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Urban soil contamination with lead and cadmium in the playgrounds located near busy streets in Cracow (South Poland)

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Abstract: The pollution of urban soil with heavy metals caused by traffic activity is increasingly becoming a great threat to human health and environmental quality. This paper presents results of research of lead (Pb) and cadmium (Cd) distribution in land on playgrounds situated near busy streets in Cracow (Poland). Samples of sand and soil were collected from the most top layer (0–10 cm). Concentrations of examined metals are: Pb from 6.80 to 54.04 mg/kg and Cd from 1.60 to 2.61 mg/kg, respectively. The highest concentrations were found in sampling points near the busiest roads, and are particularly visible in the case of lead concentration in soil samples. For sand samples, metal concentrations are much lower. Although the results have not determined a high degree of soil's contamination, they indicate the problem of the children's exposure to toxic metals. Urban soil should be monitored particularly in such special places as playgrounds.

Keywords: urban soil, heavy metals, traffic pollutants, playgrounds

INTRODUCTION

The soil pollution with heavy metals, which is associated with a thriving civilization and industrial progress, is a constant problem in many regions in the world. As a result of different factors, there is accumulation of toxic metals, which negatively affects the normal development of all organisms, including human health. Uncontrolled inputs of heavy metals are undesirable because they are prone to accumulate in the soil environment and very difficult to remove. This fact contributes to their elimination from air and water, but it causes heavy contamination of aquatic sediment and soil (Aleksander-Kwaterczak 2007, Aleksander-Kwaterczak et al. 2010, Wardas et al. 2010, Aleksander-Kwaterczak & Ciszewski 2012, Ciszewski et al. 2012). This brings about many dangerous and unforeseeable phenomena occurring in the environment (Lu et al. 2009). The special threat of heavy metal contamination occurs in industrialized areas where metals are introduced into the soil along with exhaust fumes or dust, and as byproducts of automotive industry.

Road transportation is the main source of the particulate matter in the atmosphere of urban metropolitan areas (Wang et al. 2003, Vouitsis et al. 2009). Communication and transportation have been constantly evolving in recent years. Because of this fact the number of vehicles has increased, what is especially noticeable in the large cities streets. Cracow is a city with a highly developed communication network, so areas along the main roads have been constantly exposed to contaminants.

Volume of traffic pollution depends on the distance from the road, topography and traffic intensity (Niesiobędzka & Krajewska 2007, Button 2008). Dust borne heavy metals accumulate in the topsoil due to the atmospheric deposition by sedimentation, impaction and interception (Li et al. 2001,

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Sezgin et al. 2006, Lu et al. 2009). Additionally, in densely urbanized areas, decrease of concentration of the hazardous exhaust gas components, including heavy metals, is very slow with the distance from the linear emitter (Yetimoglu et al. 2007). The pollution that exists along the communication areas is due to deposition of dusty materials and fragments of tires and electric traction cables (Dziadek & Wacławek 2005). Soil in the vicinity of roads is contaminated mainly by lubricants, carcinogenic hydrocarbons, asbestos and rubber. Heavy metal emissions into the environment are caused by fuel combustion and corroded car parts. This applies primarily to lead, common in automobile exhaust. In Poland, certain standards have been introduced to regulate the content of tetraethyl lead in gasoline. In 2005, European Union countries introduced some changes to leaded petrol, or gasoline. However, it is not only lead that affects soil around the streets. For example cadmium is emitted to the atmosphere during abrasion of tires, brake discs and other parts of vehicles and is transported into the soil as the precipitation. Cadmium oxides are used for manufacturing of tires and brake linings and contain inorganic substances with high cadmium content (Beckwith et al. 1985).

Most heavy metals in high concentrations have adverse effects on human health (Selinus et al. 2005). These elements may accumulate in our body and affect the central nervous system, causing heavy metal poisoning and acting as cofactors in many other diseases (Thomas 1995). Particularly dangerous cadmium and lead, so called "metals of death" (Kowalak 1991) were investigated in this work. Such name has been earned due to the fact that, they interfere with the critical body functions, including the human nervous system, liver, and kidney. Children belong to a special risk group, because of their higher rate of absorption of heavy metals resulting from their active digestion system and sensitivity to hemoglobin (Selinus et al. 2005). Children are very vulnerable to toxic substances which they contact and are more likely to ingest soil (Jarosinska et al. 2006, Ljung et al. 2006). The development of child is largely shaped by environmental conditions in which it resides as they affect their health and growth. Younger people are especially sensitive to lead due to several reasons as they absorb more lead from the gastrointestinal tract than adults. Up to 40–50% of ingested metal is being absorbed by children, whereby for adults this ratio is only 10%. In addition, the children's circulatory system (especially for those under age of 5 years) allows direct transfer of lead to brains. The development of their nervous system is much more susceptible to toxic effects than in the mature brain, because there is no effective barrier to line the blood-brain, which protects the nervous system. This barrier develops gradually over several years (Lidsky & Schneider 2003). Finally, children can be characterized by a lack of awareness of the risks and they do not take appropriate preventive actions against the possibility of such risks on their own. Harmful compounds can affect the child's body in many ways. Penetration can occur by ingestion, inhalation and through the skin. It is also worth to mention that heavy metals accumulate mainly in the most superficial part of the soil; these that have a direct contact with children residing in playgrounds. The children's behavior itself also promotes a contact with harmful substances. There are many uncontrolled behaviors such as putting dirty hands and toys into the mouth. Their curiosity of the surrounding world, and often hyperactivity, increases risk of entering toxic compounds into their bodies.

This study aims to investigate presence and distribution of lead and cadmium in soils collected from children's playgrounds situated in urban environments near busy streets in Cracow (Poland).

MATERIALS AND METHODS

Soil and sand samples from a top layer (0–10 cm) were collected from playgrounds located near busy streets in Cracow (Fig. 1) in two districts – Mistrzejowice and Bieńczyce in late September 2013. The surface layer of ground is most commonly collected for this type of research, because this will give the best evidence of anthropogenic impact and it is the part of the land that children have direct access on playgrounds. Sand samples are characterized by the dominant grain fractions of 0.2–2.0 mm and the surface, from which it was taken, was not vegetated. In order to determine the variability of Cd and Pb concentration in soil depending on the distance from a main road, two transects were used with three playgrounds in each of them.

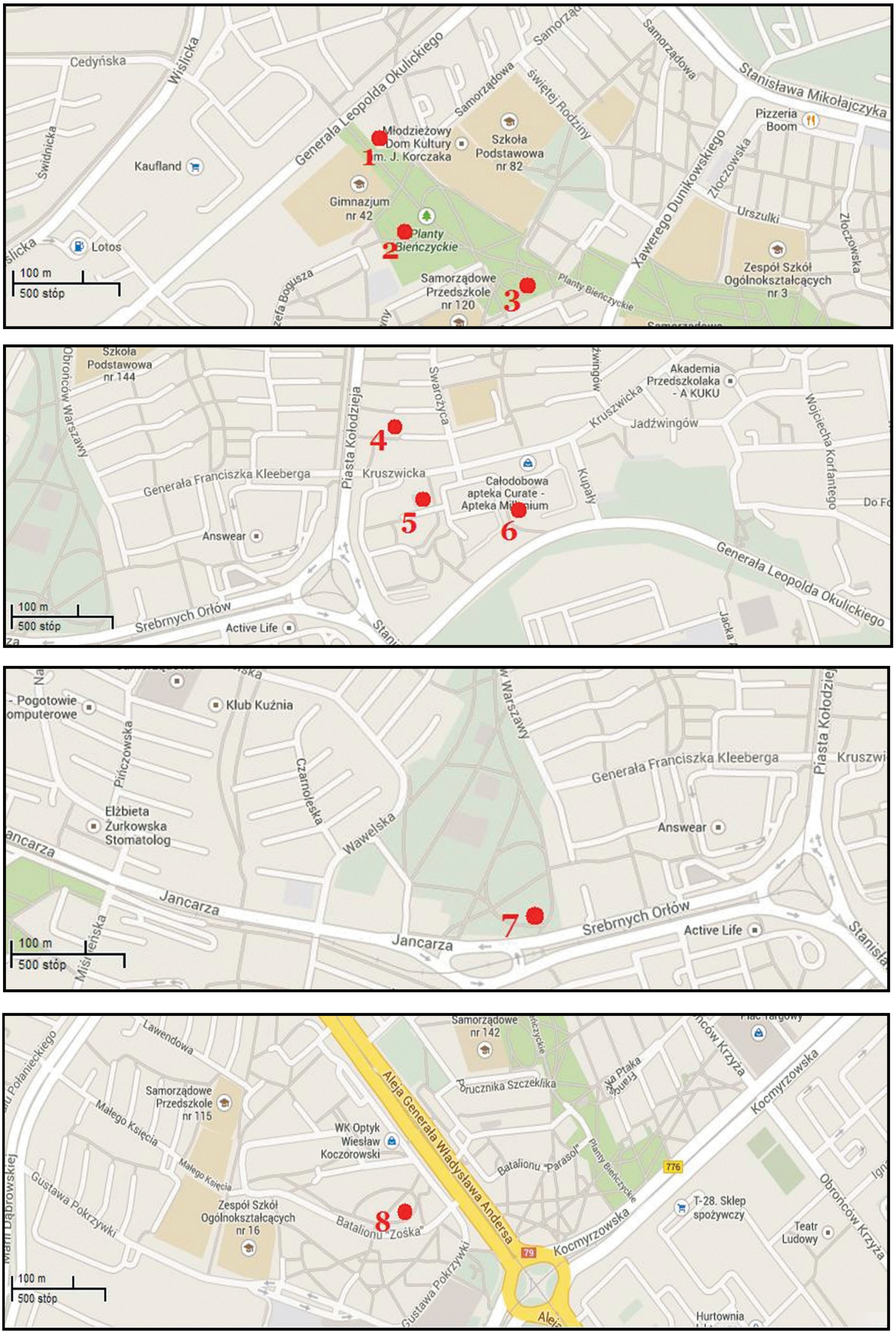

Fig. 1. *Area of research and sampling point locations (1–8)*

The first transect included playgrounds located near Okulickiego Street, while the second one was at Piasta Kołodzieja Street (Fig. 1). Two more sampling areas were located near busy traffic roads and a busy traffic rondo (Fig. 1, Tab. 1). In total, 25 soil or sand samples from eight playgrounds were collected from the places located close to the playground equipment such as swings, slides, carousels etc. In the laboratory, samples were dried at room temperature and sieved through the plastic sieve into <2 mm fraction. All samples were homogenized, quarteredand and ground in an agate mortar in order to obtain a fine and homogeneous powder less than 0.2 mm and then digested with HNO_3 (65%) acid in temperature 130°C. The concentrations of Pb and Cd in solutions were determined with an inductively coupled plasma-mass spectrometer (Perkin Elmer ELAN 6100).

Table 1
Playground location and sampling point's characterization

Playground location and characterization	Sample number	Place where material was downloaded	Type of ground
Transect I – Okulickiego Street			
1. Playground in the distance of 50 m from street	1.1	sandpit	sand
	1.2	chute	sand
	1.3	spring swinging	sand
	1.4.	bench	soil
2. Playground in the distance of 170 m from street. Nearby, at a distance of approx. 20 m there is a car parking lot	2.1.	spring swinging	soil
	2.2.	sandpit	sand
3. Playground in the distance of 300 m from street, but at a distance of approx, 10 m there is a car parking lot	3.1.	sandpit	sand
	3.2.	chute	soil
	3.3.	climbing wall	soil
Transect II – Piasta Kołodzieja Street			
4. Playground in the distance of 45 m from street	4.1.	sandpit	sand
	4.2.	bench	soil
	4.3.	spring swinging	soil
5. Playground in the distance of 100 m from street. Approx. 30 m there is smaller Kruszwicka Street	5.1.	sandpit	sand
	5.2.	chute	sand
	5.3.	swings	sand
	5.4.	spring swinging	sand
6. Playground in the distance of 260 m from street. Nearby there are two other busy streets and car parking lot	6.1.	sandpit	sand
7. Playground is located about 20 m from the Srebrnych Orłów Street. It borders with city park	7.1.	sandpit	sand
	7.2.	swings	soil
	7.3.	chute 1	soil
	7.4.	chute 2	soil
	7.5.	climbing wall	soil
8. Playground is located 60 m from Andersa Street and 180 m from the traffic rondo.	8.1.	chute	sand
	8.2.	swings	sand
	8.3.	table to play chess	soil

Table 2
Cadmium and lead concentration and pH values of the soil/sand samples from playgrounds in Cracow

Play-ground	**Sample number**	**Pb**	**Cd**	**pH**
		[mg/kg]		
1	1.1.	20.95	1.98	6.78
	1.2.	31.89	1.72	6.41
	1.3.	20.37	1.85	5.81
	1.4.	53.32	**2.61**	6.75
2	2.1.	49.21	2.22	6.25
	2.2.	24.70	1.86	7.60
3	3.1.	22.93	1.67	6.85
	3.2.	27.08	2.11	6.63
	3.3.	25.41	2.56	**8.83**
4	4.1.	36.02	2.19	7.11
	4.2.	34.91	2.13	7.04
	4.3.	31.15	2.34	7.12
5	5.1.	8.38	1.81	8.21
	5.2.	8.95	2.16	6.63
	5.3.	6.05	1.91	5.86
	5.4.	11.41	1.60	5.82
6	6.1.	6.80	1.72	5.39
7	7.1.	14.41	1.97	7.70
	7.2.	25.08	2.48	7.03
	7.3.	33.09	1.81	6.56
	7.4.	27.62	2.60	6.36
	7.5.	21.31	2.51	5.72
8	8.1.	33.82	1.72	7.31
	8.2.	33.37	1.89	6.79
	8.3.	**54.04**	2.58	6.62
Minimum		6.80	1.60	5.39
Maximum		**54.04**	**2.61**	**8.83**
Arithmetic average		26.49	2.08	–
Median		25.41	1.98	–
Standard deviation		13.36	0.33	–

Metal analyses were performed according to the standard certified analytical quality control procedure. Accuracy and precision of the results were verified by analysis of the reference materials (AGH S-1 – Polish soil, LGC). Organic matter content (expressed as Loss of Ignition) in the samples was estimated by ignition at 550°C for 4 hrs. Value of pH (1M KCl: water ratio, 1:5 v/v) was also measured.

RESULTS

The investigation results of the total concentration of heavy metals in soil and sand and pH values are shown in Table 2. The average lead concentration in the analized samples was 26.49 mg/kg, and the average cadmium content was 2.08 mg/kg. Some differences in the content of metals were noted not only between different playgrounds but also between sampling poins within a border of individual areas. Generally the highest concentration of these elements was revealed in the samples collected near the most traffic street – Okulickiego Street (point 1.4, Tab. 2) and traffic rondo closed to Andersa Street (point 8.3). Considering the distribution of metals along transects, it can be observed that concentration decreases with the distance from the main street. However this phenomenon is more noticeable for lead. The differences in the metal content at each of the sites are primarily due to the type of material found on the surface of the land. It is obvious that the higher content of Cd and Pb are present in soil than the sand.

The pH values vary from slightly acidic (pH 5.39) to slightly alkaline (pH 8.83).

DISCUSSION

The main objective of this study was to determine the content of Pb and Cd in the top layer of soil/sand profiles at the selected Cracow's playgrounds. Obtained data shows that in case of all samples, lead and cadmium are within accepted standards regulated by Regulation of the Ministry of the Environment of 9 September 2002 *On soil quality standards and Earth quality standards* (Dz. U. 2002 nr 165 poz. 1359) and within the limits adopted by the Institute of Soil Science and Plant Cultivation (Kabata-Pendias & Pendias 1995) in Poland (Tab. 3).

Table 3
Permissible concentrations of Cd and Pb in soils

Country	Permissible concentrations	Pb [mg/kg]	Cd [mg/kg]	References
Poland	Polish standards for soils	100	4	*Regulation of the Minister of Environment* (Dz. U. 2002 nr 165 poz. 1359)
	Limits by Institute of Soil Science and Plant Cultivation	50–100	5–10	Kabata-Pendias & Pendias (1999)
Brasil	The prevention value	72	1.3	CETESB (São Paulo) (2005)
Dutch	Target standards values	85	0.8	Dutch Target and Intervention Values 2000
Norway	Quality criteria for soil in day-care centers, playgrounds and schools	100	10	Norwegian Institute of Public Health (TA-2263/2007), Alexander (2006)
	Safe guideline concentrations	60	1.5	Geological Survey of Norway (2009)
Australia	Threshold values in Queensland	300	40	Department of the Environment (1998)
	Health investigation levels for soil contaminants	300	20	National Environment Protection (Assessment of Site Contamination) Measure 1999 (2013)
Canada	Soil Quality Guidelines for the Protection of Environmental and Human Health	140	10	Canadian Council of Ministers of the Environment (1999)
Sweden	Normative values	80	0.4	Swedish the Environmental Protection Agency, Naturvårdsverket (1997)
Serbia	Normative values	85	0.8	Marjanović et al. (2009)

There are several factors related to the fact that concentrations of heavy metals on selected playgrounds were lower than anticipated. One of them is the vegetation present in the direct vicinity of the examined soil. The amount of heavy metals could have been smaller due to their accumulation in plants, which in consequence reduces the amount of metal deposited in the soil. Additionally, the lead content in the tested soil that was not exceeding standards may be due to the introduction of mandatory use of unleaded petrol. In addition, samples of sand which were analyzed may exhibit a lower concentration of heavy metals due to the systematic exchange of this material on playgrounds.

Providing characteristics of heavy metal concentration in municipal soil is a challenging task because of significant impact of sorption properties, pH, redox potential, soil cover properties and its lifetime. Most studies indicate a high load of soils on roadside areas. However it cannot be forgotten that these areas have been under intense construction for several years. This involves significant material removings in the soil profile. Soils are often less polluted at a greater depth than the layers above. As a result of such action, soils are contaminated less than initially anticipated (Greinert 2008). A short-term suggested solution for the soil contamibnation is re-mixing of deeper and cleaner soils layers awith shallower, more contaminated layers. This concept will make soil monitoring even more difficult. It can also cause change of physico-chemical conditions that can lead to mobilization of metals.

By analysing the obtained results (Tab. 2), the following trend has been noted: the closer proximity of the playground in relation to the road, the greater soil contamination is. But as we all know elevated content of the heavy metal is not limited only to large busy streets, but also to smaller local roads, access roads and car parking lots, which are located in close proximity to the analyzed playgrounds. Based on research results, it can be concluded also that the heavy metals are present in higher concentrations in the soil than in sandy material. This may be related to sand replacement contrary to the soil, which is unlikely to be subject of frequent replacement and the role of organic substances and clay minerals in binding metals.

Disturbing is the fact that children playgrounds are ofen placed in the close vicinity of increased traffic flow and parking lots. Among the numerous scientific papers on soil pollution with heavy metals and other toxic substances, there are few publications on material from urban soils, especially on the playgrounds in Poland. This subject has been recognized and disussed as potentially serious health risk for children in other coutries. Comparing degree of contaminantion of playground soils in Cracow with other types of land uses is difficult to be implemented due to the small amount of researches on this subject. Limited studies conducted in Cracow's parks indicate that the concentration of Pb in the parks located in the city centre was 65.2 mg/kg and for Cd it was 1.92 mg/kg, respectively. In contrast, on the outskirts of the city, the concentrations were 41.8 mg/kg for lead and 1.29 mg/kg for cadmium, respectively (Baran et al. 2010). The content of cadmium and lead was also estimated in the sand collected from sandboxes located on playgrounds in housing estates and municipal urban parks (Jasiewicz et al 2009). In this research no case of exceeding the values of heavy metals permissible for urbanized areas (group B), as described in the Polish regulation of the Minister for Environment, was revealed (Tab. 3). The most complex project on this aspect was the study of children's exposure to heavy metals in soils at playgrounds, sports fields, sandpits and nursery grounds in the area of Upper Silesia. These studies have indicated concentrations of heavy metals above regulating norms, suggesting possible health risks for children. For example, samples showed a lead content between 10 and 20-fold excess of the norm. Cadmium content exceeded this value 5-fold and 9-fold, respectively. As for the source of these pollutants, mining industry, especially non-ferrous metal ores that led to the dispersion in an enormous quantity of heavy metals can be mentioned. Despite the technological changes in this industry, aimed at reducing emissions, the problem of environmental pollution with heavy metals is still among priorities related to human health's issue. The results highlight the need to monitor the content of metals in soils and to apply preventive measures in the form of periodic replacement of sand in sandboxes as well as health education (Nieć et al. 2013).

The problem of urban soil contamination with heavy metals is very well known around the world. This has been investigated by the numerous studies conducted in many countries, p. ex.: in Spain (Madrid et al., 2002), Italy (Imperato et al. 2003), China (Chen et al. 2005), the UK (Johnson et al. 2011) and many others. In terms of urban soils, it should be mentioned that it is really important to focus scientific research on soils located in playgrounds. Moreover, people have become more conscious and they pay attention to several ongoing research investigations, for example those conducted in Madrid. The results have shown that the level of elements in sandy soils is not much higher than similar levels in the natural background soil in the region and they are much lower than in other cities. For example, the concentration of Pb in the sand ranged from 10 to 106 mg/kg, and Cd from 0.1 to 0.5 mg/kg. For comparison, in Hong Kong Pb concentration ranged from 1.8 to 263 mg/kg, and Cd from 4.6 to 13.7 mg/kg. This fact is probably due to the periodic replacement of playground sand. However, despite the lack of concentrations exceeding regulated norms exposure to heavy metals has been described as posing considerable health risks. This result is a consequence of high levels of exposure of children staying at playgrounds in Madrid, children who live in warm, dry climate and spend a long time outside where the risk of exposure to heavy metals contained in the soil is larger (De Miguel et al. 2007). Similar studies were also carried out in Sweden in Uppsala. The average lead content there was 25.5 mg/kg and for cadmium – 0.21 mg/kg. Normative values are not exceeded, which soils in Sweden (Swedish the Environmental Protection Agency) (Tab. 3) are in the case of Pb 80 mg/kg Cd 0.4 mg/kg. Among surrounding areas there were industrial areas, the city center and the road, but the expected impact on soil pollution was not noticed. An increasing trend of metal concentrations as compared to older playgrounds have been, however, identified (Ljung et al. 2006). Soil survey of green areas and parks were also performed in Serbia (Belgrade), where special attention has been paid to areas where children spend their free time actively. Higher contamination level has been observed: the average of Pb content is 299 mg/kg, and Cd – 1.8 mg/kg, wherein the limit value is 85 mg/kg for Pb and 0.8 mg/kg for Cd (Tab. 3) (Marjanović et al. 2009). Children's play areas are very strictly regulated by the State of Queensland, Australia (Tab. 3) (Department of the Environment 1998, Imray & Langley 2001). Consequently, urban authorities have taken steps to limit metal contamination in such public recreational spaces (Mostert et al. 2010). But threshold values for Pb and Cd are less restricted than Polish standards. Whatever the results are, in each of the places where the assessment addresses the soil contamination with heavy metals, it was found that each elevated concentrations of toxic elements may have a negative impact on children's health. This occurs through contact with contaminated soil and its gradual accumulation in human body.

Soil found on playgrounds may come from various sources. This may be a native soil, which in large cities is often anthropogenically transformed. It occurs naturally in the area or it is imported from neighboring areas to complement topography. This type of material is often most polluted, as it may accumulate the contaminants for considerable length of time and not be replaced for a long time. Another type of soil encountered in these locations is a garden soil, which is particularly used for planting vegetation for aesthetic purposes. The material, which often dominates in the areas meant for children's playgrounds is sand, which can be found not only in sandboxes, but also near the equipment used to leisure activities. Sand typically contains lower concentrations of pollutants, as it should be replaced at intervals to be clean and safe for users (Ottesen et al. 2009). Analysis of the chemical data obtained from the playgrounds in public parks in south-east Queensland indicated that most metals occurring in the surfaces of these playgrounds are derived from rocks occurring in the area. Other sources include various vehicular emissions (18.7%) and paints, probably derived from playground equipment (8.4%) (Mostert et al. 2012).

CONCLUSION

The content of heavy metals in the surface ground layer located in the childrens' playgrounds in Cracow varies widely. Concentrations of lead and cadmium are from 6.80 to 54.04 mg/kg and from 1.60 to 2.61 mg/kg, respectively. Research has shown that soil contamination by heavy metals can have significant impact done by pollution from road traffic. They come from large, busy streets, but also from car parking lots, smaller roads and housing real estates. Such pollution can include byproducts of vehicle's corrosion, brake pad wear, tire treads, engine operations, and road surfaces. Lead and cadmium in the examined in soil and sand samples do not exceed the regulated limit values. It is possible that it is due to the withdrawal of leaded petrol. However, this should not lead to the idea to give reduced monitoring efforts for these elements in the environment. Permanent concern of the children's safety on playgrounds is required. There is a number of important steps that should be implemented to prevent future pollution and provide clean soil inside nurseries and playgrounds. Sand and soil in these places should be replaced at certain intervals. Of course, supplied material must be clean and its parameters should be documented by toxicological studies, including the presence of heavy metals. Moreover, during the renovation works related to playground objects, several special precautions should be undertaken to prevent from penetrating construction materials to the soil. For example, soil covers can be provided to avoid the dispersion of waste fragments. Soil material should be monitored by conducting appropriate research. None of the results can be underestimated, especially those that in excess of the standard norms. To sum up, it is worth to highlight that there is no chance to have clean environment without clean soil. It does not only impact children who "eat their own playground" (Greinert 2008) but also complex food chains – from the soil by vegetables, fruits, herbs, animals to the human body.

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