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TRACE ELEMENT CONTENT (Cd, Cu, Ni, Pb, Zn) IN FARM-LAND SOILS IN POLAND

HENRYK TERELAK, ARKADIUSZ TUJAKA, TERESA MOTOWICKA-TERELAK

Institute of Soil Science and Plant Cultivation, Soil Science, Erosion Control and Land Conservation Department, 24-100 Puławy, ul. Czartoryskich 8, Poland

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ZAWARTOŚĆ PIERWIASTKÓW ŚLADOWYCH (Cd, Cu, Ni, Pb, Zn) W GLEBACH UŻYTKÓW ROLNYCH POLSKI

W pracy przedstawiono zasady, zakres i metodykę badań dotyczącą oceny stanu ekologicznego gleb użytków rolnych Polski. W próbkach glebowych oznaczono skład granulometryczny, odczyn, zawartość materii organicznej oraz zawartość metali ciężkich (Cd, Cu, Ni, Pb, Zn). Na podstawie istniejących kryteriów (tab. 1) dokonano oceny stanu zanieczyszczenia gleb użytkowanych rolniczo w ujęciu dla kraju i poszczególnych województw. Średnia zawartość (mg/kg) Cd, Cu, Ni, Pb i Zn w powierzchniowej warstwie gleb użytków rolnych Polski wynosi odpowiednio: 0,21; 6,5; 6,2; 13,6 i 32,4. Gleby użytków rolnych Polski zawierają w głównej mierze naturalną i nieco podwyższoną zawartość badanych metali ciężkich. Pozwala to na produkcję wysokiej jakości surowców roślinnych przeznaczonych na paszę i do konsumpcji.

Summary

The research system of soils for evaluation of the ecological state of farm-land soils in Poland is presented in this paper. Granulometric composition, pH, organic matter content and the content of heavy metals (Cd, Cu, Ni, Pb, Zn) in soils were determined. On the basis of existing criteria (tab. 1) the state of soil pollution with heavy metals for separate provinces and whole country was estimated. The average heavy metal contents (mg/kg) in surface layer of soils in Poland are as follows: Cd-0.21, Cu-6.5, Ni-6.2, Pb-13.6, and Zn-32.4. The farm-land soils of Poland generally contain natural and slightly elevated level of the investigated heavy metals. This allows to produce high quality of agricultural materials appropriate for consumption and feeding of animals.

INTRODUCTION

Soil is unrenewable and with great potential public welfare, therefore it must be protected and rationally used in a delicate way to preserve appropriate production of good quality raw materials necessary not only for the present but

also for the future generation. In the years of intensive development of agriculture and industry this upper rule was often neglected [16].

Involvement of heavy farm equipment, land drainage, excessive use of agricultural chemical substances, emission originating from mining, metallurgical and chemical industry, public utilities and transport [6, 9] containing toxic chemical substances (nitric and sulphur oxides, PAHs) and trace elements (heavy metals) caused, in some cases, strong changes of soil properties.

Taking above into consideration, the Regional Agrochemical Stations jointly with Soil Science and Plant Cultivation Institute in Puławy and on behalf of Ministry of Agriculture in years 1992–1998 carried out research focused on soil chemical properties (pH, organic matter, cadmium, copper, nickel, lead, zinc, sulphur content) and current status of soil contamination with heavy metals.

This paper presents the scope and methodology of research as well as heavy metal (Cd, Cu, Ni, Pb, Zn) contents in farm-land soils of Poland and their pollution with these elements.

THE SCOPE AND METHODOLOGY OF INVESTIGATION

Distribution of research points and their documentation. Heavy metals and organic matter content in soils together with the knowledge of soil pH and granulometric composition allow, on the base of established criterions, assess the state of soil contamination with these elements, recommend the way of such soils usage [7] or their remediation [1, 10, 12] and furthermore draw on appropriate maps the contours of differently contaminated soils. Above aims are able to gain having wide network of research points and number of labdata. Taking above into account it was established that one research point should be represented by about 400ha (4 km^2) of agricultural area [15]. Therefore it was necessary to take about 45 000 soil samples for precise determination of ecological state of arable lands in Poland. The acceptable assumption was that the localization of the research points should be uniform, independent of soil contamination degree caused by economic activity. Independly on accepted geographical network, at localization of research points there were also taken for granted sort of farm land, occuring soils and ecological endangerment area. Each research point located in each province was located on soil-agricultural maps and topographical maps (at the scale of 1 : 100 000), indicating them by numbers from 1 to n. The system permitted for location of each measurement point in accordance with geographical coordinates.

For each research point documentation was gathered taking into account the following information: point number, geographical coordinates (latitude, longitude), symbol of the topographical map sheet (1 : 100 000 map scale), the sort of farm (individual, State Agrifarm), village, town district, administrative district, province, point situation in relation to possible contamination sources, kind of land utilization, soil (type, kind, species, soil capability class, complex of

agricultural usefulness), the type of cultivated plant (in the year of soil sample taking) etc.

Representative mean soil samples for 100 m^2 area were taken from 0 – 20 cm and 0 – 10 cm depth of arable land and green land, respectively, from each research point. Mean samples were mixtures of single samples (15 – 20 samples) collected by means of the stick made of stainless steel.

Labwork and data archivization. In the air dried soil samples, passed through a 1mm-mesh sieve soil particle distribution and pH (pH_{H2O} and pH_{KCl}) were determined. Organic matter and heavy metals contents were analyzed in soil samples ground in agate mortar (20 min) and sieved to 0.1 mm. The concentration of Cu, Ni and Zn in soils was determined in $HNO_3 + HCl$ mixture (aqua regia) by means of AAS method in acetylene-air flame but the concentration of Cd and Pb was measured by AAS method after extraction from the solution obtained during soil mineralization by aqua regia and condensation to organic phase using ammonium 1-pyrrolidinecarbodithioic acid (APDC) [2]. The quality of the measurements was proved by incorporation to each analitical series standard sample (SRM – Standard Reference Material) and doubled samples which were approximately 10% of each analized series.

The gained knowledge on measured points and the results of analitical work were acquisited in the computer database operated by computer – based system MONIT.EKO.GLEB. With applications help adjusted to spatial information system (GIS – Geographic Information System) different recipients can use the information collected in database: governmental and not-governmental administration, human society, different kind of national and international institutions etc.

The assessment of soil pollution with heavy metals was estimated according to criteria presented in Table 1.

Within each soil quality class three groups (A, B, C) of soils with different granulometric composition, pH_{KCl} and organic matter content were distinguished (7). These groups are as follows:

A – very light soils with a very low content of silt and clay fractions (< 10%) regardless of soil pH,
  – light soils (10 – 20% of silt and clay fractions), very acid (pH < 4.5) and acid (pH 4.5 – 5.5),

B – light soils (10 – 20% of silt and clay fractions), slightly acid (pH 5.6 – 6.5) and neutral (pH > 6.5),
  – medium light soils (20 – 35% of silt and clay fractions), very acid (pH < 4.5),
  – heavy soils (> 35% of silt and clay fractions), acid (pH 4.5 – 5.5) and very acid (pH < 4.5),
  – mineral-organic soils (organic matter content 6 – 10%),

C – medium heavy soils (20 – 35% of silt and clay fractions) and heavy soils (> 35% of silt and clay fractions), weakly acid (pH 5.5 – 6.5) or neutral (pH > 6.5),
  – mineral-organic soils and organic soils (organic matter content > 10%).

Table 1. Classes of soil surface (0–20 cm) pollution with heavy metals

Metal	Soil group	Soil pollution classes					
		0	I	II	III	IV	V
		Element contents – mg/kg					
Lead (Pb)	A	30	70	100	500	2500	> 2500
	B	50	100	250	1000	5000	> 5000
	C	70	200	500	2000	7000	> 7000
Zinc (Zn)	A	50	100	300	700	3000	> 3000
	B	70	200	500	1500	5000	> 5000
	C	100	300	1000	3000	8000	> 8000
Copper (Cu)	A	15	30	50	80	300	> 300
	B	25	50	80	100	500	> 500
	C	40	70	100	150	750	> 750
Nickel (Ni)	A	10	30	50	100	400	> 400
	B	25	50	75	150	600	> 600
	C	50	75	100	300	1000	> 1000
Cadmium (Cd)	A	0.3	1	2	3	5	> 5
	B	0.5	1.5	3	5	10	> 10
	C	1.0	3	5	10	20	> 20

Soil pollution classes:
0 – natural content, I – slightly elevated content,
II – weak pollution, III – medium heavy pollution,
IV – heavy pollution, V – very heavy pollution.

RESULTS AND DISCUSSION

Cadmium reveals a great mobility in soil environment, especially in light and acid soils. In these conditions even not so high cadmium concentration in soils can be toxic for people and animals. This is directly connected with cadmium uptake by plants and exceedance of permissible cadmium content in farm crops [5, 8].

The natural cadmium contents in soils depend on the soil bed rock granulometric composition, grade of particulate emission, age of soils, intensity of soils parent rocks weathering and their geological origin [8]. The mean cadmium content in soils of the world varies between 0.2–1.05 mg/kg of soil, but as a rule do not exceed 0.5 mg/kg [8]. Soils of Poland consist of 0.21 mg Cd/kg of soil, at the range of fluctuations 0.01–49.73 [13, 14]. The expected range (0.10–0.46 mg Cd/kg of soil) obtained after rejection of 5% of extreme soil cadmium content gives real state of cadmium content in soils and hazard degree for plant raw materials. The expected range of this

element content in Polish soils indicates that cadmium concentrations in soils of Poland are comparable with the content of this element in soils of the world.

The data showed in Table 2 indicate, that mean cadmium content in soils of Poland do not exceed value 0.50 mg/kg, generally accepted as a mean cadmium content in soils of the world. The confirmed high cadmium content in soils in some areas of Poland (23.36 – Małopolska province and 49.73 mg/kg – Silesia province) has a local character. It should be assumed that this state is due to metallic dust from the industry and non-ferrous metals metallurgy. There are also the outcrops of non-ferrous metals ores and soils created from flysh and cadmium-riched Tertiary-origin materials on the large areas of the above areas. The accumulation of cadmium in soils exceeding natural content is often related with the application of high doses of wastes and sewage sludge not acceptable by relevant criteria of usefulness, broadcasting of phosphorus Cd-riched fertilizers and high dust emission from non-ferrous metal metallurgy [8]. The reason for regional excideence of Cd content in soils can be combustion of the rabish and different sort of waste materials.

The data demonstrated in Table 2 show that local soil degradation with cadmium considerably varies. Without details examining it is necessary to assume that the majority of soils in Poland have cadmium content at non-polluted (0°) and a little bit increased (I°) level. In the country-scale these soils amounting to about 89% and 9.5% respectively (totally about 98.5%) of the total agricultural area of Poland can be used for cultivation of all crops with limitation to vegetable crops for children on the areas revealing exceeded cadmium content. On weakly contaminated soils with cadmium (II°) accounting of 1.1% of farm land areas should be exlused some vegetables growing (lettuce, spinach, cauliflower, carrot, parsley etc.). Larger complexes of medium heavily contaminated soils with Cd (III°) accounted of 0.29% of farm land soils exist only in southern areas of Poland (Małopolska and Silesia province). Strongly (IV°) and very strongly (V°) influenced agricultural area with cadmium is small (0.25%). As a matter of fact these soils should be exclouded from agricultural production. The best soils can be used for cultivation of industrially proceeced plants as well as for production of plant breeding materials, seeds etc. The poor soils should be intended for afforestation and sod formation.

The copper content in soils is strongly differentiated and indicates relevant relation with the clay content in soils [8, 14]. Unpolluted soils of the world contain 1–140 mg Cu/kg, but 6–53 mg/kg in soils of Poland [8, 14]. The average copper content in soils of Poland is very low and accounts for 6.5 mg/kg – Table 3 [14], at wide range of estabilished contents (0.2–725.0 mg Cu/kg). The excepted range accounting for 3.1–13.6 mg Cu/kg is regarded as a significant index of soil copper abundance and moreover does not exceed geochemical background values.

Table 2. Content of cadmium (mg/kg) in surface layer of farm-land soils in Poland and the degree of soil pollution with this element

Lp.	Province	Number of samples	Geometric average	Ranges		Percentage of soils in pollution degree							
				determined	expected	0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	0.23	0.02–2.22	0.13–0.39	94.37	5.54	0.09	0	0	0	99.91	0.09
2	kujawsko-pomorskie	3042	0.19	0.07–3.75	0.12–0.29	98.14	1.83	0.03	0	0	0	99.97	0.03
3	lubelskie	4148	0.17	0.01–5.70	0.09–0.32	95.76	4.03	0.14	0.07	0	0	99.79	0.21
4	lubuskie	1424	0.12	0.01–3.03	0.07–0.21	98.81	1.19	0	0	0	0	100.00	0
5	łódzkie	3426	0.20	0.01–6.10	0.10–0.40	88.72	10.14	0.70	0.26	0.15	0.03	98.86	1.14
6	małopolskie	2593	0.57	0.01–23.36	0.25–1.29	54.74	37.76	6.16	0.96	0.23	0.15	92.50	7.50
7	mazowieckie	5971	0.15	0.01–1.56	0.08–0.28	96.10	3.87	0.03	0	0	0	99.97	0.03
8	opolskie	1746	0.33	0.02–9.00	0.18–0.63	79.17	18.72	1.20	0.34	0.40	0.17	97.89	2.11
9	podkarpackie	2548	0.28	0.01–2.60	0.17–0.47	91.33	8.63	0.04	0	0	0	99.96	0.04
10	podlaskie	3075	0.21	0.07–0.96	0.14–0.30	97.20	2.80	0	0	0	0	100.00	0
11	pomorskie	2383	0.22	0.01–4.32	0.12–0.40	90.07	9.85	0.04	0.04	0	0	99.92	0.08
12	śląskie	2187	0.87	0.08–49.73	0.35–2.13	32.73	45.77	13.08	4.30	2.79	1.33	78.50	21.50
13	świętokrzyskie	2133	0.28	0.02–11.00	0.16–0.49	82.61	17.11	0.23	0	0	0.05	99.72	0.28
14	warmińsko-mazurskie	3337	0.15	0.01–1.31	0.07–0.34	97.43	2.51	0.06	0	0	0	99.94	0.06
15	wielkopolskie	4463	0.14	0.01–4.17	0.08–0.24	97.70	2.26	0	0	0.04	0	99.96	0.04
16	zachodniopomorskie	2795	0.20	0.02–3.60	0.11–0.35	91.50	8.42	0.04	0.04	0	0	99.92	0.08
	Poland	48590	0.21	0.01–49.73	0.10–0.46	88.87	9.53	1.06	0.29	0.17	0.08	98.40	1.60

Table 3. Content of copper (mg/kg) in surface layer of farm-land soils in Poland and the degree of soil pollution with this element

Lp.	Province	Number of samples	Geometric average	Ranges		Percentage of soils in pollution degree							
				determined	expected	0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	15.4	0.7–725.0	8.7–27.5	85.61	12.14	1.23	0.30	0.72	0	97.75	2.25
2	kujawsko-pomorskie	3042	4.7	0.3–37.7	2.6–8.4	99.81	0.16	0.03	0	0	0	99.97	0.03
3	lubelskie	4148	4.8	0.7–566.7	2.3–9.8	98.58	0.87	0.34	0.12	0.05	0.04	99.45	0.55
4	lubuskie	1424	6.0	0.9–70.0	3.2–11.1	97.12	2.60	0.28	0	0	0	99.72	0.28
5	łódzkie	3426	4.8	0.3–184.0	2.7–8.5	98.82	0.61	0.20	0.20	0.17	0	99.43	0.57
6	małopolskie	2593	13.4	1.0–663.2	7.5–24.0	91.53	7.85	0.42	0.08	0.12	0	99.38	0.62
7	mazowieckie	5971	3.7	0.5–92.6	2.0–6.9	99.21	0.57	0.13	0.07	0.02	0	99.78	0.22
8	opolskie	1746	9.0	1.3–89.6	5.5–14.6	98.52	1.20	0.11	0.17	0	0	99.72	0.28
9	podkarpackie	2548	9.6	0.9–48.5	5.0–18.7	97.29	2.63	0.08	0	0	0	99.92	0.08
10	podlaskie	3075	5.6	1.3–40.2	3.6–8.8	99.67	0.33	0	0	0	0	100.00	0
11	pomorskie	2383	6.7	0.8–153.4	3.6–12.8	98.39	1.44	0.13	0	0.04	0	99.83	0.17
12	śląskie	2187	11.1	0.5–106.5	5.4–22.8	91.05	8.18	0.59	0.18	0	0	99.23	0.77
13	świętokrzyskie	2133	5.9	0.5–78.8	2.9–11.8	98.97	0.98	0.05	0	0	0	99.95	0.05
14	warmińsko-mazurskie	3337	6.1	0.2–126.0	3.4–11.0	99.31	0.63	0	0	0.06	0	99.94	0.06
15	wielkopolskie	4463	4.9	0.3–143.0	2.6–9.3	96.67	3.22	0.09	0	0.02	0	99.89	0.11
16	zachodniopomorskie	2795	9.2	1.0–90.0	5.0–16.8	90.92	8.72	0.36	0	0	0	99.64	0.36
	Poland	48590	6.5	0.2–725.0	3.1–13.6	96.56	3.04	0.25	0.07	0.08	0	99.60	0.40

The contamination of soil surface horizons is very high in some countries in the world and some areas in Poland. As a rule they are localizated in mining and copper processing areas and the copper content often exceeds even several thousand mg/kg of soil [10]. The main sources of soil pollution with copper could be some crop protection chemicals, mineral and organic wastes involved as fertilizers and furthermore unreasonable fertilization by means of copper. The results of the research [13] indicate, that soils of southern and south-western sites of Poland have reasonably higher copper concentration than the rest part of the country. It is obviously connected with the quality of native soil cover (pedosphere) and after all pollutant emission derivated from copper extraction and processing. Some small contours of soils contaminated with Cu are possible to be found within another parts of Poland. Generally, it is possible to state, that almost 97% of Poland's agricultural area is not contaminated with Cu (0°). Soils with an elevated copper content (I°), which should be used for growing all crops except vegetables, used to feed children account of 3% agricultural area. The limitation of vegetable cultivation on copper weakly contaminated soils (II°) concern 0.2% farm land in Poland. The monitoring of the quality of plant raw materials produced on medium heavily contaminated soils with copper (III°) concerns agricultural products from nearly 0.07% country agricultural area, but heavily (IV°) and very heavily (V°) contaminated soils which commonly account for 0.1% of the agricultural land demand exclusion from agricultural production.

Summarizing the results of research concerned the copper content in agricultural land of Poland and soil pollution with this element it should be assumed, that copper is not significantly responsible for consumption and feed quality of plant raw materials produced in Poland [13].

The nickel content in soils depends mainly on its concentration in the bed rock [3, 14], soil clay content, sewage sludge application and nickel imission from the polluted atmosphere. Binding of nickel by soil colloids and ferrous hydroxides and intensive phosphorus fertilization as well as soil liming restrict Ni mobility in soils and decrease nickel phytoavailability.

The mean nickel content in soils of the world varies at about 8 – 33 mg/kg and 10 – 92 mg/kg in the light and heavy soils, respectively. Generally, the content 100 mg Ni/kg of soil was estabilished for an admissible nickel content in farm-land soils [8].

The mean nickel concentration in agricultural soils of Poland accounts of 6.2 mg/kg [13, 14], at the range from 0.1 to 328.3 mg/kg and from 2.6 to 14.7 mg/kg (Table 4) of established and expected value respectively, is lower than Ni content (10 mg Ni/kg) assumed as nickel limited concentration in light soils.

The results of investigations demonstrated in Table 4 indicate that the nickel concentration in soils of Poland is comprised with the natural nickel content limits in unpolluted soils of the world. However, there are many places with the higher natural Ni content in soils of Poland. This situation is not only conjuncted with industrial influence, but also with the geological background of the soil bed rock [3, 8, 11].

Table 4. Content of nickel (mg/kg) in surface layer of farm-land soils in Poland and the degree of soil pollution with this element

Lp.	Province	Number of samples	Geometric average	Ranges		Percentage of soils in pollution degree							
				determined	expected	0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	8.3	0.1–260.0	3.7–18.6	96.00	3.43	0.39	0.18	0	0	99.43	0.57
2	kujawsko-pomorskie	3042	6.1	0.4–52.0	3.3–11.5	98.05	1.92	0.03	0	0	0	99.97	0.03
3	lubelskie	4148	6.3	0.1–64.0	2.8–13.8	98.29	1.61	0.10	0	0	0	99.90	0.10
4	lubuskie	1424	4.9	0.2–32.9	2.5–9.6	95.01	4.99	0	0	0	0	100.00	0
5	łódzkie	3426	4.6	0.2–34.2	2.4–8.7	98.78	1.22	0	0	0	0	100.00	0
6	małopolskie	2593	15.3	0.4–210.4	7.2–32.8	80.80	15.97	2.77	0.31	0.15	0	96.77	3.23
7	mazowieckie	5971	3.1	0.1–44.5	1.4–6.5	99.00	0.95	0.05	0	0	0	99.95	0.05
8	opolskie	1746	9.4	0.4–35.0	5.4–16.5	95.83	4.06	0.11	0	0	0	99.89	0.11
9	podkarpackie	2548	13.5	0.3–290.0	5.9–30.9	83.40	15.46	0.86	0.24	0.04	0	98.86	1.14
10	podlaskie	3075	5.3	0.4–44.0	3.1–9.0	99.74	0.23	0.03	0	0	0	99.97	0.03
11	pomorskie	2383	7.2	0.2–52.9	3.5–14.8	95.65	4.18	0.17	0	0	0	99.83	0.17
12	śląskie	2187	12.9	0.5–328.3	6.2–26.7	83.31	15.09	1.19	0.32	0.09	0	98.40	1.60
13	świętokrzyskie	2133	7.2	0.5–82.5	3.1–16.6	94.60	5.02	0.38	0	0	0	99.62	0.38
14	warmińsko-mazurskie	3337	7.9	0.1–295.0	4.1–15.1	98.06	1.82	0.09	0.03	0	0	99.88	0.12
15	wielkopolskie	4463	3.1	0.1–80.0	1.6–6.1	99.38	0.58	0.02	0.02	0	0	99.96	0.04
16	zachodniopomorskie	2795	5.6	0.1–51.8	2.5–12.7	94.85	4.90	0.25	0	0	0	99.75	0.25
	Poland	48590	6.2	0.1–328.3	2.6–14.7	95.36	4.23	0.34	0.06	0.01	0	99.59	0.41

Analizing the nickel contamination of soils (Table 4) it is necessary to state, that above 95% farm land area of Poland does not indicate contamination with nickel (0°). Approximately 4.2% agricultural land is characterized by elevated nickel content (I°). These soils cannot be used for growing vegetables used to direct consumption by children. The soils contaminated (II° – IV°) with this element account of nearly 0,4% agricultural production area. There are not so large areas of above contamination degree in different regions of Poland. Furthermore, there are not very heavily nickel (V°) contaminated soils in Poland.

Concluding the results of investigations on nickel content in soils and their contamination with this element (Table 4) it is necessary to confirm, that nickel from the ecological and agricultural point of view is not the limiting factor of agricultural lands usfulness to plant raw materials production with high consumption and feeding value.

The lead content in soils depends mainly on the soil bed rock origin, emission level from industry and transport as well as utilization of different kind of industrial wastes and sludges as fertilization substances [3, 4, 8, 10]. It is necessary to state, that soils not directly influenced by industrial pollution do not indicate elevated accumulation of lead and soils geochemical background in different parts of the world is included in range 25 – 40 mgPb/kg [8].

The results of the research work on lead in soils of Poland proved mean value of the soil lead content accounting of 13.6 mg/kg at oscillating range of stated values from 0.1 to 5000.0 mg/kg and expected values from 7.4 to 25.0 mg/kg (Table 5). Significantly narrower range of variation of lead stated concentration than range of expected value proves that there are only small areas of highly contaminated soils with lead in Poland.

The data obtained show that only in several regions of Poland (Silesia, Małopolska, Opole, Podkarpacie and Dolny Śląsk provinces) the mean lead content in soils is higher than in Poland as a whole. It is evidently related to soil contamination with this heavy metal by industry and to the sort of soil parent material.

The data connected with the farm land contamination with Pb show that nearly 97% agricultural area does not demonstrate soil pollution with this element. The share of soils with lead elevated content (I°) does not exceed 2.5%. Moreover, differently contaminated soils with lead (II° – IV°) posses about 0.7% farm land soils. These soils occur in highly industrialized areas (Silesia and Małopolska provinces).

Concluding, it should be assumed that with regard to lead geochemical properties, as well as agricultural areas with defined contamination degree, the hazard of lead accumulation in soil environment is considerably lower than cadmium and zinc [14]. There are 99.3% non-contaminated (0°) and with elevated (I°) lead content agriculturally utilized soils in Poland. As a matter of fact they are pure and clean soils except small areas of farm land soils (2.4%) with elevated lead content (I°). These soils can be used to all crops growing.

Table 5. Content of lead (mg/kg) in surface layer of farm-land soils in Poland and the degree of soil pollution with this element

Lp.	Province	Number of samples	Geometric average	Ranges		Percentage of soils in pollution degree							
				determined	expected	0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	20.6	1.2–370.0	12.5–34.2	95.57	3.95	0.45	0.03	0	0	99.52	0.48
2	kujawsko-pomorskie	3042	11.7	2.4–73.2	7.9–17.4	99.77	0.23	0	0	0	0	100.00	0
3	lubelskie	4148	10.8	1.1–345.0	7.0–16.5	99.57	0.34	0.07	0.02	0	0	99.91	0.09
4	lubuskie	1424	9.9	0.6–61.7	5.8–16.9	99.16	0.84	0	0	0	0	100.00	0
5	łódzkie	3426	13.9	0.8–177.5	8.8–22.2	98.19	1.55	0.23	0.03	0	0	99.74	0.26
6	małopolskie	2593	29.1	2.4–2787.0	16.2–52.1	88.26	9.31	1.19	1.12	0.12	0	97.57	2.43
7	mazowieckie	5971	9.3	0.1–136.7	5.9–14.6	99.33	0.65	0.02	0	0	0	99.98	0.02
8	opolskie	1746	20.9	4.7–236.4	14.3–30.5	96.05	3.72	0.23	0	0	0	99.77	0.23
9	podkarpackie	2548	17.5	1.4–107.7	11.3–27.1	99.72	0.24	0	0.04	0	0	99.96	0.04
10	podlaskie	3075	10.2	2.8–30.0	7.8–13.3	100.00	0	0	0	0	0	100.00	0
11	pomorskie	2383	12.2	1.3–188.5	7.4–20.4	98.69	1.31	0	0	0	0	100.00	0
12	śląskie	2187	39.8	3.6–5000.0	19.1–83.0	69.17	21.08	5.58	3.89	0.23	0.05	90.25	9.75
13	świętokrzyskie	2133	13.8	1.5–100.2	8.3–23.1	97.80	2.06	0.14	0	0	0	99.86	0.14
14	warmińsko-mazurskie	3337	12.2	1.0–105.0	7.9–18.7	99.58	0.36	0.06	0	0	0	99.94	0.06
15	wielkopolskie	4463	10.1	0.2–206.7	6.6–15.7	99.28	0.54	0.09	0.09	0	0	99.82	0.18
16	zachodniopomorskie	2795	12.6	0.2–135.0	7.3–21.6	98.34	1.62	0.04	0	0	0	99.96	0.04
	Poland	48590	13.6	0.1–5000.0	7.4–25.0	96.89	2.44	0.40	0.25	0.02	0	99.33	0.67

Weakly (II°) and medium heavily (III°) contaminated soils include 0.4% and 0.25% agricultural area respectively. The cereals, root crops and fodder crops are allowed to be cultivated on these soils but permanent control of metal level in edible and fooder products is necessary.

The mean **zinc** content in soils of the world is sophisticately differentiated and varies between 30–235 mg/kg [8]. Authors given above claim that non-contaminated soils of Poland contain on the average about 40 mg Zn/kg and it is value close to ones in adjacent countries. The zinc content in soils depends mainly on soil type and demonstrates strong relation to granulometric composition of soil. Sandy soils consist of 30 mg Zn/kg, light loamy soils 60 mg Zn/kg and heavy loamy soils 80 mg Zn/kg [8].

The main source of soil contamination with zinc is immission of metallic dust in soils and utilization of sewage sludge as fertilizers originating from communal and industrial sewage treatment plant.

The data in Table 6 demonstrate that the mean zinc content in farm land soils is 32.4 mg/kg. The expected range of zinc content in soils (16.1–65.2 mg/kg) significantly differs in comparison to the stated range (0.5–5754.0 mg/kg). This clearly indicates that low as well as high zinc concentration in agriculturaly utilized soils in Poland appears accidentally.

The relatively high mean content of zinc in soils of some areas in Poland arise from high natural richness of these soils with this metal (heavy soils originating from before Quaternary period materials, flysh materials etc.) and also industrial pollution with zinc.

Considering soil contamination with zinc a conclusion can be drawn that zinc is in the same way as cadmium a significant factor of soil degradation especially within highly antropopressed regions. Within country-scale about 88% agricultural area is not contaminated (0°) with zinc soils and 10.6% show the elevated (I°) zinc content. Thus, non-contaminated Zn soils and soils with elevated Zn content represent jointly about 98.5% agricultural area. Variously contaminated soils with zinc (II°, III°, IV°, V°) account of only 1.5% agriculturaly used area. Furthermore there exists hazard of the zinc contamination of plant raw materials produced on these soils.

The contamination of soils with all heavy metals (Cd, Cu, Ni, Pb, Zn). The results concerning present actual status of soil environment of Poland (Table 7) an over all doubt indicate, that about 80% agricultural area is characterized by natural (0°) analized heavy metals content. The soils are destined to all of crops growing. Non-contaminated (0°) and a little bit elevated heavy metals content include near 97% total agricultural soils. On the contrary, only about 3% farm land soils are classified to soils contaminated in various degrees (II°, III°, IV°, V°). The data given above demonstrate that more serious limitation in agricultural land utilization for crop production concern considerably smaller area than thought before with regards to necessity of quantitative requirement satisfaction related to plant raw materials. The research carried out enabled

Table 6. Content of zinc (mg/kg) in surface layer of farm-land soils in Poland and the degree of soil pollution with this element

Lp.	Province	Number of samples	Geometric average	Ranges		Percentage of soils in pollution degree							
				determined	expected	0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	54.9	1.0–651.2	31.5–95.8	71.80	26.57	1.60	0.03	0	0	98.37	1.63
2	kujawsko-pomorskie	3042	23.3	4.0–245.0	14.4–37.8	97.84	1.70	0.46	0	0	0	99.54	0.46
3	lubelskie	4148	23.6	2.4–158.0	13.9–40.2	98.67	1.06	0.27	0	0	0	99.73	0.27
4	lubuskie	1424	31.7	4.6–280.7	19.6–51.3	91.93	7.79	0.28	0	0	0	99.72	0.28
5	łódzkie	3426	25.1	1.0–1448.0	13.9–45.2	95.63	3.47	0.52	0.38	0	0	99.10	0.90
6	małopolskie	2593	79.2	2.4–5754.0	45.4–138.2	48.43	47.84	3.23	0.38	0.08	0.04	96.27	3.73
7	mazowieckie	5971	22.4	0.7–425.0	12.7–39.4	95.76	3.70	0.52	0.02	0	0	99.46	0.54
8	opolskie	1746	43.6	1.7–810.0	25.3–75.2	89.76	9.04	1.14	0.06	0	0	98.80	1.20
9	podkarpackie	2548	40.1	0.5–212.0	22.8–70.5	91.60	8.24	0.16	0	0	0	99.84	0.16
10	podlaskie	3075	19.5	4.7–82.3	13.6–27.9	99.87	0.13	0	0	0	0	99.87	0.13
11	pomorskie	2383	36.7	3.3–537.6	21.7–62.2	90.79	8.50	0.63	0.08	0	0	99.29	0.71
12	śląskie	2187	90.6	1.0–2837.5	38.4–213.6	39.83	43.35	12.57	3.66	0.59	0	83.18	16.82
13	świętokrzyskie	2133	39.1	2.0–271.5	19.9–76.9	83.03	15.47	1.50	0	0	0	98.50	1.50
14	warmińsko-mazurskie	3337	29.4	1.0–492.5	17.2–50.4	95.55	4.24	0.18	0.03	0	0	99.79	0.21
15	wielkopolskie	4463	25.3	1.0–625.0	14.6–43.8	94.86	4.47	0.65	0.02	0	0	99.33	0.67
16	zachodniopomorskie	2795	36.6	1.7–368.0	21.7–61.5	88.29	10.92	0.79	0	0	0	99.21	0.79
	Poland	48590	32.4	0.5–5754.0	16.1–65.2	87.84	10.63	1.27	0.25	0.03	0.01	98.47	1.53

Table 7. Pollution of surface layers with Cd, Cu, Ni, Pb and Zn of farm-land soils in Poland

Lp.	Province	Number of samples	Percentage of soils in pollution degree							
			0	I	II	III	IV	V	0+I	II–V
1	dolnośląskie	3319	61.87	33.95	2.92	0.54	0.72	0	95.82	4.18
2	kujawsko-pomorskie	3042	94.69	4.76	0.55	0	0	0	99.45	0.55
3	lubelskie	4148	92.48	6.36	0.84	0.22	0.05	0.05	98.84	1.16
4	lubuskie	1424	85.47	13.97	0.56	0	0	0	99.44	0.56
5	łódzkie	3426	86.25	12.12	0.93	0.35	0.32	0.03	98.37	1.63
6	małopolskie	2593	36.80	51.46	9.08	1.89	0.58	0.19	88.26	11.74
7	mazowieckie	5971	91.73	7.45	0.72	0.08	0.02	0	99.18	0.82
8	opolskie	1746	73.72	23.13	2.06	0.52	0.40	0.17	96.85	3.15
9	podkarpackie	2598	75.40	23.19	1.10	0.27	0.04	0	98.59	1.41
10	podlaskie	3075	96.91	3.06	0.03	0	0	0	99.97	0.03
11	pomorskie	2383	81.14	17.84	0.85	0.13	0.04	0	98.98	1.02
12	śląskie	2187	20.30	52.81	16.96	5.63	2.97	1.33	73.11	26.89
13	świętokrzyskie	2133	68.54	29.16	2.25	0	0	0.05	97.70	2.30
14	warmińsko-mazurskie	3337	91.47	8.03	0.38	0.06	0.06	0	99.50	0.50
15	wielkopolskie	4463	89.91	9.10	0.83	0.09	0.07	0	99.01	0.99
16	zachodniopomorskie	2795	74.34	24.32	1.30	0.04	0	0	98.66	1.34
	Poland	48590	79.34	17.63	2.18	0.50	0.27	0.08	96.97	3.03

spatial demonstration of the heavy metals accumulation in farm land soils in suitable for general analysis needs scale (maps at 1 : 500.000 scale). Usefulness of existing knowledge on regional and local level requires precise indication of polluted areas on appropriate maps. In the end it permits for risk prediction of heavy metals running to trophic chain and for determination of the quality of plant raw materials dependly on natural condition system and influence of the human factor. The creation of prediction system can be the ground for rationalization of decisions undertaken in scope of restructurization tasks within the hazard places as well as localization and infrastructure development in regions especially to the purpose of plant raw materials production satisfying high qualitative requirements.

CONCLUSIONS

The paper presents the present ecological status of farm-land soils in Poland estimated on the basis of the heavy metals (Cd, Cu, Ni, Pb, Zn) contents determined in 48,590 soil samples taken from the surface layer of soils. The pollution degree of farm-land soils with the above-mentioned elements is also presented. The results of the investigations allow making the following generalizations:

The present expected and means contents (mg/kg) of heavy metals in soils are as follows:

Cd:	0.01 – 49.73;	0.10 – 0.46;	0.21
Cu:	0.9 – 725.0;	3.1 – 13.6;	6.5
Ni:	0.1 – 328.3;	2.6 – 14.7;	6.2
Pb:	0.1 – 5000.0;	7.4 – 25.0;	13.6
Zn:	0.5 – 5754.0;	16.1 – 65.2;	32.4

About 80% of Polish farm-land soils are characterized by natural (0°) and 17.6% elevated (I°) content of heavy metals. Soils with the elevated heavy metal content are suitable to grow all crops with the exception of vegetables to be processed or to be directly consumed by children. About 3% of farm-land soils are contaminated with heavy metals to various degrees (II° + III° + IV°V°). Weakly (II°) and medium heavily (III°) contaminated soils which jointly account for 2.7% of the farm-land soils of Poland should be excluded from the cultivation of crops which are directly consumed. They can be used to grow root crops, small grains and fodder crops while monitoring their heavy metal content. Heavily (IV°) and very heavily (V°) contaminated soils account for 0.27% and 0.08% of the total farm-land area. They can be used for growing industrial crops such as flax, hemp, rapeseed, sunflower etc., to reproduce seed and nursery-garden material. The poorest soils should be reforested or regrassed.

The results of the study do not support the opinion on heavy pollution of Polish soils with heavy metals. There are some areas in industrialized south and south-western part of Poland, which are contaminated with heavy metals

in various degrees. It is necessary to establish in these areas the contours of soils contaminated with heavy metals and propose appropriate methods of their utilization.

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