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Original Research

Biomonitoring Road Dust Pollution Along Streets with Various Traffic Densities

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Abstract

Three lichen species (*Phaeophyscia orbicularis, Physcia adscendens,* and *Xanthoria parietina*), were sampled from the deciduous trees along nine streets of various traffic densities in Prešov, Slovakia. The total concentrations of risk elements (Al, As, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Zn) were determined by the ICP-OES method. *Phaeophyscia orbicularis* showed the best ability to accumulate all evaluated risk elements except Pb and Cr. *X. parientina* was found to be the least suitable for bioaccumulation purposes. The concentration of evaluated risk elements in lichen insoles came predominantly from traffic, which was confirmed by a significant positive correlation between risk elements and traffic density. Based on the results of contamination factor, evaluated streets were most polluted by Cr, Fe, Ni, Pb and Zn and only slightly polluted by Cd. Provably higher values of Cd, Cu, Fe, Ni and Zn were measured in streets with higher traffic density. According to the cluster analysis, two groups of risk elements, expressing their origin, were found.

Keywords: lichens, air pollution, traffic density, fuel combustion, risk element

Introduction

The rapid development of modern society and continuous demand of land for infrastructural development in urban areas has caused great contamination pressure on the local environment [1]. Despite extensive environmental steps, the number of vehicles are growing at an unprecedented rate. The increasing volume of emissions originates from fuel combustion (Pb and Ba), tyre, brake, engine and vehicle component deterioration (Cd, Cr, Cu, Fe, Mn, Ni, Sb, V, and Zn) and, indirectly, by resuspension of soil (Al, Fe, and associated elements) and street dust [2-3]. Among various heavy metals emission sources, vehicle emissions are known to be one of the main contributors in urban areas [4-6]. It has been shown repeatedly that road dust emissions containing heavy metals cause health problems such as black lung disease, silicosis, allergies, anaemia, cancers, asthma, etc. [7-8]. plant damage (photosynthesis disruption, cell membrane permeability problems, damages to root structures, reduction of chlorophyll content etc.) [9-10], and animal

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body damage (neurological damage, skeletal calcification and asphyxiation, reproduction decreasing etc.) [11], and reflects significantly on human health [12-14].

Prešov, the third largest city in Slovakia with a population of more than 93,000, has in recent years experienced a significant increase in traffic. Because a bypass to the city is missing, traffic passes through the centre of the city. Increasing traffic problems lead to decreasing air quality. Road dust and an accumulation of solid particles in the form of organic and inorganic pollutants affect human life quality and the quality of the environment [15-16].

Use of vegetation as a bioindicator of atmospheric risk element accumulation has received more attention worldwide due to the fact that this method has been found to be effective, cheap and simple to use [17-18]. Among the different organisms, lichens are considered one of the best bioindicators of environmental pollution because of their ability to accumulate airborne substance to concentrations far greater than those in the atmosphere, and the element contents of lichen thalli have proven to be directly correlated with environmental levels [19-20]. Additionally, lichens occur on various substrates, including rocks, which is mainly due to their resistance to desiccation in extreme temperature and efficiency in accumulating nutrients [21].

These features of lichens, combined with their extraordinary capability to grow in a large geographical area, rank them as an ideal reliable bioindicator of air pollution. Lichens were used by many authors in order to determine road dust emissions [22-24]. In the areas where lichen are absent, alternative methods based on transplants (lichens collected elsewhere, exposed in small nylon bags in selected stations), known as the “lichen bag technique” described by Godman and Roberts [25], should be used.

The main objectives of the study were: 1) to determine the levels of risk elements in lichens collected along streets with various traffic density, 2) to assess differences in risk element accumulation abilities between lichen species, and 3) to determine the influence of traffic density to the risk element concentration in lichen samples.

Material and Methods

Study Area

The study was performed in Prešov [49°00’00.00’N; 21°14’19.72’’E] in the eastern part of Slovakia (Fig. 1). The city itself covers 70.4 km^2 and the average altitude is 255 m a.s.l. Climate features are typical for a moderately warm–moderately wet and moderately cold-moderately wet climate region, with an average January temperature of -2 to -6ºC [26].

For research purposes, nine different streets of various traffic densities were selected (Fig. 1). The streets were, according to the traffic density, included in traffic density categories. The cars were counted during the expected rush hour, 6:30-8:30 a.m., and again 3:00-5:00 p.m. during a one-week (7 days) period. The average number of cars per hour was calculated. Based on the results, streets were included in three traffic groups: high traffic density (HD): >600 cars per hour, medium traffic density (MD): 599-200 cars per hour and low traffic density (LD): <199 cars per hour. Detailed information about the sampled streets is listed in Table 1.

Lichen Sampling

Three lichen species (*Phaeophyscia orbicularis* (Necker) Moberg, *Physcia adscendens* (Th. Fr.) H. Olivier, *Xanthoria parietina* (L.) Th. Fr.) commonly occurring in the middle-European geographical location were sampled along the nine streets in Prešov. The lichen samples were taken from deciduous trees (*Aesculus* sp., *Cerasus* sp., *Tillia* sp., *Fraxinus* sp., *Populus* sp.) that were approximately the same height, same circuit and approximately of the same bark characteristics (roughness). Lichen samples were taken up to 2 m high from the side facing the road. Control samples (two samples of each lichen species: *Phaeophyscia orbicularis*, *Physcia adscendens*, *Xanthoria parietina*) were taken in the neighbouring villages, approximately 3 km from Prešov city border,

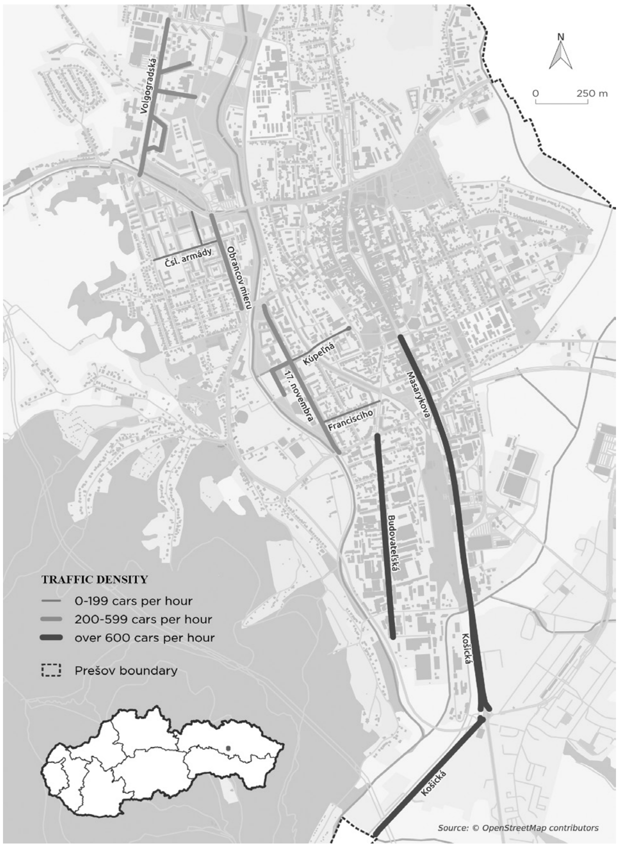

Fig. 1. The localization and traffic density categories of streets selected for monitoring in Prešov, Slovakia.

Table 1. Characteristics of the selected streets.

	Name of the street	Traffic density	GPS coordinates	
			Latitude	**Longitude**
1	Obrancov mieru (OMS)	MD	48° 59’ 53.765”	21°.14’54.985”
2	Masarykova (MS)	HD	48° 59’ 13.326”	21° 14’54.985”
3	Košická (KES)	HD	48° 58’ 13.061”	21° 15’07.112”
4	17. Novembra (NS)	MD	48° 59’ 29.749”	21° 14’03.552”
5	Volgogradská (VS)	MD	48° 59’ 29.749”	21° 14’03.552”
6	Budovateľská (BS)	HD	48° 53’ 30.026”	21° 14’37.096”
7	Francisciho (FS)	LD	48° 59’ 16.688”	21° 14’20.237”
8	Kúpeľná (KS)	LD	48° 59’ 16.328”	21° 14’20.234”
9	Československej armády (CAS)	LD	48° 59’ 49.844”	21° 13’23.818”

HD- high traffic density, MD-medium traffic density, LD-low traffic density

on trees at a distance of at least 0.5 km from the main road. Totals of 47 lichen samples and 6 controls were collected and stored in plastic bags at -20ºC prior to analysis.

Lichen samples were sampled in two replicates, during June and September 2017. Average daily temperature was 18.5ºC in June and 17ºC in September. Sampling was continued during dry days (without rain), with an average June and September humidity of 65% and 61%. The wind force in both cases was under 4 m/s.

Sample Preparation and Elemental Analysis

Lichen samples were air-dried at 40ºC in a hot oven Venticell 111 (BMT, a.s., Czech Republic) and homogenized using ceramic mortar. The dried and homogenized samples were digested with 5 mL of 69% HNO_3, 1 mL of 30% H_2O_2 (TraceSELECT, Honeywell-Fluka, Bratislava) and 5 mL double deionized water (ddH_2O) from Simplicity 185 (Millipore SAS, Molsheim, France) in PTFE (polytetrafluoroethylene) vessels under pressure in an Ethos One microwave system (Milestone Srl., Italy). The mineralized solutions were subsequently filtered through a quantitative filter paper Filtrak No. 390 (Munktell and Filtrak GmbH) and filled to a volume of 50 mL with ddH_2O. A blank was carried out in the same way. The concentration of risk elements was determined using an ICP-OES Agilent 720 (Agilent Technologies, Germany). The operating conditions for ICP-OES spectrometer were: RF power: 1200 W; plasma Ar flow rate: 15 L min^{-1}; nebulizer Ar flow rate: 0.75 L min^{-1} and auxiliary Ar flow rate: 1.5 L min^{-1}. For calibration

Table 2. Risk element concentrations in lichen samples sampled along the streets in Prešov city (Slovakia) and the values of contamination factor (C_f) determined for sampling sites.

	Risk elements [mg kg^{-1} DW]										
	Al	As	Ba	Cd	Cr	Cu	Fe	Li	Mn	Ni	Pb
Min	1060	0.90	ND	0.15	3.39	11.7	1721	1.26	36.8	1.55	12.0
Max	2426	10.6	198	1.46	682	173	12125	8.04	765	11.6	3908
Median	1796	3.25	67.5	0.79	10.2	58.3	5591	3.39	159	5.36	44.3
Average	1778	4.04	76.8	0.77	26.0	69.5	5938	3.85	182	5.99	135
St. dev	321	2.58	49.8	0.35	131	46.8	2830	1.78	141	2.81	756
Contamination factor (C_f)											
Min	1.78	1.36	ND	0.15	1.99	0.24	4.38	1.85	0.62	2.47	0.64
Max	4.07	16.0	16.9	1.41	401	3.56	30.9	11.8	13.0	18.3	210
Median	3.01	4.91	5.77	0.77	5.98	1.19	14.2	4.99	2.72	8.50	2.38
Average	2.99	6.12	6.56	0.74	15.3	1.42	15.1	5.65	3.09	9.50	7.29
St. dev	0.51	3.74	4.05	0.32	27.6	0.93	6.96	2.51	1.99	4.32	30.3

curve, a mixed standard solution with content of 10 mg L^{-1} was used (100 mg L^{-1} for Fe) (ICP 5 standard, Sigma-Aldrich, Germany).

Contamination Factor and the Degree of Contamination

In order to detect levels of polution in the evaluated streets, monitored through lichens, contamination factor and the degree of contamination were determined. Contamination factor provides a useful way of monitoring the time-course contamination process or its pattern in time [27].

The degree of contamination (C_d) is given by means of contamination factors (C_f). C_f is the ratio of the current concentration of an element to the backgrounf level of that element in the evaluated media (soil, sediment or plant):

$$C_f = Cl/Bl \quad (1)$$

...where Bl is the background level of trace risk elements (mg kg^{-1} DW) obtained from the control area or the lowest concentration value detected for each element [28-29]. In our case the average values of risk elements determined in control samples were used as background values. The background levels of Al, As, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb and Zn are 595; 0.66; 11.7; 1.03; 1.7; 48.7; 393; 0.68; 58.9; 0.63; 18.6; 4.52 mg kg^{-1} DW. Degree of contamination is considered as negligible when $C_d \geq 1$; moderate when $1<C_d \leq 3$; severe when $<3C_d \leq 6$; and very severe when $C_d>6$. Contamination factors were calcuated for each metal at each lichen sample. Subsequently, the degree of contamination was calculated for each sampling site as the mean of contamination factors of individual trace elements. Degree of contamination was calculated in general for each evaluated street in Prešov.

Map Processing, Data Processing and Statistical Evaluation

The map outputs were processed using the open source Geographic Information System (GIS) using software QGIS (version 2.18) and open data from OpenStreetMap contributors [30]. In order to determine the differences in risk element concentrations between lichen species, streets and various traffic density categories, one-way ANOVA test for normally distributed and Kruskal-Wallis test for non-normally distrubuted data were used. Analysis was completed by Tukey‘s post-hoc test in order to detect species with signifficantly different risk elements accumulation ability. Spearman‘s correlation analysis was used to determine the correlation relationship between risk elements themeselves, and between risk elements and road traffic density. One-way Anova test/Kruskall-Wallis test was the same as Spearman's correlation coefficent, which were considered statistically significant if P value was less than 0.05 and 0.01. Cluster analysis (CA) was performed using Euclidean distances in order to group risk elements based on their contamination factor. PCA (principal component analysis) was used in order to distinguish between streets based on occurrence the risk elements. All statistical analyses were performed using R studio (R Studio Team, Boston). Statistical analyses were carried out after the data were log transformed (normalized).

Results and Discussion

The descriptive statistic for the values of risk elements determined in lichen samples sampled along the streets of Prešov and the values of contamination factor expressing the level of pollution, especially for each evaluated risk element, are listed in Table 2. The concentration of risk elements in lichen samples ranged from 1060-2426 mg kg^{-1} for Al; ND (not detected) -198 mg kg^{-1} for Ba; 0.15-1.46 mg.kg^{-1} for Cd; 3.39-682 mg kg^{-1} for Cr; 11.7-173 mg kg^{-1} for Cu; 1721-12125 mg kg^{-1} for Fe; 1.26-8.04 mg kg^{-1} for Li; 36.8-765 mg kg^{-1} for Mn; 1.55-11.6 mg kg^{-1} Ni; 12.1-3908 mg kg^{-1} for Pb; 49.3-467 mg kg^{-1} for Zn; 0.90-10.6 mg kg^{-1} for As; and ND-1.16 mg kg^{-1} for Se.

The values of Cu were considered as extremely high comparing studies of authors Zigmond and Urák [31] and Klimek et al. [32], where the values of Cu ranged between 0.42-6.51 mg kg^{-1} and 5.7-9.0 mg kg^{-1}, respectively. The values of Ni in the study of Klimek at al. (2015) also reached lower values (0.9-1.5 mg kg^{-1}). According to Markert [33, 34] and Aksoy and Öztürk [35], normal levels of Pb, Zn, Cu, Mn and Fe in uncontaminated areas are 2-10 mg kg^{-1}, 20-300 mg kg^{-1}, 5-20 mg kg^{-1}, 20-100 mg kg^{-1} and 50-250 mg kg^{-1}, respectively. The values of Mn and Fe were exceeded in all cases and the values of Pb, Cu and Zn were exceeded in most of the samples. In the study investigated in Isfahan metropolis, central Iran, mean concentrations of As, Cd, Cu, Ni, Pb and Zn were 22.2, 2.14, 182, 66.6, 393 and 707 mg kg^{-1} [1]. Average values of listed risk elements were much lower in our case. Nine streets in Prešov, which were selected for sampling, were divided into three categories according to traffic density. In the lichen samples collected along the streets with the highest traffic density, the values of Al, Ag, Ba, Cd, Cr, Cu, Fe, Li, Mn, Ni, Pb, Sr, Zn, As and Se were approximately 17, 60, 53, 40, 84, 72, 46, 40, 23, 42, 88, 23, 63, 99, and 88% lower, respectively, compared with the results reached from the lichens sampled on the streets with the lowest traffic densities (Fig. 2). Differences between average values of risk elements sampled in the streets with low traffic density and medium traffic density were not significant. Actually, in the case of Cd, Mn, Sr and As, the values were higher in the streets with low traffic density.

The correlation relationship between evaluated risk elements except Cr, Pb and Mn, gave significant positive

Table 3. Correlation relationships between risk element values themselves and between risk element values and traffic density (TD).

	Al	Ba	Cd	Cr	Cu	Fe	Li	Mn	Ni	Pb	Zn	As
TD	0.43**	0.52**	0.51**	0.50**	0.71**	0.57**	0.45**	0.09	0.58*	0.44**	0.67**	0.28*
Al		0.65**	0.51**	0.03	0.66**	0.84**	0.85**	0.63**	0.82**	0.02	0.59**	0.59**
Ba			0.76**	-0.19	0.79**	0.82**	0.69**	0.54**	0.86**	-0.19	0.69**	0.67**
Cd				0.18	0.74**	0.77**	0.62**	0.47**	0.81**	0.18	0.78**	0.66**
Cr					0.16	0.14	0.03	0.06	0.09	0.99**	0.43**	0.28
Cu						0.81**	0.68**	0.56**	0.86**	0.16	0.88**	0.67**
Fe							0.91**	0.76**	0.97**	0.13	0.78**	0.75**
Li								0.78**	0.91**	0.02	0.56**	0.63**
Mn									0.73**	0.03	0.47**	0.43**
Ni										0.07	0.78**	0.75**
Pb											0.42**	0.28
Zn												0.74**

correlation with car density, which indicates that they are related to traffic (Table 3). The main emission source of Pb into the earth's atmosphere was the combustion of gasoline. Despite its phasing-out and the decreasing trend in the atmosphere, Pb remains a significant urban air pollutant [36]. According to UNECE (United Nations Economic Commission for Europe), As and Se exhaust emissions are released during fuel combustion while Cd, Cr, Cu, Ni, Pb, and Zn exhaust emissions are released during lubricant oil combustion [37]. According to previous reports [38-40], Zn in dust can also originate from the wear and tear of vulcanized vehicle tyres and corrosion of galvanized automobile parts. Barium is used as $BaSO_4$ to increase the density of brake pads. Sternbeck et al. [41] found that heavy-duty vehicles are strong emitters of Ba-containing fine particles. Lithium is contained in petrol, aluminium is used as a corrosion inhibitor and iron is observed in car construction [42].

Significant positive correlation between risk elements, suggest common sources of them [43]. Zinc gave significant positive correlation with all evaluated risk elements, probably because it is related to vehicle corrosion the same as oil combustion. All evaluated risk elements (except Mn) gave significant positive correlations between themselves. They are released into the environment as the result of violation of the vehicle body, because they are part of alloys, coatings, or sheets. Lead gave significant positive correlation only with Cr.

The values of risk elements determined in different lichen species collected along Prešov streets are listed in Table 4. The highest average values of all evaluated risk elements except Pb and Cr were determined in the samples of *P. orbicularis.* The lowest risk element concentration was, in all cases, determined in the samples of *X. parietina. P. Orbicularis,* which was found to be a very effective bioindicator of traffic pollution [44], and showed good resilience and high accumulation ability [21]. Scerbo et al. [45] used *X. parientina* for air quality biomonitoring in Italy. Determined values of risk elements in *X. parientina*, were, in our case, at least two times higher.

Contamination Factor and Degree of Contamination

In general, Prešov streets are negligibly contaminated by Cd, moderately contaminated by Al and Cu, severely contaminated by As, Ba, Li, Mn and Pb and very severely contaminated by Cr, Fe, Ni, Pb and Zn.

The level of pollution on Prešov streets was expressed by the degree of contamination (C_d) (Figs 3-4) which was calculated for each sampling site, and subsequently the average value for each street was expressed. The values of C_d decreased in the order MS>KES>BS>NS>CSA>OMS>FS>VS>KS, which does not correspond with the observed traffic density. The values of risk element and finally the values of C_d are, in our view, predominantly influenced by traffic density, but total pollution could be affected by other factors such as local air flow influenced by the surrounding built-up areas, the presence/absence of green areas, and the presence of local pollution sources (industrial factories, landfills), etc.

One-Way ANOVA Test

One-way ANOVA test confirmed significant differences in risk element concentrations between streets with various traffic densities. Significantly higher values of Ba, Cd, Cu, Fe, Ni, Sr, Zn and As in lichen insoles were determined at streets with the highest traffic densities (Table 5). The highest values of all evaluated risk elements (except Ba, Li, Mn, Pb and Se) were determined in lichen samples collected along

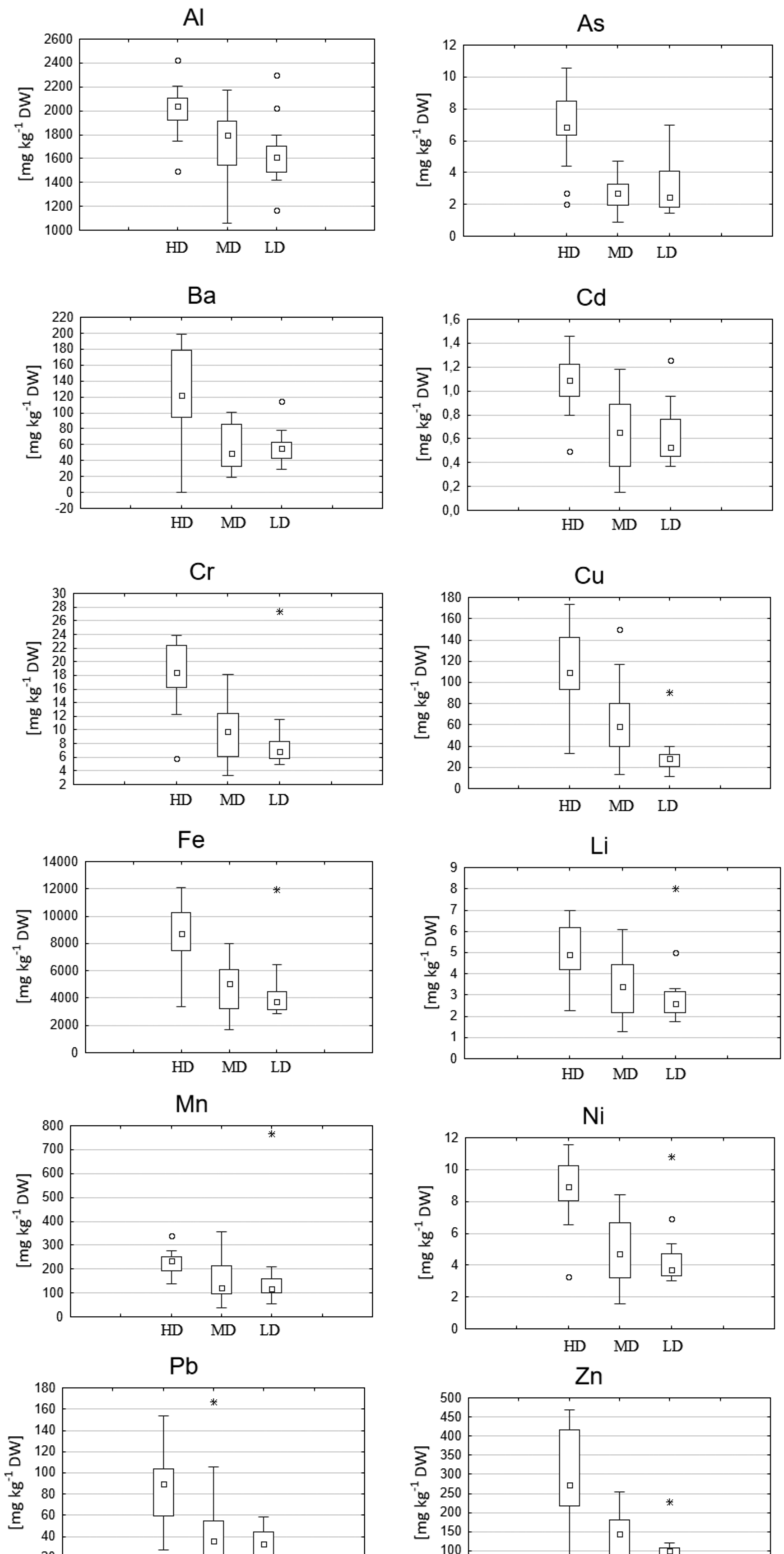

Fig. 2. Average values (□ median; |--| min-max; □□25% - 75%, ° outlying value, * extreme value) of risk elements in lichen samples according to traffic density (TD) categories (HD- high traffic density, MD-medium traffic density, LD-low traffic density).

Table 4. Values (minimum-maximum (median ± standard deviation)) of risk elements determined in different lichen species (regardless the street).

Risk element [mg kg^{-1}]	Lichen species	
	P. orbicularis	*P. adscendens*
Al	1490-2426 (1924±217)	1060-2295 (1650±346)
Ba	40.2-198 (94.9±46.7)	0.0-135 (45.4±35.1)
Cd	0.37-1.46 (0.92±0.31)	0.15-1.26 (0.63±0.31)
Cr	5.75-23.8 (15.2±5.55)	3.39-682 (8.22±146)
Cu	21.8-173 (88.8±45.9)	12.9-141 (41.0±34.4)
Fe	3171-12125 (7341±2463)	1721-11933 (4356±2555)
Li	1.95-6.96 (4.85±1.48)	1.26-8.04 (2.67±1.53)
Mn	80.9-354 (229±74.4)	36.8-765 (110±152)
Ni	3.0-11.5 (7.88±2.47)	1.55-10.8 (4.40±2.38)
Pb	20.4-166 (59.3±38.9)	12.3-3908 (36.4±844)
Zn	66.0-451 (197±114)	49.2-467 (128±110)
As	1.85-10.6 (4.03±2.52)	0.9-9.47 (2.86±2.24)

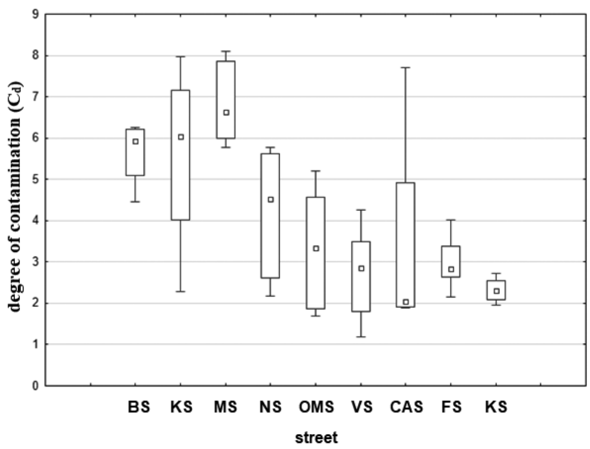

Fig. 3. Degree of contamination in nine streets in Prešov: BS - Budovateľská; KES - Košická; MS - Masaryková; NS - 17. Novembra; OMS - Obrancov mieru; VS - Volgogradská; CAS - ČS armády; FS - Francisciho, and KS – Kúpeľná, with various traffic densities based on the risk elements determined in lichen samples (□ median; |--| min-max; □□25%-75%).

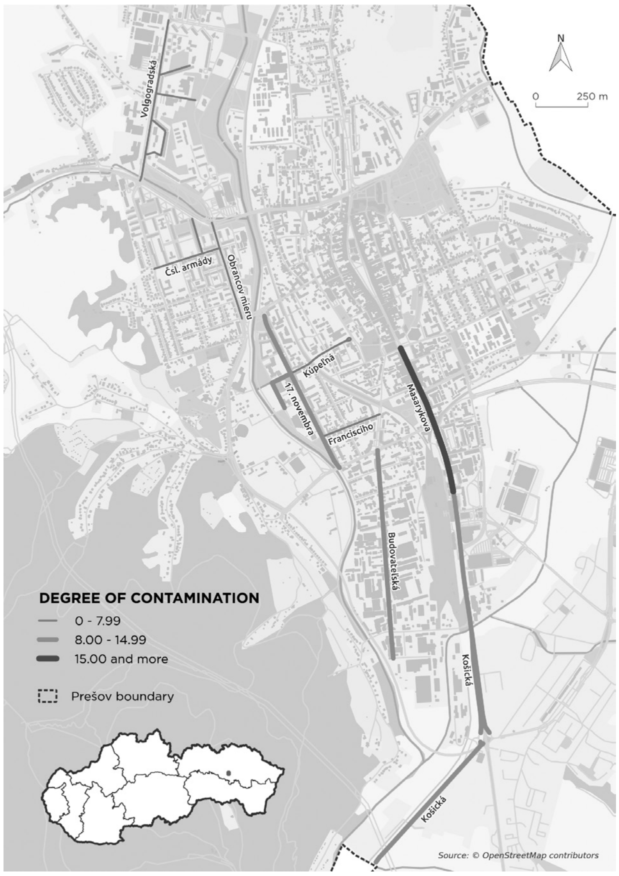

Fig. 4. Degree of contamination on evaluated streets in Prešov, Slovakia.

MS. The values of Cr, Cu, Fe and Pb were much higher compared with the other two streets, included the high traffic density group. Especially the average value of lead, which on the other streets ranged 23-72 mg kg^{-1}, reached the MS average value of 740 mg kg^{-1}.

The significantly highest ability to accumulate Al, Ag, Ba, Cd, Cu, Fe, Li, Ni and Sr was found for *P. orbicularis.* Tukey post hoc test confirmed significant differences in the ability to accumulate As between *X. parientina* and *P.orbicularis,* and in the ability to accumulate Se between *P. orbicularis* and *P. adscendens.*

Significant differences were also found between individual streets. MS included in the HD group was found to be the most polluted. The values of Cd, Cu, Fe, Ni and Zn were significantly highest at the samples sampled in this street.

Cluster Analysis and PCA Analysis

Cluster analysis (squared Euclidean distance) and Wards method were performed to identify groups of risk elements with similar origins. For analysis needs, the values of contamination factor were used. Results are shown in dendrogram (Fig. 5), where two groups of risk elements were identified. Group 1 includes Zn, Pb and Cr. The main source of these elements in rural

Table 5. One-way ANOVA test for comparing the values of risk elements in lichen samples between streets with various traffic densities, between different lichen species and different streets.

Element	Factor	df	F	p	Factor	df	F	p	Factor	df	F	p
Al	Traffic density	2	2.44	0.09	Lichen species	2	5.13	0.01**	Street	2	2.11	0.06
As		2	4.44	0.02**		2	3.75	0.03*		2	8.21	$2.2e^{-06}$**
Ba		2	5.88	0.005**		2	9.27	0.001**		2	3.59	0.003**
Cd		2	6.92	0.002**		2	4.19	0.02*		2	5.84	$7.1e^{-05}$**
Cr		2	1.19	0.315		2	0.480	0.62		2	0.96	0.48
Cu		2	12.6	$4.8e^{-05}$**		2	7.73	0.001**		2	8.52	$1.4e^{-06}$**
Fe		2	3.34	0.02*		2	6.66	0.003**		2	4.20	0.001**
Li		2	2.37	0.105		2	8.93	0.001**		2	2.02	0.07
Mn		2	0.19	0.83		2	1.98	0.15		2	1.62	0.15
Ni		2	4.83	0.01*		2	8.36	0.001**		2	4.39	0.001**
Pb		2	1.29	0.28		2	0.46	0.63		2	0.99	0.47
Sr		2	6.37	0.003**		2	7.77	0.001**		2	2.43	0.031*
Zn		2	13.42	$2.8e^{-05}$**		2	2.1	0.13		2	19.1	$3.9e^{-11}$**

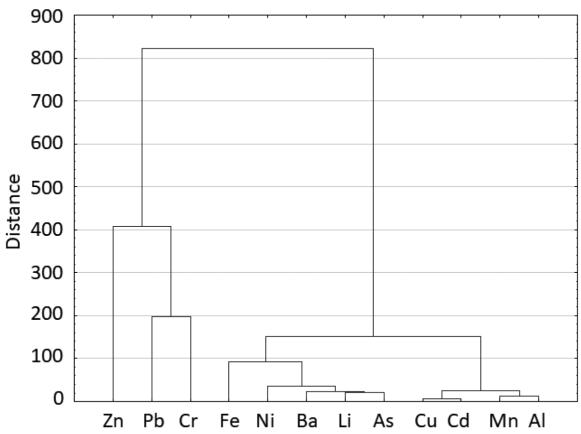

Fig. 5. Dendrogram observed by contamination factor values.

environments is vehicle exhaust and combustion [21, 46], and chromium may also be released from traffic emissions due to tire, brake and engine wear [47]. Risk elements included in Group 1 correlated between themselves and correlate also with traffic density – except for Zn, which does not correlate with other risk elements.

Group 2 includes all other evaluated risk elements. Their origin could be affected not only by traffic, but to a large extent by various industrial activities. Inside group 2 we can identify two sub-groups. The elements Fe, Ni, Ba, Li and As are released into the environment not only by vehicle exhaust but also through the combustion of coal or other fossil fuels. Additionally, nickel and iron are widely used in the steel industry and construction materials [48]. Barium is extensively used

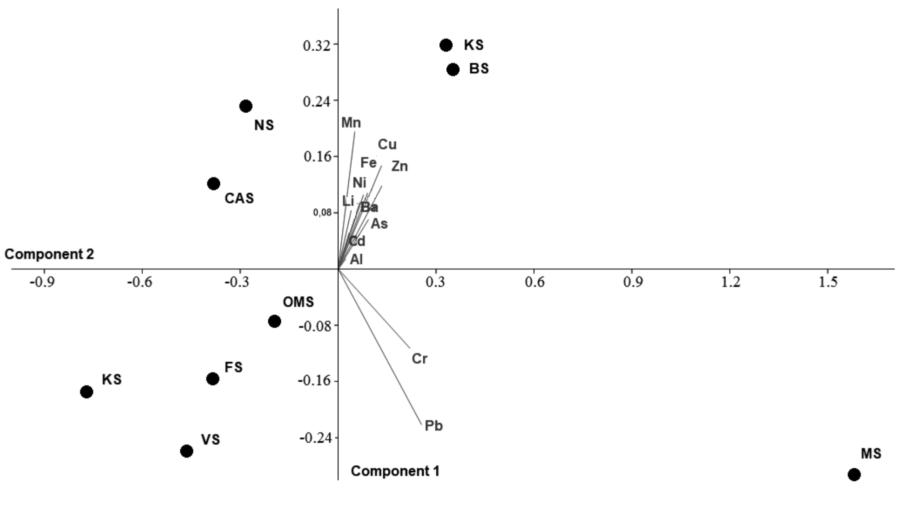

Fig. 6. PCA biplot showing separation of different risk elements based on various street densities.

in the rubber industry and could be released from tires [42]. The elements Cu, Cd, Mn and Al, which create the second sub-group, have very low contamination factor values. They are widely used in car-body materials, for example in alloys against corrosion and various industries [8].

Principal component analysis distinguished streets based on risk elements. The PCA displays the separation of different streets based on the determined parameters (Fig. 6). Principal component analysis resulted in a reduction of the initial dimension of dataset to two components, which explained 93.6% of the data variation (component 1: 83.5%; component 2: 10.1%). The streets classified as HF were determined to be the most influenced by risk element pollution. Risk elements such as Al, As, Ba, Cd, Cu, Li, Mn, Ni and Zn showed similar direction and participated to the contamination of Košická and Budovateľská streets. The contamination by Pb and Cr was the most extensive at Masaryková Street.

Conclusions

The values of risk elements at the streets categorized as HD were several times higher comparing LD streets. The difference between the streets with low and medium density wasn't significant. Traffic as the main source of risk elements was confirmed by Spearman's coefficient, which shows significant correlation between most of evaluated risk elements with traffic density. Comparing lichen species used for research, P. orbicularis was found to be the most suitable and *X. parientina* the least suitable for risk element monitoring purposes. Based on the results of contamination factors, the streets of Prešov were most polluted by the elements Cr, Fe, Ni, Pb and Zn.

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Conflict of Interest

The authors declare no conflict of interest.

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