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APPLICATION OF GEOCHEMICAL INDICES FOR ASSESSING LEAD AND CADMIUM CONTAMINATION IN RECREATIONAL PARKS OF THE CITY POZNAN

ZASTOSOWANIE WSKAŹNIKÓW GEOCHEMICZNYCH DO OCENY ZANIECZYSZCZENIA OŁOWIEM i KADMEM W REKREACYJNYCH PARKACH POZNANIA

Abstract: Recreational Parks (RP) of the city Poznan were investigated in October 2009 in order to evaluate contamination state of their soils by lead and cadmium. From the Recreational Park Marcinkowski – RPM, Recreational Park Solacki – RPS, Recreational Park Wodziczko – RPW and Recreational Park Piatkowo – RPP the soil samples were collected at two depths, ie 0–10 and 10–20 cm, in the quantity of 36, 52, 32 and 34, respectively. The total content of Pb and Cd was determined in these samples, as well as some their selected physical and chemical properties. Detailed assessment of the soil contamination state was undertaken on the basis of different indices such as geochemical accumulation index (I_{geo}), factor (C^i_f) and degree (C_{deg}) of contamination.

The evaluation of soils made by applying Pb-I_{geo} has shown that parks may be ranged as follows: RP Piatkowo < RP Solacki < RP Wodziczko < RP Marcinkowski. The concern and threat related to the impact of Pb on humans requires more restrictive limits of content, hence geochemical background (GB) values as reported by Czarnowska [20] may be considered as more adapted for protecting from potential health hazards. In the case of cadmium, the Cd-I_{geo} based contamination assessment allowed to organize parks accordingly: RP Piatkowo < RP Marcinkowski < RP Solacki < RP Wodziczko. Cadmium contribution in the overall contamination (C_{deg}) changed as did the Cd-I_{geo} indices. This was mostly reflected in the RPs Wodziczko and Solacki and intermediately in the RP Marcinkowski. On the basis of the performed geochemical evaluation of soil Recreational Park Piatkowo is the sole to be classified as free from Pb and Cd contamination threat.

Keywords: recreational parks, Poznan, Pb, Cd, soil, geochemical indices, contamination factor and degree

As a number of people living in towns and cites has increased, larger human populations are being exposed to the negative effects of the urban environment. Sources of pollution vary according to specific industrial, geographical, geological, climatic and sociological conditions, but in all cases road traffic is one of the most important ones and it influences all parts of the environments [1, 2]. The chemistry of pollutants,

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including metals, in urban soils is far from understood, and several aspects of the dynamics of metals pollutants in urban soils need further study. In the last few years, soils in many cities have been studied [3–11].

In pollution research soil is mainly considered as a medium of plant growth and agriculture production but in urban conditions, changes in the chemical nature of the soil may lead to adverse interactions with building materials, toxicity to soil flora and fauna and influence exposure of the population particularly young children, to toxic substances. Among the various toxic elements in the urban environment, lead and cadmium are considered to be the most hazardous. In the case of lead, its harmful effects are still debated, some reports have presented evidence of its neurotoxicity, especially for children [12–15].

Pollution of soil by potentially toxic metals is often assessed on the basis of total metal concentrations. However, many forms of metals are strongly held in soils and generally become immobile, although several factors (changes in pH or redox conditions, soluble organic complexing agents, etc) may mobilize such forms [16–18]. Several approaches have been used for evaluating the degree of heavy metals contamination in different ecosystems. They are commonly based on the amounts of metals extracted by applying specified soil tests or on the elaboration of phytotests, which are expected to confirm or not metal concentrations extracted by soil tests [19–22]. Indices-based assessment of soils contamination by heavy metals seems to be a useful geochemical method, since they simplify and reorganize quantitative data into unitless parameters [10, 23–25].

Therefore, the current work is intended to focus on indices, such as the index of geoaccumulation (I_{geo}), contamination factor (C_f) and degree of contamination (C_{deg}) for evaluating the potential contamination by Pb and Cd of soils of selected Recreational Parks of the city Poznan.

Materials and methods

Soil samples were collected at two depths, 0–10 and 10–20 cm, in October 2009 at four Recreational Parks (RP) within the city Poznan. This sampling procedure was adopted in order to outline the possible effect of maintenance practices (lawn and paths establishment) on metal levels. These are Recreational Park Marcinkowski – RPM (36 samples), Recreational Park Solacki – RPS (52 samples), Recreational Park Wodziczko – RPW (32 samples) and Recreational Park Piatkowo – RPP (34 samples). Details about physical and chemical analyses of soil materials are reported in the paper *Assessment of heavy metals contamination of selected Recreational Parks of the city Poznan*, this issue (Ecol. Chem. Eng. A 2011, 18(9–10), 1211–1217). Total contents of lead (Pb), and cadmium (Cd), (mean of 0–10 and 10–20 cm), were assayed by hot-digestion in *aqua regia* chemical test [26]. The indices-based assessment of the soils contamination state of these sites was undertaken throughout applying reference data [19, 20]. Specific developments are listed as under:

a) Index of geoaccumulation (I_{geo}). This index enables the assessment of heavy metal contamination by comparing current and preindustrial metal contents. It was originally used for bottom sediments [23], but may be applied for assessing soil contamination on the basis of the following equation:

$$I_{geo} = \log_{10} \frac{C_n}{1.5\,B_n} \tag{1}$$

where: C_n – the concentration of the element n in the pelitic sediment fraction (< 2 μm),
B_n – the geochemical background value in the fossil argillaceous sediment (ie, average shale),
1.5 – the constant allows for involving natural fluctuations in the concentration of a given substance in the environment and very small anthropogenic influences.

Seven classes of soil quality were suggested by Muller [23] on the basis of index of geoaccumulation value (Table 1).

Table 1

Classes of soil quality on the basis of index of geoaccumulation value [23]

Class	Value	Soil quality
0	$I_{geo} \le 0$	Practically uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

A modified method was applied in the current paper for the computations of the I_{geo} values and deals with the following details: C_n expresses the total content (mean values) of a given metal in the surface layer (ie 0–10 and 10–20 cm) of the tested soils, while B_n, the content of the same metal expressed as the *Background Level for Poland* (BLP) [19] and *Geochemical Background* (GB) [20]. These values are reported in Table 5.

b) Contamination factor (C_f^i) and degree of contamination (**C_{deg}**). Soil contamination was also evaluated by using indices such as the contamination factor (C_f^i) and the degree of contamination (C_{deg}) [24], which were computed on the basis of the below equation:

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \tag{2}$$

where: C_{0-1}^i – the mean content of metals from at least five sampling sites,
C_n^i – the preindustrial content of individual metals.

A modification was done and consisted of using the content of metals expressed as the Background Level for Poland (BLP) [19] and Geochemical Background (GB) [20]. Four categories have been suggested by Hakanson [24] (Table 2).

Table 2

Categories of contamination factor on the basis of C_f^i value [24]

Contamination factor	Description
$C_f^i < 1$	Low contamination factor
$1 \leq C_f^i < 3$	Moderate contamination factor
$3 \leq C_f^i < 6$	Considerable contamination factor
$6 \leq C_f^i$	Very high contamination factor

Moreover it should be mentioned that C_f^i is a single-element index. The sum of C_f^i for all studied metals yields the so-called contamination degree (C_{deg}) of the ecosystem and is represented by four classes (Table 3).

Table 3

The contamination degree (C_{deg}) of the ecosystem

Contamination degree	Description
$C_{deg} < 8$	Low degree of contamination
$8 \leq C_{deg} < 16$	Moderate degree of contamination
$16 \leq C_{deg} < 32$	Considerable degree of contamination
$32 \leq C_{deg}$	Very high degree of contamination

Computations were made by using the Excel® Sheet and simple statistical analysis by the Statgraphics Software facilities.

Results and discussion

The occurrence of lead and cadmium in elevated concentrations or in excess in the environment is being widely reported due to the harmful effects of these metals. In fact the determined amounts do not uniformly give a common consent in terms of direct or indirect awareness. The application of geochemical indices for classifying significantly disparate sites may be treated as a useful tool in this matter.

Data listed in Table 4 decidedly show the great heterogeneity in Pb and Cd contents (with standard deviation – SD values) in soils of Recreational Parks. These amounts as compared with the Background Levels for Poland (Pb_{BLP}) revealed that only the RP Marcinkowski may be considered as moderately contaminated by Pb, whereas when referred to the Geochemical Background (Pb_{GB}), the contamination state shifted even into very severe contamination/ pollution (case of RPs Marcinkowski, Solacki and Wodziczki). Cadmium contents appeared to be of great concern, since all were decidedly beyond both Cd_{BLP} and Cd_{GB}. Therefore, the application of geochemical-

-based indices for evaluating Pb and Cd contamination state of these parks may provide targeted information, whether we are facing a threat or a slight contamination.

Table 4

Total heavy metal content of soils within investigated Recreational Parks of the city Poznan (mean of 0–10 and 10–20 cm)

Metal	*RPM* (n = 36)[a]	*RPS* (n = 52)[b]	*RPW* (n = 32)[c]	*RPP* (n = 34)[d]
	$[mg \cdot kg^{-1}]$			
Pb	[α]56.4 ± 25.0[β]	32.0 ± 20.6	40.1 ± 18.2	13.0 ± 15.3
Cd	1.58 ± 0.42	2.12 ± 1.57	2.42 ± 1.58	0.87 ± 1.20
Reference values $[mg \cdot kg^{-1}]$				
Background Level for Poland[x]	Pb_{BLP}	40.0	Cd_{BLP}	0.65
Geochemical Background[y]	Pb_{GB}	9.8	Cd_{GB}	0.18

Recreational Parks: [a] – Marcinkowski, [b] – Solacki, [c] – Wodziczko, [d] – Piatkowo; [α] – Mean value; [β] – Standard Deviation; [x] – acc. to Kabata-Pendias et al [19]; [y] – acc. to Czarnowska [20].

Lead

Lead geoaccumulation indices (Pb-I_{geo}) indicated a contamination state, whose magnitude depended on the BLP and GB values exhibiting Pb-I_{geo} indices in the ranges from –0.85 to –0.08 and –0.24 to 0.53, respectively (Table 5).

Table 5

Geochemical indice (I_{geo}) values calculated for the investigated parks

Parameter	Metal	Recreational Park			
		Marcinkowski	Wodziczki	Solacki	Piatkowo
I_{geo}	Pb_{BLP}*	–0.08	–0.23	–0.36	–0.85
	Pb_{GB}	0.53	0.39	0.25	–0.24
	Cd_{BLP}	0.20	0.31	0.22	–0.23
	Cd_{GB}	0.75	0.87	0.77	0.33

* Explanations see Table 4.

These ranges fit the contamination class [23] extending mostly from < 0 to 1 and may be designated as practically uncontaminated in the case of BLP based Pb-I_{geo} to moderately contaminated for the GB. On the basis of these indices the contamination level of soils within parks follows the order, ie from the less contaminated up to the most: RP Piatkowo < RP Solacki < RP Wodziczko < RP Marcinkowski.

A specific evaluation of the overall contamination level was carried out throughout the degree of contamination (C_{deg}), (Table 6). Furthermore, a detailed estimation was undertaken by using contamination factors (C^i_f), which mean values allowed to classify [24] soils moderate contamination factor accordingly to BLP and GB values.

Table 6

Contamination factors and degrees for particular Pb of the investigated Recreational Parks for BLP and GB values*

Recreational park	Contamination factor (Range)			Mean	Share [%] of C_f^i to C_{deg}
Marcinkowski	Pb_{BLP}	C_f^i	0.96–2.63	1.41 ± 0.63	40
	Pb_{GB}		1.46–10.74	5.75 ± 2.55	
Wodziczko	Pb_{BLP}		0.31–2.17	1.00 ± 0.47	28
	Pb_{GB}		1.58–8.86	4.09 ± 1.94	
Solacki	Pb_{BLP}		0.10–2.47	0.80 ± 0.51	23
	Pb_{GB}		0.42–10.07	3.26 ± 2.10	
Piatkowo	Pb_{BLP}		0.05–2.34	0.33 ± 0.41	9
	Pb_{GB}		0.20–9.53	1.33 ± 1.69	
Degree of contamination (BPL) $\left[C_{deg} = \sum(C_f^{\text{Pb, Cd}})\right]$			1.42–11.03	3.54 ± 2.02	—
Degree of contamination (GB)			3.66–39.20	14.43 ± 8.28	

* Explanations see Table 4.

Three classes were operationally established, relatively to both values:

– Pb_{BLP}: only RP Marcinkowski exhibited a moderate contamination factor,

– Pb_{GB}: all parks represented a considerable contamination factor, except the RP *Piatkowo*, characterised by moderate contamination factor.

Importantly it should be observed, that the mean C_{deg}-based BLP and GB reference values varied from 3.54 to 14.43, respectively, describing decidedly a low degree (C_{deg} < 8) and moderate degree of contamination (8 < C_{deg} < 16) as suggested by Hakanson [24]. The overall share of Pb in the level of contamination of investigated parks decreased similarly to the Pb-I_{geo} indices. The impact of Pb in the bulk contamination was ca 26 % for the RP Solacki and Wodziczki, but raised up to 40 % in the case of the RP Marcinkowski. The last one is located in the city centre, hence reflected the direct anthropogenic origin of Pb. The re-evaluation of the degree of contamination revealed that the application of both reference values was found useful for such specific sites like city Recreational Parks. The concern and threat related to the impact of Pb to humans requires more restrictive limits, hence geochemical background (GB) values as reported by Czarnowska [20] may be considered as more adapted for protecting from potential health hazards [12, 14, 15, 17].

Cadmium

Indices of Cd geoaccumulation (Cd-I_{geo}) indicated general ranges varying from –0.23 to 0.87 of which the Cd-I_{geo} based BLP and RV values fluctuated accordingly: –0.23 to 0.31 and 0.33 to 0.87 (Table 2). Contamination assessment based on these indices may create some discrepancies related to the establishment of a proper Cd-I_{geo} class. Therefore, it could be reasonable to group both classes into one with a range varying from 0.20 to 0.87, ie, uncontaminated to moderately contaminated [23]. This outlines the cadmium contamination status, which seems to be of great concern, irrespective of the investigated parks and ranged in decreasing order as follows: RP Piatkowo < RP Marcinkowski < RP Solacki < RP Wodziczko. Interestingly, it may be observed, that this order is divergent from that established for Pb-I_{geo}.

Data listed in Table 4 deal with values of contamination factors (C_f^i) [24] and those related to the overall contamination degree (C_{deg}) accordingly to the reference values BLP and GB. The ecological specificity of cadmium resides in its enhanced mobility [27] and hence its contamination is easily disseminated in the environment. The RPs Solacki and Wodziczko undergo frequent and intensive maintenance activities involving among others the incorporation of compost-like materials for improving grasses and shrubs growth conditions. This may explain the position they occupy in these ranges in the case of cadmium. Changes observed in the case of the C_f^i indices reflect the contamination state, which varied proportionally with reference values. Then for the BLP [19], C_f^i values fluctuated within the range 1.34–3.72 implying the occurrence of a moderate to considerable contamination factor, whereas for the GB [20] based C_f^i evaluation, quite all indices (except the RP Piatkowo) exceeded the threshold, ie $6 < C_f^i$, indicative of a very high contamination factor. This concerns particularly the RPs Wodziczko and Solacki characterised by C_f^i amounting to 13.43 and 11.78, respectively, followed by the RP Marcinkowski, ie $C_f^i = 8.78$.

The overall contamination degree (C_{deg}) as suggested by Hakanson [24] exhibited significantly high (C_{deg}-based BLP) and exceptionally very high (C_{deg}-based GB) indices, amounting accordingly 10.75 and 38.82 (Table 7). The latter ones fitted the ranges $8 < C_{deg} < 16$ designated as moderate degree of contamination and $32 < C_{deg}$, ie very high degree of contamination.

Table 7

Contamination factors and degrees for particular Cd of the investigated Recreational Parks for BLP and GB values*

Recreational park	Contamination factor (Range)			Mean	Share [%] of C_f^i to C_{deg}
Marcinkowski	Cd_{BLP}	C_f^i	1.31–4.29	2.43 ± 0.65	23
	Cd_{GB}		4.72–15.50	8.78 ± 2.36	
Wodziczko	Cd_{BLP}		0.91–10.25	3.72 ± 2.49	35
	Cd_{GB}		3.28–37.00	13.43 ± 8.99	
Solacki	Cd_{BLP}		0.57–9.48	3.26 ± 2.54	30
	Cd_{GB}		2.06–34.22	11.78 ± 9.18	
Piatkowo	Cd_{BLP}		0.32–11.02	1.34 ± 1.95	12
	Cd_{GB}		1.14–39.78	4.83 ± 7.04	
Degree of contamination (BPL) $\left[C_{deg} = \sum(C_f^{Pb,Cd})\right]$			3.11–35.04	10.75 ± 7.63	—
Degree of contamination (GB)			11.20–126.35	38.82 ± 27.57	

* Explanations see Table 4.

Cadmium contribution in the overall contamination changed as did the Cd_{Igeo} indices. This was mostly reflected in the RPs Wodziczko and Solacki and intermediately in the RP Marcinkowski. Less concern related to Cd contamination may be observed in the case of the RP Piatkowo, where Cd and Pb direct contribution in the overall contamination share was quite similar. On the basis of the performed geochemical evaluation this park is the sole to be classified as free from any contamination threat.

Conclusions and statements

The assessment of the state of Poznan Recreational Parks contamination of soils by lead and cadmium undertaken by applying geochemical indices (I_{geo}, C^i_f and C_{deg}) has revealed the impact of anthropogenic pressure on these ecosystems. Data have shown, that on the basis of Pb based I_{geo} indices the contamination level of soils within parks follows: RP Piatkowo < RP Solacki < RP Wodziczko < RP Marcinkowski. Moreover it was suggested that the concern and threat related to the impact of Pb on humans requires more restrictive limits, hence geochemical background (GB) values as reported by Czarnowska [20] may be considered as more adapted for protecting from potential health hazards.

The cadmium contamination status of soils appears to be of great concern, irrespective of the investigated parks and represented the order: RP Piatkowo < RP Marcinkowski < RP Solacki < RP Wodziczko. Cadmium contribution in the overall contamination (C_{deg}) changed as did the Cd_{Igeo} indices. This was mostly reflected in the RPs Wodziczko and Solacki and intermediately in the RP Marcinkowski. On the basis of the performed geochemical evaluation Recreational Park Piatkowo soil is the sole to be classified as free from any contamination threat.

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ZASTOSOWANIE WSKAŹNIKÓW GEOCHEMICZNYCH DO OCENY ZANIECZYSZCZENIA OŁOWIEM i KADMEM W REKREACYJNYCH PARKACH POZNANIA

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Abstrakt: Rekreacyjne Parki (RP) miasta Poznań zbadano w październiku 2009 r. w celu oceny stanu zanieczyszczenia ich gleb ołowiem i kadmem. Z Parku Marcinkowskiego – RPM, Parku Sołackiego – RPS, Parku Wodziczki – RPW i Parku Piątkowo – RPP pobrano próbki gleby z dwóch głębokości (0–10 i 10–20 cm) w ilości odpowiednio: 36, 32, 52 i 34. Oznaczono całkowitą zawartość Pb i Cd oraz wybrane właściwości fizyczne i chemiczne tych próbek gleby. Szczegółową ocenę stanu zanieczyszczenia gleb przeprowadzono na podstawie różnych wskaźników, takich jak: geochemiczny indeks akumulacji (I_{geo}) oraz współczynnik (C^i_f) i stopień (C_{deg}) zanieczyszczenia.

Ocena gleb na podstawie I_{geo} wykazała, że w przypadku Pb parki można uszeregować następująco: RP Piątkowo < RP Sołacki < RP Wodziczki < RP Marcinkowskiego. Z uwagi na negatywne oddziaływanie Pb na ludzi, progi jego zawartości powinny być bardziej restrykcyjne, stąd należałoby rozważyć zastosowanie wartości tła geochemicznego (GB) wg Czarnowskiej [20] jako bardziej odpowiedniego dla ochrony przed potencjalnym zagrożeniem zdrowia. Na podstawie stanu zanieczyszczenia gleb kadmem (Cd-I_{geo}) badane parki można uszeregować następująco: RP Piątkowo < RP Marcinkowskiego < RP Sołacki < RP Wodziczki. Udział Cd w ogólnym zanieczyszczeniu gleb (C_{deg}) kształtował się zgodnie z wartościami wskaźników Cd-I_{geo}. Najwyraźniej zaznaczyło się to w RP Wodziczko i Sołacki oraz pośrednio w RP Marcinkowski. Na podstawie wykonanej oceny geochemicznej gleb jedynie Rekreacyjny Park Piątkowo można sklasyfikować jako wolny od zagrożenia zanieczyszczeniem ołowiem i kadmem.

Słowa kluczowe: parki rekreacyjne, Poznań, Pb, Cd, gleba, wskaźniki geochemiczne, indeks i stopień zanieczyszczenia