



Metal leaching in a highway embankment on field and laboratory scale



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HIGHLIGHTS

- Metal levels in the embankment were up to 30 times higher than at 800 m distance
- Concentration of all metals exceeded the target values of the German legislation
- Dissolved metal concentrations in soil solution were higher than in the road runoff
- Retardation capacity of AVUS roadside soil increased during operational time
- Metal concentrations of 1:10 elution are in a similar range as field soil solution data

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ABSTRACT

Increasing worldwide motor vehicle traffic leads to the question of the possible environmental consequences. This paper aims to analyse metal leaching in a highway embankment using both field and laboratory experiments. Soil, soil solution and road runoff were collected along one of the oldest highways in the world to characterize leaching of the metals Cd, Cr, Cu, Ni, Pb and Zn. Batch, column and adsorption experiments were carried out to study the reliability and transferability of laboratory approaches. Depending on the element, the ratio of particle-bound metals in road runoff varied between 15–90%. Metal levels in embankment soils were significantly higher compared to a reference site in a forest at 800 m distance (up a factor of 30). High metal concentrations in soil solution at 50 cm soil depth were not a direct result of road runoff but rather of elevated concentrations in the soil matrix. The use of batch S4 elution was found to be the best overall laboratory method to predict soil solution concentrations in field. Adsorption experiments showed a relative increase in retention capacity in roadside soil of up to a factor of 20 after nearly 100 years of operation. The input of alkaline dust and organic carbon into roadside soils increases its retention capacity in the long term.

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1. Introduction

Highways and intensively trafficked roads are major sources for pollutants introduced into the environment. The growing volume of worldwide traffic leads to increasing emission rates causing a contamination of roadside soils (Monks et al., 2009). Emissions from traffic contain a complex mixture of pollutants such as carbon monoxide, nitrogen oxide, hydrocarbon and sulphur dioxide, polycyclic aromatic hydrocarbons and metals which can occur in particulate and dissolved form (Westerholm and Egeback, 1994; Zehetner et al., 2009). The traffic-derived pollutants originate from a variety of sources including incomplete and complete fuel combustion, fuel losses and oil leakage from hydraulic systems. Corrosion, de-icing activities and vehicle component wear and tear (tires, brakes, clutch and engine) are also important

sources of traffic emissions (Hjortenkrans et al., 2007; McKenzie et al., 2009). Another relevant pollutant source is the dust resulting from the abrasion of the road construction material itself (Lindgren, 1996; Thorpe and Harrison, 2008). Folkesson et al. (2009) classified the pollution sources of road traffic into the following five groups: traffic and cargo, pavement and embankment material, road equipment, maintenance and operation and external sources.

Most pollutants are emitted in gaseous form or as fine particles which deposit directly on the roadway and/or the surrounding vegetation and soils. The composition and amount of dry and wet deposition depends on many factors, such as traffic intensity (Ward, 1990; Arslan and Gizir, 2006), wind direction, wind velocity, rain events and intensity, previous dry periods, highway design or vegetation cover (Barbosa and Hvitved-Jacobsen, 1999; Pagotto et al., 2001; Lee et al., 2011). The road design plays a decisive role in the level and the dispersion of soil pollution. Depending on road construction and inclination of the embankment, spray water and road runoff can be transported up to a distance of 10 m (Golwer, 1991; Kocher et al., 2005). According to Steiner et al. (2007) wind and airflow may carry fine dust particles up

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to a distance of 25 m, whereas Zechmeister et al. (2005) measured fine particle transport at a distance of 250 m. Golwer (1991) defined three different loading areas for roadside environments:

- (I) 0–2 m: dominated by runoff and splashing water
- (II) 2–10 m: splashing water and partly runoff depending on inclination
- (III) 0–100 m, covered by the influence of airflow and wind

Metals are the pollutants of greatest concern because of their long-term toxicity for microorganisms, plants, animals and humans. Among others, Cd, Cr, Cu, Pb, Ni and Zn are the most widely recognized and examined metals in roadside environments (Münch, 1993; Folkesson et al., 2009; Kayhanian et al., 2012). The infiltration of road runoff as well as dust deposition leads to elevated metal concentrations in soils adjacent to the road. Furthermore, the leaching of galvanised crash barriers and road signs by rain and splashing water releases a considerable amount of metals (Van Bohemen and Van de Laak, 2003). Soil metal contamination typically decreases with increasing soil depth and distance to the road edge (e.g. Harrison et al., 1985; Pagotto et al., 2001; Carrero et al., 2013; Modrzewska and Wyszowski, 2014). Roadside soils often significantly change their original physical, biological and chemical properties due to road construction and maintenance. The most important influencing factors are the rearrangement of the topsoil layer in the course of road construction, the deposition of traffic-derived sediments on the embankment, and the elevated infiltration of road runoff (Pouyat et al., 2007; Kluge and Wessolek, 2012).

The mobility of metals in roadside soils is strongly influenced by soil pH and organic matter as several authors pointed out (Turer and Maynard, 2003; Walraven et al., 2014; Werkenthin et al., 2014). Turer and Maynard (2003) found a strong positive correlation between soil organic matter and certain metal concentrations. The easily exchangeable metal fraction could be mobilised if soils are subjected to extreme weather conditions like dry periods (oxidation) or long intensive rain periods (reducing condition) (Hjortenkrans et al., 2008). The use of de-icing agents for road maintenance promotes a high dispersion and leaching of organic matter in roadside soils. This in turn leads to increased metal mobilization in roadside soils (Bäckström et al., 2004; Ramakrishna and Viraraghavan, 2005). The long-term accumulation of metals in roadside soils may lead to high concentrations in seepage water. This could result in groundwater pollution or contamination of receiving waters with negative effects for surrounding water catchments. Therefore roadside soils play an important role in (ground-) water protection.

One possibility to estimate this risk is to perform laboratory leaching studies on highway soils. Indeed, this has been carried out with increasing frequency in recent years (e.g. Barbosa and Hvitved-Jacobsen, 1999; Hjortenkrans et al., 2007; Saeedi et al., 2009). Another possibility is to determine the soil solution concentrations on-site next to the affected roads and highways (Reinirrens, 1996; Dierkes and Geiger, 1999; Bäckström et al., 2004; Kocher et al., 2005; Kluge and Wessolek, 2012). To our knowledge no comparative study of laboratory and field measurements on metals leaching in roadside soils exists. Although it is well documented that certain metals in road runoff are, to a large extent, bound to particles (Legret and Pagotto, 1999; Helmreich et al., 2010), only Roulier et al. (2008) performed a field measurement on preferential particle-bound Pb transport in roadside soils. They could show that the proportion of particle-bound Pb in soil solution reached up to 85% of total metal concentration. Recent laboratory studies (Blecken et al., 2011) on stormwater infiltration indicate that also significant proportions of particle-bound Zn, Cu and Cd are transported vertically via soil solution.

Therefore the objective of this study was to measure dissolved and particle-bound metal concentrations (Cd, Cr, Cu, Ni, Pb and Zn) in road runoff, roadside soil and soil solution along the AVUS Autobahn, one of the oldest highways in the world, in order to determine the leaching characteristics of roadside soils. Another aim was to evaluate the

reliability and transferability of different laboratory experiments to field measurements. Adsorption experiments were carried out with a sample of embankment soil and a soil considered as a reference soil in this study to determine the change of retardation capacity after a long-term highway operation.

2. Material and methods

2.1. Study site

The AVUS highway is located in the southwest of the capital Berlin; Germany (52° 28' 43.8" N, 13° 14' 54.69" E) and connects the express highway A100 of the inner ring with the outer Berliner Ring highway A 10 (Fig. 1). The study site was part of the old AVUS racetrack, opened in 1921 and considered to be the oldest highway in the world (Bayliss, 1990). The AVUS has three asphalt lanes per direction with a width of 4 m per lane with an annual average daily traffic (AADT) of 90.000–100.000 vehicles per day.

At the study site the AVUS highway is surrounded by a mixed pine-oak forest at a distance of about 15 m from the road. The soils in the surrounding area of the AVUS highway are Spodo-Dystric Cambisols (FAO, 2006). According to the environmental agency of the State of Brandenburg, mean background concentrations of Cd, Cr, Cu, Ni, Pb and Zn are 0.15, 2.2, 10, 0.8, 22 and 16 mg/kg respectively (LABO, 2003). Annual average temperature is 8 °C and precipitation is 580 mm.

2.2. Sampling in field

2.2.1. Soil

Samples of embankment soils (T = transect) were collected along a transect of 25 m × 10 m at three different distances from the road (2.5 m, 5 m and 7.5 m). A stainless steel shovel was used to collect the top 0–25 cm soil layer at every meter. Soil horizons from 0–10 and 10–25 cm were sampled at least at five locations and mixed to one representative sample of about 3 kg. The reference samples were taken in a forest at 800 m distance to the road. Before chemical analysis, all soil samples were mixed again, air-dried and sieved through <2 mm. A sample of about 400 kg of embankment soil was collected near the roadside gateway Hüttenweg (52° 27' 47.6" N, 13° 15' 36.63" E) at a distance of 7.5–10 m to the edge of the AVUS (0–25 cm) as a representative



Fig. 1. Location of the study site-AVUS A115, Berlin, Germany.

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