Air, runoff and soil monitoring of highway pollution by metals along highway corridors

L. Y. Li & H. Preciado
University of British Columbia, Canada

Abstract

Heavy metal contamination resulting from vehicles is a continuing global problem. This study monitored a highway, and evaluated the contribution of traffic to metal contamination of roadside soils from atmospheric and runoff processes. The metals investigated were Pb, Zn, Cu, Fe, and Mn. Dust deposition measured using a Frisbee dust gauge showed a rapid decrease in deposition with distance from the highway. Surface soil samples in the right-of-way (ROW) exhibited a similar pattern for lead, copper and zinc up to the edge of the ROW (12 m from the shoulder). At the edge of the ROW, deposition was still two or three times greater than background dust loadings. Total metal concentrations in runoff were consistent with road dust concentrations and decreased in concentration in the order Fe>Zn>Mn>Cu≥Pb. Concentrations tended to increase as road dust load continued to accumulate. Sweeping of the highway had an impact on runoff quality and dust deposition loadings, highlighting the role of best management practices for pollution control in urban watersheds and roadside soils.

1 Introduction

Vehicles cause pollution affecting air, runoff and soil. Anthropogenic pollutants include heavy metals, suspended solids, micro-organics, oils and chlorides. These result from traffic activities, atmospheric deposition, roadway degradation and highway maintenance [1]. Nearly 25% of the priority pollutants defined by the U.S. EPA are present in the highway system [2]. Heavy metals which accumulate in roadside soils and sediments of water bodies through runoff [3, 4] exert a continuous impact on the biology of the system, as they provide a source of slowly-dissolving toxic materials [5].

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Roadside soil contamination of lead has been reported extensively due to its toxic nature [6]. Lead contents in roadside soils often exceed local environmental regulations. Its concentration decreases with distance from the road and depth. Concentrations of lead decreased to background level at a depth of 0.6 m [6]. Lead partitioning through sequential extractions showed that a minor fraction of metal was exchangeable and that complexation with manganese and iron oxides, together with organic matter, were the most important retention mechanisms in surface soils. Lead has low environmental mobility.

Other studies indicated a high accumulation of metals Zn, Cu, Mn, and Pb in plants and soil near highways [7]. Pagotto et al. [8] analysed road dust and roadside soil near a major rural highway in France and found that Pb and Cu were not highly mobile, but that there was a significant risk of Zn mobilization under acidic conditions.

Until recently, speciation of metals in atmospheric dust has received little attention due to the real difficulties in measuring even the total concentration of most metals in aerosol samples [9]. Environmental mobility of airborne particulates collected in urban areas using a sequential leaching procedure by Tessier et al. [10] have been studied by others [11]. However, these types of speciation studies have not addressed atmospheric particulates from highway sources deposited in roadside soils.

Mass balance calculations of metal loadings from atmospheric and runoff processes in roadside environments have been performed in the past by the U.S. Federal Highway Administration (FHWA). However, these data are considered to be obsolete due to changes in gasoline, automobile manufacture and traffic behaviour.

This research aimed to (1) find an effective dust sampler for measuring atmospheric dust deposition, (2) determine road dust characteristics and accumulation rates, (3) measure runoff characteristics and loadings, (4) investigate the amount and pattern of atmospheric dust loadings relative to roadside soils metal accumulations. The results are useful in identifying the influence of road dust and runoff characteristics on the surrounding soil. In addition, the quantity and quality of atmospheric dust particulates loadings are helpful in characterizing the export rates of dust and associated metals via atmospheric processes and help delineate the area of atmospheric and runoff influence on neighbouring soils. This information is useful for formulating environmental best management practices, as well as future highway planning and design.

2 Field methods and materials

A background site was selected and used to monitor dust loadings from anthropogenic non-traffic related sources and to compare efficiency of sampling technologies. A simple site on Highway 17 in British Columbia, with minimal influence from industry activities, was chosen for this study. The locations of the background and the study site are shown in Figure 1. Further details on the highway and site are given below.

Figure 1: Location of study sites.

2.1 Background site and dust samplers

The Canadian Wildlife Services (CWS) facility in Reifel, B.C., approximately 9 km northwest of the studied location on Highway 17, was selected as a convenient background location for dust deposition monitoring. Pollutants from atmospheric processes such as rainfall and dust-fall were collected and analysed.

A Frisbee dust gauge was installed and used to compare with standard dry and wet deposition samplers used in the National Atmospheric Deposition Program (NADP). The Frisbee dust gauge was set up and sampled according to protocols recommended by the Stockholm Environment Institute at York [12]. The standard samplers consisted of an Aerochem metrics ACM 301 collector and a MIC type B1 precipitation collector. Figure 2 shows the dry Frisbee dust gauge and standard samplers at the CWS facility.

Figure 2: Dust gauges.

2.2 Study site

The construction of Highway 17 was completed in the 1970s. It connects the port of Tsawwassen to Richmond and Vancouver, and carries large volumes of ferry traffic, as well as commuter traffic to suburbs like White Rock, B.C. This site was chosen based on site selection criteria suggested by Gupta et al. [13]. Agricultural farms are the only land use in the surrounding area. The traffic counts for Highway 17 are 20,417 and 22,899 vehicles/day Northbound (NB) and Southbound (SB), respectively (Information provided by B.C. Ministry of Transportation and Highways). There are three lanes of asphalt-paved roadway in each direction with flush shoulder surface drainage and a middle

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concrete barrier. The site chosen was on a level and straight stretch of highway in the open countryside. A meteorological station was installed at a nearby farm to monitor precipitation and wind conditions.

The right of way on both sides of Highway 17 in Delta, B.C. at the intersection with the overpass of Road 34B was monitored and studied at various times during normal operation and after road dust sweeping. Analyses included distribution of metal contents, dust deposition, runoff and accumulation in roadside soils.

2.3 Road dust

Road dust was swept in two stages at the beginning and/or the end of each monitoring period. In stage 1 sweeping, a miele®S3121 industrial vacuum was used to sweep the highway surface to collect road dust according to the procedures for sampling surface/bulk dust loading outlined in the USEPA AP-42 document [14] and recommendations given by the Air Quality Monitoring and Assessment Division from the Greater Vancouver Regional District (GVRD). The collected road dust was analyzed for metals and grain size distribution. Six road dust samples were collected from both the northbound and southbound lanes. The samples were homogenized according to the ASTM method, and grain sizes were analysed with standard stainless steel sieves. Six aliquots of the 2 mm fraction were separated for total metal analyses.

The rest of the road dust was collected with a Johnston®610 series, road sweeper. The information collected from the second stage sweeping was to provide an indication of the efficiency of road dust sweeping (stage 1 sweeping) in terms of its usefulness in metal pollution control practice.

2.4 Atmospheric dust particulate deposition

The atmospheric migration of dust and metal was monitored using six dry Frisbee dust deposit gauges on the right of way (ROW). Three Frisbees were located in normal transects at both sides of the highway, one at the edge of the shoulder (0 m) and at 5 m and 10 m from the edge for the northbound ROW and 0, 6 and 12 m for the southbound ROW, providing a spatial distribution of atmospheric loadings from the highway onto roadside soils. The duration of the atmospheric dust collection period depended on the amount of particulate deposited onto the gauges.

2.5 Highway runoff measurement and sampling

Runoff volumes were measured with one right-angle aluminium v-notch weir box on each side of the road. The dimensions of the weir box were 1.22 m long, 0.61 m wide and 0.31 m deep. The notch is at 75 mm above the bottom of the box. The water level was measured manually on-site.

2.6 Surface soil sampling

Surface soil was sampled parallel to the dry Frisbee dust gauge transects at 1 m intervals from the highway. Surface soil was removed to a depth of 50 mm using

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a stainless steel shovel and pick. Samples were placed in plastic bags and stored at 4°C until further metal analyses.

3 Results and discussion

3.1 Background dust deposition monitoring

The dry Frisbee dust deposit gauges captured at least 40% more atmospheric particulates than the standard (dry and wet) deposition sampler. This is in agreement with Vallack [12] who carried out a field evaluation for Frisbee-type gauges against standard dust samplers and concluded that the dry Frisbee was superior in sampling efficiency compared with standard dust samplers. Figure 3 shows dust deposition results from April to October 2002. The results show a decreasing collection efficiency of the standard samplers towards the end of summer and the beginning of fall. This could be due to an increase in atmospheric turbulence during the fall season. Since dry Frisbee dust gauges provide more realistic atmospheric pollutant loadings and deposition onto roadside soils than a standard dust sampler, the dry Frisbee dust gauges are used for the atmospheric dust monitoring throughout the remainder of this study.

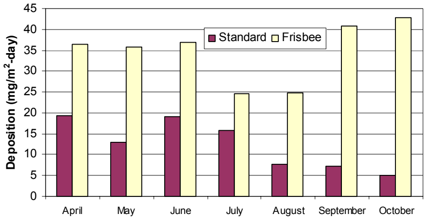

Figure 3: Dust deposition at CWS background location.

3.2 Characteristics of road dust via sweeping

Physical characteristics from composite road dust samples taken from the NB and SB corridors during the 8-month monitoring period are summarized in Table 1. The masses of road dust collected in the two halves of the 8-month monitoring period were similar; suggesting that the rate of pavement and vehicle wear was nearly constant.

Results from the first half of the monitoring period (March 25, 2002 to July 11, 2002) showed a larger amount of accumulated road dust and higher percentage of finer particulates than the second-half monitoring period (July 11, 2002 to November 29, 2002). This difference may be due to more dry days during the second-half monitoring period. Dry weather favours deposition and transport of fugitive dust emissions, whereas wet conditions favour the aggregation of fine particulates, which require higher kinetic energy to disperse such aggregated particulates from the pavement surface by traffic.

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Figure 4 shows the particle size distribution of all road dust samples collected from Highway 17 during the study period. The curves show the difference in particle size, but also the similarities in distribution shape.

Table 1: Road dust composite.

Date	Location	Mass (Kg)	Metal (mg/Kg)				
			Copper	Iron	Lead	Manganese	Zinc
25/03/02	NB	n.a	101	30150	98	277	394
	SB		70	29567	72	237	270
11/07/02	NB	137	87	22800	84.2	293	336
	SB		126	30200	51.3	322	435
29/10/02	NB	109	104	31000	181	257	346
	SB		127	30200	54.4	266	411

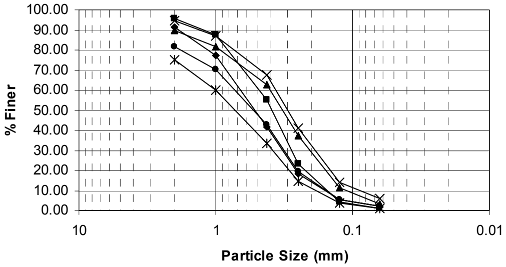

Figure 4: Size distribution of road dust.

Metal concentrations in road dust sampled through highway vacuuming during the highway sweeping operations are quite consistent throughout the 8-month monitoring period. Concentration decreases in the order Fe>Zn>Mn>Cu≥Pb, although copper and lead concentrations are not statistically different ($t = 0.57$, $P = 0.584$).

3.3 Atmospheric dust particulate loadings

Typical deposition patterns along the study area in Highway 17 for a total of 8 months of monitoring appear in Figure 5. These indicate similar patterns of fall-off in atmospheric dust loadings with distance from the highway over the entire 8 months (March to November 2002). Figure 5 shows dust loadings at the beginning (i.e. March 25-April 8)of the first four-month period, starting with a highway surface just recently swept and loadings close to the end of the first half of the period (i.e. June 3-June 25) when road dust has accumulated on the pavement surface. Both northbound (NB) and southbound (SB) locations show an increase in dust loadings to the right of way towards the end of that period.

The second 4-month period (July to Oct, 2002) demonstrated a similar pattern of dust deposition. Therefore, it appears that road dust accumulation does have an impact on the amount of dust particulate exported to the right of way.

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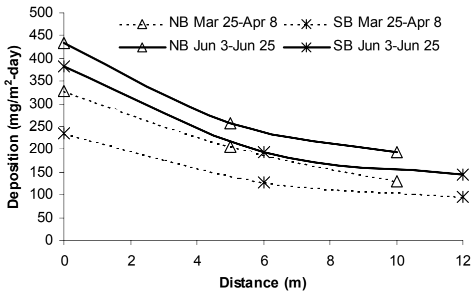

Figure 5: Dust deposition pattern.

3.4 Metal analyses of atmospheric dust particulate

Metal concentrations of the atmospheric dust particulate collected from Frisbee gauges for different months throughout the 8-month study period are shown in Figures 6 and 7.

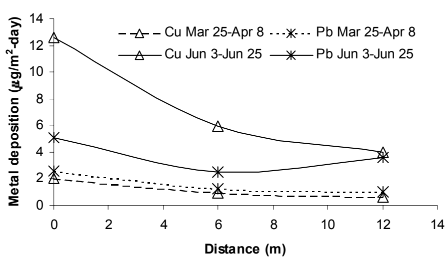

Figure 6: Cu and Pb deposition.

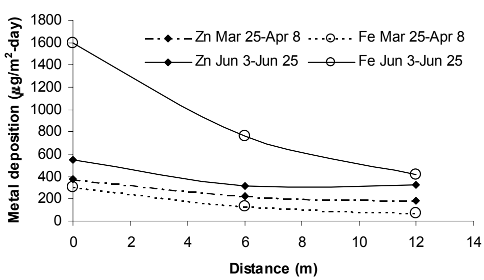

Figure 7: Zn and Fe deposition.

The metals concentrations are Fe>Zn>Mn>Cu≥Pb, a similar order to that of metal concentrations found in road dust by sweeping. It is worth nothing that Pb loadings are at least two orders of magnitude lower than reported by Kobriger and Geinopolos [15] who determined total particulate matter next to roads in U.S. FHWA pollutant migration studies in the early 1980s. Lead in particulate matter was then primarily associated with the use of alkyl lead additive in automotive fuel, whereas now that alkyl lead has been eliminated from gasoline,

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lead sources are only those naturally occurring in gasoline, paint (although this source has been removed in B.C. highways), tire wear, lubricating oil and grease, and bearing wear. The results indicate that the updated road dust information and their characteristics can be used as a footprint to predict the present atmospheric metal loadings due to vehicle activities on roadside soils.

3.5 Highway runoff loadings

Suspended Solids and Specific Conductance tended to increase as the road dust accumulated on the pavement surface over the observation period; runoff was slightly acidic, and runoff coefficients were greater for the SB than the NB corridor, which had a larger drainage area. Metal concentrations showed a similar trend to dust deposition i.e. runoff quality decreased as the accumulation of road dust on the pavement grew. Results confirm the strong association of metals and solids, confirming the importance of Best Management Practices (BMPs) that target suspended solids and road dust removal. The ranking of metal concentrations was very similar to those found in road dust and dust deposition loadings on the right-of-way as shown in Figure 8.

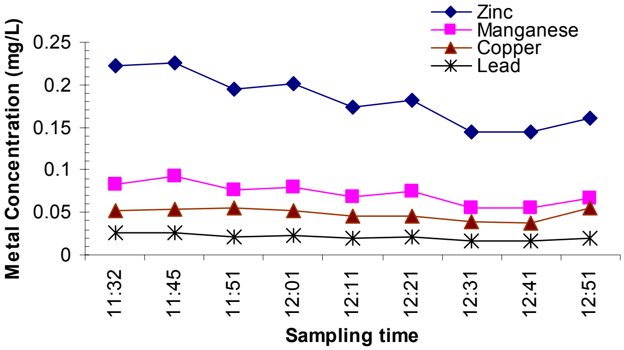

Figure 8: Metal concentrations in runoff.

For the runoff, Pb concentrations were lower than Cu, reflecting the strong attachment of lead to colloids, its precipitation under close to neutral pH environments and its low leachability from road dust particulates. All metal concentrations exceeded the water-quality parameters of the Canadian Council of Ministers of the Environment [16] for protection of freshwater aquatic life.

3.6 Metal concentrations on surface roadside soil

Metal concentrations on surface roadside soils for the northbound and southbound right-of-way are presented in Figures 9. Surface roadside soil showed a decrease of metal concentrations with distance from the highway. Southbound concentrations were greater, reflecting the influence of dominant winds which tend to blow to the west and a possible influence of the greater amount of traffic on this direction. Correlations among all metals were significant, with Cu and Zn showing the highest association ($r^2 = 0.84$).

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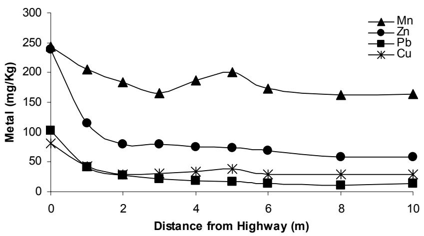

Figure 9: Metal concentration in roadside soil.

4 Conclusions and recommendations

1. Dry Frisbee dust gauges had at least 40% (per weight basis) higher atmospheric dust particulates deposited onto the gauges than standard dust dry and wet deposition samplers combined, indicating that information from dry Frisbee dust gauges provide more representative values than standard dust samplers used in the past.
2. The mass and metal concentrations of the road dust sampled through highway vacuuming during the highway sweeping operations were quite consistent throughout the 8-month monitoring period, suggesting that the rate of pavement and vehicle wear was fairly constant. Metal concentrations follow the ranking Fe>Zn>Mn>Cu≥Pb.
3. Atmospheric dust deposition patterns along Highway 17 show a decrease in dust loadings with distance from the highway edge. The metals concentrations were in the order Fe>Zn>Mn>Cu≥Pb, similar to that of metal concentrations determined in road dust collected by sweeping.
4. Suspended solids and specific conductance tended to increase as the road dust accumulated on the pavement surface over a period without road dust sweeping. Metal concentrations showed a similar trend to dust deposition. Runoff quality decreased as the accumulation of road dust on the pavement continued. The quality of runoff showed a strong correlation between metal and solids, demonstrating the importance of BMP's that target suspended solids and road dust removal.
5. Surface roadside soil showed a decrease of metal concentrations with distance from the edge of the highway. Correlations among all metals were significant, with Cu and Zn showing the highest association.
6. The common maintenance practice of scraping the roadside soil and distributing scrapings onto the right-of-way should be discontinued because they contain high metal concentrations.

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