Compositions and source apportionment of $PM_{2.5}$ during haze and non-haze episodes in Kuala Lumpur, Malaysia and its potential impact to human health

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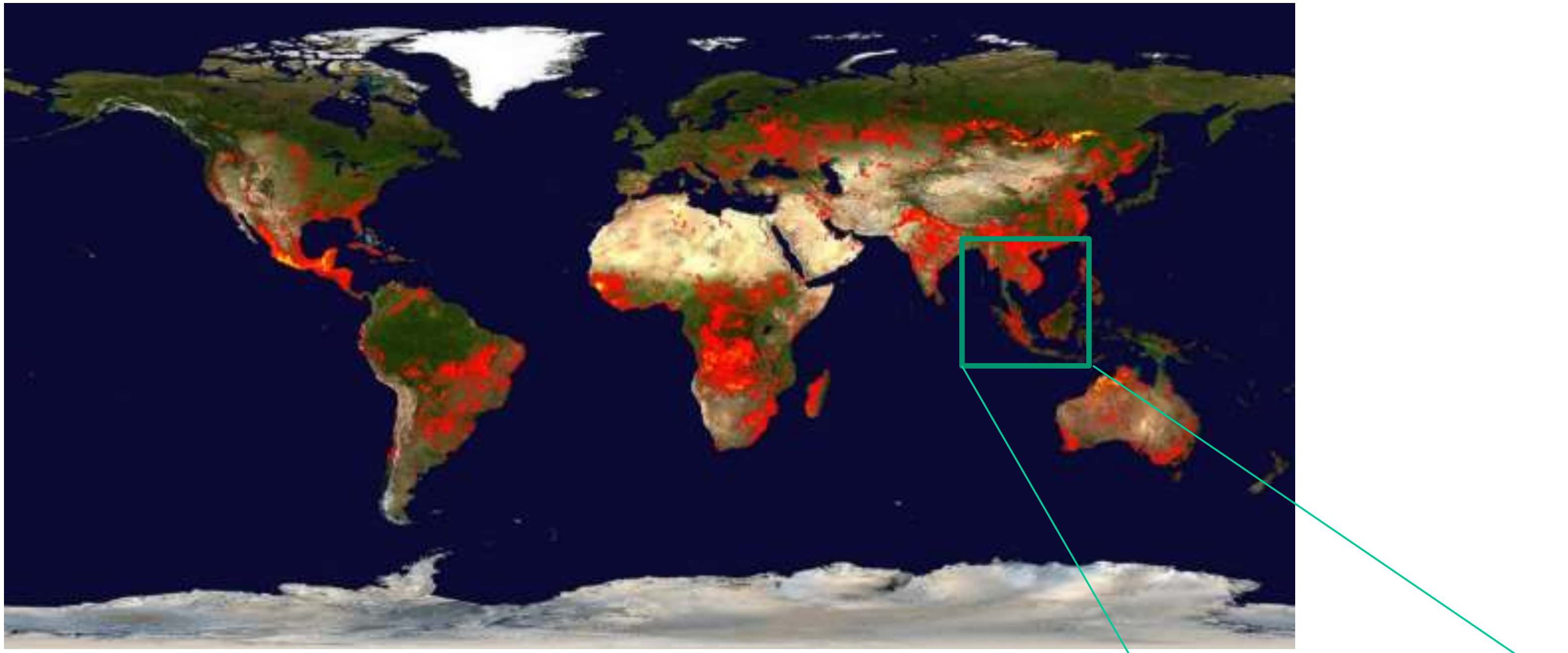
Introduction

Biomass burning in Southeast Asia

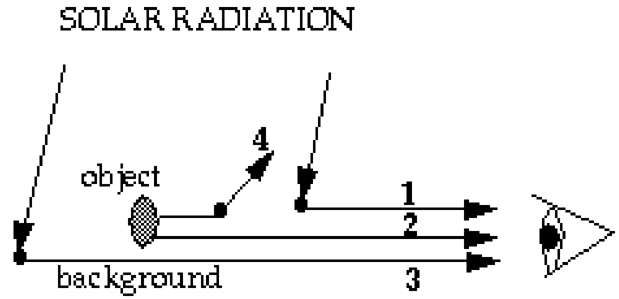


Ichoku and Kahn (2012)

Kuala Lumpur Hazy Condition

(Bernama, Sep 15, 2015)

- $PM_{2.5} \geq 35\ \mu g\ m^{-3}$
- Visibility < 10 km
- Dry/Low humidity



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Biomass Burning from Forest and Peat Soil

Slash and Burn

Deforestation

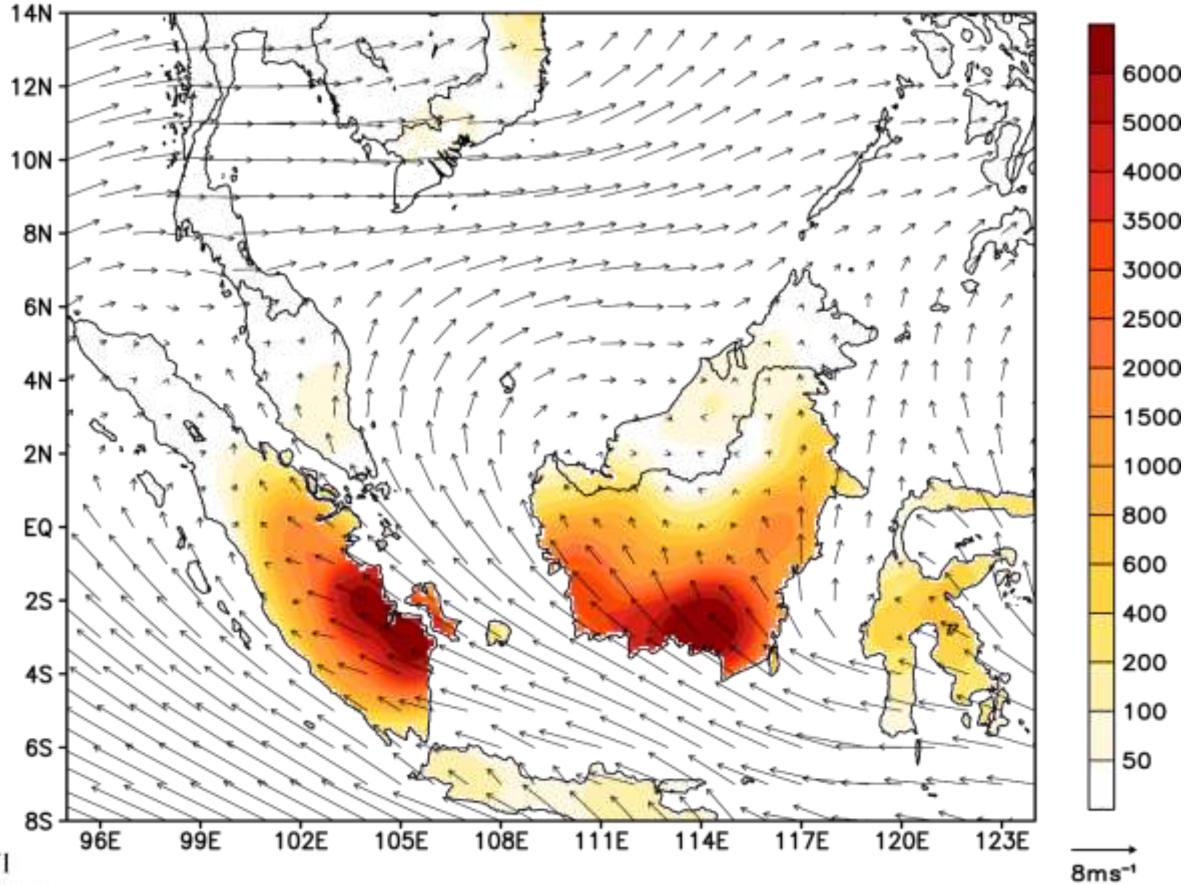
Peat Combustion

Plantation

Haze: Bad new folks! Sumatra hotspots double to 118 on Saturday

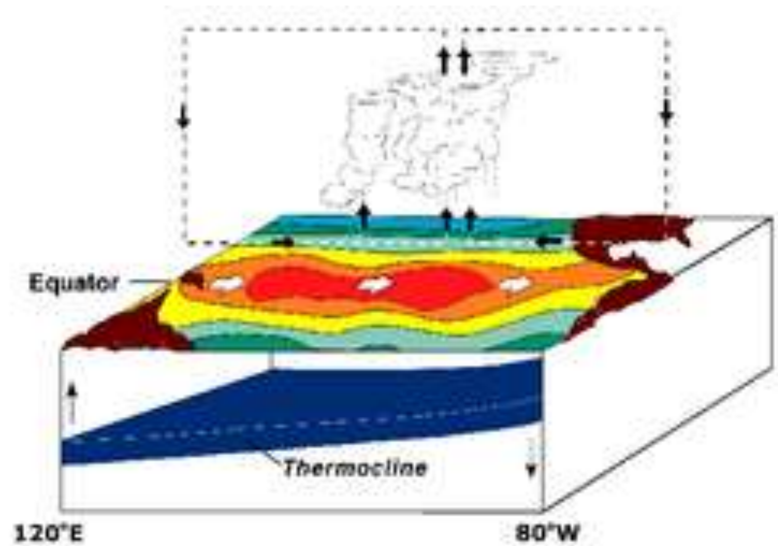
JUNE 23, 2013 BY ADMIN   LEAVE A COMMENT

Wind Direction – Southwest Monsoon

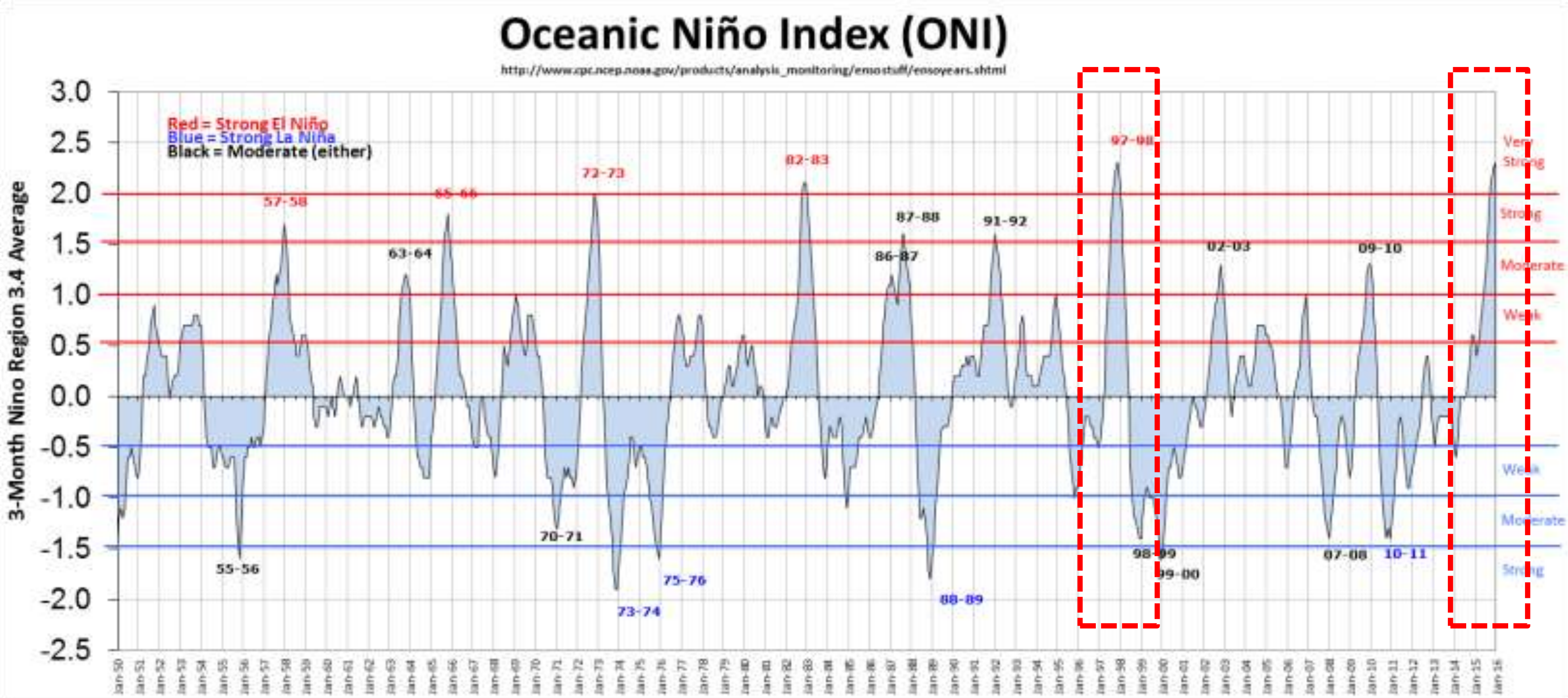


Trigger to Biomass Burning

- El Ni˜no–Southern Oscillation (ENSO) event have repeatedly created conditions that make even rainforest susceptible to wildfires.



El-Niño and La-Niña



Research Objectives

- To determine the concentrations of $PM_{2.5}$ in Kuala Lumpur and its inorganic compositions during pre-haze, haze and post-haze periods.
- To predict the $PM_{2.5}$ concentration transported towards Kuala Lumpur using Numerical Atmospheric-dispersion Modelling Environment (NAME) together with the Global Fire Assimilation System (GFAS).
- To apportion possible sources of $PM_{2.5}$ using Positive Matrix Factorisation (PMF).
- To estimate the carcinogenic and non-carcinogenic health risks among specific age groups during pre-haze, haze and post-haze episodes.

Study Location – Kuala Lumpur Urban Environment

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$PM_{2.5}$ Sampling

- Tisch HVS $PM_{2.5}$
- Flowrate of 1.13 m^3 min^{-1}
- 24 h sampling/filter
- Quartz filter [Whatman QM-A; 8’ X 10’]
- June 2015– January 2016
- Nine samples per month

$PM_{2.5}$ Samples

$PM_{2.5}$ Mass

Microbalance

Major Ions

IC

Trace Metals

ICP-MS

Results Interpretation

Descriptive statistics
Source Apportionment (PMF-MLR)
Health Risk Assessment

Backward Trajectories

- Numerical Atmospheric-dispersion Modelling Environment (NAME), a Lagrangian particle dispersion model, produced by the United Kingdom's Met Office's.

- The backward trajectories started at the latitude-longitude coordinates of the measurement site in Kuala Lumpur within an altitude range of 0 – 100 m and ran for 5 days.

Modelled $PM_{2.5}$ concentration

- Global Fire Assimilation System (GFAS) $PM_{2.5}$ emissions data.
- This dataset relies on fire radiative power (FRP) observations obtained from the Terra and Aqua satellites - Moderate Resolution Imaging Spectroradiometer (MODIS) instruments.
- Combination of emission sensitivities derived from NAME with the GFAS emissions - modelled $PM_{2.5}$ concentration

Modelled $PM_{2.5}$ concentration

- Combination of emission sensitivities derived from NAME with the GFAS emissions - modelled $PM_{2.5}$ concentration

Mass/cubic meter ($\mu g\ m^{-3}$)

= Emission sensitivities ($s\ m^{-1}$) x GFAS emissions ($g\ m^{-2}\ s^{-1}$) x 10^6 ($\mu g\ g^{-1}$)

Source Apportionment of $PM_{2.5}$

- Positive Matrix Factorization (PMF) 5.0 model from the United States Environmental Protection Agency (US EPA).

$$X_{ij} = \sum_{i=1}^{p} g_{ik} f_{kj} + e_{ij}$$

Normalized data

Source profile

Source contribution

Measurement error

Other Air Pollutants and Meteorological Data

- Temperature, rainfall, relative humidity, visibility, wind speed and wind direction (MetMalaysia Petaling Jaya station, 9 km from the sampling station)
- Air Pollution Index (API) data was collected from Malaysian DOE (Batu Muda Station, 6 km from the sampling site)

Carcinogenic Metal Health Risk

Lifetime average daily dose (LADD) ($\mu g kg^{-1} day^{-1}$) = $\frac{C \times IR \times ED \times EF}{BW \times AT}$

C = Concentration of the contaminant in the atmosphere (ng m^{-3}),

IR = inhalation rate (m^3 day^{-1})

ED = exposure duration (years)

EF = exposure frequency (day $year^{-1}$)

BW = body weight (kg)

AT = averaging time (70 years x 365 days).

Excess lifetime cancer risk (ELCR Inhalation)

= LADD × inhalation unit risk ($\mu g\ m^{-3}$)$^{-1}$

Non-Carcinogenic Metal Health Risk

Average daily dose ($mgkg^{-1}day^{-1}$) = $\frac{C \times IR \times ED \times EF}{BW \times AT}$

Hazard quotients (HQ) =ADD/RfC

ADD = average daily dose
RfC = reference concentration

HI = $\sum$ HQ

If the HQ ≤ 1, it is believed that there is no risk of developing non-cancer health effects.
Non-cancer effects may occur if the HQ > 1.
An adverse effect is deemed more likely to occur if the HQ value is larger.

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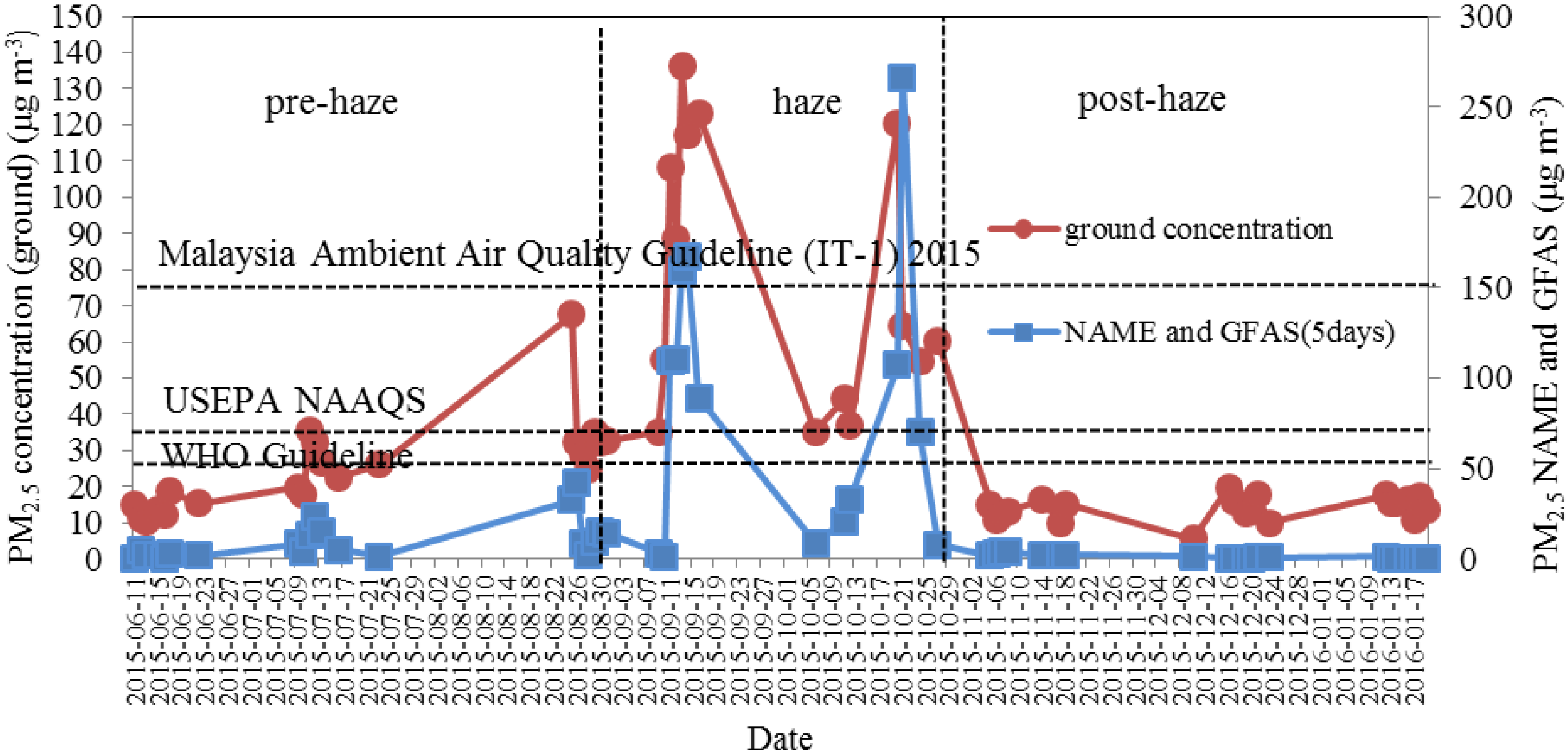
Exposure factors for calculating the exposure dose in health risk assessment

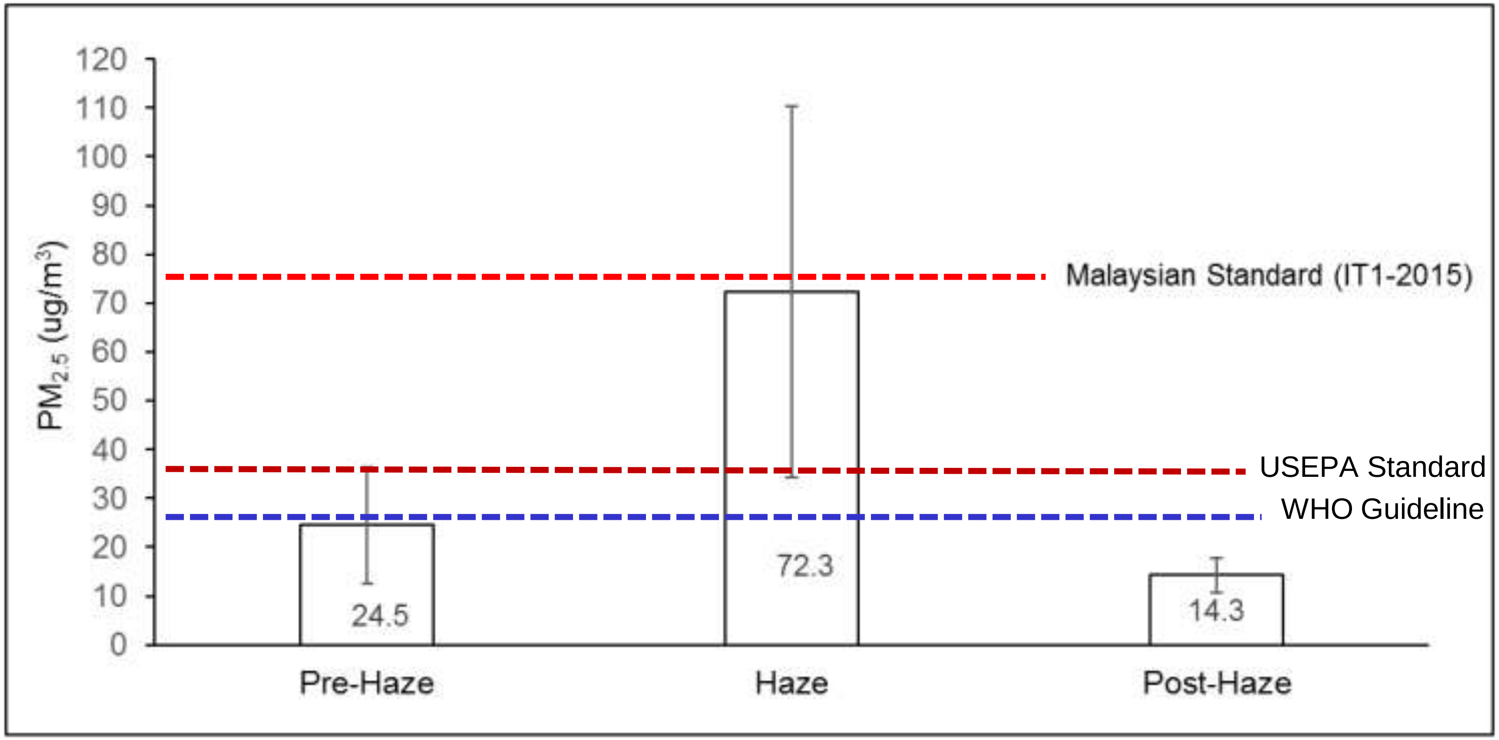
EP	Unit	Infant	Toddler	Children	Adolescent	Adult
		0-<1year	1-<6years	6-<12years	12-<18years	18-<70years
IR	m^3 day^{-1}	5.4	9	12	15.7	15.7
ED	years	1	5	6	6	52
EF	days $year^{-1}$	60[a], 305[b]	60, 305	60, 305	60, 305	60, 305
BW*	kg	7	15	31.2	38	66
AT	years	70**, 1***	70, 5	70, 6	70, 6	70, 52

* Adapted from National Health and Morbidity Survey III 2006 (NHMS III, 2008)
a exposure factors of haze episode
b exposure factors of non-haze episode
** AT for carcinogens (fixed at 70 years of exposure)
*** AT for non-carcinogens (average years of exposure)

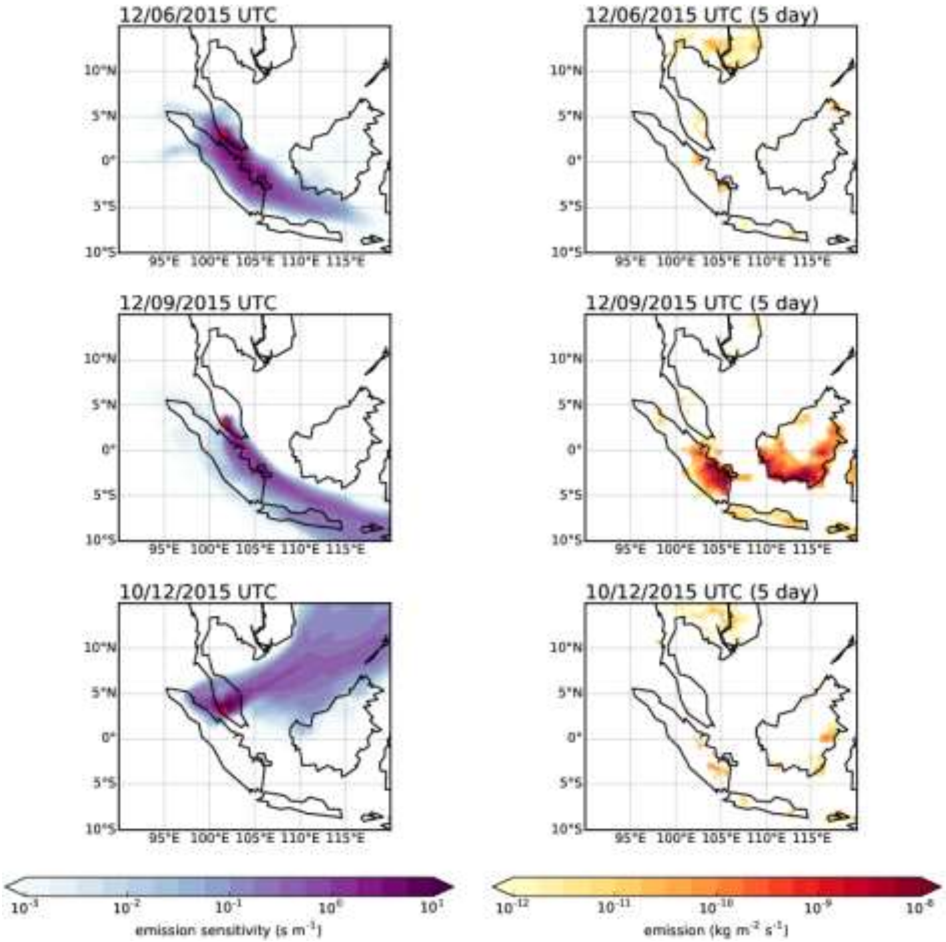
Measured HVS $PM_{2.5}$ vs Predicted NAME-GFAS $PM_{2.5}$



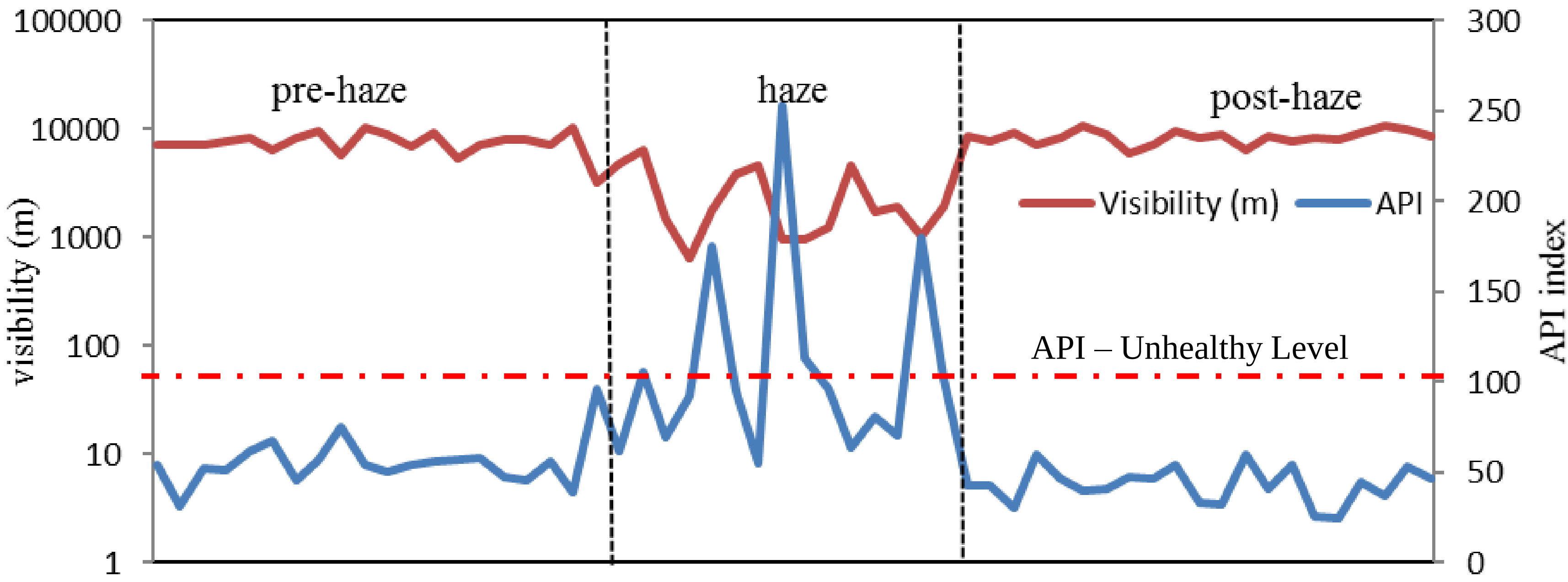
Average $PM_{2.5}$ Concentration



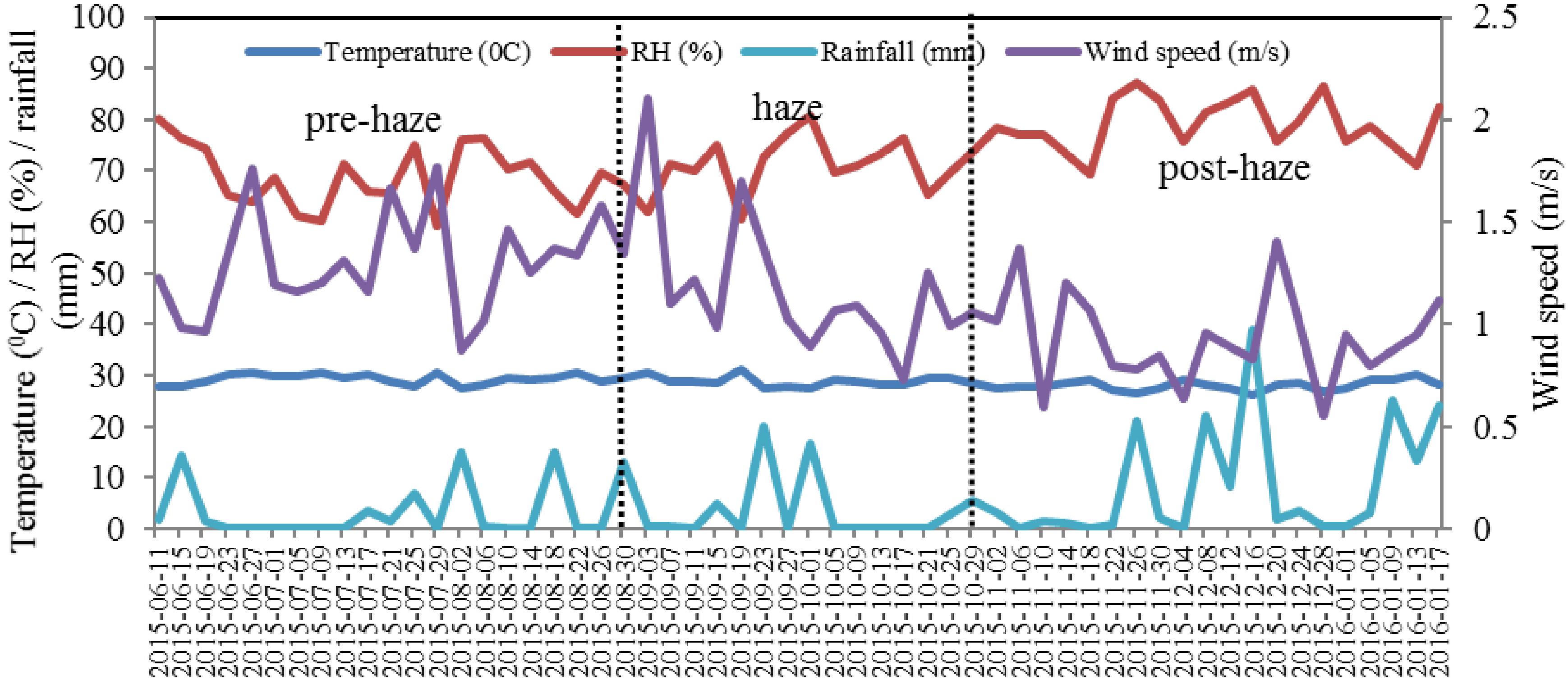
Emission Sensitivity and Emission



Visibility and API Index



Other Meteorological Data



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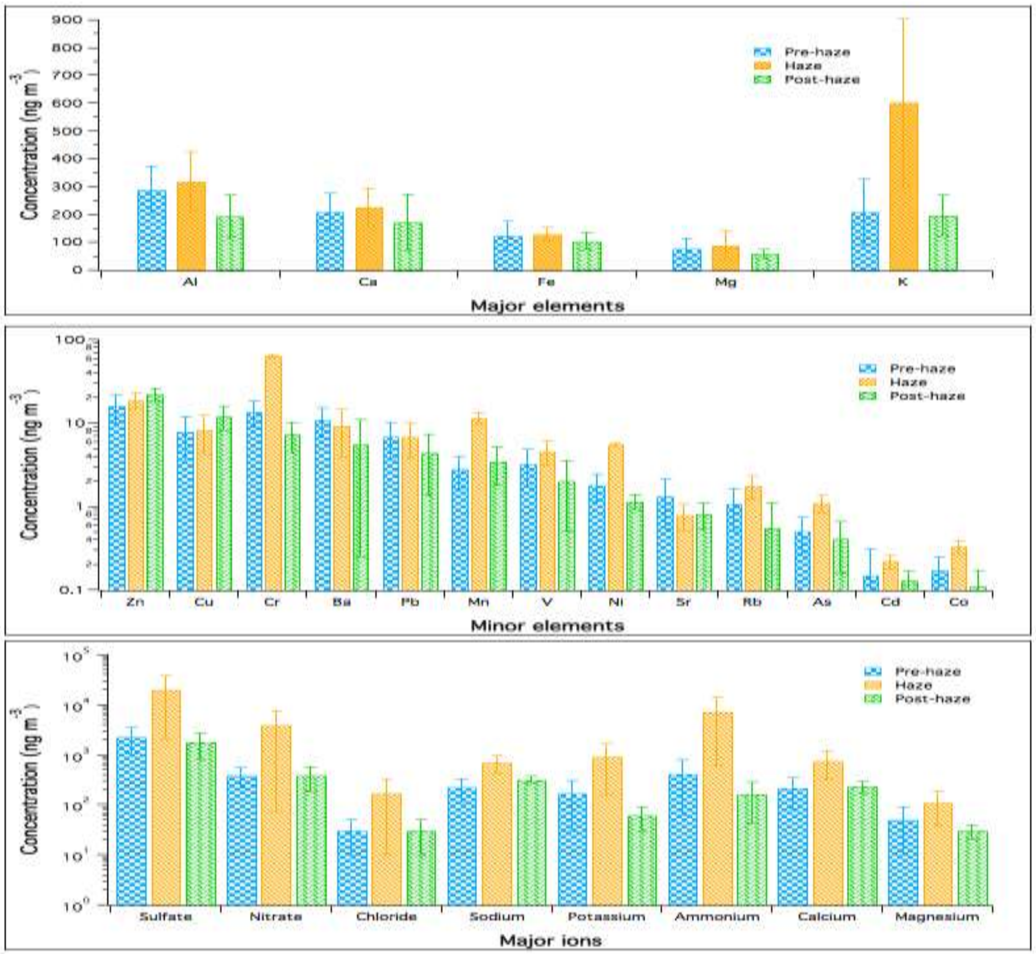
$PM_{2.5}$ Inorganic Composition



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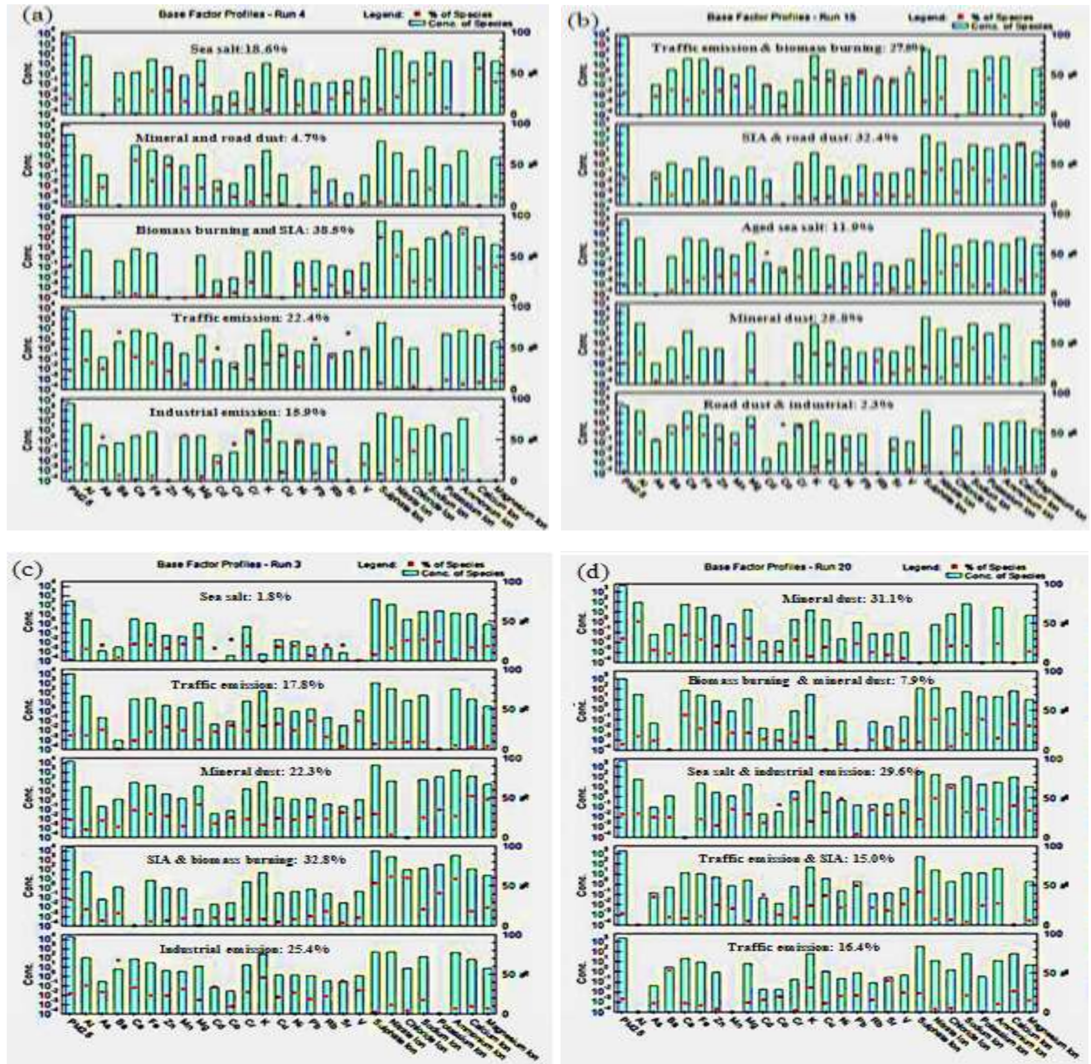
Atmosphere Investigation

Source Apportionment



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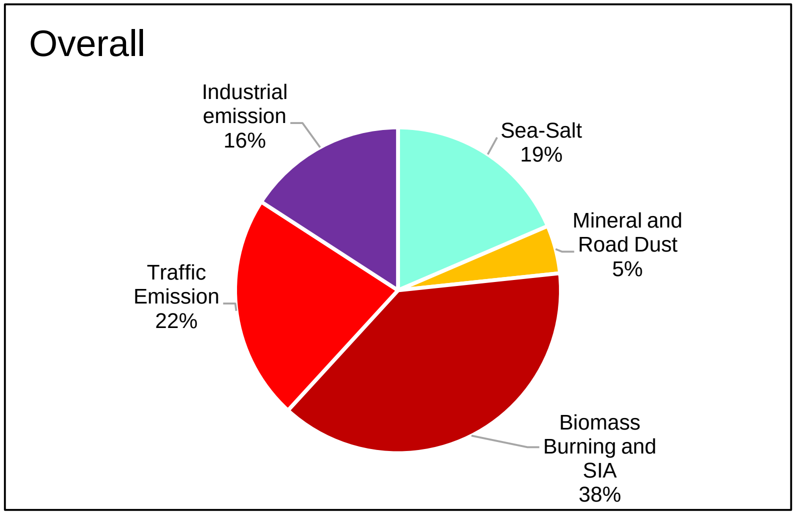
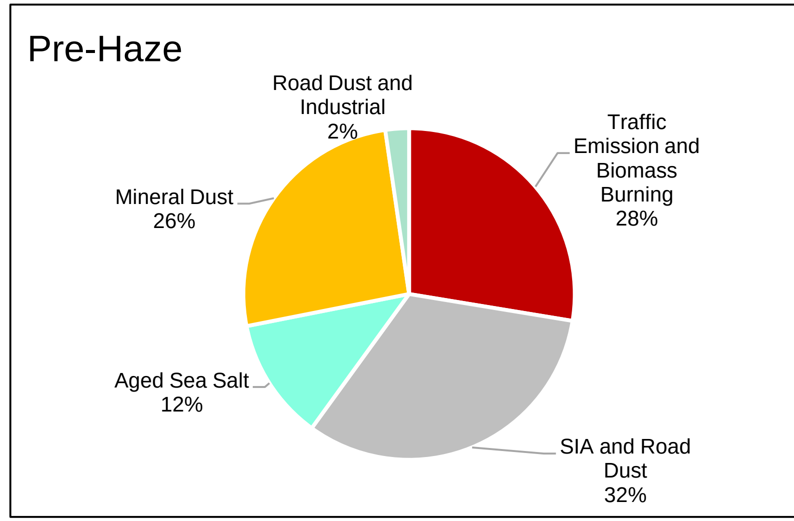
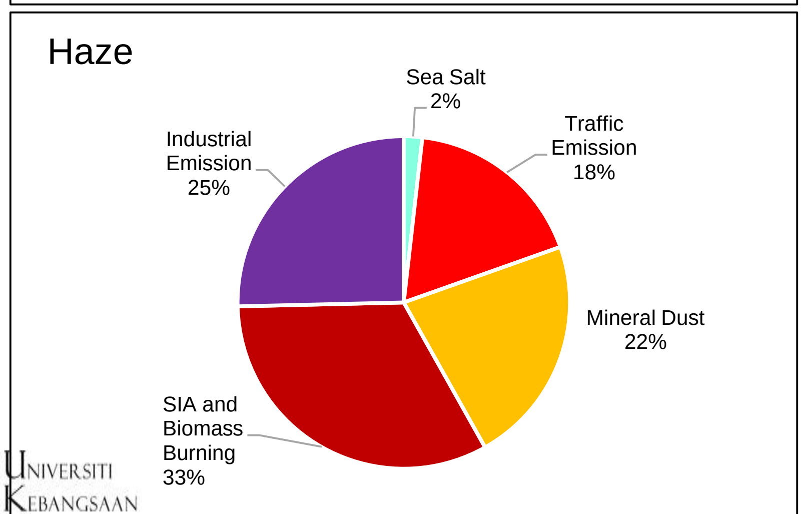
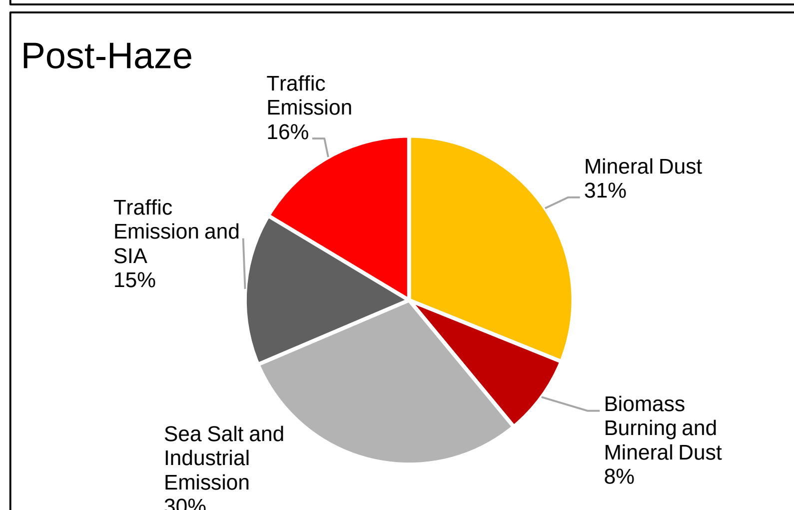
Source Apportionment -Overall







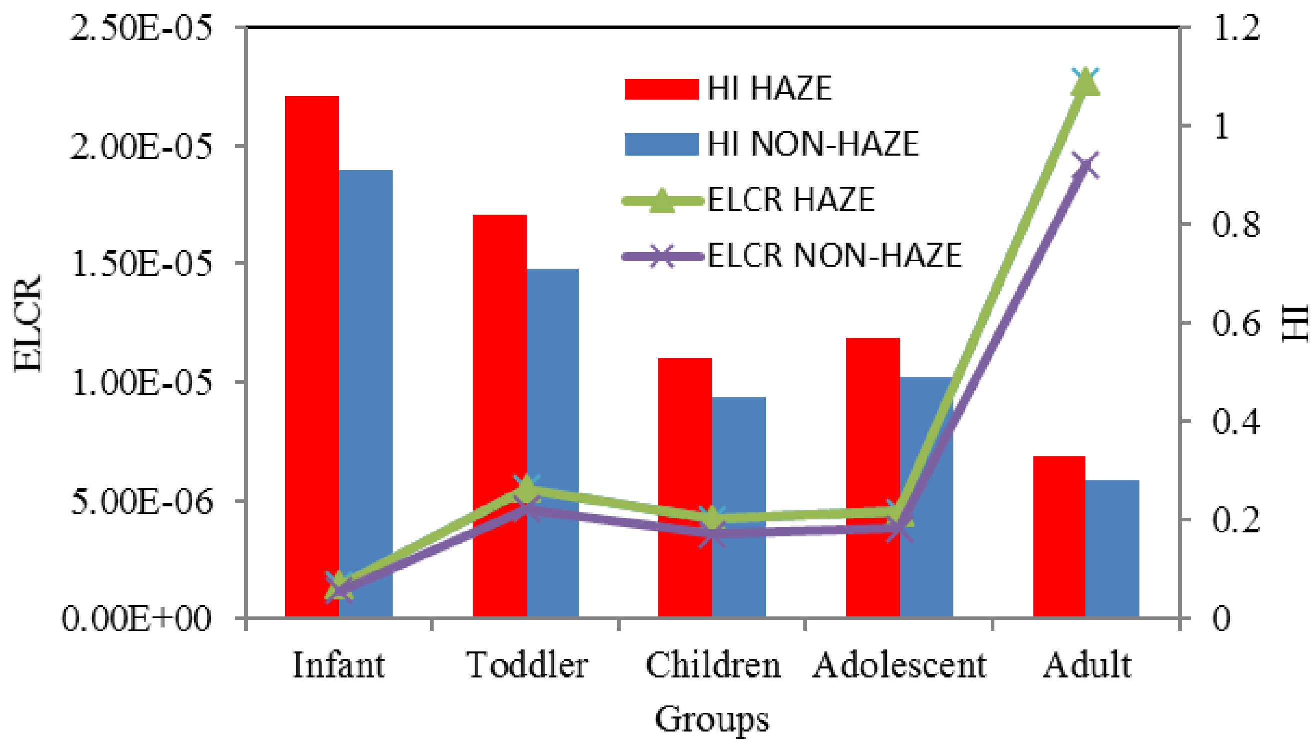


Hazard index (HI) and hazard quotient (HQ)

Elements	RfC (mg m^{-3})	HQ				
		Infant 0-<1year	Toddler 1-<6years	Children 6-<12years	Adolescent 12-<18years	Adult 18-<70years
Pre-haze						
Cr	8.00×10^{-6}	1.10×10^{0}	8.59×10^{-1}	5.50×10^{-1}	5.91×10^{-1}	3.40×10^{-1}
Mn	5.00×10^{-5}	3.60×10^{-2}	2.80×10^{-2}	1.80×10^{-2}	1.93×10^{-2}	1.11×10^{-2}
Ni	2.00×10^{-4}	5.70×10^{-3}	4.46×10^{-3}	2.86×10^{-3}	3.07×10^{-3}	1.77×10^{-3}
Cd	1.00×10^{-5}	9.67×10^{-3}	7.52×10^{-3}	4.82×10^{-3}	5.18×10^{-3}	2.98×10^{-3}
As	5.00×10^{-5}	6.57×10^{-3}	5.11×10^{-3}	3.28×10^{-3}	3.52×10^{-3}	2.03×10^{-3}
∑HI		1.16	0.90	0.58	0.62	0.36
Haze						
Cr	8.00×10^{-6}	1.02×10^{0}	7.93×10^{-1}	5.08×10^{-1}	5.46×10^{-1}	3.14×10^{-1}
Mn	5.00×10^{-5}	2.94×10^{-2}	2.29×10^{-2}	1.47×10^{-2}	1.58×10^{-2}	9.07×10^{-3}
Ni	2.00×10^{-4}	3.51×10^{-3}	2.73×10^{-3}	1.75×10^{-3}	1.88×10^{-3}	1.08×10^{-3}
Cd	1.00×10^{-5}	2.79×10^{-3}	2.17×10^{-3}	1.39×10^{-3}	1.49×10^{-3}	8.60×10^{-4}
As	5.00×10^{-5}	2.81×10^{-3}	2.19×10^{-3}	1.40×10^{-3}	1.51×10^{-3}	8.68×10^{-4}
∑HI		1.06	0.82	0.53	0.57	0.33
Post-haze						
Cr	8.00×10^{-6}	5.87×10^{-1}	4.57×10^{-1}	2.93×10^{-1}	3.15×10^{-1}	1.81×10^{-1}
Mn	5.00×10^{-5}	4.53×10^{-2}	3.52×10^{-2}	2.26×10^{-2}	2.42×10^{-2}	1.40×10^{-2}
Ni	2.00×10^{-4}	3.67×10^{-3}	2.86×10^{-3}	1.83×10^{-3}	1.97×10^{-3}	1.13×10^{-3}
Cd	1.00×10^{-5}	8.38×10^{-3}	6.52×10^{-3}	4.18×10^{-3}	4.49×10^{-3}	2.58×10^{-3}
As	5.00×10^{-5}	5.29×10^{-3}	4.11×10^{-3}	2.63×10^{-3}	2.83×10^{-3}	1.63×10^{-3}
∑HI		0.65	0.51	0.32	0.35	0.20
∑HI	Haze	1.06	0.82	0.53	0.57	0.33
∑HI	Non-haze*	0.91	0.71	0.45	0.49	0.28

Excess lifetime cancer risks (ELCR) of carcinogenic

Elements	IUR $(\mu g\ m^{-3})^{-1}$	Excess lifetime cancer risk $(\mu g\ m^{-3})^{-1}$ Infant 0-<1year	Toddler 1-<6years	Children 6-<12years	Adolescent 12-<18years	Adult 18-<70years
Pre-haze						
Pb	1.20×10^{-5}	7.53×10^{-10}	2.93×10^{-9}	2.25×10^{-9}	2.42×10^{-9}	1.21×10^{-8}
Cd	1.80×10^{-3}	2.49×10^{-9}	9.67×10^{-9}	7.44×10^{-9}	8.00×10^{-9}	4.00×10^{-8}
Cr	1.20×10^{-2}	1.51×10^{-6}	5.89×10^{-6}	4.53×10^{-6}	4.86×10^{-6}	2.43×10^{-5}
Ni	2.40×10^{-4}	3.93×10^{-9}	1.53×10^{-8}	1.18×10^{-8}	1.26×10^{-8}	6.31×10^{-8}
As	4.30×10^{-3}	2.02×10^{-8}	7.85×10^{-8}	6.04×10^{-8}	6.49×10^{-8}	3.24×10^{-7}
Co	9.00×10^{-3}	1.41×10^{-8}	5.48×10^{-8}	4.22×10^{-8}	4.53×10^{-8}	2.26×10^{-7}
∑		1.56×10^{-6}	6.05×10^{-6}	4.65×10^{-6}	5.00×10^{-6}	2.49×10^{-5}
Haze						
Pb	1.20×10^{-5}	1.50×10^{-10}	5.83×10^{-10}	4.49×10^{-10}	4.82×10^{-10}	2.41×10^{-9}
Cd	1.80×10^{-3}	7.17×10^{-10}	2.79×10^{-9}	2.15×10^{-9}	2.31×10^{-9}	1.15×10^{-8}
Cr	1.20×10^{-2}	1.40×10^{-6}	5.44×10^{-6}	4.18×10^{-6}	4.49×10^{-6}	2.24×10^{-5}
Ni	2.40×10^{-4}	2.41×10^{-9}	9.37×10^{-9}	7.21×10^{-9}	7.74×10^{-9}	3.86×10^{-8}
As	4.30×10^{-3}	8.65×10^{-9}	3.36×10^{-8}	2.59×10^{-8}	2.78×10^{-8}	1.39×10^{-7}
Co	9.00×10^{-3}	5.38×10^{-9}	2.09×10^{-8}	1.61×10^{-8}	1.73×10^{-8}	8.63×10^{-8}
∑		1.42×10^{-6}	5.50×10^{6}	4.23×10^{-6}	4.55×10^{-6}	2.27×10^{-5}
Post-haze						
Pb	1.20×10^{-5}	4.91×10^{-10}	1.91×10^{-9}	1.47×10^{-9}	1.58×10^{-9}	7.87×10^{-9}
Cd	1.80×10^{-3}	2.15×10^{-9}	8.38×10^{-9}	6.45×10^{-9}	6.92×10^{-9}	3.46×10^{-8}
Cr	1.20×10^{-2}	8.06×10^{-7}	3.13×10^{-6}	2.41×10^{-6}	2.59×10^{-6}	1.29×10^{-5}
Ni	2.40×10^{-4}	2.52×10^{-9}	9.80×10^{-9}	7.54×10^{-9}	8.10×10^{-9}	4.04×10^{-8}
As	4.30×10^{-3}	1.62×10^{-8}	6.31×10^{-8}	4.86×10^{-8}	5.22×10^{-8}	2.60×10^{-7}
Co	9.00×10^{-3}	8.29×10^{-9}	3.22×10^{-8}	2.48×10^{-8}	2.66×10^{-8}	1.33×10^{-7}
∑		8.35×10^{-7}	3.25×10^{-6}	2.50×10^{-6}	2.68×10^{-6}	1.34×10^{-5}
∑ ELCR	Haze	1.42×10^{-6}	5.50×10^{-6}	4.23×10^{-6}	4.55×10^{-6}	2.27×10^{-5}
∑ ELCR	Non-haze*	1.20×10^{-6}	4.65×10^{-6}	3.58×10^{-6}	3.84×10^{-6}	1.92×10^{-5}


2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
ELCR
1.2
1
0.8
0.6
0.4
0.2
0
HI
HI HAZE
HI NON-HAZE
ELCR HAZE
ELCR NON-HAZE
Infant
Toddler
Children
Adolescent
Adult
Groups

Conclusion

- $PM_{2.5}$ mass collected during pre-haze (24.5±12.0 µg m^{-3}), haze (72.3±38.0 µg m^{-3}), and post-haze (14.3±3.58 µg m^{-3} events in Kuala Lumpur were significantly different ($p < 0.005$). The highest concentration of $PM_{2.5}$ during haze episode - 5 times higher than WHO guidelines
- The SIA (SO_4^{2-}, NO_3^- and NH_4^+) dominated the composition of $PM_{2.5}$ - contribute to 43% inorganic composition of $PM_{2.5}$ mass during haze compared to pre-haze and post-haze, where they only contributed 12% and 16%, respectively.
- The non-carcinogenic health risk assessment - infant group faced more significant health risk than the other age groups during haze (HI = 1.06).
- The carcinogenic health risk assessment - adult group is the most affected group for haze exposure (ECLR= 2.27×10^{-5})

Further information…

Sulong, N. A., Latif, M. T., Khan, M. F., Amil, N., Ashfold, M. J., Wahab, M. I. A., Chan, K. M., and Sahani, M. (2017). Source apportionment and health risk assessment among specific age groups during haze and non-haze episodes in Kuala Lumpur, Malaysia. *Science of The Total Environment* 601–602, 556-570

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THANK YOU