OPEN ACCESS

GAVIN PUBLISHERS

Archives of Environmental Sciences and Environmental Toxicology

Korzeniowska J and Panek E. Arch Environ Sci Environ Toxicol 2: 110.

DOI: 10.29011/AESET-110.100110.

Research Article

Trace Metal Concentrations in the Moss *Pleurozium schreberi* and the Common Dandelion *Taraxacum officinale* along the Road No. 7 at Chyżne, Southern Poland

Joanna Korzeniowska[1*], Ewa Panek[2]

[1]Department of Sustainability and Environmental Management, Pedagogical University of Cracow, Kraków, Poland

[2]Department of Environmental Management and Protection, AGH University of Science and Technology, Kraków, Poland

***Corresponding author:** Joanna Korzeniowska, Department of Sustainability and Environmenta Management, Pedagogical University of Cracow, Kraków, Poland. Email: epanek@agh.edu.pl

Citation: Korzeniowska J, Panek E (2019) Trace Metal Concentrations in the Moss *Pleurozium schreberi* and the Common Dandelion *Taraxacum officinale* along the Road No. 7 at Chyżne, Southern Poland. Arch Environ Sci Environ Toxicol 2: 110. DOI: 10.29011/AESET-110.100110.

Received Date: 05, February, 2019; **Accepted Date**: 28, February 2019; **Published Date**: 08, March 2019

Abstract

The aim of this study is to test two plant species, the common dandelion *Taraxacum officinale* and moss *Pleurozium schreberi,* as bio monitors of trace metal pollution emitted by motor vehicles. The samples of the moss *Pleurozium schreberi* (green segments) and the common dandelion *Taraxacum officinale* (leaves) were collected within 12 transects along the state road no. E77 near Chyżne, Sothern Poland. The transects were located on the eastern and western side of the road (downwind and upwind towards prevailing winds), at the following distances from the road: 5, 50, 100, 300 500 and 600 m. Total concentrations of Cr, Cu, Ni, Pb, Sb and Zn in the plant material were determined. The studied species accumulated trace metals in the similar amounts. Statistically significant differences in metal concentrations between two plant species were observed only in the case of Cu and Pb. Copper concentrations were higher in the common dandelion, while the moss *Pleurozium schreberi* accumulated considerably higher amounts of Pb. There is a statistically significant negative correlation between the trace metal concentrations in plants and the distance to the road. There are also statistically significant differences in concentrations of Cr, Cu, Ni, Pb and Zn in the common dandelion between the samples collected from the opposite sides of the road: upwind/downwind towards the prevailing wind direction at the distance up to 300 meters. The concentrations are higher on the downwind side of the road.

Keywords: Biomonitoring; Plants; Southern poland; Spatial distribution; Trace metals; Traffic pollution

Introduction

Road traffic is associated with emissions of many known hazardous and toxic substances. These include heavy or trace metals, Polycyclic Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOCs) and de-icing salts, among others [1,2], which are emitted by motor vehicles and road infrastructure.

The following metals: Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Pd, Pt, Rh, Sb, Se, Sr, V, Zn are among the road traffic contaminants Zechmeister, et al. [3]. Among the most frequently studied heavy or trace metals, associated with road traffic pollution, are the most toxic and emitted in the highest amounts: antimony, arsenic, barium, cadmium, chromium, cobalt, copper, iron, mercury, molybdenum, nickel, lead, platinum group elements (PGE: platinum, palladium, rhodium), vanadium and zinc.

Traffic-related metals introduced into the environment derive from many different sources of emissions, including vehicular: tires, brake and clutch linings, car bodies, motor parts, fuel additives, lubricants [4,5] and non-vehicular sources: road pavement and embankment, roadside screens, de-icing substances [6-9] identify the following sources of road pollution: traffic and cargo, pavement and embankment materials, road equipment, maintenance and operation and external sources.

The main sources of Ba, Cd, Cr, Cu, Mo, Pb, Sb, Zn are brake linings (pads) and tires [1,4,10,11], Cd, Cr, Cu, Hg, Ni, Pb, V and Zn derive from road pavement materials [6,12], Ba, Cd, Cu, Ni, Zn from lubricants (Jaradat and Momani 1999 and Cd, Cr, Cu, Ni, Pb and Pt, we come from fossil fuel combustion, catalyst and antiknock additives [5]. The use of new technologies and materials has resulted in introducing new trace metals in the environment. For instance, banning leaded petrol (and introducing lead-free fuel) has resulted in a considerable decrease of Pb emissions. Pb is no longer an indicator of road pollution. However, such elements like Ba, Cr, Cu, Mo, Sb, Zn and also Platinum Group Elements (PGE) have been suggested as new tracers of traffic pollution [10,11,13,].

Roadside pollution depends on many factors, i.e. distance to the road, traffic density, road profile and also on environmental factors including: topography of adjacent area [3,7,14-18], land cover [8] and meteorological factors including precipitation, wind speed and wind direction [14,19-21].

Road location with respect to the dominant wind directions determine propagation and dispersion of traffic emissions. The dominant wind direction may influence the extent to which the road affects the surrounding environment and may also cause disproportions in pollutant deposition on the both sides of the roads [14,15, 22,23].

In particular, dominant wind directions on the exposed road sections, crossing mountain ranges and open flat area, may influence irregularity in pollutant deposition on the both sides of the road. However, the wind direction in the mountain valleys follows the shape of the valley and hence the road direction [14,16,17,19,23,24] report that road pollutants measured in road dust, soil and plants, at the same distance upwind and downwind of the road exhibit different concentration. The higher pollutant concentrations are usually observed on the downwind side of the road. The authors explain this pattern with the differences in dominant wind directions in the studied areas, which help remove pollutant particles from one side of the road to another.

Bernhardt-Römermann M, et al. find a nearly fivefold difference in UFP ultrafine particle concentrations between the upwind and downwind sites of the mayor road in North Carolina, USA [23]. The highest UFP concentrations were observed in the near vicinity of the road on downwind direction. Studies conducted by Bakirdere S [19] confirm the higher concentrations of Pb content in road dust measured in the downwind than the upwind side of the road. Deposition of deicing substances and nitrogen compound in the soil, according to Markert BA, et al. [24] affects motorways in Southern Germany up to 230 m on the downwind side of the road, in contrast to the upwind side, where it does not exceed 80 m. Naszradi T, et al. [16] and Viard B, et al. [17] report distinctions in trace metals concentrations in soil samples collected at the same distance from both the sides of the road, explaining them by differences in wind directions and strength in the studied areas.

There is a very scarce literature, if any, concerning the influence of prevailing wind directions on the discrepancies in pollutant concentrations in plants on the upwind versus downwind sites of the road, for instance Graminaceae species [19] and mosses *Pleurozium schreberi, Hylocomium splendens Scleropodium purum* and *Abietinella abietyna* [1].

Plant species are known as biological monitors and indicators of the environmental pollution. Their indication availabilities will reflect either the level of cumulated pollutants (bio monitors) or harmful effects imposed on organisms (bio indicators) [25]. Widely applied studies with use of bio monitors give the quantitative information on the quality of the environment e.g., on atmospheric pollution. Most of the research dealing with bio monitors provides information on trace element or heavy metal pollution. Mosses are regarded to be very sensitive bio monitors of the pollution, because these species reflect atmospheric deposition of heavy metals and have been applied for several decades in environmental studies [1]. The level of heavy metals in mosses can be influenced by air pollution emission factors and modified by other factors such as: climate (precipitation), altitude, species, age and part of moss [25,26]. Moss species *Pleurozium schreberi* (Brid.) Mitt. along with *Hylocomium splendens* (Hedw.) B.S.G. are the most often used monitor species [27-30]. The species *Pleurozium schreberi* (Brid.) Mitt. is highly recommended because of its widespread occurrence as well as its exceptional ability to accumulate elements from the air, reflecting environmental pollution. Well-developed surface of the plant helps to trap easily pollutant particles from the air, and the lack of cuticula layer enables it to retain and accumulate pollutants [25, 31]. The moss species including *Pleurozium schreberi* have been also used for monitoring of traffic related pollutants, i.e., trace metals [1,3,16,22,32].

In recent decades, vascular plants have been commonly applied as bio indicators and bio monitors because of their high abundance and widespread presence. Vascular plants monitor environmental changes in space and time [25]. However, most of the vascular species accumulate trace metals to the considerably lesser extent than mosses and lichens. For a long time, many authors have recommended the common dandelion *Taraxacum officinale* Weber as a suitable worldwide trace metal bio monitor and bio indicator reflecting quantitative air pollution [33-40]. The species is easy to identify, geographically widespread and occurs in meadows and pastures of various localities, including urban, industrial and agricultural areas, polluted to the various extent. The species reflects traffic-born pollution including trace metals [37-42].

The aim of this study is to test two plant species, the common dandelion *Taraxacum officinale* and moss *Pleurozium schreberi,* as bio monitors of spatial trace metals traffic pollution.

Material and Methods

Study Area

The study area was situated along the state road no. E77 (national road DK7) between villages Jabłonka and Chyżne, county Nowy Targ in Sothern Poland, in the vicinity of the border crossing to Slovakia. Geographical coordinates: the latitude and longitude and elevation are 49˚43' N, 19˚67' E and 649 m a.s.l., respectively. According to Köppen classification, the area is characterized by temperate continental climate (Dfb). The data for the average annual precipitation, temperature and wind speed are about 115 mm, 7.5 ˚C and 10 km/hour, respectively [43]. The dominant wind directions are S, SSW and W were 1319, 956 and 759 hours per year, respectively. The simulated meteorological data are available for Jabłonka, Chyżne and Czarny Dunajec locations (Weather, https://www.meteoblue.com/pl).

The road no E77 plays an important role in the transit traffic towards southern Europe. The traffic density on the road section between Jabłonka and the state border was 5359 vehicles per day in 2015 and the speed limit was 90 km per hour (GPR, http://www.gddkia.gov.pl/pl/2551/GPR-2015).

Sampling

The samples were collected in 12 transects near the Slovak state border. The transects were located perpendicularly to the road, on the eastern and western side of the road, in the open area: meadows and pastures as well as in the woodland.

With respect to the prevailing wind direction, the transects were located upwind "non-road emission source" (E transects) and downwind "from road emission source" (W transects) relative to the road Figure 1. Each transect included six sampling sites at the following distances from the edge of the road 5, 50, 100, 300, 500, 600 m (Figure 2). In order to avoid the influence of local pollution sources sampling sites were situated at least 500 m from housing estates. The reference area was situated south of Chyżne village in the Jeleśnia stream valley, at the minimal distance of about 5 km from roads and individual houses.

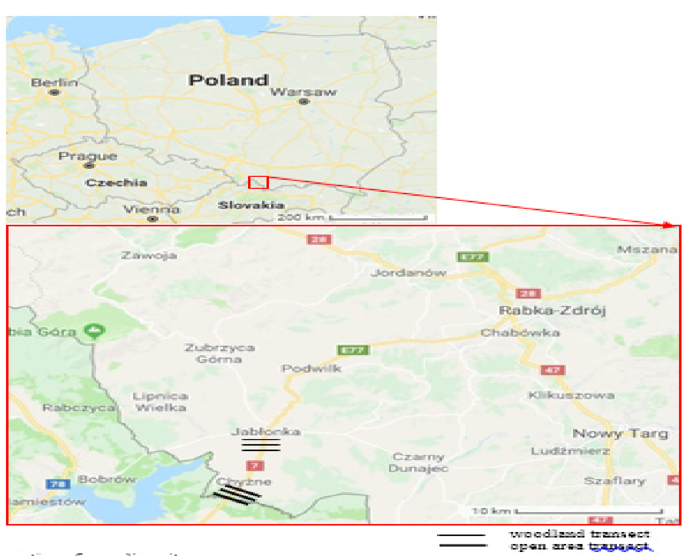

Figure 1: Location of sampling sites.

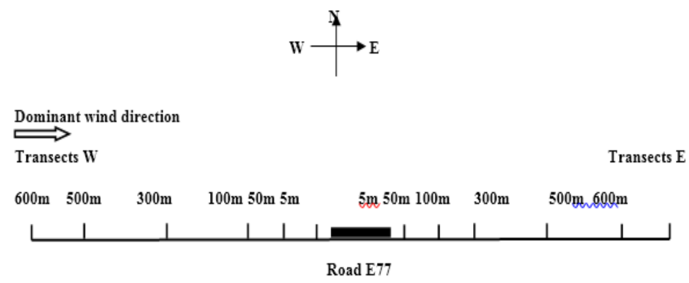

Figure 2: Scheme of sampling transect.

Material

Two biomonitor species, the moss species *Pleurozium schreberi* (Willd.) Mitten.) and the common dandelion *Taraxacum officinale* Weber, were selected for the study. The selection criterion for species was their wide (common) distribution within sampling area.

Samples of the common dandelion were taken within six transects located in the open area and the moss samples within six transects in the woodlands (Figure 1). Each species was sampled at 36 road sites. The mean sample of each species consisted of ten primary replicate samples collected in one site. In case of *Taraxacum officinale* the primary replicate sample consisted of 10-30 fully developed leaves, without imperfections, such as chlorosis or necrosis, taken from 3-5 individual plants. In case of carpet forming moss species *Pleurozium schreberi,* the primary replicate samples (green segments of shoots) were collected at least from 5 individual patches (clumps). In total 84 mean plant samples, including 12 reference samples, were taken. Field sampling was conducted after a few days without rainfall in September 2015. Material was placed in polyethylene bags.

Methods

Chemical Analysis

According to suggestions of the following authors: Monaci, et al. [10], Maňkovska, et al. [44] and Sawidis, et al. [45] concerning sample preparation procedure, the plant material was left unwashed. The samples were dried in an electric drier at the temperature of 40 ^{0}C for 72 hours. Needles were separated from branches. Equal amounts of biomass from primary samples from the same plot were combined. Dry and homogenized samples were pulverized in an electric grinder. Portions of 0,4 g dry weight material were placed in Teflon vessels. 5 ml of 65% HNO_3 and 3 ml of 36% H_2O_2 were added to each vessel. The mixture was mineralized in a microwave Berghof Speed Wave in temperature 200 ^{o}C and at pressure of 40 bar. After processing the samples were diluted with deionized water to a total volume of 50 ml and filtered through hard paper filter. The final solutions were analyzed for trace metals using Flame Atomic Absorption Spectrometry (FAAS) with a spectrophotometer model Hitachi Z 2000. Total concentrations of Cr, Cu, Ni, Pb and Zn were determined.

Statistical Analysis of the Data

The statistical analysis was conducted using Statistica 10.0 software. The Shapiro-Wilka test was used to test whether the data followed the normal distribution. The Mann-Whitney U test was performed to examine whether differences in plant metal levels on upwind and downwind locations (sites) were statistically significant. The Mann-Whitney U test was also used to compare metal concentrations between the moss *Pleurozium schreberi* and the common dandelion *Taraxacum officinale.* The relationship between metal concentrations in plants and the distance from the road was tested by means of the Spearman R rank correlation coefficient R. The significance level α = 0.05 was established.

Results

Plant Species Variations

The mean concentrations of Cr, Cu, Ni, Pb, Sb and Zn in the moss species *Pleurozium schreberi* and the common dandelion *Taraxacum officinale* at the distances 5, 50, 100, 300, 500 and 600 m from the road are presented in Table 1.

Plant species	Side of the road	Distance [m]	Trace metals [µg/g d.w.]					
			Cr	Cu	Ni	Pb	Sb	Zn
Moss	W (upwind)	5	84.3±14.8	8.2±1.8	39.0±8.1	9.5±2.0	0.68±0.28	33.3±5.0
		50	75.0±12.1	7.7±1.8	37.4±8.5	9.4±2.6	0.67±0.24	33.0±4.3
		100	72.2±12.4	7.6±1.2	37.0±10.3	9.3±2.3	0.67±0.21	32.8±5.4
		300	53.2±15.8	6.6±1.8	33.5±13.3	7.9±2.1	0.57±0.26	28.9±12.2
		500	36.2±12.1	4.7±2.1	26.4±8.2	5.9±2.2	0.45±0.16	22.0±7.1
		600	35.2±10.3	4.5±1.2	26.0±6.4	5.3±1.7	0.28±0.13	21.0±4.1
	E (downwind)	5	75.5±29.8	8.0±2.4	38.5±8.5	8.6±3.2	0.82±0.28	35.6±10.2
		50	70.9±22.3	7.3±2.0	35.5±11.1	8.6±3.1	0.78±0.36	35.0±9.9
		100	63.3±24.6	7.6±3.2	38.2±11.8	9.4±3.4	0.73±0.32	34.3±9.9
		300	63.5±19.2	7.7±2.0	35.9±9.7	8.2±1.9	0.68±0.26	31.6±11.6
		500	43.5±10.3	6.4±2.2	33.3±11.7	8.8±3.5	0.5±0.2	29.6±7.9
		600	46.1±10.9	5.5±2.5	30.4±13.4	7.2±2.7	0.39±0.17	27.1±8.6
	Reference sites		35.0±4.4	5.0±1.6	25.8±6.3	5.7±1.1	0.29±0.16	20.0±7.6
Dandelion	W (upwind)	5	88.9±14.3	11.4±6.0	48.6±6.9	8.4±3.8	1.40±0.67	89.9±17.7
		50	56.5±13.6	7.6±3.8	38.1±7.3	7.5±3.5	0.72±0.26	39.4±9.7
		100	47.4±20.5	6.4±2.1	31±14.3	6.2±2.4	0.84±0.63	40.8±17.3
		300	41.7±10.6	8.2±4.8	26.2±12.2	6.9±2.8	0.59±0.27	22.8±8.9
		500	37.8±12.0	7.4±3.5	25.5±5.8	6.2±2.3	0.38±0.19	24.0±8.9
		600	35.7±8.6	5.9±1.7	26.6±6.9	4.4±1.6	0.34±0.15	18.8±5.0
	E (downwind)	5	108.8±31.6	20.7±9.6	75.1±14.3	14.2±5.0	0.95±0.48	148.0±50.1
		50	76.2±24.8	20.4±7.3	43.2±12.9	11.1±4.6	0.80±0.36	53.3±15.6
		100	70.7±23.2	19.0±5.9	36.7±9.4	7.3±3.0	0.74±0.34	39.1±19.3
		300	59.1±11.7	12.9±5.1	33.1±13.7	6.0±1.7	0.62±0.35	33.2±13.9
		500	44.8±7.8	7.9±1.5	30.2±7.7	4.4±2.0	0.55±0.30	29.9±9.2
		600	37.9±12.8	6.5±1.6	29.7±7.9	3.8±1.3	0.48±0.26	25.5±8.3
	Reference sites		35.9±7.8	5.9±1.5	24.9±6.8	4.0±1.2	0.18±0.08	19.2±5.9

Table 1: Mean concentrations and standard deviations of trace metals in the moss species *Pleurozium schreberi* and the common dandelion *Taraxacum officinale* in µg/g dry weight, n= 6

The metal concentrations in the moss species *Pleurozium schreberi* calculated for all sites (5E, 50E, 100E, 300E, 500 E, 600 E, 5W, 50W, 100W, 300W, 500Wand 600W and the reference sites) were as follows: 56.4±23.0 µg Cr/g d.w, 6.6±2.3 µg Cu/g d.w, 33.1±10.6 µg Ni/g d.w, 7.8±2.8 µg Pb/g d.w, 28.9±9.8 µg Zn/g d.w. and 0.56±0.29 µg Sb/g d.w and in the common dandelion *Taraxacum officinale*: 55.5±27.1 µg Cr/g d.w, 10.4±7.0 µg Cu/g d.w, 35.3±16.2 µg Ni/g d.w, 6.8±4.0 µg Pb/g d.w, 43.1±38.3 µg Zn/g d.w and 0.63±0.46 µg Sb/g d.w respectively. Chromium was accumulated in the highest amounts in both plant species, while Sb was accumulated to a lesser extent. Descending sequences of average metal concentrations were as follows: for the moss *Pleurozium schreberi* Cr > Ni > Zn > Pb > Cu > Sb and for the common dandelion: Cr > Zn > Ni > Cu > Pb > Sb.

The examined plant species accumulated trace metals in similar amounts. The Mann-Whitney U test showed statistically significant differences in metal concentrations between species only in the case of Cu and Pb. Copper concentrations were higher in the common dandelion (p<0.001), the moss *Pleurozium schreberi* accumulated considerably higher amounts of Pb (p<0.001), whereas the interspecies differences for other metal contents were not statistically significant.

Distance to the Road

There was a systematic relationship between metal concentrations in plants and the distance to the road. The moss and the common dandelion in the direct vicinity of the road (5 m) accumulated higher amounts of metals than those located at the distances of up to 600 m. Enrichment coefficients calculated as a quotient of Cr, Cu, Ni, Pb, Sb and Zn concentrations in the moss and in the common dandelion at the distances of 5 and 600 m to the road were 2.0, 1.6, 1.4, 1.5, 2.2, 1.4 and 2.7, 2.6, 2.2, 2.8, 3.0, 5.3, respectively. Hence, one may conclude that the plants were influenced by vehicle emissions to the considerable extent. There was a negative and statistically significant correlation between metal concentrations in sampled plants and the distance to the road, regardless of whether the upwind or the downwind side of the road was considered and regardless of the plant species considered. In the case the moss *Pleurozium schreberi,* the most significant correlation was observed for chromium (R= -0.82; p<0.001) and anthymone (R= -0.61; p<0.001). The weakest correlations were found for lead and nikel. However, in the case of the common dandelion the most statistically significant correlations were found for chromium (R=-0.78; p<0.001), lead (R=-0.72; p<0.001), anthymone (R=-0.72; p<0.001) and zinc (R=-0.80; p<0.001), while the weakest correlations pertained to Cu contents of copper and nickel.

Downwind Versus Upwind Roadside Variations

The differences in metal concentrations between the downstream and the upstream group of roadside plants, regardless of the distance, were tested using the Mann-Whitney U test. The U test did not show statistically significant differences between the wind direction (downwind "from road emission source" and upwind "non-road emission source") and metal concentrations in the moss *Pleurozium schreberi*, however, for the common dandelion statistically significant differences were observed in the case of Cr (p<0.05), Cu (p<0.001) and Ni (p<0.05). The concentrations of the above-mentioned metals were higher on the downwind side of the road.

There were statistically significant differences (p<0.05) between metal concentrations in the dandelion samples collected up and downwind roadside, at the same distances. In particular, differences occurred in the case of Cu at distances of 5, 50, 100 and 300 m, Cr for 50, 100, 300 m and in the case of Ni, Pb and Zn only for 5 m from the road (Table 2). In the moss *Pleurozium schreberi* statistically significant differences (p<0.05) were found only for chromium at the distance of 600m (p=0.049).

Distance [m]	Metal					
	Cr	Cu	Ni	Pb	Sb	Zn
5	n.s.	0,005741**	0,000583**	0,017216*	n.s.	0,005796**
50	0,041098*	0,000580**	n.s.	n.s.	n.s.	n.s.
100	0,034227*	0,000181**	n.s.	n.s.	n.s.	n.s.
300	0,004044**	0,031146*	n.s.	n.s.	n.s.	n.s.
500	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
600	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 2: Differences in trace metal concentrations in the common dandelion *Taraxacum officinale* on the upwind and downwind roadside (Mann-Whitney Test U).

* p<0.05

** p<0.01

n.s. – not statistically significant

Discussion

Kabata-Pendias and Pendias [46] have established the typical range of trace metal levels for mature leaf tissue in various species of vascular plants. These are as follows: 0.1-0.5 µg Cr/g, 5 to 30 µg Cu/g, 0.1-5.0 µg Ni/g, 5-10 µg Pb/g, 7-50 µg Sb/g, 27-150 µg Zn/g d.w. The above-mentioned authors also classified the following ranges 5-30 µg Cr/g, 20-100 µg Cu/g, 10-100 µg Ni/g, 30-300 µg Pb/g, 150 µg Sb/g and 100-400 µg Zn/g d.w. as toxic concentrations.

In our study, only Cr and Ni concentrations in green segments of the moss *Pleurozium schreberi* and in the leaves of common dandelion sampled at the distance of 5 m from the road exhibited toxic contents quoted by [46]. Chromium concentrations were almost three times higher than the toxic range. The data obtained for Ni were higher than the normal range and reached the toxic values. In addition, zinc contents were lower than toxic ranges and only slightly exceeded normal concentrations. Copper and lead contents did not reach toxic values for plants and fell within the normal range for plants. Antimony concentrations measured in this study were lower than normal ranges **[**46].

Generally, the level of element accumulation depends on the plant species. Nevertheless, the moss *Pleurozium schreberi* and the common dandelion did not differ widely in uptake efficiency. Regardless of the distance to the road, the common dandelion accumulated metals to a slightly higher extent than the moss species, with the exception of Pb. This finding contradicts the earlier studies by [47,48] carried along the forest area at the road Krakow-Zakopane, section Pcim –Zabornia, Southern Poland, which stated that the concentrations of Cr, Cu, Ni, Pb and Zn in the moss *Pleurozium schreberi* were higher than those found in the common dandelion. The contents of Cu, Pb and Zn in *Pleurozium schreberi* at Chyżne were 2-3 times lower than those observed along the road Krakow-Zakopane. It may be explained, to some extent, by the fact that traffic density on the road Krakow-Zakopane was twice as high as that of the road no E77 at Chyżne state. In the case of the common dandelion, metal concentrations at Chyżne were higher than those found along the road Krakow-Zakopane. The results obtained for the *Pleurozium schreberi* indicate that the roadside moss species accumulated several times higher amounts of metals than those observed in several moss species by Harmens, et al. [48] in Europe and Krommer, et al. [49] in Wienerwald Biosphere Reserve. There are available data on trace metal concentrations in the moss species *Pleurozium schreberi* along traffic routes are very scarce. Suoranta, et al. [32] reported the following concentrations 17-460 110 µg Cr/g, 4.6-31 11µg Cu /g, 2.2-16 6.2 µg Ni /g, 2-9.3 3.3 µg Pb /g, 0.13-1.4 0.46 µg Sb /g and 46-130 73 µg Zn /g for the highway in Oulu, Finland. Our present data for Ni, Pb and Sb were several times higher when compared to those given by [32] for the Finnish roads.

The common dandelion *Taraxacum officinale* is regarded as a convenient environmental indicator. The background values of metal content reported by Rule [50] are: 0.2–0.5 µg Cr /g, 5–20 µg Cu /g, 0.5–6.2 µg Ni /g, 0.8–6.5 µg Pb /g, and 20–110 µg Zn /g. In contrast to the *Pleurozium schreberi* moss species, there are many studies referring to roadside metal pollution monitoring, using the *Taraxacum officinale* species(Marr, et al. [35] for Montreal, Czarnowska , et al [41] for Warsaw, Diatta, et al. [36] for Poznan, Djingova,_et al. [37] for highways in Germany, Ligocki , et al. [38] for Szczecin, Giacomino, et al. [42] for Cuneo province, Italy and Kováčik, et al. [40] for Košice, Slovakia). Those results considerably exceeded background values reported by Rule [50] in the case of Cr and Ni and only slightly for Pb, regardless of the distance from the road.

Proximity to the road is regarded to be the main factor affecting roadside environments. Road traffic results in higher pollutant concentrations in the environmental components in the direct proximity to the road. Metal concentrations in soils and plants decrease with distance from the road to reach background level at the distance ranging widely according to the various authors up to several hundred meters (Piron-Frenet, et al. [41], Viscari, et al. [22], Viard, et al. [19], Zechmeister, et al. [1,3]).

In our study, metal concentrations in plant samples were significantly correlated with the distance to the road, regardless of the plant species considered. Our data showed considerably higher Cr, Ni, Zn concentrations in the direct proximity to the road, when comparing to the figures reported by Kováčik, et al. [40] for the vicinity of traffic roads in Košice and by Giacomino, et al. [42] for Italian province of Cuneo. The data referring to the distance of 300 – 600m matched the data reported by Kabata-Pendias, et al. [33] for Poland, Marr, et al. [35] for Montreal, Diatta, et al. [36] for Poznań, Czarnowska and Milewska [41] for Warsaw, Ligocki, et al. [38] for Szczecin, Čurlik, et al. (2016) for Slovakia.

The existing literature finds differences between upwind and downwind concentrations of particle matter PM Roorda-Knape, et al.[51], Garcia, et al. [52], Hagler, et al. [23], McGee, et al. [53], metal contents in the roadside soils (Viard, et al. [19], Bakirdere and Yaman [16] and Masoudi, et al.[17]) and in roadside plants (Viard, et al. [19], Zechmeister, et al. [1]). However, the results are mixed. Hagler, et al. [23] find significant differences in ultrafine particle UFP concentrations between the upwind and downwind sites of the road with the higher amounts of UFP being observed downwind from the road. However, the results in Garcia, et al. [52] concerning particle matter PM concentrations near highways show no evidence of a significant upwind source influence. Roorda-Knape, et al. [50] and McGee, et al. [53] report no correlation between PM concentrations and down/upwind road locations.

Viard, et al. [19], Bakirdere and Yaman [16] and Masoudi, et al. [17] find Cu, Pb, Zn different concentrations in the soils at the upwind and downwind locations from the road at the same distance. The higher pollutant concentrations are usually observed at the downwind side of the road, towards the prevailing wind direction.

Among very few studies on influence of wind direction on metal concentrations in roadside plants, those performed by Viard, et al. [17] and Zechmeister, et al. [1] show differences of some trace metal contents in plants collected from two sides of the road. The authors conclude that higher values are found downwind from the road.

The prevailing wind direction, across our study area, is a southern one (1319 hours per year). Eastern winds are four times less frequent (190 hours per year than Western winds (759 hours per year)). The differences in prevalence of Western and Eastern winds may explain higher metal pollution on the downwind, eastern side of the southbound road.

Our study revealed statistically significant differences between metal concentrations in the common dandelion at the two sides of the road. The concentrations were higher on the west side (downwind from traffic emission sources). However, no differences in metal concentrations in the moss *Pleurozium schreberi* were observed. Plant cover influences, to some extent, pollutant dispersion in the vicinity to the road. The samples of the common dandelion were collected in the open area, whereas the moss *Pleurozium schreberi* in the forest. The forest trees may have played a role of natural screen, trapping dust particles, causing disturbances of wind stream, and thus hindering road pollutant propagation. This conclusion is in line with the work of Sucharowa and Suchara (2004) who reported dependence of metal content in mosses on land cover: open area and woodland. Concentrations decreased with increasing tree density and canopy density.

Our results indicating statistically significant differences in metal contents in the common dandelion between upwind and downwind side of the road are similar to the conclusions of Viard, et al. [17] for the *Graminaceae* and of Zechmeister, et al. [1] for the mosses (though not for the moss *Pleurozium schreberi*).

Conclusions

1. The distance to the road influenced metal concentrations in both plant species. Cr, Cu, Ni, Pb, Sb and Zn concentrations decreased with the distance to the road.
2. Statistically significant differences in the metal content in the common dandelion between the upwind and the downwind sides of the road were observed. As expected, higher concentrations were found at the downwind locations.
3. The common dandelion accumulated trace metal in higher amounts than the moss species *Pleurozium schreberi,* however, the differences were not statistically significant. Nevertheless, it can be regarded as a very suitable phytoindicator of metal traffic pollution in the open area, occurring wide spreadly at the highly polluted sites, including direct vicinity to the road.

Acknowledgement

The study was performed in the Department of Environmental Management and Protection of the AGH Faculty of Mining Surveying and Environmental Engineering, Department of Environmental Management and Protection. It was financed by research project no. 11.11.150.008.

References

1. Zechmeister H, Hohenwallner D, Riss A, Hanus-Illnar A (2005) Estimation of element deposition derived from road traffic sources by using mosses. Environmental Pollution 138: 238-249.
2. Wessolek G, Kluge B, Toland A, Nehls T, Klingelmann E, et al. (2011) Urban soils in the vadose zone. In W. Endlicher (Ed.), Perspectives in Urban Ecology (pp. 89-133) Berlin: Springer.
3. Zechmeister H, Hagendorfer H, Hohenwallner D, Hanus-Illnar A, Riss A (2006) Analyses of platinum group elements in mosses as indicators of road traffic emissions in Austria. Atmospheric Environment 40: 7720-7732.
4. Harrison RM, Tilling R, Romero M, Harrad S, Jarvis K (2003) A study of trace metals and polycyclic aromatic hydrocarbons in the roadside environment. Atmospheric Environment 37: 2391-2402.
5. Ozaki H, Watanabe I, Kuno K (2004) As, Sb and Hg distribution and pollution sources in the roadside soil and dust around Kamikochi, Chubu Sangaku National Park, Japan. Geochem. J 38: 473-484.
6. Lindgren Ǻ (1996) Asphalt wear and pollution transport. Sci. Total Environ 189-190 : 281-286.
7. Turer D (2005) Effect of non-vehicular sources on heavy metal concentrations of roadside soils. Water, Air and Soil Pollution 166: 251-264
8. Zehetner F, Rosenfellner U, Mentler A, Gerzabek MH (2009) Distribution of road salt residues, heavy metals and polycyclic aromatic hydrocarbons accross a highway-forest interface. Water Air Soil Pollut 198: 125-132.
9. Folkeson L, Bękken T, Brenčič M, Dawson A, Frančois D, et al. (2009) Sources and fate of water contaminants in roads. Geotechnical, Geological and Earthquake Engineering, 5. In Andrew Dawson (Ed.), Water in Road Structures (pp. 107-146). Netherlands: Springer.
10. Monaci F, Moni F, Lanciotti E, Grechi D, Bargagli R (2000) Biomonitoring of airborne metals in urban environments: new tracers of vehicle emission, in place of lead. Environmental Pollution 107(3): 321-327.
11. Werkenthin M, Kluge B, Wessolek G (2014) Metals in European roadside soils and soil sollution – A review. Environ. Pollut 189: 98-110.
12. Kluge B, Wessolek G (2012) Heavy metal pattern and solute concentrations in soils along the oldest highway of the world – the AVUS Autobahn. Environ. Monit. Assess 184: 6469-6481.
13. Hjortenkrans D, Bergbäck B, Häggerud A (2006) New metal emission patterns in road traffic environments. Environmental Monitoring and Assessment 117: 85-98
14. Piron-Frenet M, Bureau F, Pineau A (1994) Lead accumulation in surface roadside soil. Its relationship to traffic density and meteorological parameters. Sci. Total Environ 144: 297-304.
15. Veranth J, Pardyjak E, Seshadri G (2003) Vehicle-generated fugitive dust transport: analytic models and field study. Atmospheric Environment 37: 2295-2303.

16. Naszradi T, Badacsonyi A, Nemeth N, Tuba Z, Batic F (2004) Zinc, lead and cadmium content in meadow plants and mosses along the M3 Motorway (Hungary). J. Atmospheric Chem 49: 593-603.

17. Viard B, Pihan F, Promeyrat S, Pihan J-C (2004) Integrated assessment of heavy metal (Pb, Zn, Cd) highway pollution : bioaccumulation in soil, Graminaceae and land snails. Chemosphere 55: 1349-1359.

18. Saeedi M, Hosseinzadeh M, Jamshidi A, Pajooheshfar SP (2009) Assessment of heavy metal concentration and leaching characteristics in highway side soils, Iran. Envion. Monit. Assess 151: 231-241.

19. Bakirdere S, Yaman M (2008) Determination of lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. Environ. Monit. Assess 136: 401-410.

20. Masoudi SN, Ghajar Sepanlou M, Bahmanyar MA (2012) Distribution of lead, cadmium, copper and zinc in roadside soil of Sari-Ghaemshahr road, Iran. Afr. J. Agric Res 7: 198-204.

21. Viskari E, Rekilä R, Roy S, Lehto O, Ruuskanen J, et al. (1997) Airborne pollutants along a roadside: assessment using snow analyses and moss bags. Environmental Pollution 97: 153-160.

22. Hagler GS, Baldauf RW, Thoma ED, Long TR (2009) Ultrafine particles near a major roadway in Raleigh, North Carolina: Downwind attenuation and correlation with traffic-related pollutants. Atmospheric Environment 43: 1229-1234.

23. Bernhardt-Römermann M, Kirchner M, Kudernatsch T, Jakobi G, Fischer A (2006) Changed vegetation composition in coniferous forests near to motorways in Southern Germany: the effects of traffic-born pollution. Environmental Pollution, 143: 572-581.

24. Markert BA, Breure AM, Zechmeister HG (2003) Bioindicators and biomonitors. Principles, concepts and application. Amsterdam: Elsevier

25. Zechmeister H, Hohenwallner D, Riss A, Hanus-Illnar A (2003) Variations in heavy metal concentrations in the moss species Abietinella abietina (Hedw.) Fleisch. according to sampling time, within site variability and increase in biomass. The Science of the Total Environment 301: 55-65.

26. Grodzińska K, Szarek-Łukaszewska G, Godzik B (1999) Survey of heavy metal deposition in Poland using mosses as indicators. The Science of the Total Environment 229: 41-51.

27. Szarek-Łukaszewska G, Grodzińska S, Braniewski S (2002) Heavy metal concentration in the moss Pleurozium schreberi in the Niepołomice forest, Poland: changes during 20 years. Environmental Monitoring and Assessment 79: 231-237

28. Rühling Å, Tyler G (2004) Changes in the atmospheric deposition of minor and rare elements between 1975 and 2000 in south Sweden, as measured by moss analysis. Environmental Pollution 131: 417-423.

29. Suchara I, Sucharová J, Hola M, Reimann C, Boyd R, et al. (2011) The performance of moss, grass, and 1- and 2- year old spruce needles as bio indicators of contamination: A comparative study at the scale of the Czech Republic. Science of the Total Environment 409: 2281- 2297.

30. Kosior G, Samecka-Cymerman A, Kolon K, Kempers AJ (2010) Bioindication capacity of metal pollution of native and transplanted Pleurozium schreberi under various levels of pollution. Chemosphere, 81, 321-326.

31. Kosior G, Samecka- Cymerman A, Kolon K, Kempers AJ (2010) Bioindication capacity of metal pollution of native and transplanted Pleurozium schreberi under various levels of pollution. Chemosphere 81: 321-326.

32. Suoranta T, Niemelä M, Poikolainen J, Piispanen J, Bokhari SNH, et al. (2016). Active biomonitoring of palladium, platinum, and rhodium emissions from road traffic using transplanted moss. Environ. Sci. Pollut. Res 23: 16790-16801.

33. Kabata-Pendias A, Dudka S (1991) Trace metal contents of Taraxacum officinale (dandelion) as a convenient environmental indicator. Environ. Geochem. Health 13: 108-112.

34. Djingova R, Kuleff I (1993) Monitoring of heavy metal pollution by *Taraxacum officinale*. In B. Markert (Ed.), Plants as Biomonitors: Indicators for Heavy Metals in the Terrestrial Environment (pp. 435-460). New York VCH.

35. Marr K, Fyles H, Hendershot W (1999) Trace metals in Montreal urban soils and the leaves of Taraxacum officinale. Can J Soil Sci 79: 385-387.

36. Diatta JB, Grzebisz W, Apolinarska K (2003) A study of soil pollution by heavy metals in the city of Poznań (Poland) using dandelion (*Taraxacum officinale* WEB.) as a bioindicator. Electronic Journal of Polish Agricultural Universities, Environmenta lDevelopment 6: http://www.ejpau.media.pl/volume6/issue2/environment/art-01.html

37. Djingova R., Kovacheva P, Wagner G, Markert B (2003) Distribution of platinum group elements and other traffic related elements among different plants along some highways in Germany. The Science of the Total Environment 308: 235-246.

38. Ligocki M, Tarasewicz Z, Zygmunt A, Aniśko M (2011) The common dandelion (*Taraxacum officinale*) as an indicator of anthropogenic toxic metal pollution of environment. Acta Sci. Pol Zootechnica 10: 73-82.

39. Petrova S, Yurukova L, Velcheva I (2013) Taraxacum officinale as a bio monitor of metals and toxic elements (Plovdiv, Bulgaria). Bulg. J. Agric. Sci 19: 241-247.

40. Kováčik J, Dudáš M, Hedbavny J, Mártonfi P (2016) Dandelion Taraxacum linearisquameum does not reflect soil metal content in urban localities. Environmental Pollution 218: 160-167.

41. Czarnowska K, Milewska A (2000) The content of heavy metals in an indicator plant (*Taraxacum officinale*) in Warsaw. Pol. J. Environ. Stud 9: 125-128.

42. Giacomino A, Malandrino M, Colombo ML, Miaglia S, Maimone P, et al. (2016) Metal content in dandelion (*Taraxacum officinale*) leaves: influence of vehicular traffic and safety upon consumption as food. J. Chem http://dx.doi.org/10.1155/2016/9842987.

43. Lorenc H (2005) Climate Atlas of Poland. Warsaw: Institute of Meteorology and Water Management.

44. Maňkovska B, Godzik B, Badea O, Shiparyk Y, Moravcik P (2004) Chemical and morphological characteristic of key tree species in the Carpathian Mountains. Environ. Pollut 130: 41-54.

45. Sawidis T, Breuste J, Mitrovic M, Pavlovic P, Tsigaridas K (2011) Trees as bio indicator of heavy metal pollution in three European cities. Environmental Pollution 159: 3560-3570.

46. Kabata-Pendias A, Pendias H (2001) Trace elements in soils and plants. Boca Raton London New York Washington DC, CRC Press.

47. Panek E, Targońska J (2006) Trace metals (cadmium, chromium, copper, manganese, nickel, lead, zinc) in the roadside plants *(Pleurozium schreberi , Picea abies* L. and *Taraxacum official*) between Kraków and Zakopane, Southern Poland. In M. Anke K. Kisters U. Schäfer H. Schenkel M. Seifert (Eds.) Macro and Trace Elements (pp. 555-561) Friedrich Schiller University, Jena.

48. Harmens H, Norris DA, Sharps K, MillsG, Alber R, et al. (2015) Heavy metal and nitrogen concentrations in mosses are declining across Europe whilst some “hotspots” remain in 2010. Environmental Pollution 200: 93-104.

49. Krommer V, Zechmeister H, Roder I, Scharf S, Hanus-Illnar A (2007) Monitoring atmospheric pollution in the biosphere reserve Wienerwald by a combined approach of biomonitoring methods and technical measurements. Chemosphere 67: 1956-1966.

50. Rule JH (1994) Use of small plants as trace element phytomonitoring,with emphasis on the common dandelion, Taraxacum officinale. In D.C. Adriano ZS. Chen SS. Yang (Eds.) Biogeochemistry of trace elements (pp. 627–654) Bukhurst Hill: Science Technology Letters.

51. Roorda-Knape MC, Janssen NAH De, Hartog JJ, Van Vliet PHN, Harssema H, et al. (1998) Air pollution from traffic in city districts near major motorway. Atmospheric Environment 32: 1921-1930.

52. Garcia R, Hart JE, Davis ME, Reaser P, Natkin J, et al. (2007) Effects of Wind on Background Particle Concentrations at Truck Freight Terminals. Journal of Occupational and Environmental Hygiene 4: 36-48.

53. McGee MA, Kamal AS, McGee JK, Wood CE, Dye JA, et al. (2015) Differential effects of particulate matter upwind and downwind of an urban freeway in an allergic mouse model. Environ. Sci. Technol 49: 3930-3939.