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ASSESSMENT OF CHEMICAL COMPOSITION AND SANITARY STATE OF SAND IN SELECTED SANDBOXES IN KRAKOW

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Abstract

The aim of the research was to assess the chemical composition and sanitary state of sandboxes in Krakow. Samples of sand were collected from 42 sandboxes located on playgrounds in housing estates and municipal (urban) parks. In the samples the following were determined: reaction, organic matter and the content of total and soluble forms of several elements. The sand in the analyzed sandboxes had highest content of Zn, while the concentrations of other metal appeared in the following decreasing order: > Pb > Cr > Ni > Cu > Cd (total forms) and Zn > Pb > Cu > Ni > Cr > Cd (soluble forms). The highest potential for ingesting heavy metals by humans due to accidental consumption of sand was found for Zn, followed by Pb > Cu > Ni > Cr > Cd. Children were at a higher risk of exposition to heavy metals than adults. On no occasion, the permissible limits of heavy metals for urbanized and built-up areas (group B) – set up by the regulation of the Minister for Environment on soil and earth quality – were exceeded. The same applies to the threshold levels of contaminants established for soils polluted by man-made sources. However, the sandboxes were found to be in poor sanitary conditions.

Key word: heavy metals, sanitary condition, sandbox, children, environmental hazard.

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OCENA SKŁADU CHEMICZNEGO I STANU SANITARNEGO PIASKU W WYBRANYCH PIASKOWNICACH NA TERENIE KRAKOWA

Abstrakt

Celem badań była ocena składu chemicznego i stanu sanitarnego piasku w wybranych piaskownicach na terenie Krakowa. Próbki piasku pobrano z 41 piaskownic znajdujących się na osiedlowych placach zabaw oraz w miejskich parkach. Oznaczono: odczyn, materię organiczną oraz zawartość form całkowitych i rozpuszczalnych w 1 mol $HCl \cdot dm^{-3}$ wybranych pierwiastków. Analizowane piaskownice zawierały najwięcej cynku, a poziom metali malał w następującej kolejności > Pb > Cr > Ni > Cu > Cd (formy całkowite) oraz Zn > Pb > Cu > Ni > Cr > Cd (formy rozpuszczalne). Największe potencjalne pobranie metali ciężkich w wyniku przypadkowego spożycia piasku wykazano dla Zn, a następnie Pb > Cu > Ni > Cr > Cd. Grupą bardziej narażoną na szkodliwe działanie metali ciężkich są dzieci niż dorośli. W żadnym przypadku nie stwierdzono przekroczenia zawartości dopuszczalnych metali ciężkich dla terenów zurbanizowanych i zabudowanych (grupa B), biorąc pod uwagę rozporządzenie Ministra Środowiska dotyczące standardów jakości gleby i jakości ziemi oraz granicznych wartości dla gleb zawierających zanieczyszczenia pochodzenia antropogenicznego. Ogólnie stwierdzono zły stan mikrobiologiczny badanych piaskownic.

Słowa kluczowe: metale ciężkie, stan sanitarny, piaskownice, dzieci, narażenie środowiskowe.

INTRODUCTION

The relationship between the level of urban environment pollution and some direct health effects on people dwelling in areas directly exposed to immediate influence emission of toxic substances is well known. Pollution raises concern especially about the state of health and development of children (BIESIADA et al. 2006). Children are most sensitive to the negative effect of most chemical and biological pollutants present in the environment (DUTKIEWICZ et al. 1982, KULKA 2004, FRANCISZEK et al. 1990). Children's exposure to environmental pollution in urban areas is strongly connected with their place of residence, localisation of playgrounds, nursery schools and children's behaviour, for example putting dirty hands and toys to the mouth or ignoring rules of hygiene (KULKA 2004).

Heavy metals comprise strongly toxic elements (lead, cadmium or mercury), whose excessive presence is undesirable. Particularly toxic elements tend to accumulate in parenchymous organs, primarily in the liver, kidneys or pancreas, and under prolonged exposure also in bones and brain tissue (lead) and in hair bulbs (cadmium) (KONDEJ 2007, JAKUBOWSKI et al. 2000). Lead and cadmium disturb many metabolic processes, particularly blood formation or functions of the nervous systems (MARZEC 2006). The influence of these metals on a child's organism is often described as deceitful because the effects are usually far-reaching and may appear as disturbances in the mental development, which affects the future state of health and life. Beside chemical pollution, microbiological contamination poses a grave hazard to human health, often causing food poisoning, allergies, upper respiratory system diseases or skin lesions (OLAŃCZUK-NEYMAN 1992, ZMYSŁOWSKA 2003). Numerous toxicological investigations conducted in cities demonstrated that the main way of introducing pollutants to a child's organism is the digestive system. Among sources of pollutants other than food, sand in sandboxes, dust deposited on the ground, dirt on hands and dust at home have the greatest share (KULKA 2004, PIOŚ 1993, KONDEJ 2007). According to DUTKIEWICZ et al. (1982), up to 50-70% of lead and cadmium ingested by a child's organism may originate from these sources.

Considering the above information, the present research has been conducted to assess the chemical composition and sanitary state of sand in selected sandboxes in Krakow.

MATERIAL AND METHODS

The investigations were conducted in the spring of 2008. Samples of sand were collected from 41 sandboxes located in housing estates and parks (Table 1). Sand was taken from many points in each sandbox and the collected samples were then mixed to obtain a mean sample. These were subjected to chemical and microbiological analyses. Prior to the chemical analysis the material was dried at room temperature. The following assessments were made in the sand samples: pH in 1 mol $KCl \cdot dm^{-3}$, organic matter using Tiurin method and the contents of macroelements and heavy metals. Total element contents were determined after hot mineralisation in a mixture of HNO_3 and $HClO_3$ acids, whereas soluble forms of heavy metals were determined in 1 mol $HCl \cdot dm^{-3}$. Concentrations of elements in the solutions were assessed using inductively coupled plasma atomic emission spectroscopy (ICP-EAS) on a JY 238 ULTRACE apparatus (Jobin Von Emission). Total nitrogen was determined using Kjeldahl distillation method. Potential uptake of heavy metal in case of accidental sand swallowing by children was assessed. Micro-

Table 1

Sample collection sites of the sand from sandboxes

Parks and squares	Decjusza, Jordana, Sikorskiego
Streets, Avenues	Bydgoska, Wysłouchów, Straszewskiego, Mazowiecka, Aleksandry, Witosa Przychodnia, Strzelców, Lublańska, Młyńska, Fiołkowa, Medweckiego, Kłosowskiego, M. Dąbrowskiej, Bohaterów Września, Majora, Młodej Polski, Rejmonta, Podchorążych, Grenadierów, Łokietka, Pużaka, Kozłówek, Nowosądecka, Seweryna, 29 Listopada
Housing estates	Niepodległości, Teatralne, Górali, Sportowe, Szkolne, Hutnicze, Willowe, Na stoku, Piastów, 1000-Lecia, Oświecenia

biological analyses were conducted by means of serial dilutions. Dilutions of the tested material prepared in physiological salt solutions were placed on media. After an appropriate period of incubation culture colonies with features characteristic for individual groups were counted. The test was conducted in three replications, the results were averaged and expressed as in the number of colony forming units (CFU) per 1 g of soil. The following were counted in the samples: total saprotrophic bacteria, total moulds, coli group bacteria, *Salmonella* bacteria, enterococci, staphylococci and *Clostridium perfringens* anaerobic spore-forming bacteria (Polish Standards: PN-Z--19000-1:2001, PN-Z-19000-2:2001, PN-Z-19000-3:2001, OLAŃCZUK-NEYMAN 1992).

RESULTS AND DSICUSSION

The sand samples collected from the analyzed sandboxes were alkaline in reaction, with the pH values ranging from 7.36 to 8.17. Organic matter content fluctuated between 1.80 and 6.80 $g \cdot kg^{-1}$ (Table 2). The highest content of organic matter was in the sand from the sandbox located in Kłosowskiego Street, followed by the samples gathered in Wysłouchów St., Straszewskiego St., M. Dąbrowskiej St. and the Górali Housing Estate.

The analyses revealed moderate diversity in the content of macroelement depending on the location of sandboxes (Table 2). The largest differences occurred for nitrogen and magnesium, while the smallest ones concerned sodium. Regarding the macroelements, the tested sand samples contained the greatest amounts of calcium, followed by magnesium > potassium > phosphorus > nitrogen > sodium. The highest contents of biogenic elements, i.e. nitrogen and phosphorus, was found, like for organic matter

Table 2

Some parameters of chemical composition of the sand ($g \cdot kg^{-1}$)

Parameter		Mean	Median	Min.	Max.	SD*	V(%)
pH	KCl	7.93	7.97	7.06	8.17	0.20	2.52
Organic matter	$g \cdot kg^{-1}$	3.30	2.90	1.80	6.80	1.10	33.33
N-total		0.03	0.02	0.004	0.17	0.03	93.33
Phosphorus	$g \cdot kg^{-1}$	34.52	28.75	4.68	88.75	17.90	52.09
Calcium		1209.3	1167.5	209.0	3575.0	645.2	53.35
Magnesium		299.5	255.0	136.3	940.0	170.4	56.90
Potassium		117.0	100.0	59.25	337.5	61.14	52.26
Sodium		27.96	24.15	15.05	68.00	10.99	39.31

*standard deviation

content, in the sandbox in Kłosowskiego St., which was also the most abundant in organic matter. Potassium, magnesium and sodium were the most abundant in the sandbox in Górali Housing Estate, whereas the content of calcium was the highest in the sandbox in Wysłouchów St.

The content of total and soluble forms of heavy metals is presented in Table 3. Both forms in which the metal occurred in the sand samples from individual sandboxes were highly diverse, as evidenced by high variation coefficients (Table 3). The greatest variation of the total form (V = 97.87%) was assessed for cadmium and soluble form for lead (V = 101.65%). The least diversity was determined for copper (V = 69.71%) and cadmium (V = 61.74). As for the heavy metals, the sandboxes contained the greatest quantities of zinc, while the other elements appeared in the quantities put in the following decreasing order: >Pb >Cr >Ni >Cu >Cd (total forms) and Zn >Pb> Cu >Ni >Cr >Cd (soluble forms). The analysis of 1 mol $HCl \cdot dm^{-3}$ soluble forms revealed that soluble zinc constituted 66% of the total form, copper 62%, nickel 13%, chromium 7% and lead 64%. Cadmium prevailed as a soluble form in all the samples. It is common knowledge that acid pH increases solubility of heavy metals. Thus, we could conclude that the reaction was not a factor causing higher solubility of heavy metals in the tested sand samples as their pH value was high.

Table 3

Content of heavy metals in the sand ($mg \cdot kg^{-1}$)

Metal	Mean	Median	Min.	Max.	SD*	V(%)
Total forms						
Zinc	66.24	57.75	7.10	210.0	52.86	79.80
Copper	1.27	1.00	0.65	4.95	0.88	69.71
Nickel	1.72	1.23	0.73	6.98	1.43	83.23
Lead	13.69	9.18	1.83	46.75	12.77	93.24
Chromium	2.28	1.83	1.00	13.75	1.98	87.13
Cadmium	0.08	0.05	0.00	0.30	0.05	97.87
Soluble forms						
Zinc	39.89	28.60	0.52	147.0	38.07	95.45
Copper	0.79	0.49	0.03	2.94	0.78	98.59
Nickel	0.22	0.11	0.00	1.41	0.30	97.78
Lead	8.81	5.44	0.18	33.40	8.96	101.65
Chromium	0.16	0.11	0.04	0.52	0.11	66.09
Cadmium	0.14	0.13	0.03	0.48	0.08	61.74

*standard deviation

The highest content of total forms of the analyzed metal was found in the sand from the sandboxes situated in the following locations: Grenadierów St. (Zn), Seweryna St. (Cu), Bydgoska St. (Cr) Górali Housing Estate (Ni) and Młodej Polski St. (Pb and Cd). As for the the soluble forms, the highest levels were found in the sand samples collected from the sandboxes in Grenadierów St. (Zn, Pb), Bydgoska St. (Cu), Kłosowskiego St. (Ni, Cr) and in Decjusza Park (Cd).

According to KABATA-PENDIAS et al. (1995), the limit values of heavy metals in soils containing anthropogenic pollutants are as follows: 150 mg Zn; 25 mg Cu; 100 mg Cr; 70 mg Pb; 1 mg Cd$\cdot$kg^{-1}. On the other hand, the Regulation of the Minster for Environment (2002) on the quality standards of soil and earth allows the following concentrations of heavy metals in the top layers of build-up and urbanized grounds (group B): 300 mg Zn; 150 mg Cu; 100 mg Ni and Cr; 100 mg Pb and 4 mg Cd$\cdot$kg^{-1}. According to these criteria In the sand samples, the permissible levels of heavy metals were not exceeded in the analyzed sand samples.

The uptake heavy metal by children and adults after accidental swallowing of sand was calculated. Accidental sand swallowing happens mainly to children aged 1-6, who frequently play in a sandbox or put dirty hands or toys to their mouth. The literature states that a daily consumption of soil in this age group is 200 mg$\cdot$d^{-1}, compared to 100 mg of soil$\cdot$d^{-1} among children above 6 years old, and 60 mg$\cdot$d^{-1} for adults (BIESIADA et al. 2006). The absorbed dose [mg$\cdot$(kg b.w.$\cdot$day)$^{-1}$] of individual metals was computed according to the following formula (SZCZEPANIEC-CIĘCIAK, SZYMCZAK 1995, SZYMCZAK, SZESZENIA-DĄBROWSKA 1995):

$$D = C \cdot \frac{\mathrm{WK}}{\mathrm{MC}} \cdot \frac{\mathrm{CN} \cdot \mathrm{DN}}{T},$$

where:

- C – concentration of a chemical substance in individual environmental medium (mg$\cdot$kg-^{1} of soil);
- WK – the length of contact with an individual environmental medium per time unit (mg of soil$\cdot$d^{-1});
- CN – frequency of exposure (daily 350 days);
- DN – the length of exposure period (6 years – children, 70 years – adults);
- MC – body weight (children below 6 yrs. – 15 kg, adults – 70 kg);
- T – averaging period, usually assumed as 6 (70 years)$\cdot$350 days a year

As may be seen from this formula, quantities of heavy metals ingested by children and adults depend primarily on the content of a given element in the sand and the individual's body weight. Amounts of heavy metals ingested by children aged 1-6 years and adults due to accidental swallowing of sand are gathered in Table 4.

Table 4

Uptake of heavy metals by children (1-6 years) and adults [μg·(kg·d)$^{-1}$]

Metal	Group	Mean	Median	Min.	Max.
Zinc	children	0.53	0.38	0.007	1.96
	adults	0.03	0.02	$4\cdot10^{-4}$	0.13
Copper	children	0.01	0.007	$4\cdot10^{-4}$	0.039
	adults	$7\cdot10^{-4}$	$4\cdot10^{-4}$	$9\cdot10^{-5}$	0.002
Nickel	children	0.003	0.001	$4\cdot10^{-4}$	0.019
	adults	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$9\cdot10^{-5}$	0.001
Lead	children	0.12	0.07	0.002	0.44
	adults	0.007	0.004	$1.5\cdot10^{-4}$	0.03
Chromium	children	0.002	0.001	0.001	0.007
	adults	$1.4\cdot10^{-4}$	$9\cdot10^{-5}$	$3.4\cdot10^{-5}$	$4.4\cdot10^{-4}$
Cadmium	children	0.002	0.0017	$7\cdot10^{-4}$	0.006
	adults	$1.2\cdot10^{-4}$	$1.1\cdot10^{-4}$	$9\cdot10^{-5}$	$4\cdot10^{-4}$

On the basis of the data in Table 4, it was found that children aged 1-6 years take up over 90% more heavy metals than adults due to accidental swallowing of sand. Obviously, children are more sensitive than adults to effects produced by heavy metals because of their from slower excretion process, smaller body weight and weaker resistance to environmental poisons. The greatest potential uptake, both by children and adults, was demonstrated for Zn, followed by Pb >Cu >Ni >Cr >Cd (Table 4, Figure 1).

Among the analyzed sandboxes, the most severe hazard of heavy metals entering a child's organism via accidental sand swallowing was attributed to the sandbox in Grenadierów St. (Zn), Bydgoska and Wysłouchów St. (Cu), Łokietka and Grenadierów St. (Pb), Kłosowskiego St. (Ni and Cr) and in Decjusza Park.

The evaluation of the sanitary state of the sand samples is presented in Table 5. Considering the total number of saprotrophic bacteria, it was found that only 15% of the investigated sandboxes provided clean sand samples, whereas 75% of sandboxes contained polluted or strongly polluted sand. The lowest number of saprotrophic bacteria, up to 10^6 (CFU)·g^{-1} of sand, was detected in the sandboxes localized at the following housing estates: Sportowe, Hutnicze, Na Stoku, Piastów and Bohaterów Września. Strongly polluted sand was found in the sand samples collected from the sandboxes in Reymonta St., Podchorążych St. and in Decjusza Park. No serious hazard posed by the total amount of moulds and yeasts was attributed to most of the sandboxes, because several thousands of colony forming units per gram is normal soil microflora. Coli group bacteria and enterococci are indicators

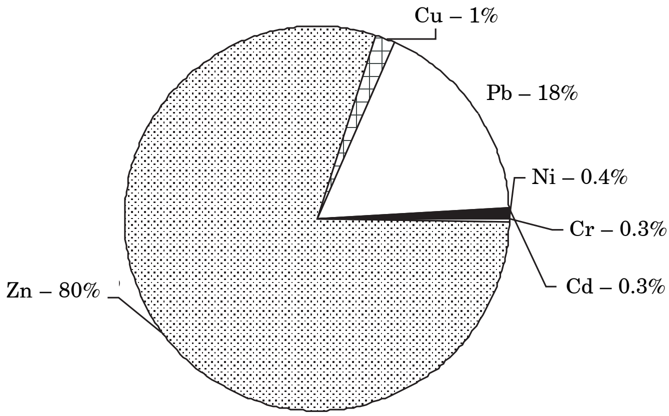

Fig. 1. Percentages of heavy metals in the total sum of their amount ingested by children (1-6 years) and adults

Table 5

Sanitary assessment of the sand

Amount ($CFU \cdot g^{-1}$)	Mean	Range	*Assessment of the sand
Saprotrophic bacteria	$3.1 \cdot 10^6$	2.10^5-$9.6 \cdot 10^6$	clean up to106, moderately polluted: 1-2.5 $\cdot 10^6$, polluted: 2.5-10 $\cdot 10^6$, strongly polluted: > 10 $\cdot 10^6$
Moulds	2388	10-15 000	if present in big amounts, they evidence presence of organic matter necessary for their development; mould and yeast should not be present in sand
Yeasts	718	0-4000	
Coli group bacteria	3046	10-33 600	their presence denotes biological contamination evidencing fecal pollution
Enterococci	15	0-440	
Salmonella	25	0-370	absent – the sand is clean
Staphylococci	74	0-510	no standards available
Count	median	range	sand assessment
Coli group bacteria	10^{-2}	10^{-4}-10^{-1}	clean up to 10^{-2} polluted < 10^{-2}
Enterococci	0	0-10^{-2}	
Clostridium perfringens	0	0-10^{-1}	clean up to 10^{-3} polluted < 10^{-3}

* The assessment by ZMYSŁOWSKA (2003)

of the sanitary state of soil (sand), since their presence suggests some faecal pollution in the nearest past. The present study has demonstrated that the sand in 59% of the sandboxes was free from coli group bacteria but 41% of the sandboxes were polluted. The lowest count, i.e. 10^{-4} (strongly polluted sand) was revealed in the sandboxes in Decjusza Park, Bydgoska St. and Seweryna St. As regards enterococci, the sand in 98% of the sandboxes proved clean, with these bacteria occurring only in the sandbox in Seweryna St. *Clostridium perfringens* anaerobic spore forming bacteria are also an indicator used for assessment of the sanitary condition of soil (sand), as their presence proves former faecal contamination. In this study, spore forming bacteria were not found in any of the analyzed sandboxes.

In conclusion, metals and microbiological contamination may be a cause of acute and chronic poisonings. Acute poisoning is usually caused by exposure to high pollutant concentrations, whereas chronic poisoning results from repeated or continuous exposure leading to accumulation of a toxic substance in the human organism. Chronic exposure to heavy metals and harmful microorganisms may occur in a workplace or at home but may be also connected with environmental pollution (KONDEJ 2007, JAKUBOWSKI 1997), as was demonstrated in the present paper. It should be emphasized that health effects of exposure to environmental pollutants raise concern among societies in many countries and the problem is one of the top priorities of social health policy, raised in numerous conferences and reports (BIESIADA et al. 2006, SMITH et al. 1995). Heavy metals in the analyzed sand might originate from metal bearing dusts generated by various processing plants operating in Krakow but also from very heavy traffic in this town. On the other hand, microbiological sand contamination was caused by dogs and other animals leaving their excrements and excretions in sandboxes. Due to their high sensitivity and close contact with environment, children require special protection against environmental pollution. Therefore, it is necessary to undertake preventive and remedial measures aimed at reducing chemical and biological contamination in individual natural environment media through improvements in the sanitary and hygienic conditions at home, in nursery schools and on playgrounds (KULKA 2004).

CONCLUSIONS

1. The sandboxes contained the highest amounts of zinc and the level of the other heavy metals was declining in the following order >Pb >Cr >Ni >Cu >Cd (total forms) and Zn >Pb >Cu >Ni >Cr >Cd (soluble forms).

2. The highest potential uptake caused by accidental sand swallowing was revealed for Zn, followed by Pb > Cu >Ni >Cr >Cd. Children are most prone to harmful effects of heavy metals.

3. No case of exceeding the values of heavy metals permissible for urbanized and built-up areas (group B) – as stated in the regulation of the Minister for Environment on soil and earth quality standards or the limit values or soils containing anthropogenic pollutants – was revealed.

4. Generally, the sandboxes analysed were found to be of poor microbiological state. The worst microbiological contamination occurred in sandboxes situated in the following locations: Młyńska St. , Nowosądecka St., Seweryna St. and 29 Listopada Ave., followed by Bydgoska, Aleksandry, Witosa, Reymonta, Podchorążych streets, as well as Niepodległości and Teatralne housing estates and Decjusza Park.

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