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Review

Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning

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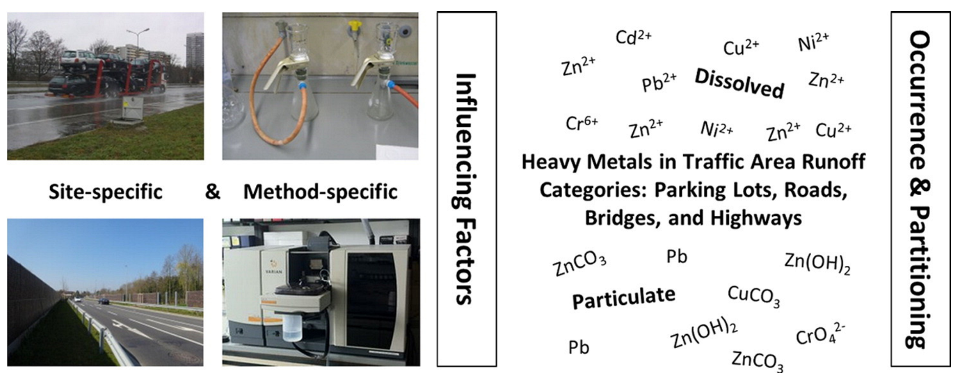
HIGHLIGHTS

- Heavy metal runoff concentrations in parking lots, bridges, and roads
- Large dataset of dissolved and total metal concentrations in traffic area runoff
- Description of site-specific and monitoring method-specific factors
- Summary of traffic-related and anthropogenic heavy metals in road runoff
- Reduction in Pb concentrations over time is one of the robust chemical results.

GRAPHICAL ABSTRACT



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ABSTRACT

A dataset of 294 monitored sites from six continents (Africa, Asia, Australia, Europe, North and South America) was compiled and evaluated to characterize the occurrence and fate of heavy metals in eight traffic area categories (parking lots, bridges, and three types each of both roads and highways). In addition, site-specific (fixed and climatic) and method-specific (related to sample collection, preparation, and analysis) factors that influence the results of the studies are summarized. These factors should be considered in site descriptions, conducting monitoring programs, and implementing a database for further research. Historical trends for Pb show a sharp decrease during recent decades, and the median total Pb concentrations of the 21st century for North America and Europe are approximately 15 μg/L. No historical trend is detected for Zn. Zn concentrations are very variable in traffic area runoff compared with other heavy metals because of its presence in galvanized structures and crumbs of car tire rubber. Heavy metal runoff concentrations of parking lots differ widely according to their use (e.g., employee, supermarket, rest areas for trucks). Bridge deck runoff can contain high Zn concentrations from safety fences and galvanizing elements. Roads with more than 5000 vehicles per day are often more polluted than highways because of other site-specific factors such as traffic signals. Four relevant heavy metals (Zn, Cu,

Abbreviations: AADT, average annual daily traffic; BR, bridge; d, dissolve; HL, highway with low AADT (>30,000) and non-urban land use; HU, highway with high AADT (>30,000) and urban land use; HWY, highway; p, particulate; Pb_21, dataset including only Pb concentrations measured in the 21st century; PL, parking lot; RL, road with low AADT (<5000); RM, road with medium AADT (5000 < AADT < 15,000); RU, road with high AADT (>15,000); t, total.

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Ni, and Cd) can occur in the dissolved phase. Knowledge of metal partitioning is important to optimize stormwater treatment strategies and prevent toxic effects to organisms in receiving waters.

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1. Introduction

Traffic area runoff summarize precipitation- and snowmelt-related discharges of mostly impervious surfaces (sidewalks, parking lots (PL), feeder streets, major roads, and highways (HWY)). The main contamination sources of traffic area runoff are related to traffic, surrounding land use, atmospheric contamination, and other meteorological and environmental conditions (Muschack, 1990; Ball, 2002; Crabtree et al., 2009; Valtanen et al., 2014). It is difficult to determine the dominant sources of pollutants because most substances have more than one origin and the water quality data of runoff from different sites are extremely heterogeneous because of differing background levels, types of uses (Göbel et al., 2007), and method-specific factors.

The substance spectrum analyzed in traffic area runoff waters includes organic parameters such as polycyclic aromatic hydrocarbons, total petroleum hydrocarbons, chemical oxygen demand, biological oxygen demand, and total organic carbon; heavy metals such as Pb, Zn, and Cu; and materials from de-icing salts such as chloride (Smullen et al., 1999; Moy et al., 2003; Eriksson et al., 2007; Kayhanian et al., 2012).

As HWY account for a small percentage of urban land use, they contribute only a small portion of pollutant loads compared with other road surfaces (Shelley et al., 1987). In urban catchments, all road surfaces represent approximately 10%–15% of the total area (Bannerman et al., 1993; Ball, 2002), and in commercial and industrial areas, PL can constitute up to 46% of the total area (Bannerman et al., 1993). Therefore, it is essential to consider all types of traffic area runoff.

In most cases, runoff waters from PL and road surfaces contain higher levels of the heavy metals than other types of runoff in drainage systems such as conventional roof runoff (Schueler, 2000; Ball, 2002). Metals in roof and road runoff contribute up to 80% of the total mass flow in combined sewer systems (Ellis et al., 1987; Boller, 1997). The present review focuses on all heavy metals in traffic area runoff that have either traffic or anthropogenic sources. These metals are transported by stormwater runoff either attached to solids or in dissolved form depending on the prevailing redox and pH conditions (Ball, 2002). However, in most cases, only total metal concentrations are analyzed from runoff waters during measurement campaigns.

Some of these heavy metals can have acute or chronic impacts as a result of their accumulation in receiving waters in terms of aquatic habitats, drinking water resources, and recreational uses (Ellis and Revitt, 1982; Yousef et al., 1984). For potential toxic effects, the partitioning between the total and dissolved heavy metals is essential because the dissolved fractions are directly biologically available (Paulson and Amy, 1993; Crabtree et al., 2008). The toxicity of traffic area runoff has been investigated by various researchers (Gjessing et al., 1984; Pitt et al., 1995; McQueen et al., 2010). A particular link to the heavy metals was made by Tiefenthaler et al. (2001), who identified trace metals (particularly Zn) as important contributors to toxicity in PL runoff, and by Kayhanian et al. (2008), who identified dissolved Cu and Zn as the primary causes of toxicity in HWY runoff. In general, the toxicity of heavy metals is a function of several factors such as metal speciation and physical characteristics of receiving waters (Revitt and Morrison, 1987). If conditions change, particulate metals transported into receiving waters have the potential to repartition into the dissolved phase (Sansalone, 2002; Westerlund and Viklander, 2006). Metal partitioning is also important for designing appropriate stormwater treatment strategies (Hilliges et al., 2013; Maniquiz-Redillas and Kim, 2014).

The present review focuses on the objectives as follows:

- To describe site-specific factors (both fixed and climatic conditions) that influence the occurrence and partitioning of the heavy metals in traffic area runoff from different sites and that should be documented in investigation programs.
- To compile and evaluate the conditions of the monitoring methods, including sample collection, sample preparation, sample analysis, and calculation methods.
- To summarize the concentrations and fractionation of the heavy metals to produce a comprehensive dataset, to characterize different types of traffic areas, and to identify relevant heavy metals.