E3S Web of Conferences **22**, 00066 (2017) DOI: 10.1051/e3sconf/20172200066
ASEE17

Pollution of soils (Pb, Cd, Cr, Zn, Cu, Ni) along the ring road of Wrocław (Poland)

Anna Hołtra[1,*], and *Dorota* Zamorska-Wojdyła[1]

[1]Wrocław University of Science and Technology, Faculty of Environmental Engineering, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Abstract. The concentrations of metallic pollution in soils and plants along the ring road of Wrocław, Poland, have been determined. Environmental samples were collected from the surface layer of the profile within 2–3 m from the edge of the road. The analysis of metals (Pb, Cd, Cr, Zn, Cu and Ni) has been carried out through FAAS and GFAAS methods. The mineralizates of soils and plants were prepared in HNO_3, 65% supra pure, using the Microwave Digestion System. The pH and conductivity of the soil solutions were measured to evaluate their active and exchangeable acidity and the salinity of the soils. The index of the enrichment of soils in metals (*Wn*) and the bioaccumulation coefficient (*WB*) have been determined. Also, histograms of the frequency of the occurrence of metals in the environmental samples and the Pearson's correlation coefficients were presented. The results of metal concentrations in soils were compared to the geochemical background in uncontaminated soils of Poland. The assessment of the results in the soils was also made relative to the standard, according to the Polish Ministry of Environment Regulation from September 1st, 2016. During the assessment of the bioaccumulation coefficients of metals in plants a reference was made to the content of undesirable substances in feed in agreement with the Polish Ministry of Agriculture and Rural Development Regulation from January 23rd, 2007.

1 Introduction

Wrocław is one of the most developed cities in Poland in terms of transport infrastructure. Pollution along the roads is caused by exhaust emissions from motor vehicles, dust emissions, leakage of fluids from installations. Another environmental threat is the surface runoff from roads and contaminated sites, e.g. due to the road maintenance in winter. Degradation of soils in Wrocław is caused by the increase of heavy metals content and fluorine, petroleum substances, polycyclic aromatic hydrocarbons, as well as the salinity of the soil solution. The content of heavy metals, polycyclic aromatic hydrocarbons and petroleum substances in soils depends primarily on traffic, distance from the road, landform (the road runoff) and the chemical composition of fuels and lubricants, and supplies used in the motor vehicles (the abrasion of tires and brake pads). Organization of traffic – frequent

* Corresponding author: anna.holtra@pwr.edu.pl

braking, accelerating and impediments in traffic are affected to the urban soil pollution. According to data presented in Athanasopoulou & Kollaros [1], the emission of metals from engine oil into roadside soils was as follows: Cd (83%), Cr (33%), Zn (28%) and Ni (25%). The emission from the abrasion of pavement was at the level of 12% of Cr and 11% of Ni, while tyre wear caused the emission of Se (58%), Zn (33%) and Ni (15%). The amount of the released zinc is 2.4–3.2 μg/km with the car tires consumption of about 0.2 mg/km [2]. Therefore, this explains the presence of zinc oxide in the drain water of ca. 1.5–2% of the tire weight. The most important source of metal emission is dust from the brake wear. Grigoratos & Martini [3] cited the concentrations of the following heavy metals (mg/kg): Cu (70–210 000), Pb (4–1 290), As (< 2–110 in PM_{10}), Ni (80–730), Zn (120–27 300), Cr (135–12 000).

Intensive traffic is conducive to the accumulation of trace metals in the upper soil layers [1, 4–6]. Metallic pollutions depending on the physico-chemical properties of soil, the presence of humus and colloids of soil are affected by the biocenosis in soil. Plants in a contaminated environment can develop adaptive or defensive mechanisms. For that reason, the plants' metal content increases proportionately to their growing period in the contaminated soil. But plants often lose their properties of selectively accumulating the contaminants in tissues. Consequently, the development of plants is disturbed and the species' diversity declines. Contaminations of dust and gas contribute to the degradation of soils and vegetation in the zone of up to 500 m from the road edge [1, 4, 7, 8].

2 Materials and methods

Environmental samples were collected along the downtown ring road in Wrocław, encircling the central districts of the city at a distance of 3 to 5.5 km from the city's main square. Places of sampling are located at the busiest road junctions, starting with the crossing of the Armii Krajowej Street with the following streets: Krakowska Street (sample no. 1), Bardzka Street (no. 2), Borowska Street (no. 3) and Ślężna Street (no. 4). Then, the ring road of Wrocław runs west to the crossing of Wiśniowa Avenue with Powstańców Śląskich Street (no. 5). Another point of sampling is at the crossroads of Hallera Street and Grabiszyńska Street (no. 6). Two locations were on the crossings of Klecińska Street with Szwajcarska Street (no. 7) and Klecińska Street with Strzegomska Street (no. 8). Three samples were collected at the crossings of Na Ostatnim Groszu Street with: Bystrzycka Street (no. 9), Legnicka Street (no. 10) and Popowicka Street (no. 11). In the northern part of the ring road of Wrocław the samples were taken from the crossing of the Millennium Bridge Street and Osobowicka Street (no. 12), also along the Nowak-Jeziorański Street at the crossings with: Obornicka Street (no. 13) and Żmigrodzka Street (no. 14). Samples of plants – grasses and dandelion (*Taraxacum officinale* F.H. Wigg.) – were collected from the same locations as soils samples.

Soil and plant samples were collected approximately 3 m from the edge of the downtown ring road of Wrocław. A total of 84 environmental samples were collected in Autumn (September) 2016. Soil samples were taken from the surface layer to a depth of 25 cm. Plant samples were harvested with root system. Each research area (location) consisted of 6 measurement positions. Samples were collected within the distance of ca. 2 meters from each other. All soil samples were sieved after drying. The process of microwave mineralization was prepared according to the PN-ISO 11465:1999. Into a sample of 0.2 g of dry matter (DM) 8 ml of nitric acid 65%, Supra pure, was added. The mineralization process was made with the use of Start D device (Milestone). Additionally, measurements of pH in water and 1 M KCl and the electrical conductivity (EC) in the soil solutions were made according to the PN-ISO 10390:1997. The soil solutions were prepared in a stoichiometric soil-to-solution ratio of 1:2.5 (m:v). The zinc, copper, nickel concentrations have been determined through the Flame Atomic Absorption Spectroscopy (FAAS) method. The lead, chromium and cadmium concentrations have been determined through the Graphite Furnace Atomic Absorption Spectroscopy (GFAAS) method. In the spectroscopy analysis iCE 3500 Solaar Thermo device (Thermo Scientific) [PN-ISO 11047:2001] was used. The arithmetic mean and the standard deviation were calculated with the six individual samples collected in measurement location.

Statistical calculations and visualisations have been carried out using the Microsoft Excel software. The pollution index of soil was calculated as the ratio of the average content of chemical element in the soil from one location to the geochemical background. The bioaccumulation coefficient of metal in a plant was calculated as the ratio of the average content of chemical element in a plant to the average content of metal in the soil from one location.

Chemical analyses have been carried out in the certified Laboratory of Toxycology and Environmental Research in the Faculty of Environmental Engineering at the Wrocław University of Science and Technology.

3 Results and discussion

The pH and salinity of soil solutions affect the behavior of metals in the soil environment. The values of pH show mostly alkaline character of soils (pH above 7.2 in 1 M KCl and 7.4 in H_2O). Lee et al. [9] confirmed a higher pH of soil solutions nearest to the road. Three samples are neutral. Only sample no. 12 has a pH of 5.26 in 1 M KCl and 6.25 in H_2O, showing a slightly acidic character of the soil. Heavy metals in soils with acidic character could be a risk to the plants [10]. All soil samples are of poor salinity. Generally, the soil solutions have conductivity of less than 25 mS/m. The highest value of conductivity (25.44 mS/m) was measured in sample no. 3.

Parameters characterizing the content of trace elements in the surface layer of soil and plant samples collected along a downtown ring road in Wrocław are presented in Table 1.

The biggest differences in the content of heavy metals in soils between locations were identified for zinc and lead, coefficient of variation (V) being 81% for Zn and 69% for Pb. The content of other metals in soils also varied, as evidenced by the 50% higher values of coefficients of variation for copper, chromium and cadmium. The lowest value of coefficient of variation was noted for nickel (44%).The maximum concentrations of Zn, Pb, Cr were observed in soil sample no. 11. In this location the average zinc content of 502.20 mg/kg DM exceeds the limit value for soils of group I (500 mg Zn/kg DM), according to the Polish Ministry of Environment Regulation from September 1st, 2016, regarding the manner of conducting the assessment of the contamination of ground [11]. High content of several metals was also observed in locations no. 7, 5 and 1. In the soil samples there were no exceedances of the content of remaining trace metals. Lower concentrations of cadmium are as compared to other metals correspond with the results of other researchers [4].

Table 1. The content of metals in soils and plants present along the downtown ring road in Wrocław.

Parameter	Soils					
	Zn	**Cu**	**Cr**	**Pb**	**Ni**	**Cd**
	[mg/kg of DM]					
Minimum	56.25(no.14)	11.27(no.14)	0.91(no.2)	10.77 (no.14)	5.33(no.13)	0.10(no.2)
Maximum	507.01(no.11)	51.81(no.12)	19.04(no.11)	104.12 (no.11)	26.31 (no.8)	0.59(no.1)
Arithmetic mean, x	146.08	27.25	9.49	32.82	12.76	0.28
Standard deviation, s	118.10	13.51	5.46	22.81	5.61	0.16
Mediana	123.00	22.94	9.27	31.40	11.77	0.20
V [%], *V* = (s/x)·100	81	50	58	69	44	57
	Grasses					
Minimum	36.18(no.8)	11.24(no.8)	1.86(no.10)	0.94(no.12)	0.82(no.10)	0.02(no.8)
Maximum	162.10(no.9)	30.23(no.9)	7.49(no.3)	13.59(no.7)	11.69(no.3)	0.41(no.1)
Arithmetic mean, x	97.36	16.45	4.42	5.94	5.48	0.13
Standard deviation, s	34.97	6.00	1.54	3.36	2.74	0.09
Mediana	95.34	13.04	4.16	5.33	4.78	0.12
V [%], *V* = (s/x)·100	36	36	35	56	50	67
	Taraxacum officinale					
Minimum	26.61(no.6)	2.01(no.1)	0.41(no.9)	0.25(no.9)	0.58(no.12)	0.01(no.9)
Maximum	74.15(no.12)	19.47(no.12)	4.08(no.13)	1.54(no.13)	4.63(no.8)	0.23(no.2)
Arithmetic mean, x	51.28	13.14	1.91	0.67	2.39	0.09
Standard deviation, s	16.16	3.72	1.02	0.33	1.24	0.06
Mediana	49.64	12.97	1.92	0.63	2.01	0.09
V [%], *V* = (s/x)·100	32	28	53	50	52	64

Analysis of the issue in Poland shows the highest content of heavy metals in soils in the Upper Silesia area (1st Maja Street in Ruda Śląska). Metal concentration ranges were as follows: 46.9–3404.2 mg Zn/kg, 9.0–378.4 mg Cu/kg, 16.5–2257.0 mg Pb/kg, 0.3–28.2 mg Cd/kg [12]. Mean content of trace elements in upper surface of soils along the heavily trafficked exit road in Warsaw amounted to 137.0 mg Zn/kg, 16.7 mg Cu/kg, 41.5 mg Pb/kg, 0.67 mg Cd/kg, 19.4 mg Cr/kg, 12.6 mg Ni/kg [13]. In soils along the South-North highway which goes through the heart of the city of Łódź concentrations of 17.8 mg Cu/kg, 50.6 mg Pb/kg, 0.42 mg Cd/kg, 25.5 mg Cr/kg, 9.92 mg Ni/kg were observed [6]. Contents of Zn and Cu along communication routes in the city centre of Wrocław amounted to 156.6 and 46.9 mg/kg respectively [5]. Mean amounts of metals in urban soil from the roadside in Torino (Italy) were as follows: 183 mg Zn/kg, 90 mg Cu/kg, 149 mg Pb/kg, 191 mg Cr/kg, 209 mg Ni/kg [14]. Soils along the highway route E 75 from Belgrade (Serbia) to Preševo (Macedonia) were contaminated with 25.3 mg Cu/kg, 40.9 mg Pb/kg, 47.8 mg Ni/kg [7]. On other continents, the ranges of metal concentrations along the main highways of Dubai, Toronto (no. 400, 401, 404), Istanbul (E-5) were, respectively: for Zn (1.23–46.6, 39.3–1367.0, 81.3–366.8, 56.8–290.9, 190.9–1852.0 mg/kg), Cu (0.94–5.81, 53.9–286.1, 113.6–392.1, 76.2–230.3, 47.3–1358.5 mg/kg), Pb (6.9–113.3, 118.3–205.0, 32.5–378.7, 124.7–212.2, 61.4–555.4 mg/kg), Cd (0.39–0.93, 0.47–0.50, 0.46–0.95, 0.48–0.56, 0.80–6.70 mg/kg), Ni (3.3–73.8, 34.0–80.0, 32.0–327.0, 16.0–62.0, 10.4–65.7 mg/kg) [1]. In roadside soils from D100 highway in Turkey the average content of lead was 120.1 mg Pb/kg [15].

Metal concentrations in grasses and dandelion (*Taraxacum officinale*) were much lower than in soils (table 1). Locations of grass samples with the highest concentrations of metals do not coincide with the locations of dandelion samples with the highest concentrations of metals. High content of several metals was observed in locations no. 9, 7, 6 for grasses and sampling sites no. 12, 13, 8 for dandelion. The content of metals in plants is characterized with lower volatility: Cd (67% for grasses/64% for dandelion), Pb (56%/50%) and Ni (50%/52%), and for Cr of 53% in dandelion (*Taraxacum officinale*).

Arithmetic means of heavy metal contents in *Taraxacum officinale* from Warsaw (Poland) were as follows: 75.6 mg Zn/kg, 14.3 mg Cu/kg, 3.1 mg Pb/kg, 0.41 Cd/kg, 4.7 mg Cr/kg and 2.2 mg Ni/kg [13]. Leaves and roots of dandelion in Ruda Śląska (Poland) showed the following ranges of chemical elements: 92.3–625.9 mg Zn/kg (leaf), 49.5–802.6 mg Zn/kg (root), 3.3–626.0 mg Cu/kg (leaf), 4.0–52.4 mg Cu/kg (root), 2.14–165.0 mg Pb/kg (leaf), 0.44–699.7 mg Pb/kg (root), 0.68–4.4 mg Cd/kg (leaf), 0.27–9.7 mg Cd/kg (root) [12]. Content of Zn and Cu in grasses along communications roads in the city centre of Wrocław (Poland) was 101.5 mg Zn/kg and 16.3 mg Cu/kg [5]. In three species of grasses (*Dactylis glomerata* L., *Arrhenatherum elatius*, *Alopecurus pratensis* L.) growing along S2 expressway areas near Siedlce (Poland) the following content of metals and coefficient of variation (*V*) were found: for lead 2.7 mg/kg (25%)/2.5 mg/kg (28%)/3.3 mg/kg (33%) and for cadmium 0.23 mg/kg (45%)/0.19 mg/kg (34%)/0.18 mg/kg (33%) [16]. Traffic pollutions of Zn, Cu, Pb, Cd, Cr and Ni in grass (*Lolium perenne* L.) from city centre areas exposed to heavy vehicular traffic in Karatay (Turkey) amounted to: 41.9–58.2 mg Zn/kg, 6.1–9.4 mg Cu/kg, 1.9–3.4 mg Pb/kg, 0.14–0.16 mg Cd/kg, 14.5–25.7 mg Cr/kg, 6.6–13.8 mg Ni/kg [17].

In addition, an evaluation of the degree of the contamination of soil with heavy metals was presented in relation to the geochemical background in Poland. Values of trace metals in geochemical background are as follows: 50 mg Zn/kg DM, 0.3 mg Cd/kg DM, 30 mg Pb/kg DM, 15 mg Cu/kg DM, 10 mg Ni/kg DM, 20 mg Cr/kg DM [18]. For every metal at each location the pollution index of soil was calculated [4]. The average value of all pollution indexes for the metal is the following: zinc (*Wn* 2.92), copper (1.82), nickel (1.28), lead (1.09). Values of *Wn* above unity indicate medium level of the contamination of soils with heavy metals (fig. 1a). *Wn* indexes for chromium and cadmium are 0.47 and 0.95, respectively. It means a lack of soils enrichment in relation to the geochemical background. The average values of all pollution indexes (*Wn*) of soils by trace elements were arranged into the following order: Zn > Cu > Ni > Pb > Cd > Cr. The median of *Wn* for soils enrichment with: zinc is 2.32, copper is 4,57, lead is 1.75, nickel is 1.05, cadmium is 0.68 and chromium is 0.24.

Pollution indexes (arithmetic mean) of top soil layer along expressway E30 in Warsaw (Poland) presented in descending order are as follows: Pb (3.91) > Zn (3.52) > Cd (3.25) > Ni (2.59) > Cu (1.90) [4]. Wn indexes for Zn and Cu in urban soils of the city centre of Wrocław (Poland) amounted to 4.80 and 8.12, respectively [5]. In roadside soils of Torino, (Italy) the Wn indexes formed the following order: Pb (7.5) > Cu (3.3) > Zn (2.9) > Ni (2.8) > Cr (2.0) [14].

DOI: 10.1051/e3sconf/20172200066

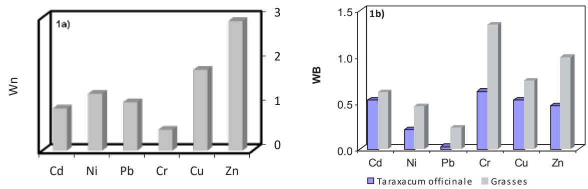

Fig. 1. *Wn* indexes for soils and *WB* coefficients for grasses and *Taraxacum officinale.*

The bioaccumulation coefficients were calculated to assess the degree and direction of mobility of heavy metals. They reflect the ability of the plant to accumulate metals from the soil and inform about their movement from the soil solution to the aerial parts of the plant. The average value of all bioaccumulation coefficients (*WB*) was higher in grasses than in dandelion (*Taraxacum officinale*) for all trace elements (Fig. 1b). *WB* coefficients of grasses formed the following order: Cr > Zn > Cu > Cd > Ni > Pb. The avarage values of *WB* in *Taraxacum officinale* can be presented in the following order: Cr > Cu > Cd > Zn > Ni > Pb. During the evaluation of metal bioaccumulation in plants, the medium level accumulation of zinc, copper, nickel, lead and cadmium (*WB* 0.1–1) was shown [18]. The accumulation of chromium in grasses amounting to *WB* 1.34 indicates the ease accumulates in plants. The medians of *WB* for grasses and *Taraxacum officinale,* respectively, are as follows: Zn 0.69 / 0.45; Cu 0.71 / 0.50; Pb 0.23 / 0.02; Ni 0.48 / 0.17; Cd 0.34/0.22 and Cr 0.40/0.32.

Mean bioaccumulation coefficients for Zn and Cu in grasses collected from the roadsides of the city centre of Wrocław (Poland) were 0.71 and 0.42, respectively [5]. Mean WB indexes of Zn, Cu, Pb, and Cd content in dandelion in relation to soil in Upper Silesia were below of unit, due to very strong contamination of soils in Ruda Śląska area. WB indexes for relationship of dandelion root/soil were as follows: Cd (0.57) > Cu (0.37)>Pb (0.22)>Zn (0.19), and for relationship of dandelion leaves/soil could bepresented in the following order: Cu (0.94) > Cd (0.33) > Zn (0.22) > Pb (0.07) [12]. Similarly, low values of WB for *Taraxacum officinale* samples from Warsaw were observed, in descending order: Cu (0.86) > Cd (0,61) > Zn (0.55) > Cr (0.24) > Ni (0.17) > Pb (0.07) [13].

The concentrations of heavy metals in grasses and dandelion (*Taraxacum officinale*) were compared to the permissible concentrations of undesirable substances in feeds according to the Polish Ministry of Agriculture and Rural Development Regulation from January 23rd, 2007 [19]. In grasses exceedances of the content of the following metals were recorded: copper in 99% of samples (acceptable limit is 10 mg Cu/kg DM), zinc in 91% of samples (100 mg Zn/kg DM) and lead in 12% of samples (10 mg Pb/kg DM). In *Taraxacum officinale* the only exceedance was that of copper content which was observed in 58% of samples. Due to the exceeding of the limit of the concentrations of heavy metals in plants, the biomass is not suitable for the animal feeds. It can be used for industrial purposes.

Linear correlation of the content of heavy metals in the soil may be the result of geochemical relationship of chemical elements in the parent rock or may inform about the sources of pollutions of the soil. Pearson's correlation coefficients (*r*) for relationships of metals are the following: Zn-Pb of 0.94 (significantly correlated – fig. 2), Pb-Cu and Zn-Cu of 0.66 and 0.60 (moderately correlated), respectively. It may point to the same source of metals' origin in soils (pollution from motor transport). Positive correlation coefficients of Pb-Cr (0.36), Zn-Cr (0.34) and Cd-Ni (0.22) show weak relationship between heavy metals in the soil.

The Pearson's correlation coefficients between different metals in soil, within the shortest distance (0.5 m) from the E30 expressway (Warsaw, Poland) shown significantly or moderately correlation of pairs of Ni-Cu (0.90), Zn-Cd (0.73), Zn-Cu (0.66), Cu-Cd (0.65) and Pb-Cu (0.57) [4]. The strongest positive correlations in Łódź (Poland) were identified for Cr-Cu (0.95) and between Cd and other trace element (Cu, Pb, Cr, Ni) averaging 0.80–0.83 [6]. Pearson's correlation coefficients for urban soils in the city centre of Wrocław (Poland) amounts to 0.51 for the pair Zn-Cu [5]. In the case of urban soils taken from Torino (Italy) positive and significant correlation was observed for Zn-Cu (0.89), Zn-Pb (0.71) and Ni-Cr (0.70). The following pairs of metals were moderately correlated: Pb-Cu (0.64), Cu-Cr (0.54) and Zn-Cr (0.51) [14].

The Pearson's correlation coefficients for relationships of Zn-Cu (r 0.81 – fig. 2) and Pb-Cu (r 0.56) in grasses are as high as in soils. Also noticed in grasses was a strong correlation of Pb-Cr (r 0,82 – fig. 2) and moderate correlation in pairs of Zn-Ni (r 0,52) and Cu-Cd (r 0,42). Weak relationships of metal pairs were observed for Pb-Zn (r 0,31), Zn-Cd and Cu-Ni (r 0,29), Ni-Cr (r 0,37), Cd-Ni (r 0,32). In dandelion (*Taraxacum officinale*) a very strong linear relationship was noted for Pb-Cr (r 0.95 –fig. 2), similarly as in grasses. Positive values of r coefficients were also observed in the following pairs of metals: Pb-Cd (0.46), Zn-Cu (0.40), Cd-Cr (0.36), Ni-Cr (0.33), Pb-Ni (0.27), Zn-Ni (0.26). For other pairs of metals in soils and plants no linear correlation was observed.

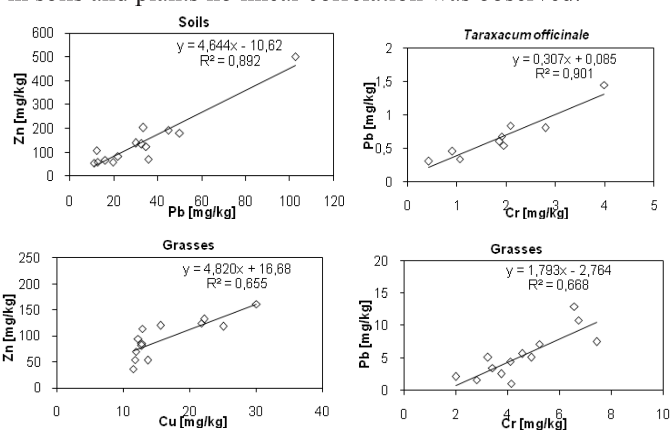

Fig. 2. Significantly correlated relationships of metal concentrations in soils and plants.

Statistically significant relationship between pH and the content of heavy metals in soils was not established. In case of copper the reported Pearson's correlation coefficient was only – 0.50 (moderate dependence). Radziemska et al. [4] reported a 0.46 linear correlation between pH and Ni content in soil. Additionally, Cd, Pb and Cu were very weakly correlated with pH.

Weak linear correlations were observed in relationships between metal content in soil and metal content in grass. The highest values of Pearson's coefficient were observed for copper (r 0.47) and zinc (r 0.38). No linear relationship between Cr (in grasses)/Cr (in soil) was found. Correlation between urban soil and grass from the city centre of Wrocław (Poland) showed higher value of r factor for copper: 0.63 (r 0.26 for Zn) [5]. Metals in samples from Karatay (Turkey) were moderately correlated: Cu (0.70), Ni (0.69) and Pb (0.44). Metals of Zn, Cr and Cd in soil and grass (*Lolium perenne* L.) were also weakly correlated [17].

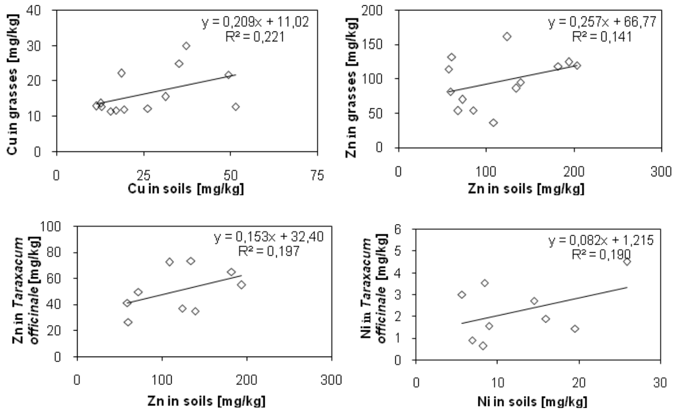

Fig. 3. Linear relationships of metal concentrations in soils and plants.

Relationship between metal content in soil and dandelion (*Taraxacum officinale*) is weakly correlated in the case of zinc and nickel (*r* 0.44). For other trace elements no linear relationships in *Taraxacum officinale* was observed (fig. 3). For samples from Warsaw (Poland) strong correlations were observed for Zn, Pb and Cd in soil/dandelion (*Taraxacum officinale*): 0.73, 0.70 and 0.57, respectively [13]. Pearson's correlation coefficients in urban soils / root of *Taraxacum officinale* for Upper Silesia (Poland) were as follows: Cu (0.85), Zn (0.60), Cd (0.49), for Pb no coefficient values were reported. In the case of dandelion leaves the coefficients were as follows: Cu (0.88), Cd (0.77), Pb (0.51), for Zn no coefficient values were reported [12].

Comparison of the frequency histograms for the occurrence of metals in soils and plants reveals deviations from the bell curve caused by substantial diversification of the content of metals in the population of investigated samples. It is due to different locations of sampling along the downtown ring road of Wrocław and also due to the diversified intensity of motor traffic. Kurtosis is mostly below zero in soils and plant samples (a Flatten-Gaussian distribution). Histograms are right-skewed, therefore most results are lower than the average value, and the arithmetic mean is higher than median. Distribution close to Gaussian curve was observed for Ni and Cr in all environmental matrices and also in the case of Zn in the grasses.

4 Conclusions

1) In location no. 11 (the crossings of Na Ostatnim Groszu Street with Popowicka Street – table 1.) the limit value of 500 mg Zn/kg DM for soils of group I, as established by the Polish Ministry of Environment Regulation from September 1st, 2016, was exceeded.
2) The coefficients of variation in urban soils are very high for Zn (81%) and Pb (69%), and close to 50% for Cr (58%), Cd (57%), Cu (50%). It may stem from the non-uniform distribution of contaminants between locations due to diverse intensity of traffic motor transport.
3) Average values of pollution indexes indicate medium level of the contamination of urban soils in Poland: Zn (2.92) > Cu (1.82) > Ni (1.28) > Pb (1.09) > Cd (0.94) > Cr (0.47).
4) Average contents of heavy metals in plants are much lower than in soils about 1.5–2.5 times in grasses, and 2–5.5 times in dandelion.
5) Due to the exceedance of the content of Cu in grasses, the biomass is not acceptable for use in animal feeds, according to the Polish Ministry of Agriculture and Rural Development

Regulation from January 23rd, 2007. Also in the samples of *Taraxacum officinale* exceedances of the content of Cu were observed (except for samples no. 1 and 6).
6) The coefficients of variation of Cd, Pb, Ni in biomass and also for Cr in dandelion are above 50%.
7) The bioaccumulation coefficients in grasses and dandelion (*Taraxacum officinale*) are arranged as follows: Cr > Zn > Cu > Cd > Ni > Pb and Cr > Cu > Cd > Zn > Ni > Pb, respectively.
8) The content for chromium and lead in grasses and dandelion are strongly correlated with each other (*r* of 0.82/0.95, respectively). Similarly strong correlation in grasses was observed for zinc and copper (*r* 0,81). In the case of soils the correlation coefficient for zinc and lead equals 0.94.

The investigations were co-financed within the framework of the order No. 0401/0068/16 with the specific subsidy granted for the Faculty of Environmental Engineering Wroclaw University of Science and Technology (W-7) by the Minister of Science and Higher Education.

References

1. A. Athanasopoulou, G. Kollaros, AJER **5**, 12 (2016)
2. Å. Lindgren, Sci. Total Environ. **189/190** (1996)
3. T. Grigoratos, G. Martini, Environ Sci. Pollut. Res. **22**, 4 (2015)
4. M. Radziemska, J. Fronczyk, Int. J. Environ. Res. Public Health **12**, 10 (2015)
5. A. Hołtra, D. Zamorska-Wojdyła, Environ. Prot. Eng. **42**, 3 (2016)
6. M.I. Szynkowska, A. Pawlaczyk, E. Leśniewska, T. Paryjczak, Pol. J. Environ. Stud. **18**, 6 (2009)
7. R.N. Pivić, A.B. Stanojković Sebić, D.L. Jošić, Pol. J. Environ. Stud. **22**, 5 (2013)
8. K. Dzierżanowski, S.W. Gawroński, Environ. **50** (2011)
9. M.A. Lee, L. Davies, S.A. Power, Environ. Pollut. **163** (2012)
10. S. Guala, F.A. Vega, E.F. Covelo, Environ. Monit. Assess. **185**, 1 (2013)
11. Journal of Laws from September 1st, 2016 pos. 1395 (Poland)
12. E. Królak, Pol. J. Environ. Stud. **12**, 6 (2003)
13. B. Gworek, A. Dećkowska, M. Pierścieniak, Pol. J. Environ. Stud. **20**, 1 (2011)
14. M. Biasioli, R. Barberis, F. Ajmone-Marsan, Sci. Total Environ. **356**, 1–3 (2006)
15. F. Çelenk, F.T. Kiziloğlu, Int. J. Res. Agric. and For. **2**, 5 (2015)
16. K. Jankowski, et. all, J. Elem. **19**, 1 (2014)
17. Onder S., Dursun S., Gezgin S., Demirbas A., Pol. J. Environ. Stud. **16**, 1 (2007)
18. A. Kabata-Pendias, M. Piotrowska. T. Witek, Evaluation of contamination degree of soils and plants by heavy metals and sulfur. (IUNG, Puławy, 1993)
19. Journal of Laws from January 23rd, 2007 no. 20 pos. 119 (Poland)