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Source apportionment and health risk assessment among specific age groups during haze and non-haze episodes in Kuala Lumpur, Malaysia

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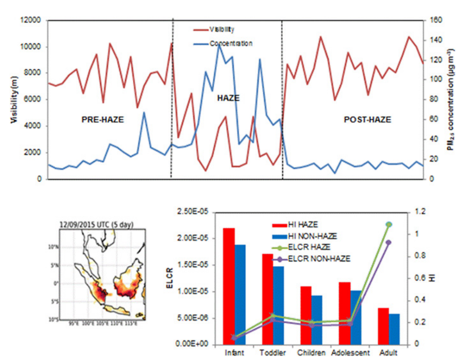
HIGHLIGHTS

- $PM_{2.5}$ concentrations during haze periods were 3–5 times higher than non-haze.
- Secondary inorganic aerosols dominated the compositions of $PM_{2.5}$ during haze.
- NAME model and GFAS indicate fire emissions from Sumatera, Indonesia.
- Biomass burning and traffic emission are main sources of $PM_{2.5}$.
- Carcinogenic and non-carcinogenic health risk affects adult and infant the most.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to determine $PM_{2.5}$ concentrations and their composition during haze and non-haze episodes in Kuala Lumpur. In order to investigate the origin of the measured air masses, the Numerical Atmospheric-dispersion Modelling Environment (NAME) and Global Fire Assimilation System (GFAS) were applied. Source apportionment of $PM_{2.5}$ was determined using Positive Matrix Factorization (PMF). The carcinogenic and non-carcinogenic health risks were estimated using the United State Environmental Protection Agency (USEPA) method. $PM_{2.5}$ samples were collected from the centre of the city using a high-volume air sampler (HVS). The results showed that the mean $PM_{2.5}$ concentrations collected during pre-haze, haze and post-haze periods were 24.5 ± 12.0 µg m^{-3}, 72.3 ± 38.0 µg m^{-3} and 14.3 ± 3.58 µg m^{-3}, respectively. The highest concentration of $PM_{2.5}$ during haze episode was five times higher than World Health Organisation (WHO) guidelines. Inorganic compositions of $PM_{2.5}$, including trace elements and water soluble ions were determined using inductively coupled plasma-mass spectrometry (ICP-MS) and ion chromatography (IC), respectively. The major trace elements identified were K, Al, Ca, Mg and Fe which accounted for approximately 93%, 91% and 92% of the overall metals' portions recorded during pre-haze, haze and post-haze periods, respectively. For water-soluble ions, secondary inorganic aerosols (SO_4^{2-}, NO_3^- and NH_4^+) contributed around 12%, 43% and 16% of the overall $PM_{2.5}$ mass

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during pre-haze, haze and post-haze periods, respectively. During haze periods, the predominant source identified using PMF was secondary inorganic aerosol (SIA) and biomass burning where the NAME simulations indicate the importance of fires in Sumatra, Indonesia. The main source during pre-haze and post-haze were mix SIA and road dust as well as mineral dust, respectively. The highest non-carcinogenic health risk during haze episode was estimated among the infant group (HI = 1.06) while the highest carcinogenic health risk was estimated among the adult group (2.27×10^{-5}).

1. Introduction

Smoke-haze episodes in Southeast Asia (SEA) occur almost every year (Nichol, 1998; See et al., 2006). Haze is defined as low visibility condition (<10 km) where the human eye's ability to differentiate between objects and the surroundings becomes restricted (Sun et al., 2006; Tan et al., 2009). Thick smoke-induced haze has enveloped SEA regions, most notably Malaysia, Singapore, Indonesia and Thailand, as a result of recurrent slash-and-burn agricultural activities (Betha et al., 2013). Biomass burning, particularly within peat soil areas in Sumatra and Kalimantan, Indonesia, contributes to high emissions of fine particles and atmospheric gases into the atmosphere (Abas, 2004; Heil and Goldammer, 2001; Muraleedharan et al., 2000; Zhao et al., 2013). Chemical interactions between primary gases, organic substances and particles contribute to high levels of secondary aerosols along the trajectories from the burning areas (Beringer et al., 2003; Heil and Goldammer, 2001; Koe et al., 2001; Rastogi et al., 2014). A previous study has shown that transboundary haze episodes in Malaysia are not caused by external sources alone but are in fact exacerbated by local emissions (Afroz et al., 2003) in addition to El-Niño's Southern Oscillation (ENSO) phenomenon which prolongs the dry season (Aiken, 2004; Jones, 2006; Juneng and Tangang, 2005). Meanwhile for non-haze periods, vehicular emissions have been found to account for over 30% of the total $PM_{2.5}$ emissions in the urban areas of the Klang Valley (Rahman et al., 2011).

A detailed understanding of the sources of particulate matter (PM) is essential if PM pollution is to be effectively controlled and managed. The receptor models which are often used for source apportionment analysis are principal component analysis-multiple linear regression (PCA-MLR) (Thurston and Spengler, 1985), chemical mass balance (CMB) (Watson et al., 2001), positive matrix factorization (PMF) (Paatero, 1997) and Unmix model (Lewis et al., 2003). In Malaysia, $PM_{2.5}$ and source apportionment studies during non-haze period have been carried out by Khan et al. (2016a, 2016b) using the PMF method where motor vehicle emissions coupled with biomass burning were identified as the predominant source in a suburban area. Another study undertaken by Amil et al. (2016) used PMF to apportion sources in the urban-industrial environment of Petaling Jaya, Malaysia during haze and non-haze periods where the main source during haze was secondary inorganic aerosols (SIA) coupled with biomass burning. In a source apportionment study carried out by Rahman et al. (2015), PMF was also applied in order to apportion $PM_{2.5}$ in an urban area of the Klang Valley, Malaysia and listed vehicle emissions as the primary source of haze events. Ee-Ling et al. (2015) determined the sources of $PM_{2.5}$ using PCA-MLR and revealed the predominant sources in Kuala Lumpur, Malaysia, as motor vehicles and soil dust. In Singapore, Balasubramanian et al. (2003) performed PCA and listed soil dust, industrial factors, biomass burning and automobile emissions, sea salt and oil combustion as the factors contributing to $PM_{2.5}$ aerosols.

Haze occurrences have often been associated with adverse health effects. A study conducted by Nasir et al. (2000) claimed that 285,227 asthma attacks, 3889 cases of chronic bronchitis in adults, 118,804 cases of bronchitis in children, 2003 respiratory hospital admissions and 26,864 emergency room visits were reported during the 1997 haze episode in Malaysia. Another study by Brauer and Hisham-Hashim (1998) revealed that there was a significant increase in hospital admissions for asthmatic and other respiratory-related problems during regional smoke-haze episodes in SEA. In addition, a study by Sahani et al. (2014) revealed that there were significant associations between haze events and natural and respiratory mortality. The most important issue to be addressed during haze periods is consequently public health concerns, especially those relating to population which have been classified as "sensitive", for example, children (below 12 years old), the elderly (senior citizens) as well as immunocompromised persons (Afroz et al., 2003). Through health risk assessments, the nature and magnitude of these health risks can be characterized. In Malaysia, Khan et al. (2016a) successfully conducted health risk assessment on $PM_{2.5}$ aerosol collected from a suburban area. The results of which demonstrated that the non-carcinogenic health risk was at a safe level while the lifetime cancer risk was slightly above the acceptable level.

Malaysia experienced deterioration in air quality between September and October 2015. This was due to a transboundary haze episode which originated from Sumatra and Kalimantan, Indonesia and was transported by a south-westerly wind. 34 out of 52 stations throughout the country recorded an Air Pollutant Index (API) of over 200 (unhealthy) on 15 September 2015, which was the worst haze day recorded (DOE, 2015). This study aims to determine the concentrations of $PM_{2.5}$ in Kuala Lumpur and its inorganic compositions (trace elements and water-soluble ions) during pre-haze, haze and post-haze periods. Numerical Atmospheric-dispersion Modelling Environment (NAME) together with the Global Fire Assimilation System (GFAS) was used to examine how $PM_{2.5}$ emitted by fires in the region was transported towards Kuala Lumpur. The PMF method was used to apportion possible sources of $PM_{2.5}$ with these three different periods. This study also estimated the carcinogenic and non-carcinogenic health risks among specific age groups during pre-haze, haze and post-haze episodes. The quantitative estimation of carcinogenic and non-carcinogenic health risks will highlight the need to effectively control and manage the sources of $PM_{2.5}$.

2. Materials and methods

2.1. Study area

The sampling took place in the middle of Kuala Lumpur city centre (3° 8′ 20.4108″ N, 101° 41′ 12.678″ E, 56 m above sea level). The $PM_{2.5}$ aerosol sampling was conducted on the rooftop (30 m above ground level) of a building within the compound of Universiti Kebangsaan Malaysia Kuala Lumpur's campus which is located on Raja Muda Abdul Aziz Road, Kuala Lumpur. Kuala Lumpur itself is Malaysia's capital city. It is located within the Klang Valley and situated in the middle of the west coast of the Malaysian Peninsula. In 2015, Kuala Lumpur had an estimated population of 1.78 million people in an area of just 243 km^2 with an average annual population growth rate of 2.4% (DOSM, 2016). The sampling site was 10, 30 and 40 m away from three congested roads in Kuala Lumpur city centre, namely: Chow Kit Road, Raja Muda Abdul Aziz Road and Pahang Road, respectively. The sampling site can be considered as an urban background site with influence by traffic emissions. Supplementary 1 shows the location of the sampling site.

2.2. $PM_{2.5}$ field campaign

Taking into account the history of haze episodes in Malaysia which predominantly occur during the southwest monsoon (i.e. June–