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DETERMINATION OF HEAVY METAL DEPOSITION IN THE COUNTY OF OBRENOVAC (SERBIA) USING MOSSES AS BIOINDICATORS. IV. MANGANESE (MN), MOLYBDENUM (MO), AND NICKEL (NI)

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Abstract — In this study, the deposition of three heavy metals (Mn, Mo, and Ni) in the county of Obrenovac (Serbia) in four moss taxa (*Bryum argenteum, Bryum capillare, Brachythecium* sp., and *Hypnum cupressiforme*) is presented. The distribution of average heavy metal content in all mosses in the county of Obrenovac is presented on maps, while the long-term atmospheric deposition (in the mosses *Bryum argenteum* and *B. capillare*) and short term atmospheric deposition (in the mosses *Brachythecium* sp. and *Hypnum cupressiforme*) are discussed and given in tabular form. Areas of the highest contaminations are highlighted.

Key words: Heavy metal deposition, mosses, bioindicators, Obrenovac, Serbia

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INTRODUCTION

This study represents the fourth part in a series (Sabovljević et al., 2005, 2007; Vukojević et al., 2006) on surveillance of heavy metals in mosses in the county of Obrenovac (W. Serbia).

The idea of using mosses to measure atmospheric heavy metal deposition was developed already in the late 1960's (Rhüling and Tyler, 1968; Tyler, 1970) and became well established in the Scandinavian countries in the 1980's.

It is based on the fact that mosses, especially the carpet-forming species, obtain most of their nutrients directly from precipitation and dry deposition. Nowadays, this method is widely used in many countries (Schaug et al., 1990; Sérgio et al., 1993; Kuik and Wolterbeek, 1995; Berg and Steinnes, 1997a; Pott and Turpin, 1998; Sucharova and Suchara, 1998; Grodzinska et al., 1999; Tsakovski et al., 1999; Fernández et al., 2000, 2002; Gerdol et al., 2000; Loppi and Bonini, 2000; Spezzano, 2000; Cucu-Man et al., 2002; Figueira et al., 2002; Peñuelas and Filella, 2002; Schilling and Lehman, 2002; Salemaa et al., 2004). Mosses have also been used to analyze contaminants spreading around thermal power plants (Tonguç, 1998; Carballeira and Fernández, 2002) or oil-fired power plants (Genoni et al., 2000).

Moreover, some bryophytes are known to be bioindicators of heavy metals in their environments (Samecka-Cymerman et al., 1997; Onianwa, 2001; Nimis et al., 2002; Cuoto et al., 2004; Schröder and Pesch, 2004) and are often used in environmental monitoring (Gstoettner and Fisher, 1997; Rasmussen and Andersen, 1999; Cuny et al., 2004; Giordano et al., 2004; Zechmeister et al., 2005).

In the present investigations, we decided to use two acrocarpous moss species (*Bryum argenteum* Hedw. and *Bryum capillare* Hedw.) that can give us an idea of long-term atmospheric deposition, inasmuch as they are attached to the substrate and also accumulate metals deposed during the last few decades in the surface layers of substrate. In addition, some other *Bryum* species are considered from the standpoint of trace metal deposition (Schintu et al., 2005). The metals studied were chosen according to the significance of their presence in their environments (Lantzy and Mackenzie, 1979).

Two pleurocarpous taxa (*Brachythecium* sp. and *Hypnum cupressiforme* Hedw.) were used to scan short-term atmospheric deposition of heavy metals, since these taxa are not strongly attached to the substrate and accumulate mostly from precipitation (Thöni et al., 1996; Faus-Kessler et al., 2001; Fernández and Carballeira, 2001; Cuoto et al., 2004).

Mosses are better than other higher plants in scanning heavy metal deposition because:

- they are perennial without deciduous periods;

- they have a high cation exchange capacity that allows them to accumulate great amounts of heavy metals between apoplast and symplast compartments without damaging vital functions of the cells (Vásquez et al., 1999); one of the main factors influencing cation exchange capacity is the presence of polygalacturonic acids on the external part of cell wall and proteins in the plasma membrane (Aceto et al., 2003).

- mosses do not possess thick and strong protective layers like cuticles.

More about hyperaccumulation of metals in plants and mosses can be found in Prasad and Freitas (2003). *Bryum argenteum* has already been shown to have special metal-accumulation properties (Aceto et al., 2003; Vukojević et al., 2004, 2005).

It should also be noted that this time-integrated way of measuring patterns of heavy metal deposition from the atmosphere in terrestrial ecosystems, besides being spatially oriented, is easier and cheaper than conventional precipitation analyses, as it avoids the need for deploying large numbers of precipitation collectors. The higher trace element concentration in mosses compared to rain water makes analysis more straightforward and less prone to contamination (Berg and Steinnes, 1997b).

Use of mosses to investigate heavy metal deposition shows trans-boundary heavy metal pollution and can indicate the paths by which atmospheric pollutants enter from other territories or reveal their sources within the investigated area.

Although 15 heavy metals were analyzed in all, only deposition and distribution of Mn, Mo, and Ni are treated in the present study, due to limitation of space. The presence and distribution of aluminium, arsenic, boron, cadmium, cobalt, chromium, copper, iron, and mercury in the county of Obrenovac as screened by mosses were considered in three already published papers (Sabovljević et al., 2005, 2007; Vukojević et al., 2006).

MATERIAL AND METHODS

The acrocarpous mosses *Bryum argenteum* and *Bryum capillare* were used to research long-term atmospheric deposition, while the pleurocarpous *Brachythecium* sp. and *Hypnum cupressiforme* were used to scan short-term atmospheric deposition in the county of Obrenovac (Serbia). *Hypnum cupressiforme* is one of the standard species used in Europe for heavy metal deposition surveys (Buse et al., 2003), whereas the other three standard species used for this purpose in Europe do not grow in the Obrenovac region. In judging which other species are eligible for heavy metal deposition monitoring, the experience of Thöni (1996), Herpin et al. (1994), Siewers and Hairpin (1998), Zechmeister (1994), and Ross (1990) was consulted.

As far as possible, moss sampling followed the guidelines set out in the experimental protocol for the 2000/2001 survey (UNECE, 2001). The procedure is given in detail in Rühling (1998).

Each sampling site was located at least 300 m from main roads and populated areas and at least 100 m from any other road or single house. In forests or plantations, samples were collected in small open spaces to preclude any effect of canopy drip. Sampling and sample handling were carried out using plastic gloves and bags. About three repeat moss samples were collected from each site. Dead material and litter were removed from the samples. Green parts of the mosses were used for analyses.

The county of Obrenovac was chosen for this investigation because of its industry and location.

Each sampling site was GPS-located with a precision of ±10 m, and GPS data (Garmin) were digitalized on maps with the OziExplorer 3.95.3b (©D & L Software) and WinDig 2.5 Shareware (©D. Lovy) softwares.

All material was collected during November of 2002.

Not more than one site was chosen per square measuring 50 x 50 m. Seventy-five out of 129 localities were chosen for comparison and further analyses based on all investigated species present and yearly biomass.

More than 500 samples were analyzed. After collecting, samples were dried as soon as possible in a drying oven to a constant dry weight (dw) at a constant temperature of 35°C, then stored at -20°C.

Following homogenization in a porcelain mortar, the samples were treated with 5+1 parts of nitric acid and perchloric acid (HNO3:HClO4 = 5:1) and left for 24 hours.

After that, a Kjeldatherm digesting unit was used for digestion at 150-200°C for about one hour. Digested samples were filtered on qualitative filter paper to dispose of silicate remains, and the volume of samples was then normated to 50 ml.

Nickel (Ni), manganese (Mn), and molybdenum (Mo) were detected by a Philips Pye Unicam SP9 AAS instrument. The content of manganese and nickel were determined with a flame of acetylene/air, while molybdenum was detected using a flame of acetylene/nitrogen-suboxide.

For explanation of the results and their map presentation, the following statistical parameters were used: average values, standard deviation, minimum and maximum values, and percent deviation. Map making and interpolation of precise data were done with Agis v1.71 32bit (©Agis Software, 2001) software.

RESULTS AND DISCUSSION

Since it was impossible to find all the sampled species at any precise locality, the average of all specimens is given on an extrapolated map to get an idea of heavy metal deposition in the county of Obrenovac (Fig. 1). However, if we separate the values of deposition obtained from pleurocarpous (*Brachythecium* sp. and *Hypnum cupressiforme*) and acrocarpous (*Bryum argenteum* and *Bryum capillare*) mosses, it can be clearly seen that the first two give us an idea of short-term deposition and the last two of long-term deposition (Table 1). This can be easily explained in terms of the life forms of these mosses and their uptake of heavy metals. Pleurocarps are not closely attached to the substrate and thus receive the bulk of deposited heavy metals directly from the atmosphere (during their paucienial life period), while acrocarps are strictly attached to substrata and get most of deposited heavy metals with the substrate solution (metals are deposited over a period of time that is longer than their pauciennial life span).

The north-central urban region of the county with green surfaces is less loaded with the studied trace metals. The central and southwest part of the county are the most loaded with manganese.

Manganese is represented in the Earth's crust with some 900 ppm (Scheffer and Schachtschabel, 1984; Kaim and Schwederewski, 2005). It is an important micro-element for plants and animals, being included in enzymatic systems and involved in production of vitamin B1 and insulin (Kaim and Schwederewski, 2005). In plants, it is an important transporter of electrons in photosystem II. The best known manganese-containing polypeptides are arginase, the diphteria toxin, and Mn-containing superoxide dismutase (Mn-SOD), which is an enzyme typically present in eukaryotic mitochondria, and also in many bacteria (this fact is in keeping with the bacterial-origin theory of mitochondria). The Mn-SOD enzyme is probably one of the most ancient. Nearly all organisms living in the presence of oxygen use it to deal with the toxic effects of superoxide, formed from the 1-electron reduction of dioxygen.

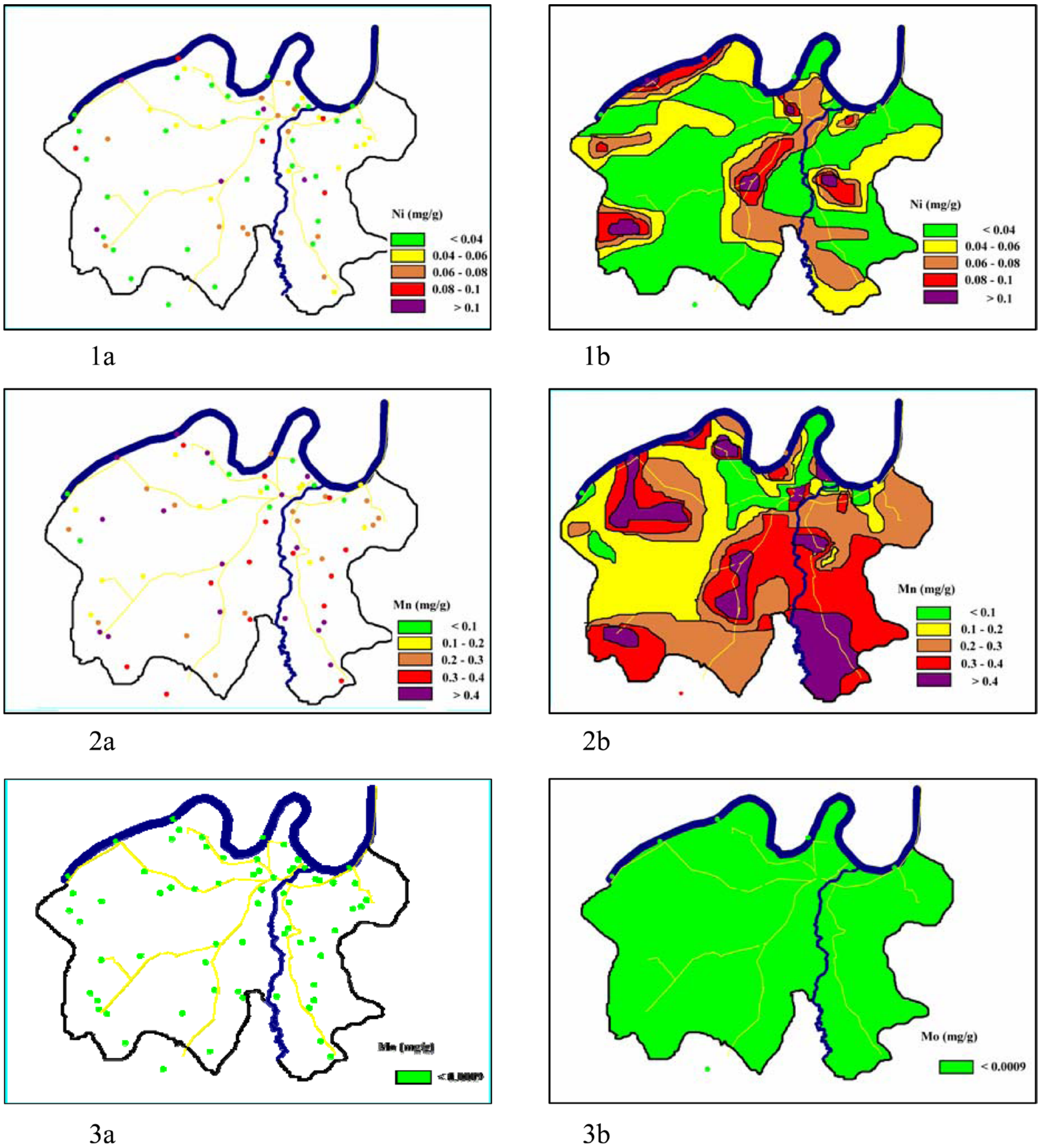

Fig. 1. Deposition of Mn (1), Mo (2), and Ni (3) in the county of Obrenovac. a – exact values, b – extrapolated maps inferred from a.

Manganese is extracted from pyrolusite (MnO_2). Due to its resemblance to iron, it is used in production of alloys, primary steel production, in the chemical industry, and in the manufacture of fertilizers and paints (Williams, 1988). The EU uses manganese in 1- and 2-Euro coins, due to its cheapness and availability.

Manganese compounds are less toxic than those of other widespread metals. Exposure to manganese dusts and fumes should not exceed a ceiling value of 5 mg/m^3. Manganese poisoning has been linked to impaired motor skills (e.g., Parkinson's desease) and cognitive disorders.

Scanning of trace metal contents in the county of Obrenovac (W. Serbia) clearly shows that the entire area of the county is loaded with manganese as a

Table 1. Deposition of manganese (Mn), molybdenum (Mo), and nickel (Ni) in mosses of the Obrenovac county (B.a. – *Bryum argenteum*, B.c. – *Bryum capillare*, Bra – *Brachythecium* sp., H.c. – *Hypnum cupressiforme*).

No.	Locality	Longitude	Latitude	Mn (mg/g)	Mo (mg/g)	Ni (mg/g)
1	Vinogradi H.c.	20.163702	44.391758	0.1378	<0.0098	0.0000
2	Moštanica 1 H.c.	20.183672	44.384249	0.1544	<0.0125	0.0106
3	Iskra 1 B.c.	20.155235	44.392722	0.3246	<0.0044	0.0663
4	Iskra 2 B.a.	20.152826	44.393284	0.3928	<0.0052	0.0574
5	Iskra 1 H.c.	20.155235	44.392722	0.3067	<0.0086	0.0073
6	Iskra 2 B.c.	20.152826	44.393284	0.2175	<0.0022	0.0489
7	Rvati 1 B.c.	20.118796	44.396930	0.6833	<0.0045	0.0677
9	Deponija B ulaz 1 B.c.	20.023331	44.383735	0.8392	<0.0020	0.0634
10	Zabrežje 1 B.c.	20.121273	44.411245	0.2704	<0.0062	0.0475
11	Ušće 2 B.c.	20.066441	44.419235	0.6832	<0.0011	0.0683
12	Vinogradi B.c.	20.163702	44.391758	0.1667	<0.0070	0.0295
13	Iskra 1 B.a.	20.155235	44.392722	0.3342	<0.0016	0.0864
14	Ušće 2 H.c.	20.066441	44.419235	0.4753	<0.0016	0.0863
15	Ušće 1 B.c.	20.070343	44.414738	0.3098	<0.0081	0.0408
16	Urozv Bra	20.079770	44.389043	0.4510	<0.0033	0.0565
17	Zabrežje 2 H.c.	20.133796	44.408293	0.2396	<0.0029	0.0271
18	Orašac 1 H.c.	20.021819	44.336717	0.2168	<0.0029	0.0197
19	Hotel B.a.	20.127451	44.394049	0.4130	<0.0027	0.0682
20	Moštanica 1 H.c.	20.183672	44.384249	0.1498	<0.0058	0.0098
21	Grabovac 1 H.c.	20.046934	44.359997	0.1189	<0.0033	0.0111
22	Šab.put nadv. B.c.	20.094085	44.391367	0.5789	<0.0025	0.1502
23	Vranić H.c	20.152122	44.347529	0.3181	<0.0037	0.0218
24	Jasenak 2 Bra	20.156246	44.360071	0.7124	<0.0020	0.0975
25	Dren 1 Bra	20.023224	44.358238	0.4598	<0.0034	0.0288
26	Veliko Polje 1 H.c.	20.108648	44.365954	0.3046	<0.0078	0.0395
27	Grabovac 1 B.c.	20.046934	44.359997	0.1147	<0.0035	0.0210
28	Belo Polje 1 B.c.	20.118064	44.382783	0.3153	<0.0050	0.0845
29	Brović 1 B.c.	20.072201	44.335108	0.2013	<0.0029	0.0242
30	Ljubinić 2 Bra	20.026762	44.334832	0.6916	<0.0030	0.1769
31	Hotel H.c.	20.127451	44.394049	0.4820	<0.0020	0.0743
32	Grabovac 1 Bra	20.046934	44.359997	0.1895	<0.0021	0.0262
33	Ljubinić 2 B.c.	20.026762	44.334832	0.7324	<0.0026	0.0262
34	Veliko Polje 4 H.c.	20.109057	44.341908	0.3979	<0.0014	0.0652
35	Zabran 3 H.c.	20.137615	44.396905	8.5753	<0.0039	0.0131
36	Zabran 1 H.c.	20.139396	44.398268	0.1411	<0.0023	0.0335
37	Orašac 3 H.c.	20.016612	44.343855	0.1386	<0.0266	0.1299
38	Orašac 2 H.c.	20.020860	44.340639	0.3977	<0.0016	0.0273
39	Zabran 2 B.a.	20.142377	44.401672	0.1421	<0.0017	0.0211
40	Belo Polje 1 B.a.	20.118064	44.382783	0.3390	<0.0044	0.0847
41	Orašac 2 Bra	20.020860	44.340639	0.2085	<0.0032	0.0190
42	Ljubinić 1 Bra	20.037630	44.322132	0.3813	<0.0018	0.0292
43	Grabovac nad. B.a.	20.092788	44.365167	0.2921	<0.0017	0.0445
44	Joševa H.c.	20.060545	44.310742	0.4393	<0.0029	0.0460

Table 1. Continued.

No.	Locality	Longitude	Latitude	Mn (mg/g)	Mo (mg/g)	Ni (mg/g)
45	Brović 2 Bra	20.088929	44.318537	0.2263	<0.0019	0.0230
46	Jasenak 2 B.a.	20.156246	44.360071	0.2714	<0.0011	0.0428
47	Garbovac nadv. Bra	20.092788	44.365167	1.0428	<0.0015	0.1337
48	Baljevac 1 B.c.	20.152044	44.340743	0.5122	<0.0021	0.0632
49	Joševa B.c.	20.060545	44.310742	0.5089	<0.0016	0.0255
50	Joševa Bra	20.060545	44.310742	0.3114	<0.0011	0.0371
51	EPS B.c.	20.120401	44.388845	0.0633	<0.0026	0.0088
52	Konatice II Bra	20.148928	44.337410	0.4258	<0.0020	0.0464
53	Zabran 1 B.a.	20.139396	44.398268	0.1314	<0.0038	0.0192
54	Mislođinl 1 Bra	20.136579	44.383096	0.2822	<0.0058	0.0295
55	Brović 1 H.c.	20.072201	44.335108	0.2012	<0.0055	0.0186
56	Mislođin 4 H.c.	20.134067	44.369616	0.3147	<0.0040	0.0202
57	Stubline 2 H.c.	20.091649	44.345095	0.5584	<0.0048	0.0771
58	Konatice 1 B.c.	20.162150	44.316265	0.1972	<0.0022	0.0226
59	Zabran 3 B.a.	20.137615	44.396905	0.1023	<0.0023	0.0138
60	Jasenak H.c.	20.143804	44.365736	0.1199	<0.0022	0.1562
61	Konatice 2 B.a.	20.155831	44.322960	0.4425	<0.0052	0.0698
62	Veliko Polje 4 B.c.	20.109057	44.341908	0.3389	<0.0033	0.0678
63	Mislođin 1 Bra	20.133857	44.387041	0.2294	<0.0026	0.0715
64	Veliko Polje 3 B.c.	20.106117	44.344670	0.2963	<0.0019	0.0718
65	Konatice II B.c.	20.148928	44.337410	0.5955	<0.0019	0.0470
66	Mislođin 6 B.a.	20.164676	44.371027	0.0036	<0.0025	<0.0021
67	Stubline 1 H.c.	20.086353	44.357185	0.3301	<0.0040	0.0504
68	Šab. put nadv. B.a.	20.094085	44.391367	0.5987	<0.0016	0.0765
69	Dren 1 H.c.	20.023224	44.358238	0.1720	<0.0041	0.0243
70	Zabran 2 B.c.	20.142377	44.401672	0.5439	<0.0069	0.0584
71	Baljevac 2 H.c.	20.129432	44.342383	0.4188	<0.0027	0.0784
72	Mislođin 5 B.a.	20.150813	44.367274	0.2582	<0.0019	0.0372
73	Orašac 1 Bra	20.021819	44.336717	0.2808	<0.0018	0.0263
74	Konatice II H.c.	20.148928	44.337410	2.4939	<0.0028	0.0192
75	Šab. put 1 Bra	20.049094	44.396566	0.1083	<0.0044	0.0560
76	TENT B 3 B.c.	20.003761	44.379624	0.1946	<0.0164	0.0276
77	Šab.put 1 H.c.	20.094085	44.391367	0.0615	<0.0076	<0.0064
78	Ratari 2 Bra	20.058939	44.387315	0.3551	<0.0026	0.0400
79	TENT<B 1 H.c.	19.593841	44.380930	0.1572	<0.0099	<0.0084
80	TENT<B 2 H.c.	20.010398	44.374841	0.3165	<0.0034	0.0058
81	Ratari 1 H.c.	20.065292	44.389672	0.2803	<0.0015	0.0497
82	Ušće Skela B.c.	20.031781	44.409564	0.3112	<0.0095	0.0483
83	Ratari 2 B.a.	20.058939	44.387315	0.4196	<0.0016	0.0361
84	TENT<B 4 B.a.	20.005827	44.387162	0.3662	<0.0011	0.0364
85	TENT<B 2 Bra	20.010398	44.374841	0.2164	<0.0031	0.0317
86	TENT<B 1 Bra	19.593841	44.380930	0.1613	<0.0091	0.0229
87	TENT<B 4 B.c.	20.005827	44.387162	0.1221	<0.0049	0.0123
88	TENT<B 3 B.c.	20.003761	44.379624	0.2286	<0.0029	0.0806

Table 1. Continued.

No.	Locality	Longitude	Latitude	Mn (mg/g)	Mo (mg/g)	Ni (mg/g)
89	Orašac 1 Bra	20.021819	44.336717	1.8459	<0.0033	0.0693
90	Ušće Skela Bra	20.031781	44.409564	0.8593	<0.0038	0.1115
91	Šab.put 1 B.c.	20.049094	44.396566	0.2133	<0.0033	0.0508
92	TENT B ulaz Bra	20.002958	44.394451	0.0949	<0.0084	0.0355
93	Depoija 1 Bra	20.087035	44.407417	0.3589	<0.0031	0.0496
94	TENT B 2 B.c.	20.010398	44.374841	0.0341	<0.0036	0.0030
95	Konatice 1 H.c.	20.162150	44.316265	0.3525	<0.0015	0.0536
96	Mislođin 6 Bra	20.164676	44.371027	0.7562	<0.0017	0.0312
97	Mislođin 3 Bra	20.136294	44.371922	0.4245	<0.0032	0.0372
98	Mislođin 6 B.c.	20.164676	44.371027	0.3827	<0.0039	0.0463
99	Jasenak 2 B.a.	20.156246	44.360071	0.3704	<0.0032	0.0834
100	Mislođin 4 B.c.	20.134067	44.369616	0.3558	<0.0023	0.0529
101	Zabran 1 Bra	20.139396	44.398268	0.1265	<0.0056	0.0377
102	Rojkovac 1 B.c.	20.117592	44.401807	0.2589	<0.0027	0.0470
103	Rojkovac 1 Bra	20.117592	44.401807	0.3932	<0.0061	0.1088
104	Rvati 1 Bra	20.118796	44.396930	0.0564	<0.0082	1.7953
105	Rojkovac 1 B.a.	20.117592	44.401807	0.3733	<0.0042	0.0609
106	Moštanica 3 Bra	20.175487	44.380355	0.4419	<0.0033	0.0692
107	Razu Bra	20.065879	44.410726	0.1045	<0.0065	0.0276
108	Ušće 3 Bra	20.084220	44.411524	0.4778	<0.0009	0.0446
109	Duboko 3 H.c.	20.176888	44.391497	0.2732	<0.0044	0.0147
110	Zabrežje 1 Bra	20.121273	44.411245	0.2908	<0.0037	0.0375
111	Zabran 3 Bra	20.137615	44.396905	0.1916	<0.0016	0.0640
112	Moštanica 2 B.c.	20.180515	44.381400	0.2521	<0.0022	0.0458
113	Razu B.a.	20.065879	44.410726	0.0143	<0.0031	0.0441
114	Rvati 3 Bra	20.115276	44.395254	0.1063	<0.0058	0.0341
115	TENT A 1 Bra	20.096950	44.402553	0.2689	<0.0040	0.0505
116	Moštanica 3 B.c.	20.175487	44.380355	0.1366	<0.0082	0.0413
117	Zabrežje 2 Bra	20.133796	44.408293	0.2430	<0.0038	0.0447
118	Urozv B.c.	20.079770	44.389043	0.1667	<0.0034	0.0228
119	Depoija 1 H.c.	20.087035	44.407417	0.0869	<0.0105	0.0178
120	Zabrežje 2 B.a.	20.133796	44.408293	0.2573	<0.0026	0.0356
121	Moštanica 1 B.c.	20.183672	44.384249	0.2967	<0.0019	0.0441
122	Vinogradi B.a.	20.163702	44.391758	0.1792	<0.0020	0.0265
123	Urozv H.c.	20.079770	44.389043	0.1262	<0.0043	0.0467
124	Razu H.c.	20.065879	44.410726	0.1369	<0.0031	0.0234
125	Duboko 1 B.a.	20.173260	44.398253	0.1089	<0.0032	0.0214
126	Vinogradi Bra	20.163702	44.391758	0.0427	<0.0039	0.0098
127	Duboko Bra	20.146281	44.397974	0.0999	<0.0035	0.0263
128	TENT A 1 B.c.	20.096950	44.402553	0.0993	<0.0022	0.0146
129	Zabrežje 2 B.c.	20.133796	44.408293	0.0043	<0.0010	0.0609
Median				0.3959	<0.0040	5.3115

result of heavy industry and intense traffic (the position of the heavily loaded area on Fig. 1 corresponds to industrial and traffic sites).

Molybdenum is spread equally over the region examined and does not exceed 0.0009 mg/g of moss mass. Molybdenum is present in the Earth's crust with an average of 1.1 g/t (Scheffer and Schachtschabel, 1984; Thöni and Seitler, 2004). The most important mineral containing molybdenum is molybdenite (MoS_2) (Greenwood and Earnshaw, 1988). However, it is a collateral product in production of copper. The yearly production of molybdenum is about 0.111 million tons (Metallgesellschaft, 1993). Some 85% of molybdenum is used in the steel and iron industry. The rest of molybdenum usage goes to production of catalysts, alloys, etc. in the organic chemical, petrochemical, and electronics industries. Also, it is used in small quantities as an additive to animal foods, vitamin preparations, and fertilizers (Trueb, 1996). The emission of molybdenum decreased from the 1970's and in 1995 it was ca. 530 tons yearly in Europe (Thöni and Seitler, 2004). Molybdenum is a micro-element that in plants takes part in many enzymatic processes. Although it is important for normal plant growth, the plant's requirements for molybdenum is very small. Tolerance of molybdenum toxicity is high and damage to the plant is rare and expressed as yellow-orange chlorosis on leaf surfaces (Merian, 1984; Bergmann, 1988). Molybdenum is essential for animal and human life. To date, there has been small risk of molybdenum poisoning. It becomes very toxic only in very high concentrations. Only some cases of heavy poisoning of oxen near industrial complexes are known to date (Merian, 1984). The legal limit in developed countries is 5 mg/kg of dry soil (Thöni and Seitler, 2004).

In the county of Obrenovac, molybdenum seems not to be a problematic trace element compared to others (see also Sabovljević et al., 2005, 2007; Vukojević et al., 2006).

Nickel is spread over the county unequally, with highest concentrations along the roads and industrial complexes. Nickel is one of the major elements in the Earth's crust with some 58 g/t (Scheffer and Schachtschabel, 1984; Thöni and Seitler, 2004). Almost 90% of nickel comes from the iron-nickel sulfide mineral pentlandite (Merian, 1984). Its production is ca. 800000 tons a year (Metallgesellschaft, 1993). Nickel is a part of more than 3000 alloys, of which the most important is chromium-nickel steel. It is widely used in the construction, chemical, food, and transportation (cars and planes) industries, as well as in housekeeping. Coins are made of copper-nickel alloys, and nickel hydride batteries are used in remote-control equipment (Treub, 1996). The annual values for emission in Europe are around 20000 tons, with a declining tendency due to greater concern for the environment and modern technological usage (Pacyna and Pacyna, 2001).

Bergmann (1988) states that it is not clear whether nickel is essential for plants. However, it is known to be toxic in acid and sand substrates, and it is species-specific. For animals and humans, nickel is probably essential, and toxicity from natural nickel is minimal. However, allergies from modern jewelry are frequent (Trueb, 1996). Nickel in constant and higher concentrations can act as a cancerogen (Merian, 1984). The legal limits in emission of stationary sources are 1 mg/m^3, 50 mg/kg in dried soil, 0.01 mg/l in drinking water, and 2 mg/l in waste waters (Thöni and Seitler, 2004).

In the county of Obrenovac, its deposition is localized at specific sites, and these sites are highlighted as potentially threatening zones for humans, animals, and plants.

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ДЕПОЗИЦИЈА ТЕШКИХ МЕТАЛА НА ПОДРУЧЈУ ОПШТИНЕ ОБРЕНОВАЦ (СРБИЈА) ПРАЋЕНА ПРЕКО МАХОВИНА КАО БИОИНДИКАТОРА. IV. МАНГАН (MN) , МОЛИБДЕН (MO) И НИКЛ (NI)

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У овом раду представљена је депозиција три тешка метала (манган, молибден и никл) на подручју општине Обреновац (Србија) праћена преко четири маховине (*Bryum argenteum, Bryum capillare, Brachythecium* sp. and *Hypnum cupressiforme*). Распоред просечног садржаја ових метала у маховинама представљен је на картама са тачним подацима и екстраполирано, док се дугорочна (вредности код маховина *Bryum argenteum* и *B. capillare*) и краткорочна (вредности код маховина *Brachythecium* sp. и *Hypnum cupressiforme*) депозиција тешких метала може видети из табеле.