DOI: 10.2428/ecea.2013.20(03)034 ECOL CHEM ENG A. 2013;20(3):351-361

Zygmunt Mariusz GUSIATIN[1*] and Marlena Małgorzata MARZEC[1]

COMPARISON OF SEQUENTIAL EXTRACTION PROCEDURES FOR As PARTITIONING IN CONTAMINATED SOILS

PORÓWNANIE METOD EKSTRAKCJI SEKWENCYJNEJ DO OKREŚLENIA FORM CHEMICZNYCH ARSENU W ZANIECZYSZCZONYCH GLEBACH

Abstract: The aim of present study was to review and characterize selected procedures for determination of As chemical forms in soil. The methodology, wherein conditions and the way of extraction for five procedures of sequential analysis (Tessier et al, Chao and Sanzolone, BCR, Wenzel et al, Matera et al) in industrial soils with different contamination degree of As were presented.

Application of individual sequential extraction procedures (SEPs) enables to analyze between 4 and 7 chemical forms of arsenic. The methods differ in the type and volume of used reagents, duration of extraction and total cost. From economical point of view the most suitable seems to be 5-step procedure by Chao and Sanzolone. Determination of detailed arsenic distribution in soil provides procedure by Matera et al.

Keywords: arsenic, soil, sequential extraction procedure

Introduction

Among anthropogenic sources of As in soils, the most important are industrial processes such as smelting of As-containing ores and by-products of fossil fuel combustion (*ie* fly coal ash) and agricultural practices. Approximately 60 % of the As emissions are associated with Cu-smelting and coal combustion [1].

Arsenic, like a number of heavy metals, introduced into the soil is bound to the surface of the mineral and organic components. In contrast to other elements, it occurs in form of oxyanions, therefore its adsorption will be higher when soil particles have a positive charge [2]. The major constituents controlling As adsorption both in acidic and alkaline soils are iron oxides and hydroxides. In acidic soils the role of Al oxides/ hydroxides, Mn oxides and some clay minerals (*ie* kaolinite, montmorilonite) is also important, whereas in calcareous soils additionally carbonate minerals [3]. Arsenic adsorption onto clay minerals is based on strong specific reactions due to their

[1] Department of Environmental Biotechnology, University of Warmia and Mazury in Olsztyn, ul. Słoneczna 45G, 10-719 Olsztyn, Poland, phone: +48 89 523 41 17, email: mariusz.gusiatin@uwm.edu.pl

* Corresponding author.

multilayer structure enabling As retaining by inner sphere complexation. On contrary, fulvic or humic acids forming stable complexes with mineral surfaces may effectively reduce arsenic adsorption or even enhance its mobility in soil.

Arsenic partitioning among different soil components results that it can occur in various, operationally defined chemical forms. Their identification is possible through the sequential extraction procedures (SEPs), based on using specific extractants to release a given element bonded to target soil phase [4]. Regardless of SEP type, extractants are applied in order of increasing reactivity so that the successive fractions refer to element of lower and lower mobility. In contrast to traditional heavy metals, the procedures of sequential extraction typical for As are less numerous. Some of them are the same as for metal cations, whereas other are similar to those adopted for phosphorous or selenium due to their anionic nature. Hudson-Edwards et al [5] reviewed about 11 procedures for arsenic sequential extraction, limiting only to giving number and type of individual forms and used extractants. However, more details on full operational conditions (time and reagents consumption) and total costs may be important criteria during selection of sequential extraction scheme.

In practice, the choice of suitable SEP has some advantages as it can be an essential tool for:

– providing data on the origin, mode of occurrence and physicochemical availability of arsenic,

– estimation of changes of As solubility in soils within short- and long-term scale,

– selecting proper remediation system for soils contaminated with As *ie* soil washing, electrokinetics, immobilization, phytoextraction), and

– determination the efficiency of a given remediation system in term of As potential environmental risk in treated soil.

The main objective of present study was characteristics of five sequential extraction procedures for determination of As distribution in soil. By comparing total number of fractions, volume of reagents, extraction time, and total cost in each procedure, the most effective method was indicated.

Characteristics of sequential extraction procedures for As

In present study five sequential extraction procedures for arsenic distribution in soil were presented, including standard procedures (Tessier et al [6], BCR [7]) and those designed and developed especially for elements showing anionic nature (Chao and Sanzolone [8], Wenzel et al [9], Matera et al [10]). For each procedure, in Table 1 there are given operationally defined fractions, reagents and operational conditions. In Table 2, there are listed examples of application of above SEPs for arsenic fractionation in industrial soils.

Tessier's procedure is considered as the first sequential extraction, although chronologically it was developed and extended on the basis of methodology given earlier in 1973 by McLaren and Crawford [11]. This method enables determination of element distribution in five fractions (Table 1). Initially, this procedure was dedicated only to river sediments for Fe, Mn, Cd, Co, Cu, Ni, Pb, Zn. However, within time it was

Table 1

Sequential extraction procedures for As fractionation in soils

Fraction	Reagents	Soil/solution ratio	T [°C]	Extraction/ reaction time
Procedure 1 – Tessier et al [6]				
Soluble and exchange able	1 M $MgCl_2$	1:8	room	1 h
Bound to carbonates	1 M NaAc (pH 5.0)	1:8	room	4 h
Bound to Fe and Mn oxides	0.04 M $NH_2OH \cdot HCl$ in 25 % acetic acid	1:20	96	5.5
Bound to organic matter	0.02 M HNO_3 (7.5 cm^3) 8.8 M H_2O_2 (12.5 cm^3)	1:8	85	2 h
	8.8 M H_2O_2 (7.5 cm^3)	1:3	85	3 h
	3.2 M NH_4Ac in 20 % HNO_3	1:5	room	30 min
Residual	10 M HCl/15.8 M HNO_3	digestion for 2 h		
Procedure 2 – Chao and Sanzolone [8]				
Soluble	0.25 M KCl (pH 7.0)	1:25	room	30 min (shaking)
Ligand-exchangeable	0.1 M KH_2PO_4	1:25	room	30 min (shaking)
Acid-extractable	4 M HCl	1:25	95 (water bath)	45 min (occasional stirring)
Oxidizable	$KClO_3$ (0.25 g) 12 M HCl	1:5	room	45 min (occasional stirring)
Residual	calculated by difference between total As and sum of the four fractions			
Procedure 3 – BCR [7]				
Exchangeable and acid soluble	0.11 M CH_3COOH	1:40	room	16 h (shaking)
Reducible	0.5 M $NH_2OH \cdot HCl$ (pH 1.5)	1:40	room	16 h (shaking)
Oxidizable	8.8 M H_2O_2	1:10	room	1 h
			85 (water bath)	2 × 2 h
	1 M NH_4OAc (pH 2.0)	1:50	room	16 h (shaking)
Residual	HCl/HNO_3 (3:1)	microwave digestion		
Procedure 4 – Wenzel et al [9]				
Non-specifically sorbed	0.05 M $(NH_4)_2SO_4$	1:25	room	4 h
Specifically-sorbed	0.05 M $(NH_4)H_2PO_4$	1:25	room	16 h
Bound to amorphous and poorly-crystalline oxides of Fe and Al	0.2 M NH_4-oxalate buffer	1:25	room	4 h (in the dark)
Bound to well-crystallized oxides of Fe and Al	0.2 M NH_4-oxalate buffer 0.1 M ascorbic acid	1:25	96 (water bath)	30 min (in the light)
Residual	HNO_3/H_2O_2	microwave digestion		

Table 1 contd.

Fraction	Reagents	Soil/solution ratio	T [°C]	Extraction/ reaction time
Procedure 5 – Matera et al [10]				
Soluble in $MgCl_2$	1 M $MgCl_2$	1:8	room	1 h
Bound to carbonates	1 M NaAc in acetic acid buffer (pH 4.5)	1:8	room	15 h
Bound to Mn-oxides	0.04 M $NH_2OH \cdot HCl$ in 25 %(v/v) acetic acid	1:20	96 (water bath)	5.5 h
Bound to amorphous Fe oxides	0.2 M oxalic acid	1:50	room	4 h (in the dark)
Bound to crystalline Fe oxides	0.2 M oxalic acid + 0.1 M ascorbic acid	1:50	100	30 min
Bound to organic matter and sulphides	0.02 M HNO_3 (6 cm^3) 8.8 M H_2O_2 (10 cm^3)	1:8	85 (water bath)	2 h
	8.8 M H_2O_2 (6 cm^3)	1:3	85 (water bath)	3 h
	3.2 M NH H_4OAc (10 cm^3) in 20 % HNO_3 (v/v)	1:20	room	30 min
Residual	$HF/HClO_4$ (5:1) $HF/HClO_4$ (10:1) $HF/HClO_4$ (0:1)	digestion		

also adopted for other type of samples, *ie* dusts [12], fly ashes of different origin [13], soils [14, 15]. This procedure is also commonly used for As fractionation (Table 2).

Sequential extraction according to Chao and Sanzolone [8], based on Tessier's assumptions, was proposed for fractionation of nonmetals and metalloids in form of anions. The original method was aimed at selenium. Ahumada et al [16] used the SEP for estimation As distribution in soils contaminated by mining in Chile (Table 2). This method distinguishes the following fractions: (i) soluble – concerning arsenic water--soluble, nonspecifically adsorbed, replaced by other competing anions (*ie* Cl^-); (ii) ligand-exchangeable – arsenic specifically adsorbed onto metal oxides and clay minerals in exchangeable form; (iii) acid-extractable – arsenic bond to amorphous Fe, Mn and Al oxides and carbonates, (iv) oxidisable – arsenic bond to sulphides and organic matter, its releasing is possible by using potassium perchlorate with concentrated hydrochloric acid as strong oxidizing mixture and (v) residual – arsenic incorporated into silicates.

The BCR procedure was formulated by the European Community Bureau of Reference (BCR), now the Standards, Measurements and Testing Program in the late of 1980s due to a need to minimize errors in the treatment and analysis of samples, to harmonize the methodology throughout the European Union, compare the results between different laboratories and produce certified reference materials for metal fractionation [17, 18]. The standardized BCR three-step procedure evolved from the procedure of Salomons and Forstner [19] was formalized by Quevauviller et al [20].

Table 2

Examples of different sequential extraction procedures for As in soils contaminated by industry

Sequential extraction procedure	Source of soil contamination/site	As content [mg/kg]	Reference
Tessier et al	area from cyanide spill/Romania	45.2–179	[23]
	Pb-Zn-Ag mining area/Mexico	4–14700	[24]
	industrial soil/Italy	292	[25]
Chao and Sanzolone	mining and agriculture zone/Chile	33–75	[16]
BCR	iron mining area/ Korea	41	[26]
	industrialized urban area/China	9.9	[27]
	Au-Ag mine area/Korea	1941–37145	[28]
Wenzel et al	abandoned smelting plant area/Korea	75.5	[29]
	pesticides application, mining activity area	26.6–640	[30]
	herbicide application area/USA	325–900	[31]
	former arsenic mining and smelting area/Poland	118–43500	[32]
Matera et al	industrial area/ France	9400–13500	[10]

In the original BCR sequential extraction procedure, step 2 involves treatment with 0.1 mol/dm^3 hydroxylammonium chloride at pH 2. However, finally it was revised by Rauert et al [7] in term of increase concentration of hydroxylammonium chloride (0.5 mol/dm^3) and lowering of pH to 1.5. The revision was aimed at improvement of the BCR reproducibility due to a more efficient dissolution of the reducible fraction of the soil matrix, mainly the iron oxyhydroxide phase.

A fractionation scheme developed by Wenzel et al [9] is optimized procedure for sequential extraction of As using similar reagents as in case of fractionation of phosphorous. This method is originated from seven-step sequential extraction procedure given by Zeien and Brummer [21]. The first fraction involves the extraction of exchangeable or readily available As from soil, whereas the second step includes arsenic bond to organic and inorganic components of soil via inner-sphere complexes. The next two steps refers to arsenic bonding to Fe and Al oxides, depending on their crystallization form. The last one is residual form based on soil digestion in mixture of strong inorganic acids (Table 1).

The procedure proposed by Matera et al [10] is a modification of two methods given previously by Tessier et al [6] and Shuman [22]. In contrast to other procedures described above, Matera et al [10] extended arsenic characteristics in reducible fraction splitting it into three sub-fractions: bound to Mn-oxides, amorphous Fe oxides and crystalline Fe oxides (Table 1).

Based on data given in Table 2, presented fractionation procedures are used in soils of different degree of As contamination. The most common are procedures proposed by Tessier et al [6], BCR [7], Wenzel et al [9].

Comparison of individual sequential extraction procedures for As fractionation in soils

In order to compare the five sequential extraction procedures, the following criteria were assumed: (1) number of fractions in a given procedure, (2) total volume of chemical reagents (3) total extraction time, and (4) total cost.

Number of fractions in individual SEPs

In Fig. 1, total number of operationally defined fractions for each SEP is given. The SEPs enable arsenic fractionation between 4-7 forms. Using of the BCR procedure results in determination the lowest number of fractions. In original extraction only three forms (F1, F2 and F3) are distinguished. However, for checking metal recovery (the ratio of an element concentration in all individual forms to its pseudo-total content), determination of residual form (F4) as additional step is recommended. Although BCR procedure enables estimation of As distribution among the main soil components, it is commonly used in practice (Table 2).

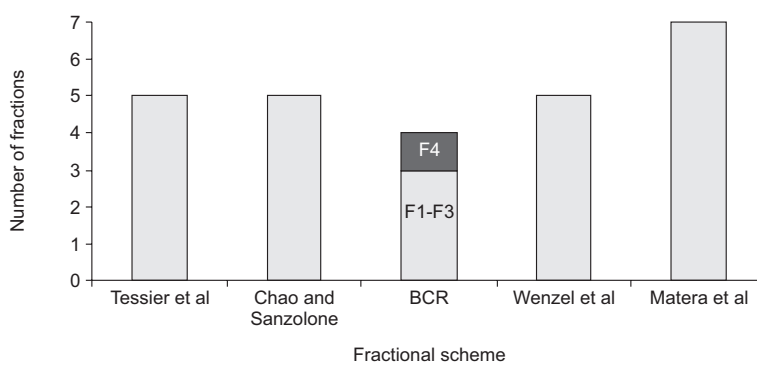

Fig. 1. Total number of operationally defined fractions in SEPs

Arsenic fractionation according to Tessier et al [6], Chao and Sanzolone [8] and Wenzel et al [9] procedures distinguishes the same number of fractions (5). Although the procedure by Matera et al [10] includes the highest number of fractions (7), it enables detailed insight in As distribution among oxides as the main sink for its adsorption in soil.

Total volume of chemical reagents

The volume of reagents used in a given sequential extraction procedure depends mainly on the number of fractions and water consumption for washing soil residues between each step of fractionation. Total volume of chemical reagents used in

individual SEPs, including extraction, digestion and washing with water are given in Fig. 2. Due to different soil weights adopted in original SEP protocols (from 1.0 to 2.5 g), all data in Fig. 2 are expressed as cm^3 per 1 g of soil.

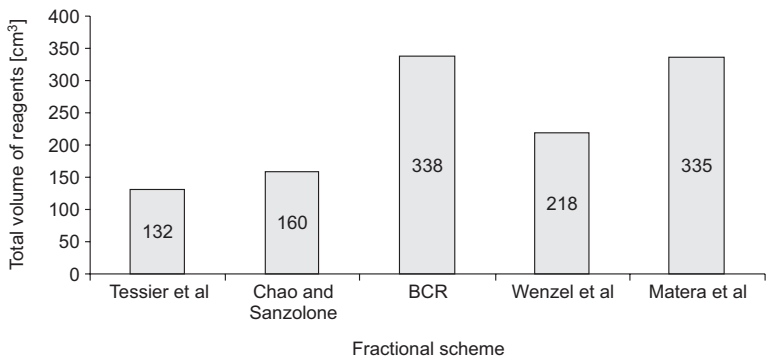

Fig. 2. Total volume of chemical reagents used in SEPs

Chemicals consumption in Tessier et al [6], Chao and Sanzolone [8] and Wenzel et al [9] procedures is the lowest, that follows from the ratio between soil and chemical reagents (m/V), varying between 1 : 5 and 1 : 25. Visibly higher, but comparable total volumes of reagents (above 330 cm^3) are needed during As fractionation by BCR [7] and Matera et al [10] procedures, despite different number of fractions. In contrast to other procedures, As extraction from the following phases in BCR procedure (F1-F3 forms) is performed at the highest m/V ratio (Table 1).

Time of SEPs

Total time of SEP is particularly important in routine applications. In fact, sequential extraction is a complex process. It includes not only As extraction, but also other operations connected with suitable sample preparation for As release from soil in successive steps.

For estimation of total time of SEP, the following operation were assumed: basic extraction, sample digestion in water bath, mineralization, centrifuging and filtration. Optionally, soil drying after extraction after each step can be included. However, it evidently extends the duration of SEP. Determination of residual fraction under laboratory conditions needs firstly sample mineralization in the present of concentrated acids. In many laboratories it is performed through conventional (in reflux condenser) or by more advanced methods (microwave digestion). The second solution is more advantageous due to shorter time and better process controlling (temperature and pressure sensors). A standard time of microwave digestion usually is about 90 min., including sample cooling stage. Digestion in reflux condenser, without cooling runs 120 min. Due to all extractants are water-based solutions, an average time of sample filtration after extraction in single step can be estimated to be 10 min. In Table 3, time

Table 3

The duration of individual operations in SEPs

Type of operation	Sequential extraction procedure				
	Tessier et al	Chao and Sanzolone	BCR	Wenzel et al	Matera et al
	time [min]				
Basic extraction	660	150	2880	1470	1590
Extraction with distilled water	40	n.d.	30	6	60
Sample digestion in water bath	300	0	300	0	300
Sample digestion with acids	120	0	90	90	90
Filtration	50	40	40	50	70
Centrifugation	60	40	60	40	180

n.d. – no data.

of each operations for an individual SEP is given, whereas total time of the whole SEP is presented in Fig. 3.

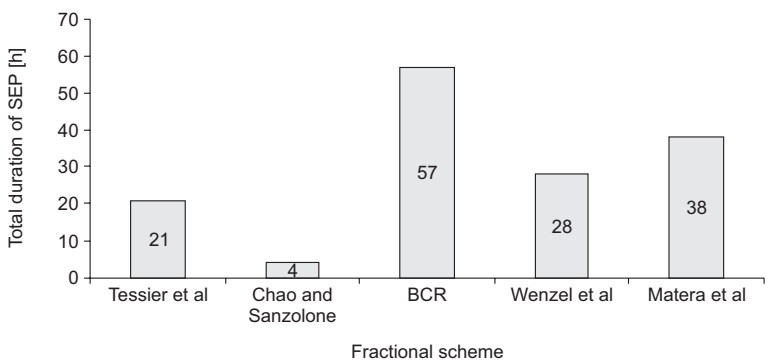

Fig. 3. Total duration of individual SEPs

From presented data it follows that total duration of individual procedures varied. The standardized BCR procedure, although concerns the lowest fraction number among all methods is the most time consuming. In contrast to others procedures As extraction in the successive extraction is the same and amounted to 16 h. The most time effective is Chao and Sanzolone procedure, at which some operational stages like water washing of soil residues, sample digestion in water bath and digestion with strong acids are omitted. As a result total duration of this procedures is only 4 h.

Total cost of SEPs

Total cost of individual SEPs was calculated based on the unit prices of each reagent used in successive steps. The prices were adopted from Sigma-Aldrich Company Itd.

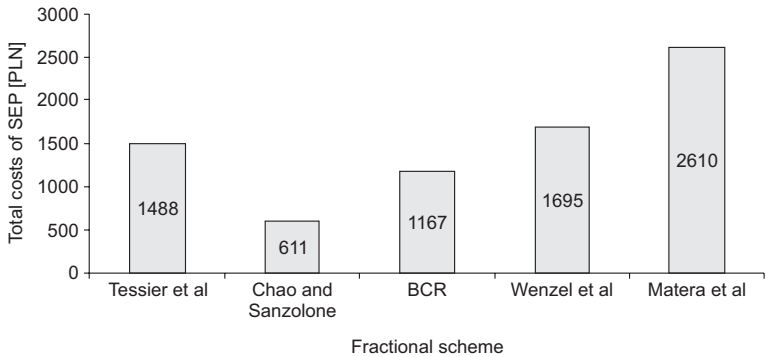

Fig. 4. Total cost of individual SEPs

(www.sigma-aldrich.com), a worldwide distributor of chemical reagents. The approximate cost (in PLN) for all procedures is given in Fig. 4. Arsenic fractionation in environmental samples is quite expensive operation. The costs varied in wide range between 611 and 2610 PLN.

Conclusions

1. Arsenic fractionation in soil is possible to be performed using sequential extraction procedures designed for elements occurring both as cations and anions.
2. The individual SEPs differ in the number and type of operationally defined fractions, chemicals used, the extraction time and total cost.
3. Taking into account the duration and cost of the extraction procedure, the most preferred can be method proposed by Chao and Sanzolone, including five chemical forms of arsenic. Standardized method of BCR (4 chemical forms) is characterized by the longest extraction time (57 h), while the method by Matera et al. (7 chemical forms) is the most expensive (2610 PLN).

Acknowledgements

The authors wish to thank the Faculty of Environmental Sciences, UWM Olsztyn for financial support (GW/2013/24).

References

[1] Hooda PS. Trace elements in soils. United Kingdom: Wiley; 2010.
[2] Sadiq M. Arsenic chemistry in soils: an overview of thermodynamic predictions and field observations. Water Air Soil Pollut. 1997;93(1-4):117-136.
[3] Mehmood A, Hayat R, Wasim M, Akhtar MS. Mechanisms of arsenic adsorption in calcareous soils. J Agric Biol Sci. 2009;1(1):59-65.
[4] Dermont G, Bergeron M, Mercier G, Richer-Laflčche M. Soil washing for metal removal: A review of physical/chemical technologies and field applications. J Hazard Mater. 2008;152(1):1-31.

[5] Hudson-Edwards KA, Houghton SL, Osborn A. Extraction and analysis of arsenic in soils and sediments. Trends Anal Chem. 2004;23(10-11):745-752.
[6] Tessier A, Campbell PGC, Blsson M. Sequential extraction procedure for the speciation of particulate trace metals. Anal Chem. 1979;51(7):844-851.
[7] Rauert G, López-Sánchez JF, Sahuquillo A, Barahona E, Lachica M, Ure AM, et al. Application of a modified BCR sequential extraction (three-step) procedure for the determination of extractable trace metal contents in a sewage sludge amended soil reference material (CRM 483), complemented by three-year stability study of acetic acid and EDTA extractable metal content. J Environ Monit. 2000;2(3):228-233.
[8] Chao TT, Sanzolone RF. Fractionation of soil selenium by sequential partial dissolution. Soil Sci Soc Am J. 1989;53(2):358-392.
[9] Wenzel WW, Kirchbaumer N, Prohaska T, Stingeder G, Lombi E, Adriano DC. Arsenic fractionation in soils using an improved sequential extraction procedure. Anal Chim Acta. 2001;436(2):309-323.
[10] Matera V, Le Hécho I, Laboudigue A, Thomas P, Tellier S, Astruc M. A methodological approach for the identification of arsenic bearing phases in polluted soils. Environ Pollut. 2003;126(1):51-64.
[11] Tlustoš P, Száková J, Stárková A, Pavlíková D. A comparison of sequential extraction procedures for fractionation of arsenic, cadmium, lead, and zinc in soil. CEJC. 2005;3(4):830-851.
[12] Banerjee ADK. Heavy metal levels and solid phase speciation in street dusts of Delhi, India. Environ Pollut. 2003;123(1):95-105.
[13] Sukandar S, Yasuda K, Tanaka M, Aoyama I. Metals leachability from medical waste incinerator fly ash: a case study on particle size comparison. Environ Pollut. 2006;144(3):726-735.
[14] Xiang HF, Tang HA, Ying QH. Transformation and distribution of forms of zinc in acid, neutral and calcareous soils of China. Geoderma. 1995;66(1-2):121-135.
[15] Maiz I, Arambarri I, Garcia R, Millán E. Evaluation of heavy metal availability in polluted soils by two sequential extraction procedures using factor analysis. Environ Pollut. 2000;110(1):3-9.
[16] Ahumada I, Escudero P, Ascar L, Mendoza J, Richter P. Extractability of arsenic copper and lead in soils of a mining and agricultural zone in central Chile. Commun Soil Sci Plant Anal. 2004;35(11-12):1615-1634.
[17] Sutherland RA, Tack FMG. Fractionation of Cu, Pb and Zn in certified reference soils SRM 2710 and SRM 2711 using the optimized BCR sequential extraction procedure. Adv Environ Res. 2003;8(1):37-50.
[18] Fernández E, Jiménez R, Lallena AM, Aguilar J. Evaluation of the BCR sequential extraction procedure applied for two unpolluted Spanish soils. Environ Pollut. 2004;131(3):355-364.
[19] Salomons W, Förstner U. Metals in the Hydrocycle. New York: Springer-Verlag; 1984.
[20] Quevauviller P, Rauret G, Muntau H. Evaluation of a sequential extraction procedure for the determination of extractable trace metal contents in sediments. Fresenius J Anal Chem. 1994;349(12):808-814.
[21] Zeien H, Brümmer GW. Chemische Extraktionen zur Bestimmung von Schwermetallbin-dungsformen in Boden. Mit Deutsch Bodenk Gesellsch. 1989;59:505-510.
[22] Shuman LM. Fractionation methods for soil microelements. Soil Sci. 1985;140(1):11-22.
[23] Konradi EA, Frentiu T, Ponta M, Cordos E. Use of Sequential Extraction to Assess Metal Fractionation in Soils from Bozanta Mare, Romania. Acta Univ Cibin Ser F Chemia. 2005.
[24] Ongley LK, Sherman L, Armienta A, Concilio A, Salinas CF. Arsenic in the soils of Zimapán, Mexico. Environ Pollut. 2007;145(3):793-799.
[25] Giacomino A, Malandrino M, Abollino O, Velayutham M, Chinnathangavel T, Mentasti E. An approach for arsenic in a contaminated soil: Speciation, fractionation, extraction and effluent decontamination. Environ Pollut. 2010;158(2):416-423.
[26] Ko I, Chang YY, Lee CH, Kim KW. Assessment of pilot-scale acid washing of soil contaminated with As, Zn and Ni using the BCR three-step sequential extraction. J Hazard Mater. 2005;127(1-3):1-13.
[27] Luo W, Lu YL, Wang G, Shi YJ, Wang TY, Giesy JP. Distribution and availability of arsenic in soils from the industrialized urban area of Beijing, China. Chemosphere. 2008;72(5):797-802.
[28] Yang J-S, Lee JY, Baek K, Kwon T-S, Choi J. Extraction behavior of As, Pb, and Zn from mine tailings with acid and base solutions. J Hazard Mater. 2009;171(1-3):443-451.
[29] Oh SY, Yoon MK, Kim IH, Kim JY, Bae W. Chemical extraction of arsenic from contaminated soil under subcritical conditions. Sci Total Environ. 2011;409(16):3066-3072.

[30] Gonzaga MIS, Santos JAG, Ma LQ. Phytoextraction by arsenic hyperaccumulator Pteris vittata L. from six arsenic-contaminated soils: Repeated harvests and arsenic redistribution. Environ Pollut. 2008;154(2):212-218.
[31] Yang L, Donahoe R J. The form, distribution and mobility of arsenic in soils contaminated by arsenic trioxide, at sites in southeast USA. Appl Geochem. 2007;22(2):320-341.
[32] Krysiak A, Karczewska A. Arsenic extractability in soils in the areas of former arsenic mining and smelting, SW Poland. Sci Total Environ. 2007;379(2-3):190-200.

PORÓWNANIE METOD EKSTRAKCJI SEKWENCYJNEJ DO OKREŚLENIA FORM CHEMICZNYCH ARSENU W ZANIECZYSZCZONYCH GLEBACH

Katedra Biotechnologii w Ochronie Środowiska
Uniwersytet Warmińsko-Mazurski w Olsztynie

Abstrakt: Celem pracy był przegląd oraz szczegółowa charakterystyka wybranych metod oznaczania form chemicznych arsenu w glebie. Zaprezentowano warunki oraz sposób ekstrakcji pięciu stosowanych procedur analizy sekwencyjnej arsenu w glebach z terenów przemysłowych, w których stopień zanieczyszczenia arsenem jest zróżnicowany. Należą do nich metoda Tessiera i in., Chao i Sanzolone, BCR, Wenzla i in. oraz Matery i in.

Zastosowanie poszczególnych metod umożliwia analizę od 4 do 7 form chemicznych arsenu. Różnią się one rodzajem i objętością zużywanych odczynników chemicznych, czasem trwania ekstrakcji oraz całkowitym kosztem. Z ekonomicznego punktu widzenia najbardziej odpowiednią wydaje się być 5-stopniowa procedura według Chao i Sanzolone. Określenie szczegółowej dystrybucji arsenu zapewnia natomiast metoda według Matery i in.

Słowa kluczowe: arsen, gleba, ekstrakcja sekwencyjna