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Microorganisms and heavy metals associated with atmospheric deposition in a congested urban environment of a developing country: Sri Lanka

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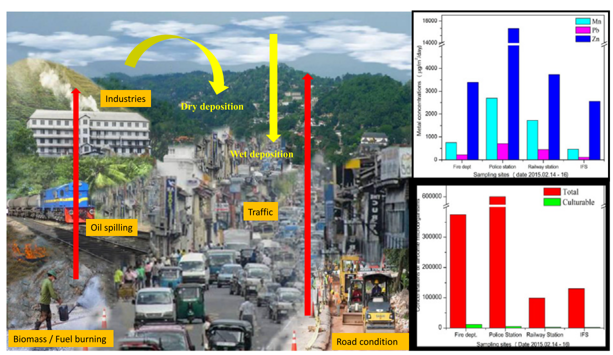
HIGHLIGHTS

- Nine bacterial species were identified, six Gram-negative and three Gram-positive.
- Al and Fe, geogenic in origin and may be re-deposited by vehicular traffic.
- High Cr, Mn, Ni, Cu, Cd and Pb are traffic influenced, galvanized roofs release Zn.
- Bacteria and heavy metals in deposition create human and ecosystem health risks.

GRAPHICAL ABSTRACT



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ABSTRACT

The presence of bacteria and heavy metals in atmospheric deposition were investigated in Kandy, Sri Lanka, which is a typical city in the developing world with significant traffic congestion. Atmospheric deposition samples were analyzed for Al, Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb which are heavy metals common to urban environments. Al and Fe were found in high concentrations due to the presence of natural sources, but may also be re-suspended by vehicular traffic. Relatively high concentrations of toxic metals such as Cr and Pb in dissolved form were also found. High Zn loads can be attributed to vehicular emissions and the wide use of Zn coated roofing materials. The metal loads in wet deposition showed higher concentrations compared to dry deposition. The metal concentrations among the different sampling sites significantly differ from each other depending on the traffic conditions. Industrial activities are not significant in Kandy City. Consequently, the traffic exerts high influence on heavy metal loadings. As part of the bacterial investigations, nine species of culturable bacteria, namely; *Sphingomonas* sp., *Pseudomonas aeruginosa*, *Pseudomonas monteilii*, *Klebsiella pneumonia*, *Ochrobactrum intermedium*, *Leclercia adecarboxylata*, *Exiguobacterium* sp., *Bacillus pumilus* and *Kocuria kristinae*, which are opportunistic pathogens, were identified. This is the first time *Pseudomonas monteilii* and *Ochrobactrum intermedium* has been reported from a country in Asia. The culturable fraction constituted ~0.01 to 10%. Pigmented bacteria and endospore forming bacteria were copious in the atmospheric depositions due to their

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capability to withstand harsh environmental conditions. The presence of pathogenic bacteria and heavy metals creates potential human and ecosystem health risk.

1. Introduction

Atmospheric deposition is potentially an important part in the biogeochemical cycling of different pollutants such as heavy metals (HMs), bacteria and polycyclic aromatic hydrocarbons (PAHs) (Bari et al., 2014; Liang et al., 2016; Smets et al., 2016). The deposition of atmospheric particulate matter (PM) on ground surfaces can occur via dry and wet deposition processes. Dry deposition (DD) occurs through gravitational settling while wet deposition (WD) occurs through scavenging by precipitation such as rain, snow or fog (Bari et al., 2014; Kara et al., 2014). These particulates along with associated pollutants such as HMs and bacteria are transported by stormwater runoff to receiving waters, posing significant risks to human and ecosystem health (Herngren et al., 2006; Wijesiri et al., 2016). Natural sources such as soil inputs and anthropogenic activities such as traffic, industrial processes, and incineration of sewage sludge and solid waste are among the primary sources of HMs to the atmosphere (Azimi et al., 2003; Tian et al., 2015). Similarly, natural sources such as agriculture, decaying organic matter, (Jeon et al., 2011; McEachran et al., 2015; Smets et al., 2016) and anthropogenic activities such as solid waste disposal and sewage treatment (Fang et al., 2005; Fang et al., 2007; Smets et al., 2016) contribute to the presence of bacteria in the urban atmosphere.

Pathogenic airborne bacteria attached to dust particles can cause detrimental human health impacts such as respiratory diseases, allergies and skin rashes in both, humans and animals (Deng et al., 2016; Kumar et al., 2011; Smets et al., 2016). However, only limited research studies have been conducted on bacteria attached to atmospheric deposited particulate matter (PM) (Bowers et al., 2013; Gao et al., 2015). Heavy metals are not biodegradable and can accumulate in fauna and flora, water bodies, and soils causing adverse impacts on ecosystem health (Duruibe et al., 2007; Soriano et al., 2012). Further, these metallic pollutants are able to travel over long distances by binding to small particles (Azimi et al., 2003). Past research studies have reported elevated concentrations of HMs in deposited atmospheric particles (Gunawardena et al., 2015; Khillare et al., 2004; Samara and Voutsa, 2005).

A major limitation in studies undertaken in relation to HMs and bacteria associated with atmospheric deposition is that they have generally been confined to urban areas in developed countries (for example Barberán et al., 2015; Gao et al., 2016) and, only a limited number of research studies have been conducted in developing countries. Though numerous studies have focused either on HMs or bacteria, the simultaneous investigation into bacteria and HMs in atmospheric deposition in urban environments is also limited (Abdel Hameed and Mounirb, 2016). This limits the ability to develop specific and evidence-based policies and control measures to mitigate the adverse impacts on human and ecosystem health. The primary objective of this study was to undertake a detailed characterisation of common HMs and bacteria present in atmospheric deposition particles in a typical city of a developing country, Sri Lanka. The study outcomes are generic and are expected to contribute to strengthening the environmental management practices across Sri Lanka and can be adopted for similar developing countries.

2. Materials and methods

2.1. Study area and sampling sites

The sampling sites were located in Kandy, which is the second largest city in Sri Lanka. Kandy is a historical city with a high population density of about 6000 persons per km^2. The City has a permanent population of >170,000 people and a daily transient population of around 100,000 people (Wickramasinghe et al., 2011) with characteristics that are typical for a city in a developing country. Kandy has a 26 km^2 land area surrounded by high mountains, facilitating thermal inversions within the city atmosphere. The daily traffic flow is over 100,000 vehicles through the four main entrances to the city center. Due to high vehicular volume and bottlenecks in the road system, the city experiences both inner-city and through traffic congestion. (Wickramasinghe et al., 2011). Incomplete combustion of fuel and construction activities are significant sources of atmospheric pollution in Kandy. Use of firewood for cooking may also contribute to atmospheric pollution. There are no significant industrial activities within the city and nearby areas. Building constructions are continuous, which enhances the emission of dust and other pollutants into the atmosphere in Kandy (Wickramasinghe et al., 2011). The average day time ambient temperature is in the range of 28–32 °C, while the monthly rainfall is in the range of 52–398 mm and the daytime relative humidity is in the range of 63–83%.

Four sampling sites with intensive traffic activities were selected for the collection of atmospheric deposition samples. These sites were designated as Fire Brigade Station (F), Police Station (P), Railway Station (R) and the National Institute of Fundamental Studies (I) (Fig. 1). Sites, F, P and R, are located near 3 or 4-way road intersections with heavy traffic, whereas site I is in a tea plantation with low vehicular and other anthropogenic activities compared to the city centre and it was considered as the control site. Fig. 1 also provides a summary of the main characteristics of the four sampling sites.

2.2. Sample collection

Atmospheric deposition samples were collected based on three consecutive rainfall events. The first rainfall event was after four antecedent dry days while the other two rainfall events were after two and three antecedent dry days. The sampling system used for collecting dry and wet atmospheric deposition samples is illustrated in Fig. S1 in Supplementary Information. The samplers were made using high density polyethylene (HDPE) bottles with polyethylene funnels and 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 Gunawardena et al. (2013). Dry deposition is the amount of deposition over a particular antecedent dry period. Bulk deposition (BD) is the dry and wet deposition at the end of a particular rainfall event including the preceding antecedent dry period (Gunawardena et al., 2013). One sampling head was used to collect DD, while the other was used to collect BD. BD and DD samples were collected on the same day, just before and just after a rainfall event. Bulk and dry deposition collectors were installed at the same time after a rainfall event as the atmospheric pollutant loads are minimum at that stage (Gunawardena et al., 2013; Ravindra et al., 2003). Prior to installation, the sampling bottles and funnels were washed with deionized water followed by an acid wash with 1:1 HHO_3 solution as part of the quality assurance measures. At the end of each sample collection, all collection materials were replaced. After collection, the funnels were covered by clean plastic bags and sealed to avoid contamination. Sample bottles were sealed and were transported to the laboratory immediately following standard quality control procedures.

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