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Research article

Health risk assessment of heavy metals in atmospheric deposition in a congested city environment in a developing country: Kandy City, Sri Lanka

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A B S T R A C T

This research study which was undertaken in a congested city environment in a developing country provides a robust approach for the assessment and management of human health risk associated with atmospheric heavy metals. The case study area was Kandy City, which is the second largest city in Sri Lanka and bears the characteristics of a typical city in the developing world such as the urban footprint, high population density and traffic congestion. Atmospheric deposition samples were collected on a weekly basis and analyzed for nine heavy metals common to urban environments, namely, Al, Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb. Health risk was assessed using hazard quotient (HQ) and hazard index (HI), while the cancer risk was evaluated based on life time daily cancer risk. Al and Fe were found to be in relatively high concentrations due to the influence of both, natural and anthropogenic sources. High Zn loads were attributed to vehicular emissions and the wide use of Zn coated building materials. Contamination factor and geo-accumulation index showed that currently, Al and Fe are at uncontaminated levels and other metals are in the range of uncontaminated to contaminated levels, but with the potential to exacerbate in the long-term. The health risk assessment showed that the influence of the three exposure pathways were in the order of ingestion > dermal contact > inhalation. The HQ and HI values for children for the nine heavy metals were higher than that for adults, indicating that children may be subjected to potentially higher health risk than adults. The study methodology and outcomes provide fundamental knowledge to regulatory authorities to determine appropriate mitigation measures in relation to HM pollution in city environments in the developing world, where to-date only very limited research has been undertaken.

1. Introduction

Atmospheric pollution is a serious problem in most cities around the world as it has a direct impact on human and ecosystem health (Gunawardena et al., 2013b). Among the various atmospheric pollutants, particulates are of significant concern because of their association with other chemical and microbial pollutants (Amodio et al., 2014; Anatolaki and Tsitouridou, 2007; Huang et al., 2009; Weerasundara et al., 2017). The atmospheric particulates can be either natural or anthropogenic in origin (Bermudez et al., 2012; Soriano et al., 2012). Natural atmospheric particulates primarily originate from roadside soil due to wind and vehicle related turbulence (Shi et al., 2008; Weerasundara et al., 2017), while anthropogenic particulates are generated by industrial activities, agricultural activities, domestic emissions, as well as automobile activities such as vehicle exhaust, tyre wear, brake wear and road pavement wear (Soriano et al., 2012; Wei and Yang, 2010; Liu et al.,

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2018). These particulates are removed from the atmosphere through wet (precipitation scavenging) and dry deposition processes by turbulent vertical transport (Connan et al., 2013).

Heavy Metals (HMs) attached to atmospheric particulates are considered as a potential threat to human health as these can be inhaled, ingested and/or contacted via dermal pathway and accumulate in the fatty tissues and affect the central nervous system, or may act as cofactors in diseases (Huang et al., 2014; Lu et al., 2014; Ma et al., 2017). Potential sources of metals in the atmosphere are primarily vehicular and industrial activities (Connan et al., 2013; Weerasundara et al., 2017). Being non-degradable, significant levels of HMs can threaten the ecosystem through stormwater pollution (Gunawardena et al., 2013a; Ma et al., 2016). Past literature on atmospheric deposition has primarily focused on the concentration, distribution and source identification (Connan et al., 2013; Egodawatta et al., 2013; Soriano et al., 2012; Wei et al., 2009). Only limited studies have focused on the assessment of their potential health risks, despite health risk assessment being an essential foundation of risk management (Wei et al., 2015).

In Kandy, Sri Lanka, atmospheric pollution has become a serious issue during the past decade (Ileperuma, 2010). As Kandy is the second largest city in Sri Lanka, it can exert significant influence on the Country's economy. More than ten schools are located in the heart of the highly congested Kandy City. Children have increased vulnerability to atmospheric particulates due to the nature of their daily activities (USEPA, 2008). Kandy also has religious and historical importance and is listed as a UNESCO World Heritage City. Therefore, Kandy attracts a large number of local visitors, and foreign tourists, who could be affected by the polluted atmosphere. Kandy bears the characteristics of a typical city in the developing world such as high population density and traffic congestion. The major pollution source in the City is attributed vehicular emissions as industrial activities are very limited within the metropolitan area. A study undertaken in 2011 (Wickramasinghe et al., 2011), confirmed a daily traffic volume of 106,000 vehicles within the Kandy City limits. It is also important to note that this traffic volume is confined to a relatively limited land area of 4 km^2 (Wickramasinghe et al., 2011). Additionally, a transient population of about 100,000 visit the City on a daily basis, resulting in a total population of more than 250,000 (Wickramasinghe et al., 2011).

Studies have been undertaken to assess atmospheric pollution through atmospheric deposition (Duan and Tan, 2013; El-Araby et al., 2011; Huang et al., 2014). Studies on atmospheric deposition of HMs and related risk assessments are limited in the context of a typical city in a developing country, particularly in the Sri Lankan context. This study was conducted to assess the human health impacts posed by HMs associated with atmospheric deposition in Kandy City and its environs. The study results provide important information to regulatory authorities to determine appropriate mitigation measures in relation to HM pollution of Kandy City atmosphere.

2. Materials and methods

2.1. Study area and sampling sites

Kandy is located at approximately 500 m above mean sea level. The average day time ambient temperature is in the range of 28–32 °C, monthly rainfall is in the range of 52–398 mm and the daytime relative humidity is in the range of 63–83%. The City is located in a valley surrounded by mountains, facilitating thermal inversions within the city atmosphere. Kandy is 26 km^2 in extent with a permanent population of more than 170,000 and a daily transient population of around 100,000 (Wickramasinghe et al., 2011). The City has four main entry points and the high daily traffic flow and the limited land area as noted above, results in high traffic congestion and exceptionally high vehicular emissions (Wickramasinghe et al., 2011).

The sampling sites were spread around Kandy and its environs. Nine sampling sites were selected considering different traffic characteristics. These sites were designated as Children's Park Station (C), Dodanwela site (D), Fire Brigade Station (F), National Institute of Fundamental Studies (I), Lewalla (L), Police Station (P), Railway Station (R), Trinity college site (TC), and Tea Research Institute (TRI) (Fig. S1). Sites C, F, P, R, and TC are in high traffic volume areas, while sites D and I are in low traffic volume areas. Sites L and TRI were selected as control sites as these two sites are located away from arterial roads and have relatively low vehicular and other anthropogenic activities.

2.1.1. Sample collection

Atmospheric deposition samples were collected weekly as dry deposition. The samplers were constructed using high density polyethylene bottles with polyethylene funnels, connected to a star picket bar, and fixed at a height of 1.5 m above ground to minimize contamination from re-suspended particles. The sample collection system was previously described by Weerasundara et al. (2017). Prior to installation, the sampling bottles and funnels were washed with deionized water followed by an acid wash with 1:1 HNO_3 solution as part of the quality assurance measures. At the end of each sample collection, sample bottles and funnels were replaced. After collection, the funnels were enclosed in clean plastic bags and sealed to avoid contamination. Sample bottles were also sealed and transported to the laboratory immediately following standard quality control procedures. The dry deposition samples were collected on a weekly basis and the sample collection was undertaken for ten weeks (ten dry deposition samples). The samples affected by rainfall were discarded.

2.2. Laboratory analysis of heavy metals in atmospheric deposition

After the samples were brought to the laboratory, the funnels and bottles were washed with autoclaved deionized water in order to transfer samples to polyethylene bottles. The samples were stored at 4 °C temperature under >2 pH until laboratory analysis was carried out. The preserved 50 mL samples were digested with 1:1 HCl and 1:1 HNO_3 acid solutions, in a water bath at a temperature of <80 °C until the volume reached 20 mL (USEPA, 1994). The HM concentrations were determined according to Method 200.8 (USEPA, 1994) using an Agilent 8800 Triple Quadruple Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The quality assurance and quality control (QA/QC) samples were prepared and tested as specified in US EPA Method 200.8 (USEPA, 1994).

2.3. Contamination assessment

Metal concentration in a given environment is influenced by a range of factors such as the nature of the substrate, environmental conditions, availability of pollution sources, and distance from emission sources (Nobi et al., 2010). Contamination factor (CF) is a tool that can be used to determine the pollution status of a given environment over a period of time (Nobi et al., 2010; Varol, 2011). Using Eq. (1), CF was calculated to determine whether a particular site is polluted with HMs (Nobi et al., 2010; Varol, 2011).

$$CF = \frac{C_n}{B_n} \qquad (1)$$

where, C_n is the concentration of contaminant in dust, and B_n is the background concentration for the particular contaminant.