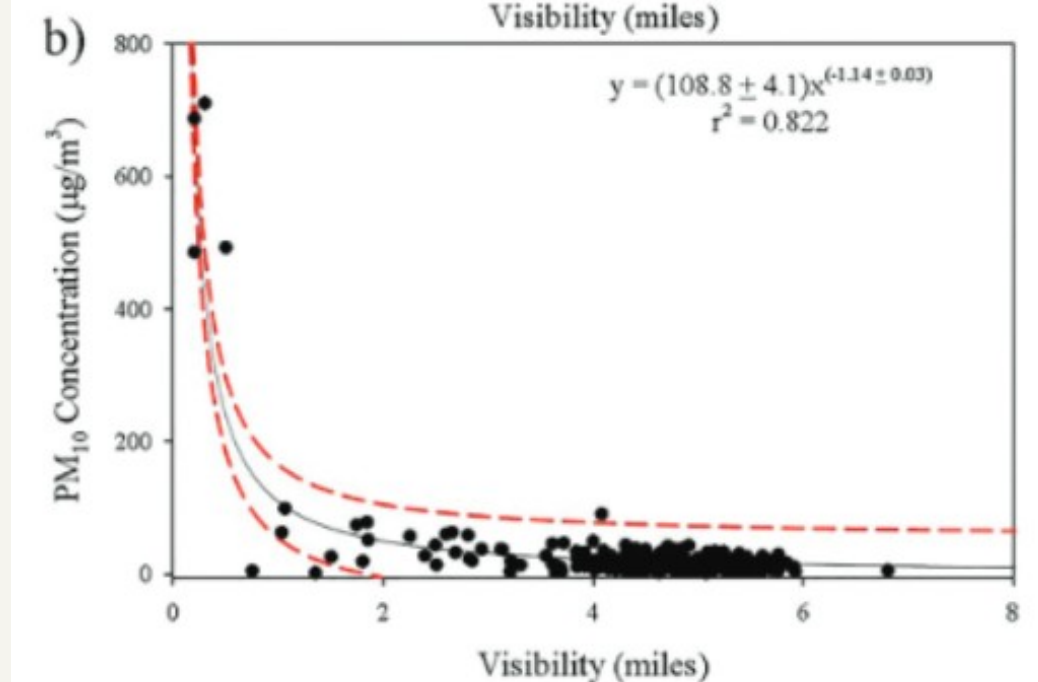
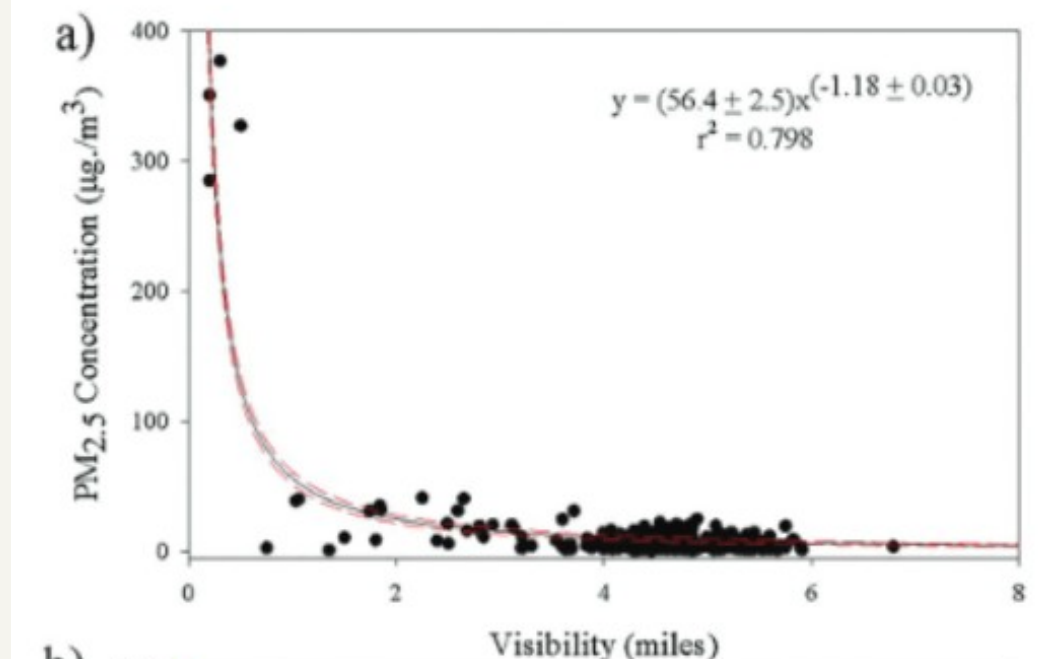
The fires in Indonesia are unlike most other fires, as Sumatra and Kalimantan have large deposits of peat. They are very difficult to extinguish because they smolder under the surface for a long time, even for months.



NASA Earth Observatory/Adam Voiland



PM concentration vs Visibility



Santoso et.al., JAWMA, 2022

SOIL EVENT IN BANDUNG, INDONESIA

Dust Storm struck the Simpsons Desert in Sept 2006

Northern Territory, Australia

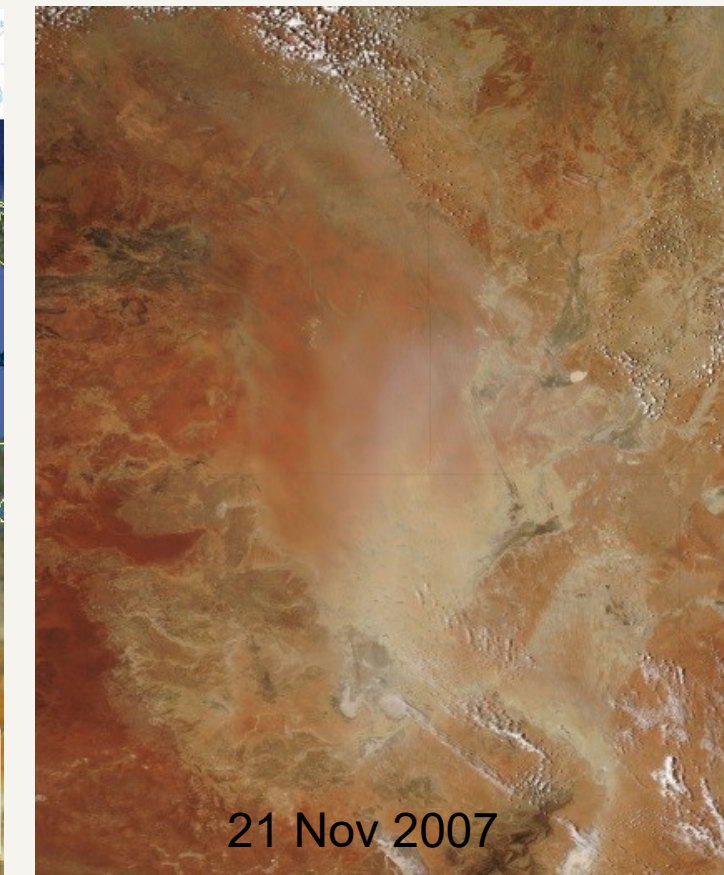
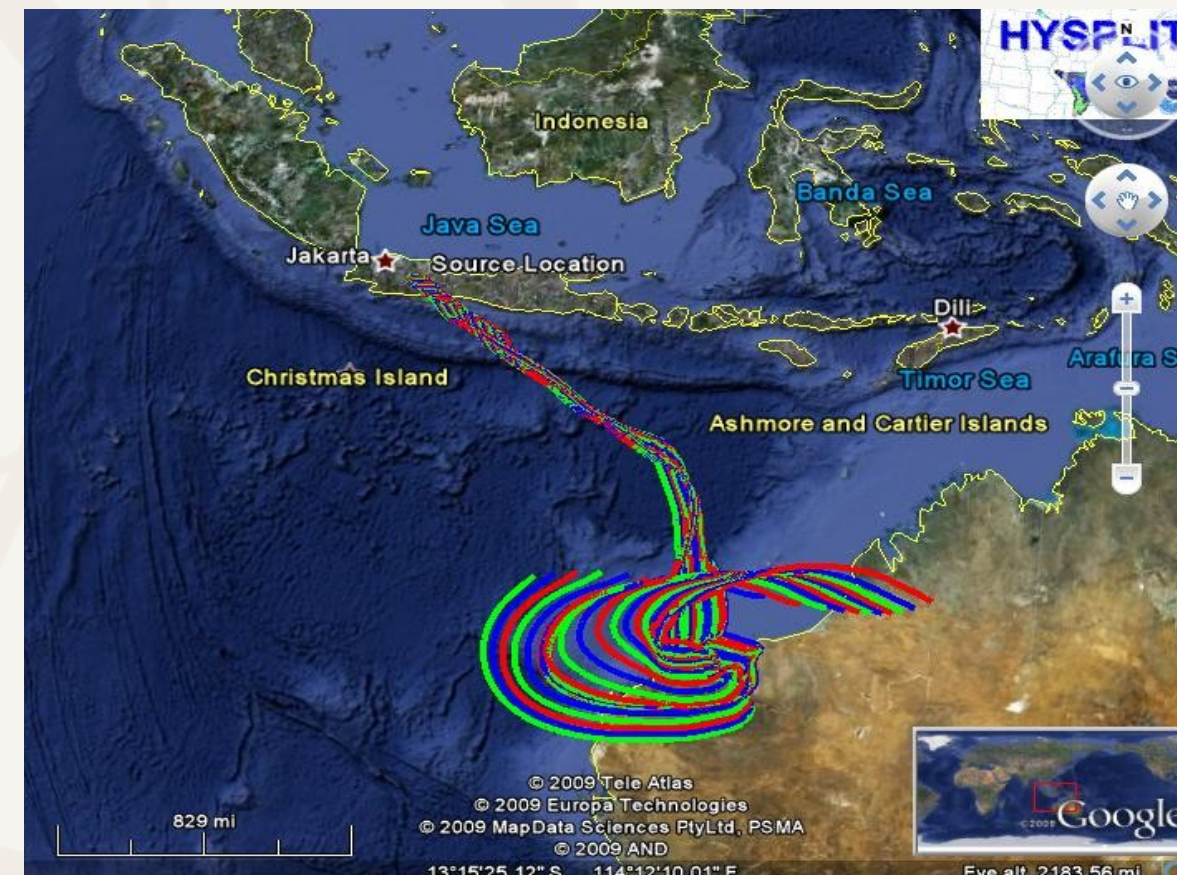
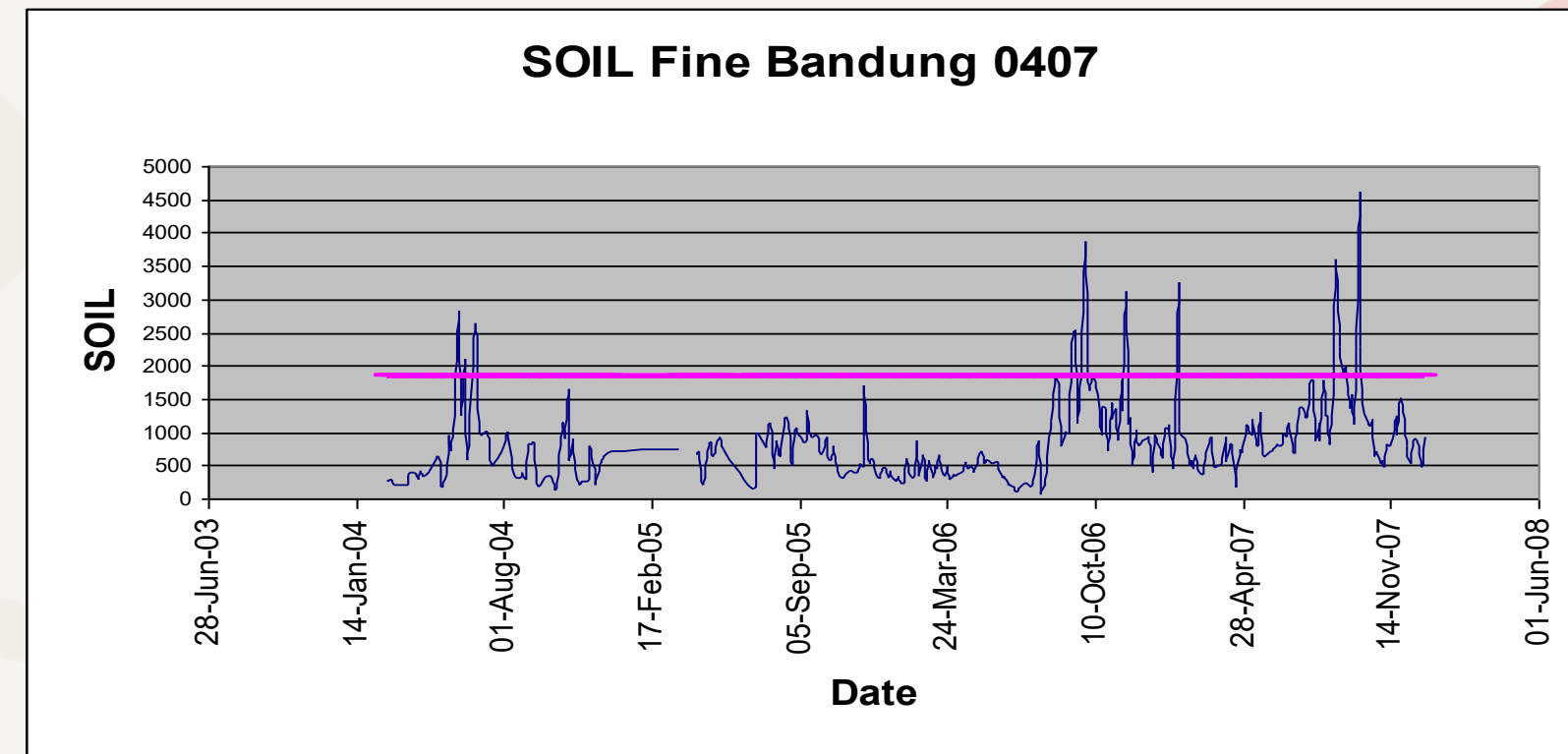
Date NASA : 24 September 2006

Date Data : 26 Sept 2006 (3881 ng/m³)

02 Oct 2007 (4616 ng/m³)

Average + 2SD : 1836 ng/m³

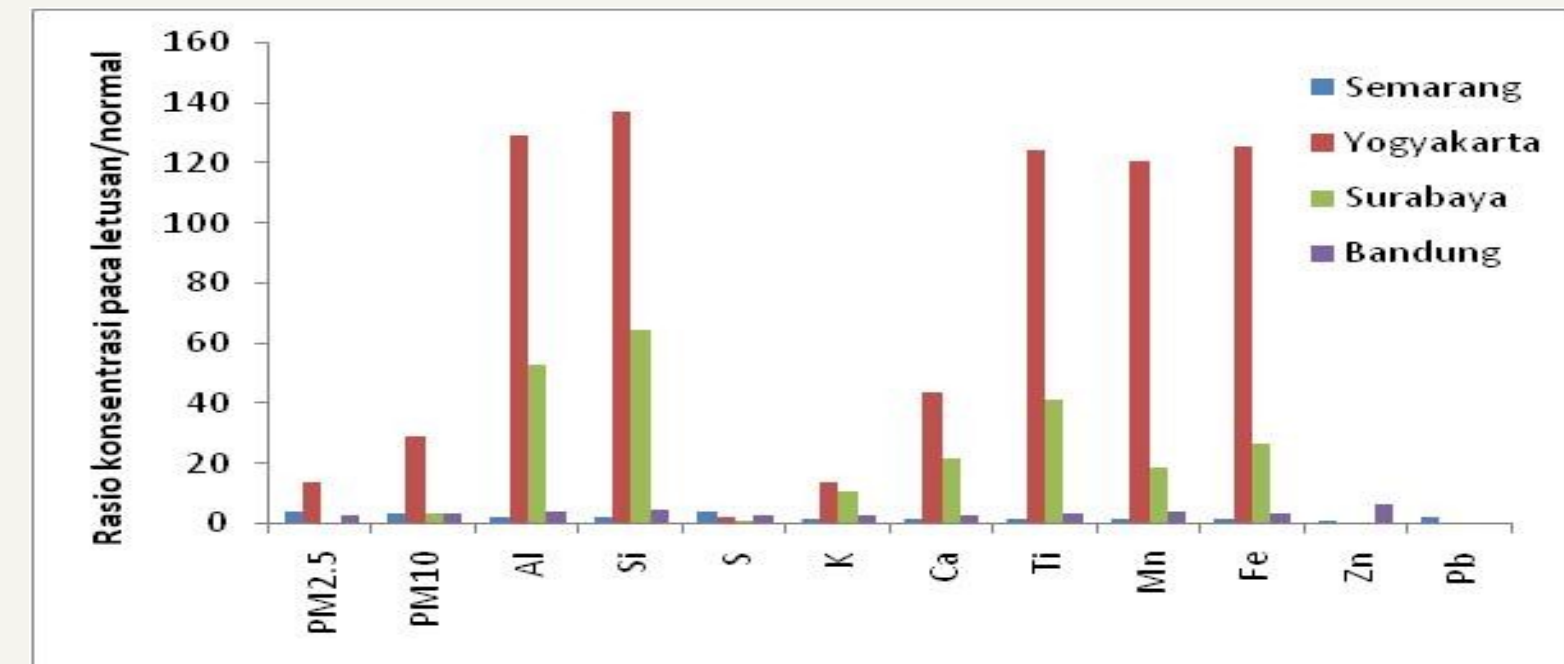
Distance : 2,232 Km



Air Quality During Mount Kelud Eruption



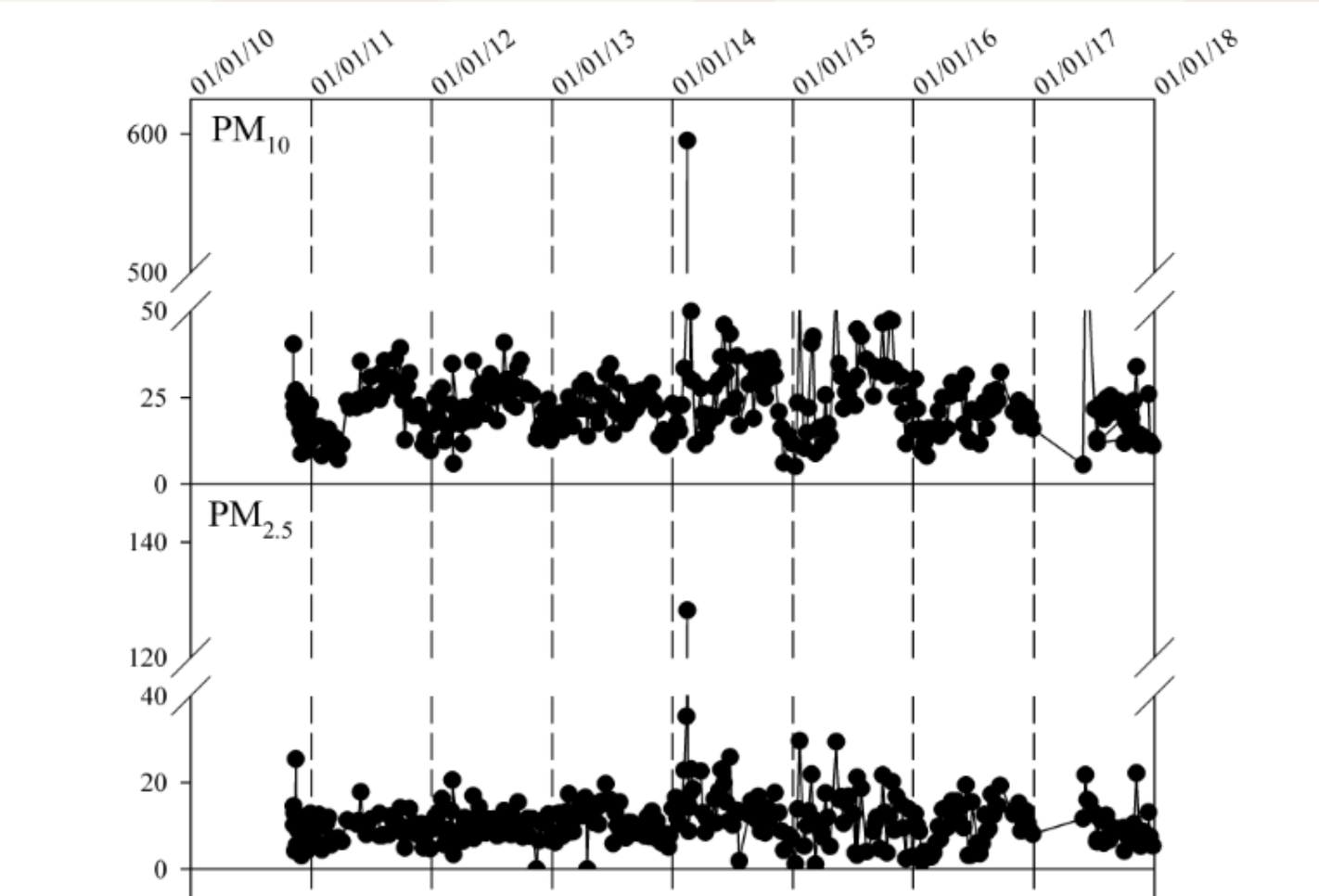
LOKASI (Waktu sampling: 14 Februari 2014)					
Parameter	Satuan	Yogyakarta	Surabaya	Semarang	Bandung
PM2.5	ug/m3	128.2	15.6	60.9 *	35.1
PM10	ug/m3	595.2	114.9	86.9 *	97.7
BC	ug/m3	1.88	2.34	2.91	4.29
Al	ng/m3	4371	628	59.9	199
Si	ng/m3	13809	1775	91.4	404
S	ng/m3	355	288	1468	1814
K	ng/m3	768	160	262	220
Ca	ng/m3	2211	381	45.2	180
Ti	ng/m3	213	30.3	2.03	14.0
Cr	ng/m3	7.20	6.63	7.37	5.83
Mn	ng/m3	69.9	13.5	2.73	12.85
Fe	ng/m3	2185	338	35.8	179
Ni	ng/m3	1.83	1.15	1.96	1.57
Cu	ng/m3	7.41	3.16	0.34	9.14
Zn	ng/m3	17.2	150	42.9	152
Pb	ng/m3	5.7	164	12.3	34.9



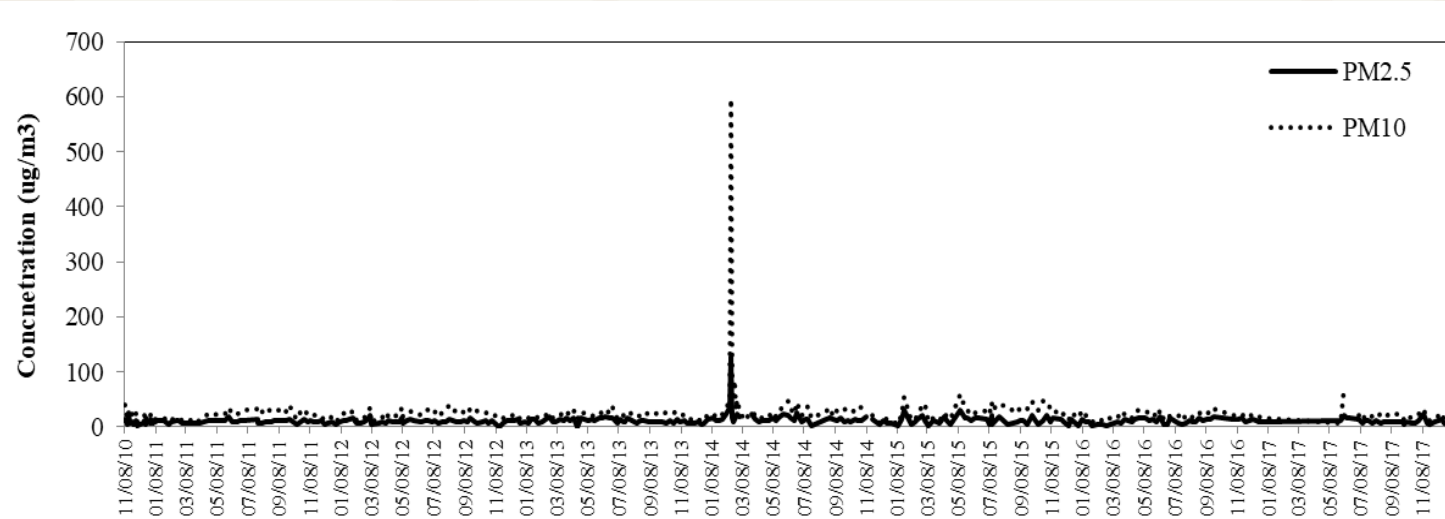
The concentrations during the eruption reached 120 times normal conditions

Kelud eruption in 2014 significantly increased Si concentration in PM_{2.5} to reach 13.8 µg/m³.

Air Quality in Yogyakarta during Mount Kelud Eruption



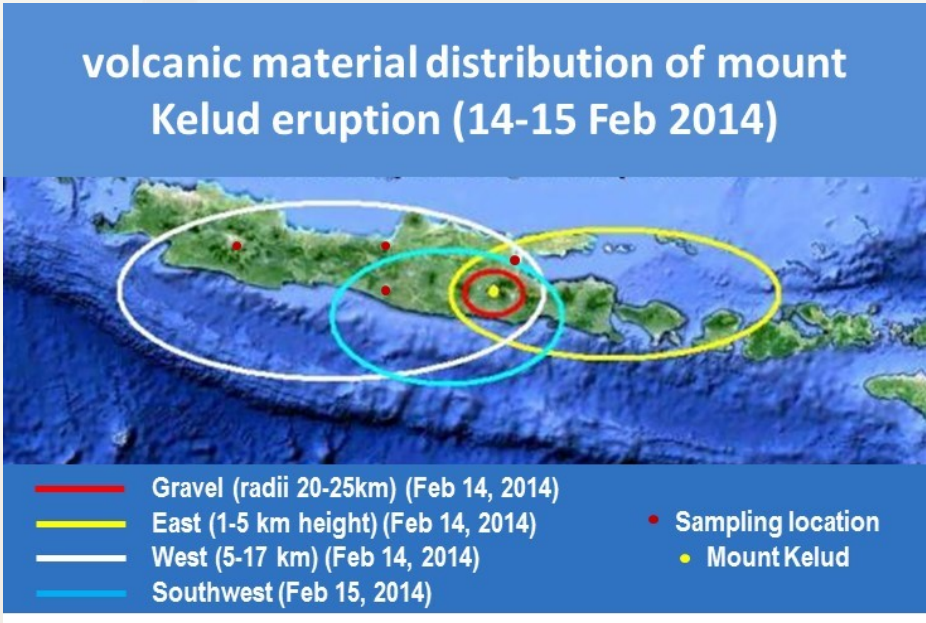
Time series of PM_{2.5} and PM₁₀ in Yogyakarta



Source: Santoso et al., Aerosol and Air Quality Research 2020



Ash fall in Yogyakarta



Volcanic eruptions produced locally high PM_{2.5} concentrations

Conclusion

- Science-based air quality management is essential for implementing action plans.
- The effectiveness of all implemented programs must be measurable and is only valid if pollutant targets and reduction projections can be determined.
- Understanding air pollution sources and the impacts of weather and climate is crucial for formulating appropriate strategies.
- Without source apportionment, air quality policies are ineffective. Air pollution control planning must explicitly link direct interventions to the dominant sources of pollution in the region.
- Each region has its own pollution characteristics related to anthropogenic activities within the region and its surrounding areas.



We need the global and local knowledge and the willingness to do what we can with what we have when we can to make things better





THANK YOU