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Understanding heavy metal and suspended solids relationships in urban stormwater using simulated rainfall

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Abstract

Urban stormwater from simulated rainfall on three different landuses in Queensland State, Australia (residential, industrial, commercial) was analysed for heavy metals and physico-chemical parameters such as Dissolved Organic Carbon (DOC) and Total Suspended Solids (TSS). Rainfall events were simulated using a specially designed rainfall simulator for paved surfaces. Event mean concentration samples were separated into five different particle sizes and analysed individually for eight metal elements (Zn, Fe, Cr, Cd, Cu, Al, Mn and Pb). Multivariate data analysis was carried out for the data thus generated. It was found that DOC and TSS influence the distribution of the metals in the different particle size classes. Zn was correlated with DOC at all three sites. Similarly, Pb, Fe and Al were correlated with TSS at all sites. The distribution of Cu was found to vary between the three sites, whilst Cd concentrations were too low to assess any relationships with other parameters. No correlation between Electrical Conductivity (EC), pH and heavy metals was found at the three sites. The identification of physico-chemical parameters influencing the distribution process kinetics of heavy metals in urban stormwater will significantly enhance the efficiency of urban stormwater management systems.

Keywords: Heavy metals; Rainfall simulation; Physico-chemical parameters; GAIA-analysis

1. Introduction

Stormwater runoff from urban areas contains significant loads of inorganic elements, particularly heavy metals (Davis et al., 2001). The presence of heavy metals in solution in urban runoff is of concern as they are most toxic due to enhanced bioavailability and potential to not degrade in the environment. Many heavy metals, especially Pb and Zn, have been recognized as traffic-related pollutants (Dong et al., 1984; Wilber and Hunter, 1979; Sansalone and Buchberger, 1997). However, specific sources of heavy metals in an urban area also include corrosion of buildings and their fittings, atmospheric deposition, transport and various industrial activities and intentional and accidental spills (Christensen and Guinn, 1979; Davis et al., 2001). Sources of heavy metals and their contribution to urban stormwater runoff is significantly dependant on the land use.

Furthermore, parameters such as Dissolved Organic Carbon (DOC) and pH can significantly enhance desorption of heavy metals from suspended solids. Tai (1991) noted that the ratio of trace metals released into the dissolved phase at pH 6 vs. pH 8.1 is about 180 for Zn, 45 for Pb and 25 for Fe. Similarly, DOC plays a major role in partitioning of metals between soluble and particulate fractions in stormwater (Hamilton et al., 1984). Consequently, interaction between DOC and heavy metals can result in complexation processes that concentrate the metals in the dissolved phase. The partitioning of heavy metals into different particle size classes in terms of their adsorption to particulates has major implications for urban water quality management. Current approaches adopted to mitigate the impacts of urban runoff on receiving waters include the use

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of structural and/or regulatory measures such as detention basins, gross pollutant traps and restrictive zoning. However, for these measures to be effective, an in-depth understanding of the processes involved in urban runoff is essential. Therefore it is imperative to understand the relationships between heavy metals and important parameters such as particle size, pH and organic carbon content.

Most of the heavy metals in urban stormwater runoff are attached to suspended solids (Bodo, 1989; Dong et al., 1984). Furthermore, metal concentrations generally increase with decreasing particle size (Liebens, 2001; Ujevic et al., 2000). This is due to the relatively large surface area of fine sediments and their higher cation exchange capacity (Dong et al., 1984). Since most metals have a greater affinity for smaller particle sizes, conventional pollutant abatement programs such as street sweeping which only pick up large particles have little effect in reducing toxic runoff levels, as fine suspended solids are readily transported in stormwater. In addition to the relationship between suspended solids and metals, parameters such as rainfall intensity and rainfall volume have been noted as important factors in influencing the export of heavy metals from an urban area (Sonzogni et al., 1980). Despite the strong affinity between heavy metals and suspended solids, the evaluation of the dissolved fraction of the heavy metal load is important as an indicator of bioavailability.

In this paper, multivariate statistical methods and rainfall simulation have been used to correlate heavy metal distribution among different suspended solids particle sizes in wash-off samples with a number of physico-chemical parameters such as pH, Electrical Conductivity (EC) and various forms of organic carbon. The suspended solids in the wash-off samples were separated into five different particle size classes in order to investigate the processes governing the affinity of heavy metals for different particle sizes. The use of an artificial rainfall simulator helps to eliminate significant constraints such as dependency on natural rainfall experienced by researchers undertaking rigorous research into urban stormwater quality. Additionally, the random nature of occurrence and characteristics of natural rainfall introduces further variables into a research arena where so little of the inherent processes are known. A specially designed rainfall simulator was used to generate artificial rainfall and to obtain pollutant wash-off samples from paved areas in three landuses. The wash-off samples collected from the paved areas were tested for a suite of heavy metals species (Zn, Pb, Cu, Cd, Cr, Fe, Al and Mn) considered common to urban areas. Due to the limitations of univariate statistical methods, multivariate analytical methods were employed to analyse the large database generated and to investigate the affinity between heavy metals and suspended solids particle sizes and relationships with a number of physico-chemical parameters.

2. Materials and methods

2.1. Study area

The research sites were located in the Gold Coast region just south of the Queensland State capital, Brisbane, Australia. The Gold Coast region is a popular holiday destination and has one of the highest population growth rates in the country. It has a subtropical climate with wet summers and dry winters.

Research site 1 was an access road (Millswyn Crescent) located in a typical suburban residential area (Residential A) with detached family houses with small gardens. The site was chosen due to its typical suburban characteristics. The road system is primarily used by the residents for access, which was reflected in the intact street surface. An early investigation of the households suggested that various chemicals were used as fertilizers or for other uses and therefore could be incorporated into the wash-off from the area. It was also found that street sweepers operate in the area every six weeks, which may influence the availability of pollutants on the road surface at certain times.

Research site 2 (Stevens Street) was located in a light industrial area. The site was chosen because of the diversity of industries located along the road. Industries at the site include a sheet metal works, a boat painter and a furniture manufacturer. Compared to the residential site, the street surface was significantly degraded.

Research site 3 was a parking lot in a suburban shopping centre in the Gold Coast area. The shopping centre has 570 parking spaces and is considered to be one of the busiest in the region with 45 specialty retailers in the complex. The condition of the parking lot was found to be fair but with a coarse texture. The coarse texture suggested that large numbers of particles could be embedded within the voids.

2.2. Rainfall simulation

A specially designed rainfall simulator was used to simulate rainfall events typical of South-East Queensland, Australia. The rainfall simulator consisted of an A-frame structure with three Veejet 80100 nozzles equally spaced on a rotating nozzle boom. Artificially created rainfall was preferred for data generation due to the limited rainfall events occurring in the area. It also helps to overcome the significant constraints associated with depending on natural rainfall events. Rainfall simulation enables the generation of large volumes of data over a relatively short period for probabilistically different rainfall events, at the researchers' convenience. Care was taken to simulate rainfall characteristics as closely as possible, including drop velocities and uniformity of distribution (Loch et al., 2001). The runoff plot area was chosen so that maximum uniformity was achieved. The uniformity of rainfall inside the plot area was