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Trace elements and nitrogen in naturally growing moss *Hypnum cupressiforme* in urban and peri-urban forests

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Abstract

We monitored trace metals and nitrogen using naturally growing moss *Hypnum cupressiforme* Hedw. in urban and peri-urban forests of the City Municipality of Ljubljana. The aim of this study was to explore the differences in atmospheric deposition of trace metals and nitrogen between urban and peri-urban forests. Samples were collected at a total of 44 sites in urban forests (forests within the motorway ring road) and peri-urban forests (forests outside the motorway ring road). Mosses collected in urban forests showed increased trace metal concentrations compared to samples collected from peri-urban forests. Higher values were significant for As, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Tl and V. Within the motorway ring road, the notable differences in element concentrations between the two urban forests were significant for Cr, Ni and Mo. Factor analysis showed three groups of elements, highlighting the contribution of traffic emissions, individual heating appliances and the resuspension of contaminated soils and dust as the main sources of trace elements in urban forests.

Key words: heavy metals, biomonitoring, Ljubljana, ICP-MS, elemental analysis, factor analysis, traffic emissions

1 Introduction

The atmosphere is constantly affected by pollutants that originate from increased anthropogenic activities, which are predominant in urban and industrial areas. Among different pollutants, trace metals are recognized to have toxic effects when they accumulate in different environmental compartments (Hart 1982, He et al. 2005, Malea et al. 1994, Rainbow and Phillips 1993, Senesil et al. 1999). Because of the significant input of pollutants in the atmosphere and their adverse effects on biota and human health, monitoring airborne pollutants is an essential part of environmental planning and control programmes (Lee et al. 2005). As an integral part of the urban environment, green spaces provide environmental, economic and social benefits (Tyrväinen et al. 2005). Airborne pollutants are absorbed onto the leaves of trees and other vegetation more effectively than on other surfaces (Escobedo and Nowak 2009, Fantozzi et al. 2013), and this contributes to the removal of air pollutants from the atmosphere. On the other hand, plants can be used as indicators in pollutant monitoring (Markert et al. 2003). Information on the presence and type of pollutant can be obtained either from monitoring the changes in the composition and structure of plants or measuring the content of the pollutants in their tissues (Wolterbeek 2002). Among different biomonitors used for assessing air pollution, lichens and mosses are the most common due to their biological and physiological features (Puckett 1988). Owing to their large surface/weight ratio, a lack of epidermis and cuticle and their high cation exchange capacity, mosses can accumulate high concentrations of trace metals (Markert et al. 1999). In addition, because mosses offer a cheap and simple sampling procedure, a large number of sites can be included in a pollution monitoring survey (Szczepaniak and Biziuk 2003, Tyler 1990). As a method for monitoring air quality, biomonitoring with mosses was first introduced in Scandinavia during the 1970s (Rühling and Tyler 1970), and today it is part of many national and regional surveys, including the repeated 5-year survey coordinated by the United Nations Economic Commission for Europe ICP-Vegetation programme (Harmens et al. 2004, Herpin et al. 1996, Schilling and Lehman 2002).

Major sources of airborne trace elements in urban areas are energy production, industry and traffic emissions (Pacyna and Pacyna 2001). Even though the concentration of Pb has decreased with the introduction of unleaded gasoline, other potentially toxic elements originating from exhaust and non-exhaust sources are significant contributors to airborne trace element pollution. Metals, such as Pb, Cd, Cu, Cr, Ni, Zn, Sb and those from the platinum group, are released from motor vehicles and deposited on the roads and plants close to the road (Ho and Tai 1988, Legret and Pagotto 2006, Zechmeister et al. 2006). Many studies have shown that urban soils and plants receive a considerable amount of trace metals mostly from motor vehicles (Biasioli et al. 2006, Naszradi et al. 2007, Oliva and Espinosa 2007). Vehicle exhausts are also considered to be a major source of atmospheric nitrogen (N) pollution in the form of nitrogen oxide (NO_x) emissions (Pearson et al. 2000). Apart from the above-mentioned sources, the resuspension of particles from road dust is another source of trace metals that cannot be neglected (Abu-Allaban et al. 2003).

The city municipality of Ljubljana is known for its green infrastructure, with many park–forest complexes including two urban forests. Urban forests, having dense canopies, act as a natural filter for air pollutants (Nowak et al. 2014). Air quality, especially sulphur dioxide (SO_2) pollution, has improved over the 45 years of continuous monitoring

(Ogrin et al. 2016) with the introduction of district heating and gasification infrastructure and applying requirements from Integrated Pollution Prevention and Control legislation (IPPC Directive) (OECD 2012). However, as evident from the Slovenian Environment Agency report (Cegnar et al. 2015), particle emissions (PM_{10}) and NO_x, mainly originating from traffic, is still of major concern in Ljubljana. Monitoring of air quality (SO_2, O_3, NO_x, PM_{10}) in the city is done at two monitoring stations by the Environmental Agency within the regular national monitoring network; however, heavy metals (Pb, Cd, Ni and As) in precipitation and particles are measured at only one sampling location. Additionally, air quality in urban forests is monitored at one monitoring station by the Slovenian Forestry Institute (Skudnik et al. 2014, Vilhar et al. 2014).

The aim of this study was i) to evaluate the trace element and N deposition in urban and peri-urban forests of the City Municipality of Ljubljana using naturally growing cypress-leaved moss *Hypnum cupressiforme* and ii) to identify the possible sources of atmospheric deposition of trace elements and N in urban and peri-urban areas by using factor analysis.

2 Materials and methods

2.1 Study area and sampling of moss material

The investigation took place in the City Municipality of Ljubljana (hereafter Municipality of Ljubljana), which is one of eleven city municipalities in Slovenia. Its centre is Ljubljana, the largest city and the capital of Slovenia (**Fig. 1**). The municipality spans across 275 km^2 and has a population of approximately 280,000 citizens. The municipality is situated in the central part of Slovenia (46°03′20″N 14°30′30″E) at an average altitude of 298 m above sea level (a.s.l.). Forests cover about 42% of the municipality area and stretch to the city centre (Urbančič et al. 2010). The climate of the city is continental (Köppen climate classification), with a prevailing wind direction from the southwest at an annual frequency of 23.2% and from the west at an annual frequency of 19.1% (**Fig. 1**). The characteristics of the Ljubljana basin include frequent temperature inversions, sometimes with more than 300-m thick inversion layers, and low local air circulation.

The industrial activity of the city is small scale, with the major industrial sources being a central heating and power plant and pharmaceutical and food-processing-related plants. There are more than 170,000 vehicles registered just in Ljubljana (SURS 2014), but since the municipality is positioned at the crossroads of pan-European transport corridors “V” and “X”, it is exposed to additional transit traffic. There is a motorway ring road around the city of Ljubljana (**Fig. 1**), and this forms the main hub of the Slovenian motorway network and connects to the A1 and A2 motorways. The ring road consists of four bypass sections: northern, southern, eastern and western, with the average daily traffic (AADT) at more than 70,000 vehicles on the northern sections; this is also the highest level of traffic in Slovenia.

The moss material *H. cupressiforme* Hedw. was collected in August 2013 at 44 sites within the Municipality of Ljubljana. The locations were divided into two categories as follows:

i. urban forests—forests inside the ring road comprising the Rožnik and Šišenski hrib forests (hereinafter, Rožnik) in the western part of the city at an elevation of 429 m a.s.l. and Golovec in the eastern part of the city at 450 m a.s.l. at the highest point (22 sampling points) and
ii. peri-urban forests located outside the ring road (22 sampling points) (**Fig. 1**).

Sampling was carried according to the guidelines of the European moss survey protocol (ICP Vegetation Coordination Centre 2010), except that the samples were collected at least 1 m away from the tree canopy and not 3 m as specified by the protocol to avoid canopy drip. We chose a shorter distance because of the absence of large forest clearings and because confidence intervals for the N values at 3 m from the canopy and at 1 m from the canopy overlapped (Skudnik et al. 2014). To avoid the direct influence of local emitters, the samples were collected at least 50 m from main roads and industries. Each sample was composed of five to seven subsamples collected within an area of 50 × 50 m.

2.2 Sample preparation and chemical analysis

In the laboratory, moss samples were cleaned of dead material and substrate, dried at room temperature, lyophilized and homogenized with the addition of liquid N. For analysis, only live green segments from the uppermost part of the plant were used. Portions of about 0.16 g moss were digested with a mixture of 4 mL concentrated Suprapur HNO_3 and 1 mL Suprapur H_2O_2 in a microwave oven (Milestone). After the digestion, samples were filtered and diluted with pure water (MiliQ) to a volume of 20 mL. Concentrations of the following elements were analysed using the Agilent 7500ce ICP-MS: As, Ca, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Se, Sr, Ti, Tl, V and Zn. Concentration of mercury (Hg) was determined using a direct mercury analyser (DMA-80; Milestone). The analyses of trace elements were performed at the Jožef Stefan Institute (Ljubljana, Slovenia). N concentrations were determined using the vario Pyro cube elemental analyser at the Slovenian Forestry Institute (Ljubljana, Slovenia). Quality control of the analytical procedures for determining both, trace elements and N, was carried out by analysing reference moss material M2 and M3 (Steinnes et al. 1997).

2.3 Statistical analysis

Concentrations of trace elements and N were not normally distributed. The differences in element concentrations in moss between urban and peri-urban forests were tested with the non-parametric Mann–Whitney U test using log-transformed data. Factor analysis was employed to identify how the elements grouped together at the urban and peri-urban sampling sites. A correlation matrix was created from the log-transformed element concentrations in the mosses. The ‘fa’ function of the R package ‘psych’ was utilised for factor analysis with orthogonal (Varimax) rotation and the maximum likelihood (ml) factoring method. The factor analysis was run using the correlation matrix, and therefore variables were standardized (each has a variance of 1). The number of factors was set to three based on the examination of a scree plot and examination of resulting factors. All statistical analyses were performed with R 3.2 (R Development Core Team 2016). Factor scores were projected on the GIS map of Ljubljana, using ESRI ArcMap software (ESRI 2015).

3 Results

3.1 Element concentrations in mosses in the Municipality of Ljubljana

Summary statistics of elemental levels in *H. cupressiforme* collected in forests of the Municipality of Ljubljana, together with median values for urban and peri-urban forests are presented in Table 1. A comparison of concentrations obtained in this survey with median levels from a Slovenian national survey performed in 2010 at 102 locations (Harmens et al. 2013) in forests throughout the country is also presented in Table 1. Differences in element concentrations between urban and peri-urban forests, expressed as median values, were statistically significant ($p<0.01$) for As, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Tl, V and N (Table 1), with higher values found in the urban forests. The median concentrations of Cr, Cu, Pb and Sb from the urban forests were also higher than the median concentrations recorded from the Slovenian 2010 moss survey.

A comparison of element concentration between the two urban forests (Rožnik and Golovec) is presented in **Fig. 2**. Concentrations of Cr, Cu, Mo and Ni were significantly higher ($p<0.01$) from Rožnik compared to Golovec. Concentrations of all other elements were similar in both forests, with somewhat higher concentrations found at Golovec.

Results obtained in our investigation are in agreement with reported data (Table 2) of in-situ mosses collected in the transect of Oslo (Reimann et al. 2006) and the Wienerwald biosphere reserve located near the city of Vienna (Krommer et al. 2007) but lower than those reported for transplanted mosses in Belgrade (Vuković et al. 2015) and Naples (Adamo et al. 2011).

3.2 Source apportionment of trace metals

Using factor analysis, three factors were extracted that accounted for 62% of the total variance of the whole data set of 44 sampling points (Table 3). Factors were identified by comparing elements with significant factor loadings.

Factor 1 (F1) comprised elements As, Fe, Hg, Pb, Ti, Tl and V and represented 27% of the total variance. The highest loading of this factor (**Fig. 3**) was found in urban forests of Rožnik and Golovec, with a decline in loadings moving away from the urban centre. This demonstrates the influence of the city centre as a source of air pollution.

Factor 2 (F2) comprised elements Cr, Cu, Mo, Ni, Sb, Se, Zn and N and explained 21% of the variance. The highest loadings of this factor were found in the urban forest of Rožnik, while some moderate loadings were also found at certain locations in the urban forest of Golovec and in the western part of the Municipality of Ljubljana (**Fig. 4**).

Factor 3 (F3) elements were Ca, Co and Mg. High loadings of this factor were present mostly in the peri-urban forests; however, Golovec forest also showed some higher loadings of this factor (**Fig. 5**).

4 Discussion

4.1 Element concentration in mosses in the Municipality of Ljubljana

Biomonitoring of trace elements using moss *H. cupressiforme* is the first pollution survey performed in the forests in the Municipality of Ljubljana. As expected, concentrations of most trace elements, especially those resulting from anthropogenic activities, in *H. cupressiforme* were higher in the urban forests compared to the peri-urban forests (Table 1). The most exposed locations were those close to the centre of the city or close to the busiest streets or coal-fired power plant (**Fig. 1**). The highest (maximum) concentrations of Hg (0.12 mg kg^{-1}), As (0.61 mg kg^{-1}) and Tl (0.11 mg kg^{-1}) were found at point G11 located in the Golovec forest at the Castle above the city centre; the highest concentrations of Cr (7.83 mg kg^{-1}), Mo (1.30 mg kg^{-1}) and Ni (4.30 mg kg^{-1}) were found at sampling point R05, located in the northern part of Rožnik forest; and the maximum concentrations of Cu (4.58 mg kg^{-1}), Pb (13.12 mg kg^{-1}) and V (5.22 mg kg^{-1}) were found at sampling point G14 (Golovec) also in close proximity to one of the major streets in the city and close to the coal-fired power plant.

On the other hand, concentrations of macroelements Ca, Fe, Mg and Mn and additionally Se and Sr were higher in the peri-urban forests, although not significantly. Since peri-urban forests in Ljubljana are not highly influenced by anthropogenic activities and/or intensive agriculture, we assume that these elements were related to the environmental conditions at the sites and were very likely supplied from the substrate. An additional investigation is needed to confirm this. Økland et al. (1999) found that concentrations of K, Ca, Mg and Cd in tissues of *Hylocomium splendens* were highest at sites with high soil pH and nutrient content. Other authors have also emphasized the substrate as a potential nutrient source for bryophytes (Brown and Bates 1990) as well as upward movements of inorganic ions in bryophyte carpets (Bates and Farmer 1990, Wells and Brown 1996). On the other hand, Reimann et al. (2006) found that plant nutrients (Ca, K, Mg, Mn, P, S) in Norway did not show any spatial dependency. They suspected that concentrations of plant nutrients in mosses are possibly so high that an additional input from either anthropogenic or geogenic sources would not be sufficient to cause spatial patterns.

An interesting finding of our survey was that the Rožnik forest is more polluted than Golovec, especially with Cr, Cu, Mo and Ni. We ascribe this to the forest's position between the busiest part of the motorway ring road and the industrial zone of the city. Additionally, households located in the southern part of Ljubljana are not connected to the district heating system (**Fig. 3-5**) and instead use traditional heating utilities, making this urban forest more susceptible to emissions from different sources within the city. Also of note is that Rožnik lies in the western part of the city and is therefore more exposed to north–east winds and the long range transport of contaminants.

From an overall comparison of median values between the Slovenian moss survey of 2010 (Harmens et al. 2013) and this survey, higher median concentrations in urban forests were observed for Cr, Cu, Pb and Sb, showing an anthropogenic influence on the urban forests. Compared to the national median values from 2010, a notable decrease in concentrations in our study was observed for Cd, Fe, Hg, Se, Sr, Ti and V, suggesting improved emission controls.

The results from our study were close to those from the Oslo transect and Wienerwald biosphere reserve (Krommer et al. 2007) located near the city of Vienna, with few exceptions: concentrations of Sr, Ti, V and Zn were lower in our study, and this difference can be attributed to the different intensity of anthropogenic activities in these areas and perhaps different lithologies.

Greater differences in concentrations of trace metals were observed between Ljubljana and Naples (Adamo et al. 2011) and Belgrade (Vuković et al. 2015), especially for Cu, Pb, Fe, Ti, V and Zn. Naples is influenced by Mediterranean xeric climatic conditions, which serve as a sink and source of trace metals originating from the resuspension of contaminated soil (which is the case for Ti and Pb) (Adamo et al. 2011). In Naples the highest concentrations of trace metals were observed in locations near coastal urban districts with high traffic flows.

4.2 Source apportionment of trace metals

Attributing elements to certain sources of pollution using factor analysis is a complex task. Often, factor analysis cannot discriminate between two sources with similar emission profiles. As a consequence, elements can be statistically ‘picked up’ and assigned to the most similar identified source, overstating its contribution (Thurston et al. 2011). We observed that two of the factors (F1, F2) identified from our survey originated from two sources with similar emission profiles.

The properties of F1 suggest that its origin was either from the mixing of crustal elements with anthropogenic emissions or quite possibly the resuspension of already contaminated soil dust. Ti, Fe and Tl are typical crustal elements (Reimann and de Caritat 1998), but the presence of As, Hg, Pb and V in F1 indicates some anthropogenic influence. The association of Pb in this group can be attributed to the resuspension of dust particles already contaminated with Pb that was most likely deposited on the surface of roads from combustion of leaded gasoline (Miguel et al. 1997). The use of unleaded gasoline in Slovenia began in 2001, and emissions of Pb from traffic have been decreasing since then. As, Hg and V are volatile elements that are usually emitted to the atmosphere from combustion sources (Meij and te Winkel 2007). According to the Slovenian Environmental Agency report (Cegnar et al. 2015), besides traffic and industry, small individual heating devices using out-of-date technology and “unclean” fuels considerably contribute to pollution with particles. The city heating network supplies the heat to almost 74% of the households in the Municipality; the remaining homes use traditional heating sources, such as coal, biomass and oil.

Most of the elements present in F2 can be attributed to traffic emissions, which was further confirmed by the high loadings (**Fig. 4**) present at locations where traffic intensity is greater (Schauer et al. 2006, Thorpe and Harrison 2008). In particular, the west wing of the ring road is not entrenched and has an AADT of 70,000 vehicles, among which 11,000 are heavy duty vehicles (Slovenian Infrastructure Agency 2014). Additionally, in the southern part of the urban forest of Rožnik, a road through the forest that connects to the northern part of the ring road is the busiest street of the city with many traffic lights and where braking is frequent. Cu is among the most important components in brake pads together with Sb (correlation between Cu and Sb, $r = 0.79$), which is added to reduce the vibrations and to improve friction stability of vehicles (von Uexküll et al. 2005). Zn particles originate from tire wear and are released more during urban driving due to increased acceleration, braking and cornering in cities (Stalnaker et al. 1996, Wik and Dave 2009). The association of N in this factor further supports traffic as the possible origin; vehicle exhaust is a main contributor to N pollution in the form of NO_x pollution (Bermejo-Orduna et al. 2014, Pearson et al. 2000, Skudnik et al. 2015).

The elements Cr, Mo, Ni and Se, however, usually have another source of emission in addition to traffic. From the analysis of particles in PM_{10} (Koleša and Planinšek 2013), a factor grouping elements Cr, Ni and Mo was obtained but represented only 3% of the PM_{10} results. The correlation coefficient for elements Cr and Ni ($r = 0.86$), Cr and Mo ($r = 0.76$) and Mo and Ni ($r = 0.74$) indicates a common source, which could be traffic, combustion and/or industry (Dongarrà et al. 2007, Johansson et al. 2009). Element Se has the highest correlation with Mo ($r = 0.57$) and Cu ($r = 0.57$) and is probably related to traffic emissions (Weckwerth 2001).

Mg and Ca are macronutrients (Glime 2006). The highest loadings of F3 were present in the peri-urban forests and to some extent in the urban forest of Golovec (**Fig. 5**); these loadings may be a result of possible uptake of elements from the substrate. Some elements (e.g. Ca, Mg, K) depend on uptake from the substrate, especially those mosses growing in the form of turfs, cushions or cover (Zechmeister et al. 2003), which could also be the case for *H. cupressiforme*. The lowest loadings of this factor were present in Rožnik. We assume that here low loadings of F3 are due to the replacement of abundant cations Ca^{2+} and Mg^{2+} with other cations (Bates 1992) that were highly represented in F1 and F2.

5 Conclusions

The results from this survey confirmed our hypothesis that the concentrations of trace elements in moss collected from urban forests were higher compared to moss collected from peri-urban and rural forests. The main sources of the trace elements identified with factor analysis emissions were traffic, individual heating appliances and the resuspension of contaminated soil. In particular, the Rožnik forest was the most exposed to pollution as determined by factor analysis. Since the official monitoring of air quality in the Municipality of Ljubljana is performed only at one location for measuring As, Cd, Ni and Pb in particulate matter, this study provides a better insight on the spatial distribution of trace elements within the city and urban forests.

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Table 1 Descriptive statistics of element concentrations (mg kg^{-1}) and comparison of median concentration in urban and peri-urban forests and the Slovenian 2010 survey (Harmens et al. 2013). Differences between concentrations in mosses collected in the peri-urban and urban forests were determined the Mann–Whitney *U* test (statistically significant differences are in bold letters)

ID	Minimum	Maximum	Standard deviation	Peri-urban median (n=22)	Urban median (n=22)	SI 2010 median (n=102)	Mann–Whitney *U* test	
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	W	p value
As	**0.06**	**0.67**	**0.14**	**0.09**	**0.14**	**0.26**	**67**	**0.001**
Ca	2162	6841	1065	4002	3744	3976	277	0.7865
Cd	0.08	0.84	0.12	0.15	0.16	0.27	256	0.870
Co	0.15	1.94	0.29	0.30	0.36	0.39	221	0.353
Cr	**0.59**	**9.64**	**2.08**	**1.24**	**3.16**	**1.56**	**108**	**<0.001**
Cu	**2.44**	**9.43**	**1.30**	**4.97**	**5.94**	**5.42**	**134**	**0.004**
Fe	222	3129	634	391	395	548	231	0.479
Hg	**0.02**	**0.13**	**0.02**	**0.03**	**0.04**	**0.05**	**123**	**0.002**
Mg	729	3278	424	1102	1043	1523	287	0.624
Mn	26	592	139	227	200	234	326	0.178
Mo	**0.004**	**1.30**	**0.22**	**0.21**	**0.30**	**0.34**	**172**	**0.043**
Ni	**0.76**	**4.30**	**0.83**	**1.32**	**2.08**	**2.12**	**72**	**<0.001**
Pb	**1.54**	**13.12**	**2.88**	**2.67**	**5.96**	**5.01**	**91**	**<0.001**
Sb	**0.05**	**0.22**	**0.04**	**0.09**	**0.14**	**0.12**	**117**	**<0.001**
Se	0.06	0.16	0.02	0.11	0.11	0.22	278	0.769
Sr	4.34	26.30	4.14	6.72	6.41	14.69	299	0.452
Ti	5.61	49.87	8.67	8.74	9.41	27.10	180	0.066
Tl	**0.01**	**0.22**	**0.04**	**0.02**	**0.03**	**0.04**	**124**	**0.002**
V	**0.56**	**5.22**	**1.11**	**0.87**	**1.23**	**2.30**	**97**	**<0.001**
Zn	10.89	45.98	8.11	24.95	25.47	29	258	0.905
N	**8.50**	**17.50**	**2.07**	**10.78**	**12.85**	**1.29**	**120**	**0.002**

Table 2 A comparison of trace metal concentrations from the Municipality of Ljubljana with other similar investigations (Oslo, Belgrade, Naples, Wienerwald)

Element	Ljubljana (mg kg^{-1}) median, n=44 *H. cupresiforme*	Oslo (mg kg^{-1}) (Reimann et al. 2006) median, n=40 *H. splendens*	Belgrade (mg kg^{-1}) (Vuković et al. 2015) median, n=153 *H. cupresiforme*	Naples (mg kg^{-1}) (Adamo et al. 2011) mean, n=24 *H.cupresiforme*	Wienerwald (mg kg^{-1}) (Krommer et al. 2007) mean, n=10 *S. purum* *H. cupressiforme* *A. abientina*
As	0.17	-	-	0.61	0.15
Ca	3777	2600	-	7580.25	-
Cd	0.16	0.17	0.44	0.29	0.24
Co	0.31	0.18	0.34	0.65	0.27
Cr	1.64	1.50	1.69	5.5	0.75
Cu	5.26	5.90	10.70	40.11	8
Fe	403	230	819	1280	503.07
Hg	0.03	0.04	-	0.07	0.04
Mg	1086	1170	-	992.87	-
Mn	214	542	-	50.8	-
Mo	0.23	0.20	-	1.30	0.21
Ni	1.50	1.60	3.06	2.61	1.23
Pb	3.68	3.46	6.18	22.77	4.53
Sb	0.10	0.13	-	-	0.15
Se	0.11	-	-	-	-
Sr	6.30	10.00	13.99	-	-
Ti	8.74	12.00	-	78.91	-
Tl	0.01	-	-	-	-
V	0.89	-	1.85	6.21	1.14
Zn	25.44	41	87	69.79	33.23

Table 3 Factor loadings and variances for obtained factors. The elements with the highest loadings for each factor are presented in bold letters

Element	Factor 1	Factor 2	Factor 3	Communality
As	**0.96**	0.06	0.17	1.1
Ca	0.01	0.13	**0.32**	1.3
Cd	0.12	–0.01	0.03	1.1
Co	0.59	0.03	**0.66**	2.0
Cr	0.51	**0.76**	0.00	1.8
Cu	0.01	**0.76**	0.20	1.1
Fe	**0.78**	–0.01	0.39	1.5
Hg	**0.71**	0.27	0.63	2.3
Mg	0.19	–0.28	**0.61**	1.6
Mn	–0.08	–0.09	0.08	2.9
Mo	0.06	**0.87**	–0.10	1.0
Ni	0.30	**0.81**	–0.04	1.3
Pb	**0.66**	0.38	0.18	1.8
Sb	–0.03	**0.68**	0.30	1.4
Se	–0.18	**0.65**	–0.17	1.3
Sr	–0.26	–0.03	0.04	1.1
Ti	**0.98**	0.00	0.06	1.0
Tl	**0.37**	–0.09	0.21	1.7
V	**0.97**	0.11	0.220	1.1
Zn	–0.24	**0.40**	–0.06	1.7
N	0.43	**0.60**	0.29	2.3
Proportion of variance (%)	27	21	9	
Cumulative variance (%)	27	47	56	

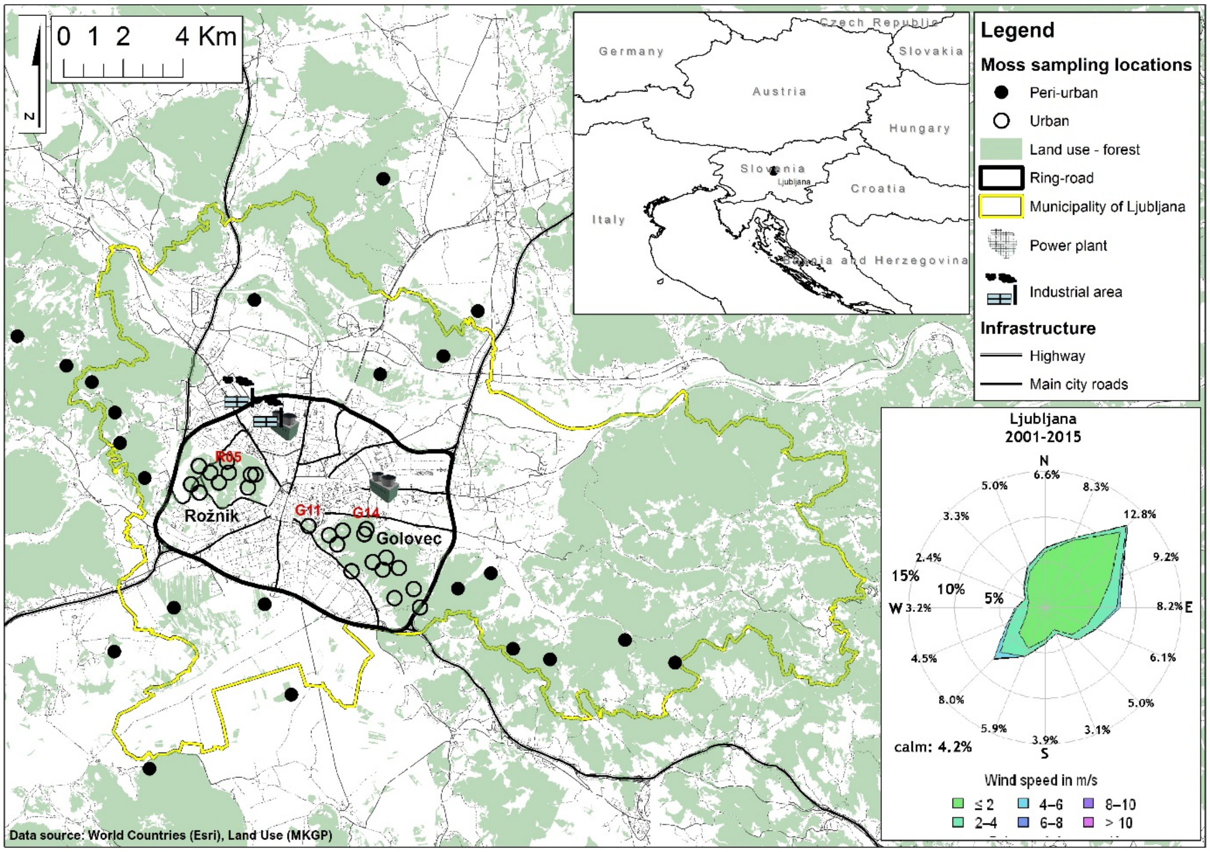


Fig. 1 Map of the study area with sampling points and a wind rose (ARSO 2016) for the Municipality of Ljubljana

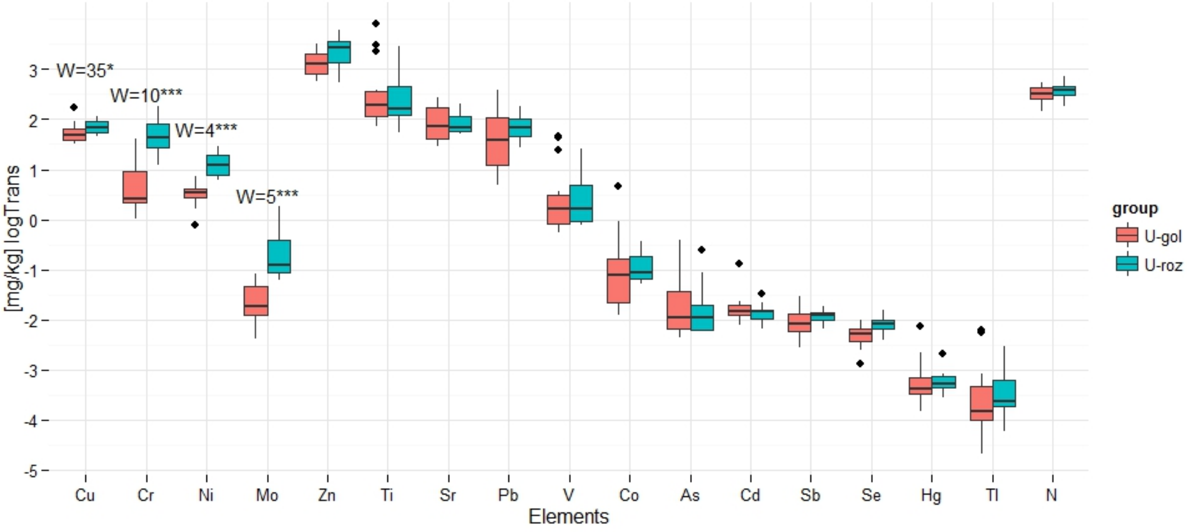


Fig. 2 Box plots showing the differences between element concentrations in mosses collected in urban forest Golovec (U-gol) and Rožnik (U-roz). (* 0.1, ** 0.01, *** 0.001)

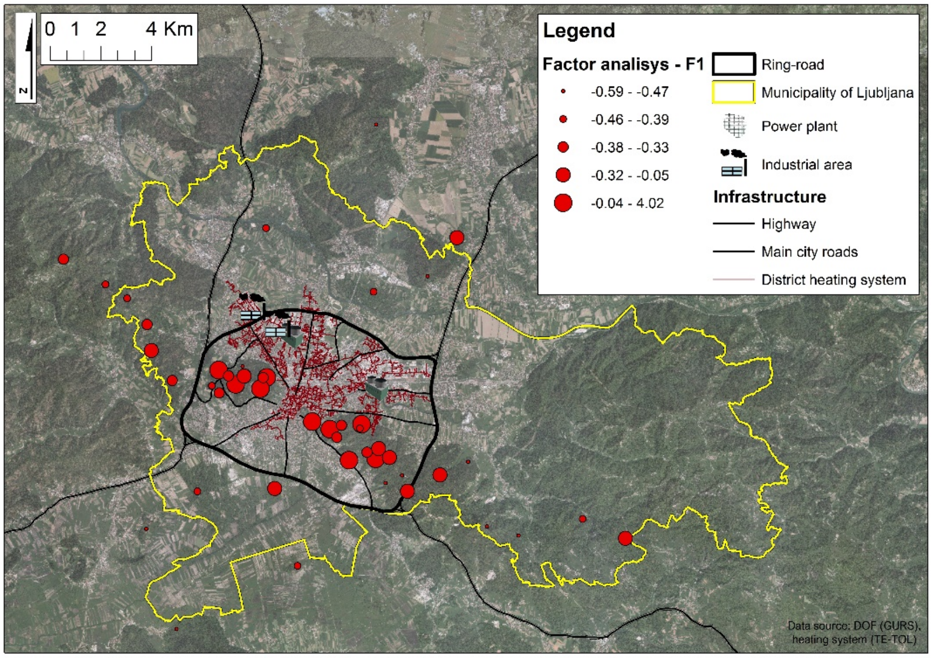


Fig. 3 Spatial distribution of Factor 1 (As, Fe, Hg, Pb, Ti, Tl, V)

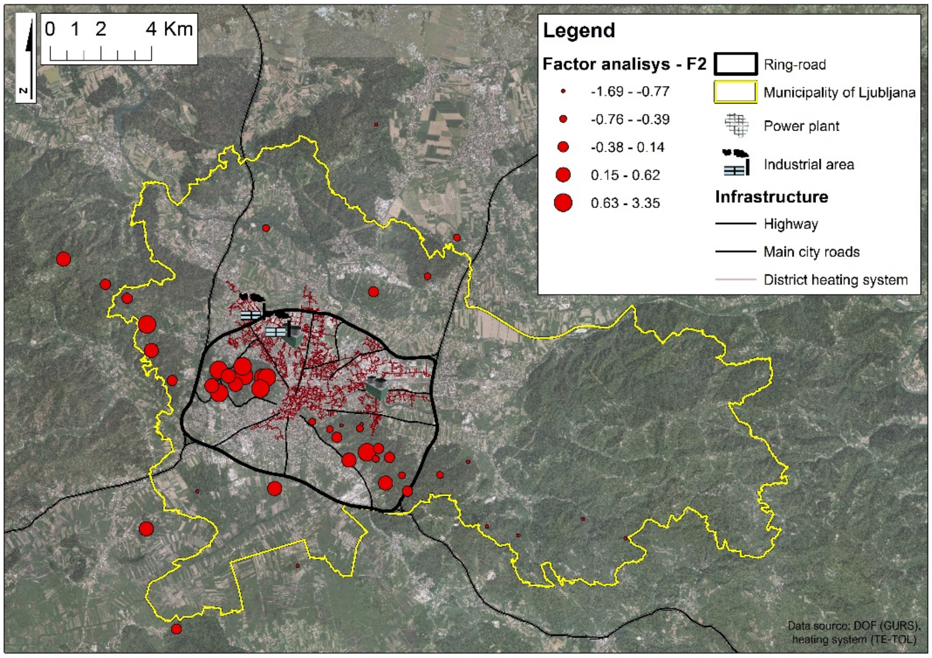
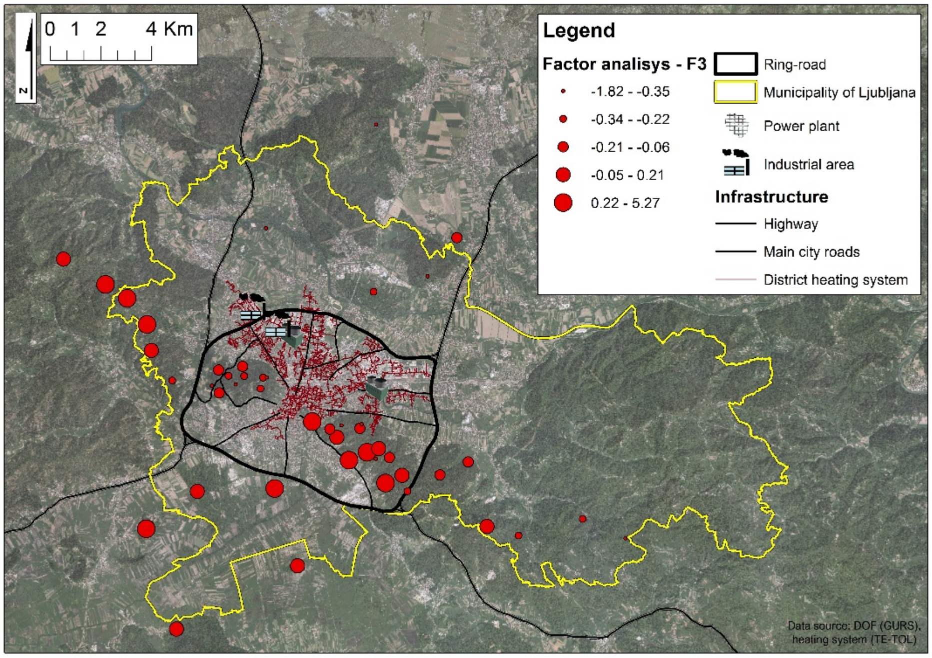


Fig. 4 Spatial distribution of Factor 2 (Cr, Cu, Mo, Ni, Sb, Se, Zn, N)



Data source: DOF (GURS), heating system (TE-TOL)

Fig. 5 Spatial distribution of Factor 3 (Ca, Co, Mg)