Metal biomonitoring near a heavily-trafficked highway using standardized methods

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Abstract

The impact of metal pollution close to a busy highway (A8, Stuttgart - München, Germany) is assessed using standardized biomonitoring methods (active monitoring with grass cultures and lichens) since 1997. Heavy metals and noble metals (Pb, Cd, Cu, Sb, Pt, Rh) are analyzed in standardized biomonitoring plants upwind and downwind from the 6-lane highway.

Metal contents at the downwind site consistently exceed those at the upwind site for Cu, Sb, Pt and Rh, but only slightly for Pb, and not so for Cd.

Accumulation of the metal elements was considerably higher in lichens compared to grass cultures, particularly for Pb (36x), Pt (9x) and Rh (7x). Lichens facing towards the highway accumulate more Cu, Sb, Pt and Rh than those oriented away from the highway.

Contents of Sb, Pt and of Cu (lichens only) in the bioindicators near the highway are clearly elevated (ca. 10x) when compared with reference data from rural areas or filtered air exposures. In contrast, content of Pb in roadside bioindicators do not exceed background levels, which, on the other hand, have dramatically decreased during the last 2 decades.

Introduction

Quantitative and qualitative composition of motor vehicle emissions has changed during recent years mainly due to reductions of, or a complete ban on lead (Pb) in gasoline, the introduction of catalytic converters and through improvements in combustion technology.

To assess the present impact of metal pollution and to identify typcial traffic-related pollutants close to busy roads, a monito-ring study is conducted along a highway in south-western Germany (Autobahn A8 (E52) Stuttgart - München) since 1997.

Methods of active biomonitoring (e.g., grass exposure method, lichen exposure method) are applied and heavy metals (Pb, Cd, Cu, Sb) and noble metals (Pt, Rh), potentially associated with road traffic, are determined in the bioindicators' biomass.

Material and Methods

The location chosen for this study is a heavily-trafficked highway (75000 vehicles/day, 18 % trucks), featuring 6 lanes (3 in each direction) and connecting Stuttgart and München ('Munich'). It is situated 20 km south-east of Stuttgart (Baden-Württemberg, Germany) at the top of a slope (4 %), with no speed limit being in effect.

In this section, the highway runs nearly rectangular to the predominant wind direction, which is west to south-westerly.

Two monitoring sites were established ca. 5 m from the outer lane, one each north and south from the highway.

Various monitoring methods were applied in accordance with the VDI Guidelines. Results of two methods are reported here: Standardized Grass Exposure (VDI 3957 /2) and Standardized Lichen Exposure (VDI 3799 /2).

Fig. 1: **Standardized Grass Exposure (VDI 3957 /2)**

Lolium multiflorum
10 x 14 days
from May through September
1997 - 2000

Fig. 2: **Standardized Lichen Exposures (VDI 3799 /2)**

Hypogymnia physodes	
1 x 360 days	
from October through October	
1997 - 2003	
1997 - 2000	lichen board
since 2001	lichen wheel ("lichen carrousel")

Plant samples were dried, digested by microwave (270°C; 75 bar), and analysed by AAS (hydride technique) for Pb, Cd, Cu, Sb, and by Differential Pulse Cathodic Stripping Voltammetry (DPCSV) for Pt and Rh.

The metals determined are:

Lead (Pb)	once one of the most typical "traffic-related" elements; dramatic decline since ban on leaded gasoline; potentially resuspended from Pb-laden soil near roads
Cadmium (Cd)	in former studies frequently elevated near roads; high environmental/toxicological relevance
Copper (Cu)	compound in brake and clutch linings; also emitted from other car parts by wear and tear
Antimony (Sb)	compound of brake and clutch linings; to be replaced in the near future
Platinum (Pt) Rhodium (Rh)	active compound in emission control devices (catalytic converters); emitted in small amounts by attrition and erosion

Results

Downwind-upwind relationships

Comparison between the southern (S=upwind) to northern (N=downwind) monitoring site may provide the best indication of traffic-related influences with this experimental set-up.

The **relationship N:S** is consistently >1 in both grass and lichens for **Cu** and **Sb**, reaching mean values of **1,16** (Cu, grass), **1,43** (Cu, lichens), **1,56** (Sb, grass) and **2,16** (Sb, lichens). This is also true for **Pb** and **Pt** [exceptions: lichens in 1998 (Pb) and 1997 (Pt)]. Mean **N:S ratios** were **1,50** and **1,66** for Pb and Pt in grass, and **1,17** and **1,70** in lichens, respectively.

In contrast, there are almost no differences between the N and S sites for **Cd** (mean N:S ratio **1,04** and **1,18** in grass and lichens, resp.). For **Rh**, results are inconsistent, with numerous values below the limit of detection (0,2 ng/g) particularly in the grass.

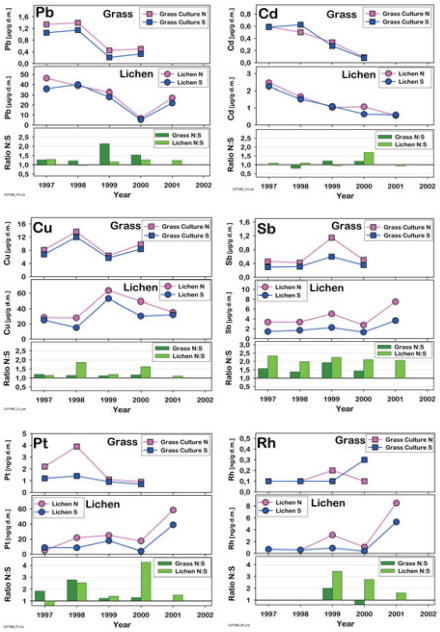
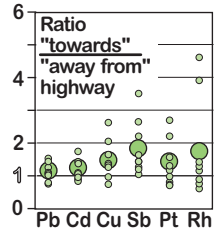


Fig. 3: Contents of the 6 metals in grass (squares) and lichens (circles) upwind (S=south, blue) and downwind (N=north, red) from the highway. The ratio N:S is shown at the bottom of each plot for both bioindiator species. For 2002 data are not yet available.

Over the first 5 years of the study (1997-2001), there is a clear decline in metal contents in both bioindicator species for Cd and Pb (exception: Pb in lichens in 2001). Contents of Sb tend to increase, while the data for Pt do not yet exhibit a clear trend when evaluated for both bioindicators.

Directional effects (lichen boards)

Directional effects were studied using the lichen boards facing towards and away from the highway. Accumuation of Sb and Rh (both 1,9x), Cu (1,5x) and Pt (1,4x) is higher in lichens facing towards the highway than in lichens oriented away from the road (1997 - 2000). For Pb (1,1x) and Cd (1,2x) this directional effect is negligible.



Comparison with reference data

When compared with reference data from grass cultures or lichens exposed to rural or background pollution levels in Central Europe or to filtered air, 2 metal elements clearly stand out:

Contents of **antimony (Sb)** and **platinum (Pt)** in grass and lichens exposed close to the highway exceed background levels by a factor of 10 or more and are well within the range of values typically found close to busy roads.

In contrast, **lead (Pb)**contents found here were in the range of (or even lower than) mean or median values from background exposure and thus underline the dramatic decline in Pb levels near roads during the last 2 decades. **Cadmium (Cd)** contents are approaching background levels during the most recent years of the study, whereas **copper (Cu)** contents were above background levels in lichens only.

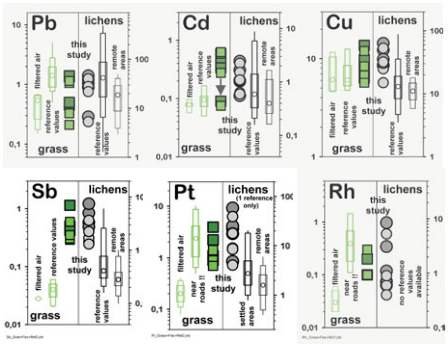


Fig. 4: Contents of 6 metals in grass cultures (left, squares) and lichens (right, circles) upwind (S, small symbols) and downwind (N, large symbols) from the highway. Reference data (rural sites) and data from filtered air exposure (grass), from remote areas (lichens) or near roads (Pt only) are presented as box plots. Note the different scales for the metal contents in grass and lichens. Data in µg/g d.w. for Pb, Cd, Cu, Sb; in ng/g d.m. for Pt and Rh.

Lichen:grass ratios

Accumulation of the metals studied was considerably higher in lichens compared to grass cultures, particularly for Pb (avg: 36x), Pt (9x) and Rh (7x). For Cd (3,8x) and Cu (4,1x) this ratio is lower, possibly (at least in part) due to uptake of these mobile metals from the growth medium into the grass cultures.

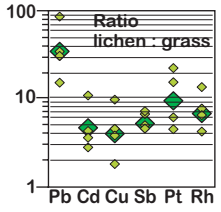


Fig. 5: Accumulation ratios of 6 metals in lichens vs. grass cultures. Note the log-scale.

Interaction of environmental factors

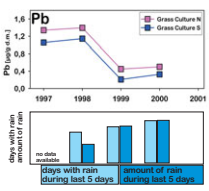


Fig. 6: Accumulation of Pb in grass cultures, and precipitation during the last 5 days of exposure.

The dynamics of Pb accumulation in grass cultures and some discrepancy between the Pb accumulation in grass and lichens during the study (see Fig. 3 top left) can be largely explained by effects of precipitation during the last phase of grass exposure.

Frequent and/or strong rain during late grass exposure considerably reduce Pb, which is largely located on the leaf surface and can easily be washed off.

Conclusions

Under the conditions in Germany, the main sources of the traffic-related metal accumulation studied here are:

- Wear from brake and clutch linings **(Sb, Cu),**
- Attrition/erosion from catalytic converters **(Pt, Rb),**
- Potential wear from tires and road surfaces.
- Lead **(Pb)** can no longer be considered a typical traffic-related pollutant, except by resuspension from road-side soils exposed during past decades.

The use of standardized biomonitoring procedures can provide reliable results and allows meaningful interpretation due to the availability of extensive background data. Temporal patterns and interaction with environmental variables can also be demonstrated.