Polish J. Environ. Stud. Vol. 15, No. 2 (2006), 211-218

Original Research

Spatial Distribution of Mercury in Bottom Sediments and Soils from Poznań, Poland

L. Boszke[1]*, A. Kowalski[2]

[1]Department of Environmental Protection, Collegium Polonicum, Adam Mickiewicz University, Kościuszki 1, 69-100 Słubice, Poland
[2]Department Water and Soil Analysis, Faculty of Chemistry, Adam Mickiewicz University, Drzymały 24, 60-613 Poznań, Poland

Received: January 25, 2005
Accepted: September 1, 2005

Abstract

The city of Poznań is located in west-central Poland. With over 578,900 inhabitants it is one of the biggest industrial centres in Poland. The aim of this study was to determine distribution of mercury in bottom sediments and soil from Poznań. Total mercury concentrations have been determined in bottom sediments (ponds, lakes, streams and rivers) and soil samples collected in 2003 from Poznań. Mercury was determined using the cold vapour atomic fluorescence spectrometry method (CV-AFS). Total mercury concentration in the bottom sediments was 97 ± 70 ng/g dry weight (range 29-283). Average total mercury concentration in the soil from urban areas was 146 ± 130 ng/g dry weight (range 17-746). The results of the study have shown that mercury distribution in the samples of water and bottom sediments, collected from various sites in Poznań, is relatively uniform. In contrast to the above, the concentration of mercury in the soil samples varies over a relatively large range. The soils were grouped according to the present land use, i.e. lawn and meadow soils, urban forests soils, soils of not current agricultural use and agricultural soils.

Keywords: mercury pollution, bottom sediment, soil, Poznań City, Poland.

Introduction

Mercury is generally considered one of the most toxic metals found in the environment. Most anthropogenic mercury emissions are released to the air as by-products of various industrial processes, including coal combustion, fossil fuel combustion, mercury vapour lights and chloroalkali production [1]. The total mass of mercury emitted to the atmosphere from industrial sources in Poland has been estimated at 40 tons per year [2]. The main source of mercury emission to the atmosphere is fuel combustion. As a consequence of this process, about 26 tons of mercury is emitted to the atmosphere per year. Processes of combustion of hard coal and lignite are responsible for the release of 44% and 18.3% of total mercury emitted to the atmosphere. Other sources of mercury, such as the cement production process and used fluorescent lamps, are responsible for the release of 16.6% and 6.4%, respectively [2]. The main sources of mercury in urban areas are combustion facilities, including coal-fired power plants, municipal solid waste incineration and hospital incineration. Other sources of mercury contamination in urban area are hazardous waste and sewage sludge [3]. Mercury is primarily emitted to air and water. Eventually, mercury accumulates in soils and, since cities often are located at rivers, also in bottom sediments. The sediments can therefore provide time integrated fingerprints of aquatic environments, at least for mercury that has a reasonably strong affinity to natural particles [4,5].

*Corresponding author; e-mail: boszke@euv-frankfurt-o.de

Poznań is a city in west-central Poland with over 578,900 inhabitants. Located by the Warta River, it is one of the oldest Polish Cities, an important historical center and the capital of Wielkopolska District. Poznań is the fourth biggest industrial center in Poland, with dominant food, mechanical, electrotechnical and chemical industries. The aim of this study was to determine a distribution of mercury in bottom sediments and soils from Poznań and to identify potential sources of mercury pollution.

Materials and methods

The concentration of total mercury was determined in 23 samples of bottom sediment samples (ponds, lakes, streams and rivers) (0-10 cm) (Fig. 1). Moreover, mercury was determined in 61 samples of urban soil (0-20 cm). Samples were collected in 2003 at sites whose geographical coordinates were measured by a GPS instrument (Garmin eTrex Summit). Sediment and soil samples were collected with a hand corer made of stainless steel. They were placed in plastic boxes of 1 L volume and transported to the laboratory where they were dried at room temperature to constant weight. Subsequently, the samples were homogenized in agate mortar. Then the samples were sieved through first 2 mm mesh, then 0.5 mm, and were once again homogenized in an agate mortar. Finally the samples were sieved through the 0.150 mm mesh.

For determination of mercury, sediment and soil subsamples (~1 g) were wet digested with aqua regia in a glass apparatus consisting of a round-bottom flask, partial condenser (30-cm long) and water cooler. 17 mL of aqua regia were added to the samples and the mixture was allowed to stand for 16 h. The flask was then gently heated for 2.0 h boiling. After cooling, the water cooler and condenser were rinsed with 5 mL of redistilled water. The digest was filtered by blotting paper and diluted with redistilled water up to 100 mL. Finally mercury content was determined by cold vapour atomic fluorescence spectroscopy (CV-AFS) using a Millenium Merlin Analyzer (PS Analytical).

Standard Reference Materials: SRM 2711 – Montana Soil, SRM 2709 – San Joaquin Soil and LGC 6137 – Estuarine Sediment were analyzed routinely as laboratory reference materials. The values for total mercury 6.06 ± 0.07 µg/g (SRM 2711, n=3), 1.44 ± 0.03 µg/g (SRM 2709, n=4) and 0.37 ± 0.01 µg/g (LGC 6137, n=4) were in agreement with the certified concentrations of 6.25 ± 0.19 µg/kg, 1.40 ± 0.08 µg/kg and 0.34 ± 0.05 µg/g, respectively. Procedural blanks were run with each set of sample analyses.

Results

In the bottom sediments from the same sites at which the samples of water were collected in Poznań, total mercury concentration was 97 ± 70 ng/g dry weight (range 29-283). A relatively high concentration was noted in the sediments from ponds 154 ± 80 ng/g (range 33-253), while lower o in the sediments from the Warta River 118 ± 96 ng/g (range 47-283) and from rivers and streams 76 ± 37 (range 33-113). Relatively the lowest average concen-

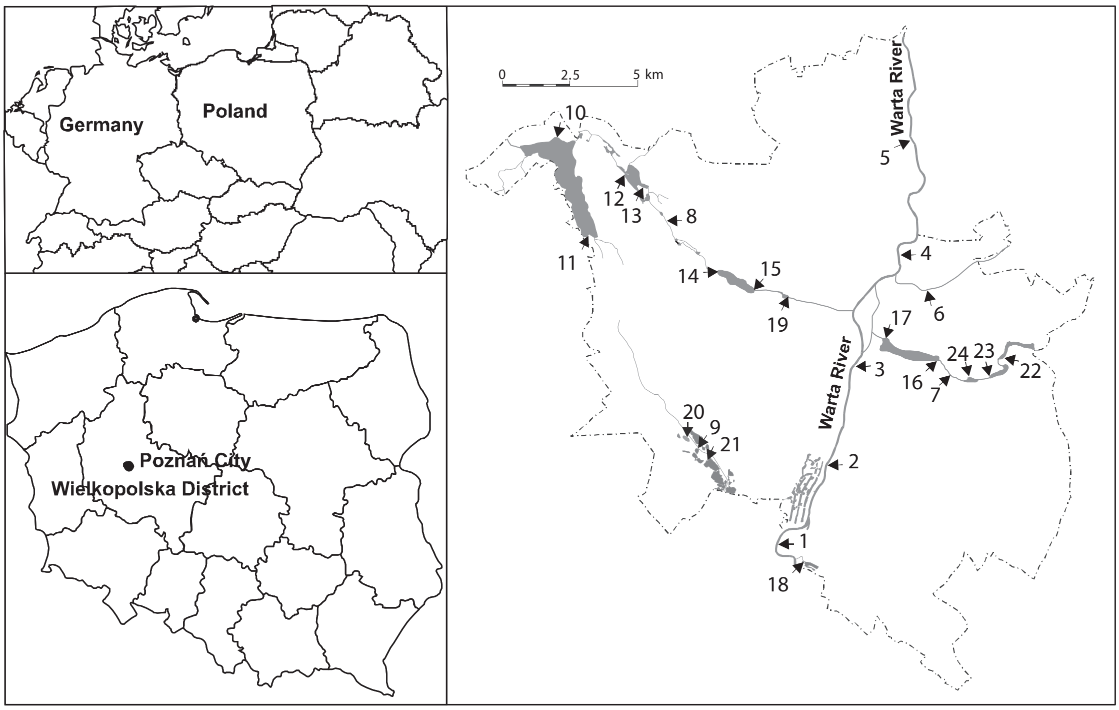

Fig. 1. Map of study area with sediment sampling points.

Table 1. Mercury concentration in samples of bottom sediments from Poznań.

Number of sample	Sampling sites and description	Geographical coordinates		Bottom sediments [ng/g]
1	Warta River - 500 meters before of reservoir of drinking water	N 52^0 22’ 25,3”	E 16^0 53’ 58,9”	60
2	Warta River - 500 meters after reservoir of drinking water	N 52^0 21’ 56,3”	E 16^0 55’ 36,8”	80
3	Warta River - Królowa Jadwiga Bridge	N 52^0 23’ 58,0”	E 16^0 56’ 31,4”	47
4	Warta River – Lech Bridge	N 52^0 25’ 52,1”	E 16^0 57’ 59,3”	121
5	Warta 500 meters after wastewater treatment plant	N 52^0 28’ 29,6”	E 16^0 58’ 17,6”	283
6	Główna River – Bridge on Gdyńska Street	N 52^0 25’ 24,5”	E 16^0 58’ 34,4”	58
7	Cybina River - between Olszak Pond and Maltańskie Lake	N 52^0 23’ 40,3”	E 16^0 59’ 46,7”	100
8	Bogdanka River – Biskupińskia Street	N 52^0 26’ 50,5”	E 16^0 50’ 24,2”	33
9	Junikowski Stream – Wykopy Street	N 52^0 22’ 21,2”	E 16^0 51’ 25,6”	113
10	Kierskie Lake – northern waterside	N 52^0 28’ 26,6”	E 16^0 46’ 57,1”	29
11	Kierskie Lake – southern waterside	N 52^0 26’ 30,2”	E 16^0 47’ 50,9”	38
12	Strzeszyńskie Lake – northern waterside	N 52^0 27’ 50,9”	E 16^0 49’ 11,5”	81
13	Strzeszyńskie Lake – southern waterside	N 52^0 27’ 27,0”	E 16^0 49’ 44,9”	64
14	Rusałka Lake – outflow Bogdanka River	N 52^0 25’ 48,7”	E 16^0 52’ 7,3”	64
15	Rusałka Lake – south-eastern waterside	N 52^0 25’ 24,4”	E 16^0 53’ 16,4”	75
16	Malta Lake - outflow Cybina River	N 52^0 24’ 27,9”	E 16^0 57’ 32,3”	63
17	Malta Lake - inflow Cybina River	N 52^0 23’ 59,7”	E 16^0 59’ 14,3”	31
18	Czapnica Lake	N 52^0 20’ 6,6”	E 16^0 54’ 52,5”	73
19	Sołacki Pond	N 52^0 25’ 17,4”	E 16^0 54’ 21,9”	253
20	Stara Baba Pond	N 52^0 22’ 33,4”	E 16^0 51’ 5,5”	209
21	Rozlany Pond	N 52^0 22’ 4,9”	E 16^0 51’ 41,9”	156
22	Młyński Pond	N 52^0 24’ 3,9”	E 17^0 01’ 18,5”	93
23	Borowik Pond	N 52^0 23’ 42,1”	E 17^0 00’ 56,9”	33
24	Olszak Pond	N 52^0 23’ 36,0”	E 17^0 00’ 19,6”	181

tration of mercury was noted in the sediments collected from lakes 58 ± 20 ng/L (range 29-81). Results of total mercury concentrations in bottom sediments are shown in Table 1.

The average total mercury concentration in soils from Poznań was 146 ± 130 ng/g dry weight (range 17-746). Relatively higher average concentrations of mercury were found in the soil samples taken from lawns and meadows 183 ± 184 ng/g d.w. (range 31-749), lower in soil collected from urban forests 151 ± 129 ng/g d.w. (range 17-469) and in the soil samples of no current agricultural use 136 ± 85 ng/g d.w. (range 50-378). The lowest average mercury concentration was determined in the samples of soils of current agricultural use 84 ± 52 ng/g d.w. (range 31-207). Generally, the samples of soils along the busy streets contained higher concentrations of mercury 170 ± 149 (range 31-746) than those collected along quiet streets 118 ± 99 ng/g d.w. (range 17-469). Spatial distribution of mercury in the soil is presented in Fig. 2.

Discussion

The concentration of mercury in bottom sediments is a good indicator of water pollution with this element. On the one hand, bottom sediments are where mercury accumulates as a result of simple sedimentation, and on the other, mercury is released from the sediments, becoming available for further biogeochemical transformations. The rates of the two processes significantly depend on the specific environmental conditions in a given aquatic system [6]. There are considerable differences in the background concentration of mercury between different types of bottom sediments. The natural total concentrations of mercury in the bottom sediments can vary from 10 to 200

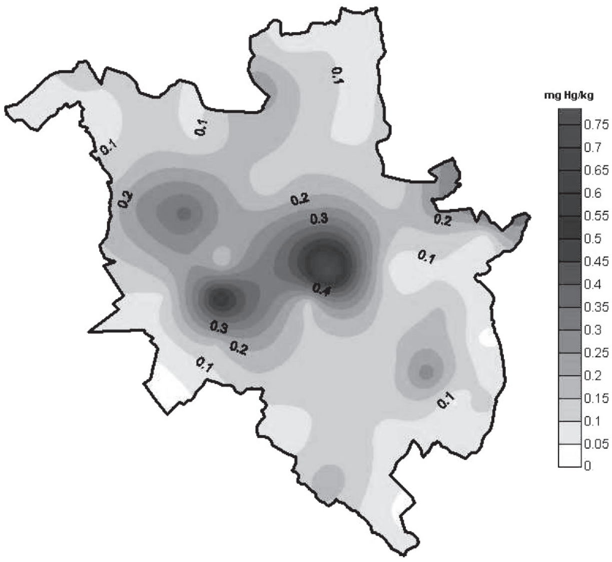

Fig. 2. Spatial distribution of mercury in soil from Poznań city.

ng/g dry mass [3, 7]. In unpolluted river sediments, the background concentration of mercury is about 200 ng/g d.w., because of a much higher proportion of suspended matter observed in rivers [3, 8]. In polluted river sediments, the concentration of total mercury reaches a few tens μg/g. For example, the total mercury concentration was up to 1000 μg/g in bottom sediments from rivers in Almaden, Spain [9].

In this study, the background concentration of mercury was exceeded only in three samples – from Warta River in the sample collected at 500 meters from the wastewater treatment plant (283 ng/g), Sołacki Pond (253 ng/g) and Stara Baba Pond (209 ng/g). Higher mercury concentration in bottom sediments from these sites may be affected not only by mercury input via the atmosphere but also by other sources, i.e. surface runoff. For the Warta River, at a sewage treatment plant may be a possible source of mercury. Higher mercury concentration in water flowing at sewage treatment plant was affected by higher particulate mercury concentration. For example, in the Chattahoochee River total particulate mercury concentration increased from 90 ng/g above Atlanta to 200 ng/g at the sewage treatment plant [10]. In the Warta River, in the water sample collected at the same site at which the sediment sample was collected, the mercury concentration was 36 ng/L [11]. It seems that at the water treatment plant mercury is effectively removed from raw sewage. For example, in the river water from the city of Winnipeg (Canada) mercury concentration ranged from 3 to 31 ng/L and in raw sewage it varied widely, from 2 to 150 ng/L [12].

Relative to the results of this study, much higher mercury concentrations in bottom sediments from the Warta River have been reported by other authors, on average 1550 ng/g (range 180-5750) [13]. The bottom sediment samples from various sites in Poland, collected at the near neighbourhood to or within the urbanized and industrialized areas, showed much higher mercury concentrations: up to 490 ng/g in ponds and streams, up to 690 ng/g in rivers, and up to 1800 ng/g in channels [14]. In the bottom sediment samples from the Odra River collected at the sites under direct influence of such cites as Eisenhuttestadt, Frankfurt/Oder, Słubice and Kostrzyn, mercury was detected up to 2990 ng/g dry weight [15,16]. Generally, the concentrations of mercury in the bottom sediment samples from the water reservoirs in Poznań are higher than in the bottom sediments from sites relatively distant from urbanized and industrialized areas in Poland. The samples of bottom sediments from streams, lakes, rivers and channels in Poland contained mercury in the following concentrations: 12 ng/g, 11-50 ng/g, 21-70 ng/g and 16-44 ng/g, respectively [14].

Soils in urban environments differ in several respects from those in other environments. Urban soils have a highly variable and often unknown history as a result of differences in land use, displacement of dirt related to e.g. excavation works, the addition of new soil materials etc. Until now, systematic quantitative knowledge regarding mercury contents in urban soils in Poznań has been limited. Generally, mercury concentrations in Poznań soils agglomeration obtained in this study do not exceed the legally acceptable value (2000 ng/g) for mercury in soils in urbanized areas in Poland [17]. The highest mercury concentrations (up to 746 ng/g) were noted in the soil sample collected from the centre of Poznań. It seems that the most anthropogenic emissions in the Poznań area are released as products of coal combustion. There are two large municipal coal-fired powerplants and many local coal-fired sources, especially in the city center [18]. The average mercury concentration in soil from Poznań obtained in this study is higher than in the earlier reports specifying the mercury concentration as 95 ng/g d.w. [19]. Relative to our results, the average mercury concentration in the Kraków area was lower (100 ng/g), while it was higher in the Warszawa area (350 ng/g) and in Upper Silesia (200 ng/g) [20]. Although the highest mercury concentration obtained in this study was 746 ng/g, it was lower than in the other urban agglomerations in Poland. The highest concentration of mercury in the urban soils was reported in Warszawa (up to 1080 ng/g), Wrocław (up to 1140 ng/g), Kraków (up to 1380 ng/g) and Upper Silesia (up to 4010 ng/g) [20]. As regards the mean mercury concentration in other parts of Europe, in urban soils it was 590 ± 1160 ng/g in Stockholm (Sweden) [21], 4240 ng/g in Mieres (Spain) [22], 570 ng/g in Aviles (Spain) [23], 480 ng/g in Oslo (Norway) [24] and Aveiro (Portugal) 15-500 ng/g [25].

The soil samples collected from Poznań city centre showed higher mercury concentrations (Fig. 2). Generally, higher mercury concentrations in city centres were noted for other urban agglomerations [21, 24]. For example, the soil samples collected from the city centre of Stockholm showed a higher mercury concentration (on, average 860 ± 960 ng/g) and concentrations of mercury were 50 times higher in the city centre than in rural (ar-

Table 2. Mercury concentration in Poznań soil samples.

Sample number	Sampling sites	Geographical coordinates		Soil [ng/g]
1	Sztormowa Street	N 52^0 28’ 51.1”	E 16^0 46’ 55.5”	113
2	Nad Jeziorem Street	N 52^0 28’ 14.1”	E 16^0 47’ 34.1”	95
3	Słupska Street and Stobnick Street – crossroad	N 52^0 27’ 14.3”	E 16^0 48’ 00.7”	91
4	Wirska Street and Międzychodzka Street -crossroad	N 52^0 26’ 23.5”	E 16^0 48’ 20.9”	131
5	Biskupińska Street	N 52^0 27’ 15.4”	E 16^0 51’ 15.5”	92
6	Koszalińska Street	N 52^0 28’ 18.5”	E 16^0 49’ 52.0”	140
7	Koszalińska Street	N 52^0 28’ 18.5”	E 16^0 48’ 58.1”	113
8	Rusa Residental	N 52^0 23’ 18.3”	E 16^0 58’ 55.5”	115
9	Serbska Street	N 52^0 26’ 09.6”	E 16^0 54’ 06.9”	114
10	Omańkowskia Street	N 52^0 27’ 05.1”	E 16^0 53’ 29.6”	173
11	Meteorytowa Street - wood	N 52^0 28’ 31.0”	E 16^0 53’ 40.3”	254
12	Łopianowa Street	N 52^0 29’ 12.0”	E 16^0 56’ 11.9”	107
13	Błażeja Street	N 52^0 27’ 21.3”	E 16^0 56’ 33.8”	99
14	Bałtycka Street - wood	N 52^0 25’ 44.8”	E 17^0 00’ 37.9”	239
15	Gdyńska Street	N 52^0 26’ 09.6”	E 16^0 58’ 46.7”	103
16	Bożywoja Street	N 52^0 27’ 44.4”	E 16^0 57’ 30.1”	86
17	Nadwarciańska Street	N 52^0 29’ 19.3”	E 16^0 58’ 03.8”	79
18	Piołunowa Street	N 52^0 30’ 10.8”	E 16^0 57’ 21.1”	86
19	Starołęcka Street	N 52^0 20’ 28.8”	E 16^0 55’ 03.0”	82
20	Głuszyna Street	N 52^0 20’ 04.0”	E 16^0 55’ 30.1”	86
21	Babicka Street	N 52^0 19’ 12.3”	E 16^0 56’ 52.8”	185
22	Silniki Street	N 52^0 18’ 41.4”	E 16^0 58’ 36.6”	73
23	Sypniewo Street	N 52^0 18’ 02.3”	E 16^0 59’ 40.9”	53
24	Sypniewo Street	N 52^0 17’ 47.6”	E 16^0 59’ 53.8”	59
25	Rusa Quarter	N 52^0 18’ 36.2”	E 16^0 59’ 50.3”	31
26	Rudzka Street	N 52^0 20’ 36.8”	E 16^0 59’ 16.2”	92
27	Skibowa Sreet	N 52^0 21’ 48.6”	E 17^0 00’ 30.4”	288
28	Gospdarska Street	N 52^0 21’ 09.9”	E 17^0 01’ 36.2”	44
29	Borecka Street	N 52^0 21’ 07.4”	E 17^0 02’ 23.7”	115
30	Boreckia Street	N 52^0 22’ 43.1”	E 17^0 02’ 37.2”	32
31	Darzyborskia Street	N 52^0 22’ 56.2”	E 17^0 02’ 20.3”	76
32	Piwna Street	N 52^0 23’ 17.7”	E 17^0 00’ 55.4”	160
33	Hetmańska Street	N 52^0 23’ 07.1”	E 16^0 54’ 00.9”	321
34	Ściegiennego Street	N 52^0 23’ 27.6”	E 16^0 52’ 24.2”	579
35	Cmentarna Street	N 52^0 23’ 27.6”	E 16^0 50’ 09.6”	91
36	Hiacyntowa Street	N 52^0 22’ 46.3”	E 16^0 48’ 24.5”	84
37	Wołczyńskiej Street	N 52^0 22’ 13.9”	E 16^0 50’ 28.3”	71
38	Ostatnia Street	N 52^0 22’ 50.5”	E 16^0 52’ 11.2”	146

Table 2 continues on net page...

39	Poligonowa Street	N 52^0 29' 44.5"	E 16^0 56' 13.3"	91
40	Glinienko Street	N 52^0 29' 33.0"	E 16^0 54' 40.9"	76
41	Strzeszyńska Street	N 52^0 28' 18.0"	E 16^0 51' 15.7"	75
42	Bojerowa Street	N 52^0 28' 17.5"	E 16^0 45' 43.4"	88
43	Pelplińska Street	N 52^0 25' 38.8"	E 16^0 49' 22.4"	278
44	5 Stycznia Street	N 52^0 25' 26.4"	E 16^0 51' 00.0"	378
45	Bułgarska Street	N 52^0 24' 37.2"	E 16^0 52' 05.4"	207
46	Złotowska Street	N 52^0 24' 25.1"	E 16^0 49' 07.7"	175
47	Złotowska Street - wood	N 52^0 24' 03.3"	E 16^0 48' 29.8"	131
48	Torowa Street	N 52^0 22' 00.9"	E 16^0 58' 57.2"	119
49	Okopowa Street	N 52^0 22' 02.0"	E 16^0 56' 49.8"	123
50	Grobla Street	N 52^0 24' 11.9"	E 16^0 56' 34.1"	746
51	Brandtstaettera Street	N 52^0 25' 33.2"	E 16^0 56' 04.1"	269
52	Droga Dębińska Street	N 52^0 23' 24.8"	E 16^0 55' 50.9"	136
53	Czekalskie Street	N 52^0 24' 19.0"	E 16^0 59' 08.6"	50
54	Ziemowita Street	N 52^0 24' 20.4"	E 17^0 00' 29.0"	97
55	Podleśna Street	N 52^0 25' 03.4"	E 17^0 02' 35.9"	67
56	Piaskowa Street	N 52^0 20' 49.3"	E 16^0 49' 39.4"	17
57	Marceliński Street	N 52^0 24' 18.5"	E 16^0 53' 28.1"	157
58	Jabłonkowska Street	N 52^0 21' 47.0"	E 16^0 53' 54.2"	158
59	Uradzka Street	N 52^0 21' 08.5"	E 16^0 51' 21.3"	48
60	Głogowska Street	N 52^0 21' 19.5"	E 16^0 50' 14.7"	31
61	Darniowa Street	N 52^0 25' 49.4"	E 17^0 03' 07.1"	469

able) soils in the Stockholm region [21]. The median value of mercury in the soil from the centre of Oslo was 480 ng/g - 8 times higher than in the rest of the city [24]. Although the soil from Stockholm region was highly contaminated with mercury, the mercury concentration in leachate was 50 times lower than the maximum concentration detected in groundwater, indicating the existence of other probable sources of contamination with mercury [26]. The average mercury concentration in soil from lawns and meadows in Poznań 183 ± 184 ng/g (range 31-749) was higher than the average mercury concentration in soils from parks and lawns in Poland [19]. In Poland, the concentration of mercury in urban soils from parks and lawns was 160 ng/g (4.7-930) [19]. In Poland, different samples of barren soil contained 430 ng Hg/g (9.94800) [19]. For example, in Stockholm the average mercury concentration was 120 ± 150 ng/g in undisturbed soils, 460 ± 610 ng/g in the soil samples from parks and 140 ± 160 in the soil collected along the roadside [21]. However, in the soil samples from Aveiro City (Portugal) no differences in mercury concentration could be traced in correlation to different land use (ornamental gardens, parks, roadsides, playground and riverbank) [25]. The average concentration of mercury in the soil samples from farmlands under direct effect of anthropopressure in Poland was 130 ng/g dry mass (range 2.3-450) [19]. Soil samples from typical villages near industrial centres in Poland showed much higher mercury concentrations [27]. In these areas the mercury concentrations were between 150 and 3700 ng/g [27]. The average mercury concentration in different soil samples from agricultural areas in Poland was 61 ng/g (range 7.3-250) [19]. The mean mercury concentration reported for European agricultural soils is very close to 100 ng/g d.w., the results vary in the range 70-120 ng/g [28]. European forest soils contain much less mercury than agricultural soils, usually 50-150 ng/g [28]. In Poland, the forest soils contained, on average, 95 ng Hg/g (range 38-250) [19].

Conclusions

The results of the study show that the distribution of mercury in the samples of bottom sediments collected from various sites in Poznań are relatively uniform. In contrast to the above, the concentration of mercury in soil samples varies in a relatively large range. The soil samples from the city centre contained higher mercury concentration. Generally, mercury concentrations in samples of bottom sediments and soils from Poznań agglomeration obtained in this study did not exceed acceptable legally admissible values for mercury in Poland. It seems that the most anthropogenic emissions in the Poznań area are released as products of coal combustion from municipal large power plants and from local sources in the city centre. Although at present the state of the Poznań city pollution with mercury is satisfactory, taking into regard the extreme toxicity of some of its species and the fact that the buffer properties of the Poznań agglomeration are unknown, the monitoring of this metal in the Poznań ecosystem should be continued.

Acknowledgement

This work was supported by the Polish Committee for Scientific Research (KBN) under grant No 3T09D07926.

References

1. UNEP - United Nations Environment Programme. Global mercury assessment. United Nations Environment Programme Chemicals. Geneva, Switzerland, **2002**.
2. MNISZEK W. Emission of mercury to the atmosphere from industrial sources in Poland. Environ. Monit. Assess. **41**, 291, **1996**.
3. KABATA-PENDIAS A., PENDIAS H. Bigeochemisty of trace elements. Wydawnictwo Naukowe PWN, Warszawa, 400 pp. **1999** (in Polish).
4. STERNBECK J., ÖSTLUND P. Metals in sediments from the Stockholm region: Geographical pollution patterns and time trends. Water Air Soil Pollut.: Focus **1**, 151, **2001**.
5. JOHANNESSON L.T., STEVENS R.L. ERIKSSON K. The influence of an urban stream on sediment geochemistry in Göteborg Harbour, Sweden Environ. Geol. **43**, 434, **2003**.
6. BOSZKE L., KOWALSKI A., GŁOSIŃSKA G., SZAREK R., SIEPAK J. Selected factors affecting the speciation of mercury in the bottom sediments: an overview Polish J. Environ. Stud. **12**, 5, **2003**.
7. FERGUSSON J.E. The heavy elements - chemistry, environmental impact and health effects, Pergamon Press, Oxford 514 pp., **1990**.
8. MASON R.P., LAWSON N.M., SULLIVAN K.A. Atmospheric deposition to the Chesapeake Bay watershed - regional and local sources. Atmos. Environ. **21**, 3531, **1997**.
9. RODRIGUEZ MARTIN-DOIMEADIOS R.C., WASSERMAN J.C., GARCIA BERMEJO L.F., AMOUROUX D., BERZAS NEVADO J.J., DONARD O.F.X. Chemical availability of mercury in stream sediments from the Almaden area, Spain. J. Environ. Monit. **2**, 360, **2000**.
10. NEUMAN K., LYONS W.B., ROSI E.J., MEYER J.L. Hg and other trace metals in water, suspended matter, and biota in the Chattahoochee River. In: Nriagu J.O. (ed.) 11th Annual International Conference on Heavy Metals in the Environment, University of Michigan, School of Public Health, Ann Arbor, MI, **2000**.
11. BOSZKE L., KOWALSKI A., SIEPAK J. Distribution of mercury in surface water and soil from Poznań City (Wielkopolska District, Poland). In: Horvat M., Ogric N., Faganelli J. Kotnik J. (eds.). Mercury as a Global Pollutant. Part 2. Biogeochemistry. Materials Geoenvironment **51**, pp. 861-863. **2004**.
12. BODALY R.A., RUDD J.W.M., FLETT R.J. Effect of urban sewage treatment on total and methyl mercury concentrations in effluent. Biogeochemistry **40**, 279, **1998**.
13. IOP - International Odra Project. Results of International Odra Project, A.-K. Meyer (ed.), Hamburg, 127 pp., **2002**.
14. FALANDYSZ J., KAWANO M., DANISIEWICZ D., STEPNOWSKI P., BOSZKE L. GOŁĘBIOWSKI M. Total mercury in freshwater and nearshore sediment from various sites in Poland. Bromat. Chem. Toksykol. **29**, 183, **1996** (in Polish with English abstract).
15. BOSZKE L., SOBCZYŃSKI T., GŁOSIŃSKA G., KOWALSKI A., SIEPAK J. Distribution of mercury and other heavy metals in bottom sediments of the middle Odra river Polish J. Environ. Stud. **13**, 495, **2004**.
16. BOSZKE L., KOWALSKI A., SIEPAK J. Grain size partitioning of mercury in sediments of the Middle Odra river (Germany/Poland) Water Air Soil Pollut. **159**, 125, **2004**.
17. POLISH ENVIRONMENTAL LAW. The Directive of the Minister of Natural Environment of Sept. 9th, 2002, on the soil quality standards, published in Dz. U. Nr 165, entry 1359, **2002** (in Polish).
18. WIOŚ – Wojewódzki Inspektorat Ochrony Środowiska (The Voivodship Inspectorate of the Natural Environment Protection). The level of pollution of the atmospheric air in Poznan. WIOŚ, Biblioteka Monitoringu Środowiska, Poznań, **2000** (in Polish).
19. FALANDYSZ J., KAWANO M., DANISIEWICZ D., CHWIR A., BOSZKE L., GOŁĘBIOWSKI M., BORYŁO A. Investigation on the occurrence of mercury in soils in Poland. Bromat. Chem. Toksykol. **29**, 177, **1996** (in Polish with English abstract).
20. LIS J., PASIECZNA A. Geochemical Atlas of Poland. Państwowy Instytut Geologiczny. Warszawa, **1995** (in Polish).
21. LINDE M., BENGTSSON H., ÖBORN I. Concentration and pools of heavy metals in urban soils in Stockholm, Sweden. Water Air Soil Pollut.: Focus **1**, 83, **2001**.
22. LOREDO J., ORDÓÑEZ A., CHARLESWORTH S., DE MIGUEL E. Influence of industry on the geochemical urban environment of Mieres (Spain) and associated health risk. Environ. Gechem. Health **25**, 307, **2003**.
23. ORDONEZ A., LOREDO J., DE MIGUEL E., CHARLESWORTH S. Distribution of heavy metals in the street dust and soils of an industrial city in Northern Spain. Arch. Environ. Contam. Toxicol. **44**, 160, **2003**.

24. TIJHUIS L., BRATTLI B., SAETHER O.M. A geochemical survey of topsoil in the city of Oslo, Norway. Environ. Geochem. Health **24**, 67, **2002**.
25. RODRIGUES S., PEREIRA M.E., SARABANDO L., LOPES L., CACHADA A., DUARTE, A. Spatial Distribution of total Hg in urban soil from an Atlantic coastal city (Aveiro, Portugal). In: Horvat M., Ogric N., Faganelli J., Kotnik J. (eds) Mercury as a Global Pollutant. Part 2. Biogeochemistry, Materials Geoenvironment **51**, 1340, **2004**.
26. ÖBORN I., LINDE, M. Solubility and potential mobility of heavy metals in two contaminated urban soils from Stockholm, Sweden. Water Air Soil Pollut.: Focus **1**, 255, **2001**.
27. UMIŃSKA R. Evaluation of mercury level in waters, bottom sediments and soils in selected rural areas. J. Hyg. Epidemiol. Microbiol. Immunol. (Prague) **31**, 9, **1987**.
28. TYLER G. (ed.) Mercury in Soil - distribution, speciation and biological effect, Nordic Council of Ministers, Copenhagen **1992**.