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ATMOSPHERIC PARTICLES AS A POLLUTANT SOURCE IN THE URBAN WATER ENVIRONMENT IN SRI LANKA – CURRENT RESEARCH TRENDS AND FUTURE DIRECTIONS

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Abstract

Human and ecosystem health impacts imposed by water pollution are a major problem in the urban areas of Sri Lanka. A primary source of pollutants to urban water sources is atmospheric particles. Hence, it is important to develop a detailed understanding of atmospheric particle characteristics, their sources of origin and the transport pathways. Several research studies have been conducted in Sri Lanka on atmospheric pollution and these studies have tended to differ in their scope, study region and the investigated pollutants. The objectives of this paper are: (1) to report the outcomes of a detailed state-of-art literature review of atmospheric pollution related studies in Sri Lanka to understand the current trends and (2) to discuss the future research activities necessary to generate the important knowledge required for the development of effective strategies to control the adverse impacts of atmospheric pollution on urban waterways.

Keywords: *Atmospheric pollution, Atmospheric deposition, Stormwater pollution, Road build-up*

1.0 Introduction

A major source of pollutants to water bodies in the urban environment is the atmospheric particles, which are emitted to the atmosphere by anthropogenic activities such as traffic and industrial emissions (Sabin *et al*. 2005). These particles eventually deposit on urban impervious surfaces via dry and/or wet deposition and are washed-off to the nearby water sources during a rain event. Consequently, the particles and any attached toxic pollutants end up in the nearby water sources. This results in the degradation of the water quality and causes various adverse aquatic ecosystem health impacts (Balestrini and Tagliaferri 2001). For example, solids can increase the turbidity and reduce sunlight penetration through the water leading to reduced plant photosynthesis. Similarly, heavy metals can deactivate the enzyme system of aquatic plants and disturb their biochemical processes (Maldonado-Magaña *et al*. 2011), while polycyclic aromatic hydrocarbons (PAHs) can have lethal and sublethal toxic effects on aquatic organisms even at a low concentration (Warren *et al*. 2003). In addition, a significant number of people in developing countries still depend on natural water sources such as rivers for their potable uses. In Sri Lanka, only 39 % of the population have access to pipe-borne water supply and 18% of the population are still dependent on rivers, lakes and other water sources for potable purposes (MoFP, 2010). This highlights the importance of mitigating water pollution in Sri Lanka as it has human and ecosystem health significance. As the atmospheric particles are a major source of water pollution, it is necessary to develop effective strategies to control the atmospheric pollution.

This will require a comprehensive understanding of the physical, chemical and microbial characteristics of atmospheric particles, the identification of their potential sources of origin and transport pathways. The knowledge of atmospheric particle characteristics will provide the knowledge required for a comprehensive assessment of the potential water pollution and associated health risks, while the identification of the pollutant sources will facilitate the effective control of pollution at the point of origin. Furthermore, the knowledge of pollutant transport pathways will be useful in identifying the route of atmospheric pollution to nearby water sources and, consequently, will assist in safeguarding urban water sources.

In general, the characteristics of atmospheric particles, their sources and transport pathways are specific to a local region since these aspects are highly dependent on local anthropogenic activities, climate conditions and geographical characteristics (Bhugwant and Brémaud 2001). The primary objectives of this paper are to:

1. review the current knowledge in relation to the characteristics and sources of atmospheric particles in Sri Lanka;
2. critically analyse the adequacy of these studies to understand the associated water pollution;
3. highlight the knowledge gaps that hinder the development of effective strategies to mitigate atmospheric particle induced water pollution.

2.0 Methodology

The literature search was performed using the Scopus database, which is the largest bibliographic database of peer reviewed articles. The key search terms used were (“Sri Lanka” AND “Air pollution”) and (“Sri Lanka AND atmospheric pollution”) as these terms would encompass any Scopus indexed atmospheric pollution related studies conducted in Sri Lanka. The search was limited to the last six years, i.e. 2008-2013, since the objective of the study was to investigate the current trends. Furthermore, only original research articles were considered. Selected papers were reviewed for the following aspects:

1. Study scope;
2. Key pollutants investigated;
3. Reported pollutant levels and sources.

Additionally, the studies were critically reviewed to determine whether their results/outcomes can help to understand the potential water pollution associated with the atmospheric particles. Scopus database identified 28 papers that have been published on atmospheric pollution in Sri Lanka in the last six years. Among them, only 12 articles were identified as relevant to the objectives of this review since they report the characteristics of atmospheric particles, while the rest of the studies are epidemiological investigations related to atmospheric pollution.

3.0 Characteristics and sources of atmospheric particles – A brief review

The air pollution studies in Sri Lanka have primarily been focused on human health impacts. Ecosystem health impacts have not been given adequate attention. Based on the sample collection protocol, the studies can be grouped into three categories (Table 1) as given below:

1. Indoor air pollution studies;
2. Outdoor air pollution studies;
3. Trans-boundary pollution studies.

Table 1: Classification of atmospheric pollution studies in Sri Lanka

Study	Category
Attanayaka and Wijeyaratne 2013	Outdoor
Senanayake *et al.* 2013	Outdoor
Nandasena *et al.* 2012b	Indoor and Outdoor
Nandasena *et al.* 2012a	Indoor
Wickramasinghe *et al.* 2012	Outdoor
Gunathilaka *et al*. 2011	Outdoor
Wickramasinghe *et al.* 2011	Outdoor
Perera *et al*. 2010	Outdoor
Elangasinghe and Shanthini 2008	Outdoor
Dharshana and Coowanitwong 2008	Outdoor
Lee *et al*. 2010	Indoor
Begum *et al*. 2011	Trans-boundary

Begum *et al.* (2011) investigated the long range transport of soil dust and smoke to Sri Lanka and found that 0.48 $\mu g/m^3$ concentration of smoke was contributed by trans-boundary transport. Compared to the local pollutant contribution to the atmosphere, this amount may not have a significant contribution to local urban waterways (Elangasinghe and Shanthini, 2008).

Lee *et al*. (2010) and Nandasena *et al*. (2012 a, b) investigated indoor air pollution, specifically due to smoking, in Sri Lanka. According to Lee *et al*. (2010), smoking contributes an average of 125 $\mu g/m^3$of $PM_{2.5}$ in the investigated areas for a smoking density of 1.2 burning cigarettes per 100 m^3. Similarly, Nandasena *et al*. (2012a) reported that smoking contributes $PM_{2.5}$ concentration ranging from 33 to 299 $\mu g/m^3$.Though the characteristics of indoor air pollution and the $PM_{2.5}$ concentration reported in these studies are critical to understand the human health impacts, they have a very limited use in understanding the potential atmospheric particle related water pollution.

The outdoor air pollution studies have been primarily focused on determining the concentration of particulate matter (PM), nitric oxide (NO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) in the ambient air. Attanayaka and Wijeyaratne (2013) investigated the variation of SO_2 and NO_2 concentrations with distance from the city, land use pattern, traffic density and light intensity. The study found that the pollutant concentrations decreased significantly when moving away from the city. Nandasena *et al*. (2012b) also reported that $PM_{2.5}$, PM_{10}, NO_2 and SO_2 levels were significantly higher in the urban areas (50.4, 68.1, 47.2 and 42.7 $\mu g/m^3$, respectively) compared to the semi-urban areas (19.2, 34.9, 10.2 and 10.0 $\mu g/m^3$, respectively). These studies suggest that the waterways may be less polluted due to atmospheric particles in areas that are away from urban centres.

Similarly, traffic density was found to have a significant impact on the pollution levels such that higher the traffic density, the higher the atmospheric pollution (Attanayaka and Wijeyaratne, 2013; Perera *et al*. 2010). Senanayake *et al*. (2013) observed high concentration of $NO_2$and SO_2 in areas with high traffic density, while Elangasinghe and Shanthini (2008) reported that the highest PM_{10} concentration was recorded at the site with the highest traffic density. In addition, other traffic related factors such as congestion and road structure were also found to have an impact on the pollutant levels in the atmosphere. For example, Elangasinghe and Shanthini (2008) noted that PM_{10} concentration was relatively high at a site with no traffic congestion. The authors speculated that it is due to the road structure, which had an upslope with a 300^{o} angle turn that could have required combustion of a relatively greater amount of fuel resulting in high emissions. Hence, it is necessary to not only manage traffic activities, but also, parameters such as the road layout in order to reduce the pollutant emissions to the atmosphere and the consequent pollutant deposition on urban waterways.

The studies by Wickramasinghe *et al*. (2011, 2012) are the only studies that the authors could find that have characterised toxic PAHs concentrations in the atmosphere. These studies reported that total particle bound PAHs was high in urban areas with high traffic activities. This is in agreement with the previous conclusions, which reported the presence of high concentration of pollutants in urban and high traffic areas. Since PAHs that can deposit on urban water sources can cause adverse impacts to aquatic organisms even at a low concentration, it is necessary to control their emission to protect the environmental quality of urban water sources.

In addition, Attanayaka and Wijeyaratne (2013) recorded the highest pollutant concentrations at a site that had less than 35% of the total area covered by vegetation. Senanayake *et al*. (2013) concluded that high population density and reduced green spaces increase the atmospheric pollution levels. Elangasinghe and Shanthini (2008) also found that PM_{10} concentration was 4 $\mu g/m^3$ inside a botanical garden compared to 110 $\mu g/m^3$ at its entrance. These studies highlight the importance of green spaces in controlling atmospheric pollution and the associated water pollution. Hence, it is necessary to manage green spaces of cities in order to reduce the atmospheric induced water pollution.

Gunathilaka *et al*. (2011) investigated metal pollution in the atmosphere by performing energy dispersive X-ray fluorescence spectrometry on lichen specimens. However, the conclusions of this study are questionable as the metal intake by lichen may have occurred through different pathways and hence it may not necessarily reflect the atmospheric pollution levels.

4.0 Current research trends and future directions

It is evident from Section 3.0 that research studies on atmospheric particles have largely focused on human health impacts. Consequently, PM, SO_2, $NO_2$and NO were primarily quantified. The knowledge generated by these studies can be a starting point to understand the potential negative impacts of atmospheric particles on urban water sources. However, it is worthy to note that not all the pollutants would end up in the urban water sources. Consequently, it is necessary to understand the deposition characteristics and pathways of atmospheric particles along with their characteristics.

In general, there are two ways that atmospheric particles deposit on urban surfaces: dry and/or wet deposition (Khaiwal *et al.* 2003). Due to the small size and gaseous nature of PM, SO_2, NO_2 and NO, it is possible that they may not settle via dry deposition. In contrast, they can settle via wet deposition during a rain event. For example, NO_2 can dissolve in water and produce HNO_3 thereby increasing the acidity of the rain water. Consequently, it can dissolve other toxic pollutants such as heavy metals that are present in pollutant build-up on urban impervious surfaces such as roads and make them more bioavailable to aquatic organisms when they eventually end up in water sources.

In contrast, toxic pollutants such heavy metals and PAHs can be attached to atmospheric particles and can settle via dry deposition (Morselli *et al.* 2003). Hence, it is necessary to characterise the dry deposition samples in order to understand their potential negative impacts on urban water surfaces. In addition to chemical pollutants, the atmospheric particles need to be characterised according to their microbial composition in order to understand the potential adverse biological impacts of atmospheric particles on urban water sources.

The knowledge of atmospheric particle characteristics needs to be integrated with an in-depth understanding of pollutant sources and transport pathways in order to formulate scientifically robust strategies to mitigate the adverse consequences of atmospheric pollution. Most studies agree that the primary source of pollutants to the atmosphere is traffic activities. This is because these studies are mainly restricted to Central and Western provinces of the country, specifically to Colombo and Kandy, where there is a relatively higher traffic activity. However, the industrial cities such as Biyagama can possibly emit higher pollutants to the atmosphere and to the nearby water sources. In addition, the pollutant composition could be different to those emitted by traffic activities. Hence, it is necessary to investigate these different areas in order to understand the potential aquatic ecosystem health impacts of industrial emissions.

Furthermore, reliable estimation and prediction of critical pollutant loads is useful for formulating mitigation strategies, future policies and resource allocation. However, such studies have not been conducted in Sri Lanka, thereby limiting the development of effective mitigation strategies. Development of prediction methodologies requires an in-depth understanding of pollutant sources and the transport pathways discussed above. Hence, a holistic approach is critical for developing prediction approaches and to safeguard our urban waterways from adverse impacts of atmospheric pollutants.

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