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Quantitative assessment of human health risk posed by polycyclic aromatic hydrocarbons in urban road dust

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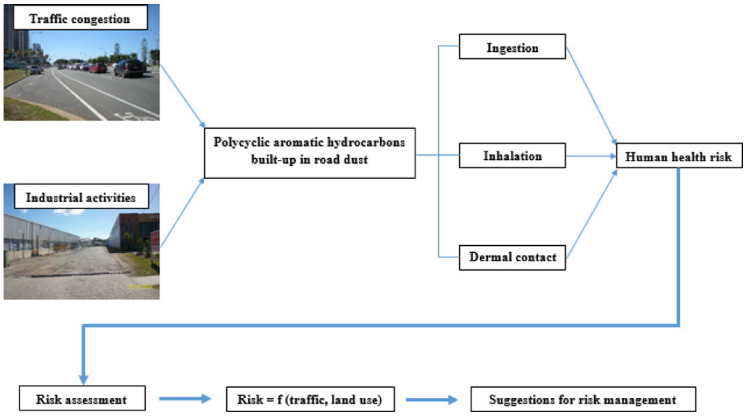
HIGHLIGHTS

- Quantitative PAHs risk assessment approach in urban road dust was developed.
- This assessment approach was based on land use and traffic characteristics.
- Hotspots can be identified by using the approach to minimise the risk.

GRAPHICAL ABSTRACT



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ABSTRACT

Among the numerous pollutants present in urban road dust, polycyclic aromatic hydrocarbons (PAHs) are among the most toxic chemical pollutants and can pose cancer risk to humans. The primary aim of the study was to develop a quantitative model to assess the cancer risk from PAHs in urban road dust based on traffic and land use factors and thereby to characterise the risk posed by PAHs in fine (<150 μm) and coarse (>150 μm) particles. The risk posed by PAHs was quantified as incremental lifetime cancer risk (ILCR), which was modelled as a function of traffic volume and percentages of different urban land uses. The study outcomes highlighted the fact that cancer risk from PAHs in urban road dust is primarily influenced by PAHs associated with fine solids. Heavy PAHs with 5 to 6 benzene rings, especially dibenzo[*a*,*h*]anthracene (D[*a*]A) and benzo[*a*]pyrene (B[*a*]P) in the mixture contribute most to the risk. The quantitative model developed based on traffic and land use factors will contribute to informed decision making in relation to the management of risk posed by PAHs in urban road dust.

1. Introduction

Urban road dust contains large amounts of chemical pollutants such as heavy metals and organic compounds (Amato et al., 2009). Among

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these pollutants, polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds which are mainly present in association with solids due to their hydrophobic properties (Dong and Lee, 2009). There are 16 PAHs identified by US EPA (1984) as priority pollutants due to their toxicity, potential to human exposure and prevalence in the urban environment. PAHs are carcinogenic to skin, lungs and bladder (Mahler et al., 2012), and the relationship between human cancer and PAHs has been well documented (Chen and Liao, 2006). There is potential for people to have direct contact with the pollutants in road dust whilst engaged in construction and recreational activities (Holmes et al., 1999), as well as being exposed to fugitive dust due to re-suspension (US EPA, 2002). For example, vehicle turbulence can entrain solids in the air, where people can ingest PAHs by respiration, particularly fine particles and also result in dermal contact. Consequently, PAHs in urban road dust can result in potential human health risks.

In order to assess the cancer risk, it is important to develop an understanding of the sources of PAHs in urban road dust. According to past studies, vehicular traffic and other anthropogenic activities such as industrial manufacturing related to urbanisation are two prominent sources of PAHs in urban areas (Brown and Peake, 2006; Gunawardena et al., 2014). For instance, vehicle exhaust emissions as a result of incomplete fuel combustion is a key source of PAHs (Rocher et al., 2004). In addition, various anthropogenic activities such as vehicle maintenance and industrial processes can also generate numerous PAHs (Fang et al., 2004). Due to the influential role of traffic and urban land use related activities in the generation of PAHs, the PAH load built-up on urban impervious surfaces such as in road dust varies with various traffic characteristics and land use characteristics (Shi et al., 2013; Gunawardena et al., 2014). As the risk is dependent on the build-up load of PAHs, the risk posed by PAHs in urban road dust can be related to traffic and land use characteristics inherent to an area.

A number of past research studies have quantitatively analysed the human health risk posed by PAHs in urban road dust (Dong and Lee, 2009; Wang et al., 2011). However, these studies are quite limited in their investigation of the role of various influential factors. For example, Wang et al. (2011) qualitatively compared the risk to people posed by PAHs in road dust collected from different residential, commercial, industrial and park areas. However, as the role of influential factors was not investigated and predictive models were not developed, assessments of this nature tends to be location specific (Yu et al., 2014; Peng et al., 2016). This is attributed to the fact that some influential factors such as land use are not easy to be quantified. Additionally, it is critical to select an appropriate technique to quantitatively relate the risk to the influential factors. Consequently, the in-depth investigation of the quantitative relationship between the risk and traffic and land use characteristics has received limited attention. The resulting knowledge gap constrains the practical estimation of the risk from PAHs associated with road dust in urban areas.

Accordingly, the primary aim of the study was to develop a quantitative model to assess the cancer risk from PAHs in urban road dust based on traffic and land use factors. It is important to note that although PAHs can be generated from various other sources such as long term atmospheric transportation of PAHs associated with black carbon (Tsai et al., 2001), the scope of this research study was focused on the influence of traffic and land use in the creation of potential health risk from the generation of PAHs. This is because traffic and land use activities are among the most common anthropogenic activities in the urban environment which generate PAHs. The qualitative influence of traffic and land use characteristics on the pollutant build-up in urban road dust has been supported by previous research (Gunawardena et al., 2014). As PAHs are commonly associated with fine particles (<150 μm) which are easily re-suspended due to wind and vehicle related turbulence, thereby compounding the risk to people (Dong and Lee, 2009; Gunawardena et al., 2013), a further aim was to characterise the risk posed by PAHs in fine (<150 μm) and coarse (>150 μm) particles, individually. The model developed, as it is quantitatively based on traffic and land use factors, will contribute to informed decision making in relation to the management of risk posed by PAHs in urban road dust.

2. Methods and materials

2.1. Study sites

Four urbanised suburbs in Gold Coast, Queensland, Australia, representing different land use types were selected as study areas. These included Surfers Paradise (commercial), Benowa (mixed commercial and residential), Nerang (industrial) and Clearview Estate (residential). As the research study only considered road dust in the urban environment, industrial, commercial and residential land use types were analysed due to their significant contribution to the PAHs load in road dust (Gunawardena et al., 2012). This is also supported by the fact that residential, commercial and industrial areas are the typical land use types in the urban environment. Four road sites with different daily traffic volumes (DTV) [average vehicles/day] were selected from each suburb. The traffic volume data and land use characteristics of each study site are provided in Fig. 1. The traffic data for each study site was obtained from Gold Coast City Council. The percentage of commercial, industrial and residential land use area (C, I and R) [%] encompassing a 1 km radius from the study site were considered as influential parameters in relation to pollutant composition in road dust. This was based on the outcomes of the study undertaken by Zhu et al. (2002) that 95% of traffic generated fine particles are transported within 1 km from the source of origin. Different land use areas were demarcated using Google Earth (Google, 2015) maps and then C, I and R [%] were calculated using ArcMap 10.1 software (ESRI, 2016).

2.2. Study approach

2.2.1. Build-up samples collection

The dust samples were collected from road surfaces at the study sites using a dry and wet vacuuming procedure (with efficiency of over 95%) which has been adopted in previous research studies (Gunawardana et al., 2014). The sampling plot at each study site was a 1 m wide strip which covered the area from the kerb to the road centre line. This was to account for the possible variability in dust build-up across the road surface. It has been noted that a relatively higher pollutant load is built-up near the kerb (Novotny et al., 1985). Sample collection was conducted twice at the same study site to take into account the variation in PAH build-up on the road surface. Accordingly, a total of 32 samples were collected. Samples were collected after seven to nine antecedent dry days as the solids build-up load on a road surface is relatively stable after this period of time (Egodawatta et al., 2009). The dry and wet vacuuming procedure described in Gunawardana et al. (2014) was used for collecting both, dissolved and particulate form. The collected samples were preserved in deionised water in glass bottles under 4 °C until analysis.

2.2.2. Laboratory testing

Build-up samples were separated into two particle size fractions, <150 μm and >150 μm, by wet sieving, and both fractions were tested for PAHs and total solids. As PAHs are highly hydrophobic, they are liable to associate with particulates in the aqueous environment rather than being soluble in water (Wu et al., 2013). Therefore, the influence of desorption of PAHs during wet sieving and sample storage was not considered. The separation of <150 μm and >150 μm was due to the differences in the build-up process of these two particle size fractions as identified by Wijesiri et al. (2016). As the samples were in dissolved and particulate form, the aqueous and particulate PAHs were separated by vacuum filtration and extracted separately. Aqueous PAHs were extracted by liquid-liquid extraction according to US EPA method 610 (US EPA, 1984). Particulate PAHs were extracted by accelerated solvent extraction (ASE) which met the requirements of US EPA method 3545

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