MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION
ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE OCHRONY ŚRODOWISKA

Annual Set The Environment Protection
Rocznik Ochrona Środowiska

Volume/Tom 17. Year/Rok 2015 ISSN 1506-218X 337–350

Criteria for Sustainable Disposal of Sewage Sludge

Aneta Czechowska-Kosacka[*], *Yucheng Cao*[**], *Artur Pawłowski*[*]
[*]*Lublin University of Technology, Poland,*
[**]*Zhejing Agriculture and Forestry University, Hagzhou, China*

1. Introduction

Phosphorus and potassium compounds are considered important for plant growth. What is more, food production for a growing number of people depends on their availability. Phosphorus and potassium compounds are delivered to soil as salts obtained from mineral deposits. The problem is that mineral resources are quickly exhausted and this threatens the fundamental paradigm of sustainable development stating that providing the currently living generations with the essential livelihoods will not deprive future generations of the ability to satisfy their own needs [2,6–8,19,21,22]. This paradigm necessitates reducing the exploitation of natural reserves of phosphorus and potassium. The search for other sources of these compounds draws attention to sewage sludge produced in sewage treatment plants.

The sludge contains about 3.2% of phosphorus and 0.4% of potassium. Their reimplementation into soil, after appropriate treatment, may significantly reduce the consumption of natural reserves of phosphorus and potassium.

Sewage sludge contains multiple compounds having agriculture values, including organic matter, nitrogen, phosphorus and potassium compounds and, to a lesser extent, calcium, sulphur and magnesium compounds.

Addition of sewage sludge to land increases organic matter in the soil. The organic matter improves the physical, chemical, biological and biochemical properties of soil. Sewage sludge contains high levels of organic matter which is beneficial to the physical, chemical and biological properties of soil. Organic matter improves the physical quality of soil and the root environment by increasing the soil water retentioncapacity and improving soil aggregation and by reducing soil bulk density (see table 1).

The improved physical properties of soil and high levels of organic matter can enhance biological properties in the soil, including improvement of enzymatic, microbial and earthworm activities.

Table 1. Physical properties of soil improved by the use of sewage sludge [16]
Tabela 1. Fizyczne właściwości gleby wzbogaconej osadami ściekowymi [16]

	Experimental period (a)	Decrease in bulk density	Increase in porosity	Increase in water holding capacity
Crop land	2~3	18	12.9	4.9
Forest land	1	4.1	2.0~3.5	8~16
Turfgrass	1	5.67~35.5	9.7~10.1	29~580

On the other hand, sewage sludge also contains an array of unfavourable substances, including (1) metallic pollutants, such as zinc, copper, nickel, cadmium, lead, mercury, and chromium, (2) persistent organic pollutants, such as organochlorine pesticides and polychlorinated biphenyls (PCBs), and (3) microorganism pollutants, such as pathogens [4,5,7]. Content of those pollutants requires careful treatment and disposal of sewage sludge.

Untreated sewage sludge also contains micro-organisms that pose health risks. Therefore, sewage sludge should be treated prior to use, in order to decrease the water content and to eliminate odours and disease-causing agents. Typical sludge treatment includes thickening, dewatering, drying and stabilization (e.g. anaerobic digestion and alkaline stabilization). In general, these unit operations take place on-site (at WWPTs) and require a large amount of energy, depending on the specific process used.

After on-site treatment, sewage sludge is normally transported off-site for safe disposal or agricultural use. Currently, in majority of countries, land application and landfilling are the most often used sewage sludge disposal methods, although there are some alternatives (e.g. incineration and pyrolysis) that have been well developed [11–14]. Landfill disposal can be regarded as the least favourable, and the most unsustainable because of the following factors:

- it commonly generates undesired emissions (e.g. leachate, landfill gas and odours) to water, air and soil,
- valuable nutrient substances (e.g. compounds of N and P) contained in sludge are wasted and become pollutants, mostly presented in leachate.

For safe management of sewage sludge it is necessary to follow strict regulations.

Therefore, regulations related to the land application of sewage sludge in EU. USA, China and Poland will be characterized.
Typical composition of sewage sludge is presented in Table 2.

Table 2. Typical chemical composition and properties of primary, activated and digested sludge [10]
Tabela 2. Typowy skład chemiczny i właściwości osadów surowych, czynnych i przefermentowanych

	Primary sludge		Digested sludge		Activated sludge
	Range	Typical	Range	Typical	Range
Total dry solids (TS), %	2.0–8.0	5.0	6–12	10	0.83–1.16
Volatile solids (% of TS)	60–80	65	30–60	40	59–88
Grease and fats (% of TS)					
Ether soluble	6–30		5–20	18	
Ether extract	7–35				5–12
Protein (% of TS)	20–30	25	15–20	18	
Nitrogen (N, % of TS)	1.5–4	2.5	1.6–6	3	2.4–5

Table 2. cont.
Tabela 2. cd.

	Primary sludge		Digested sludge		Activated sludge
	Range	Typical	Range	Typical	Range
Phosphorous (P_2O_5, % of TS)	0.8–2.8	1.6	1.5–4	2.5	2.8–11
Potash (K_2O, % of TS)	0–1	0.4	0–3	1	0.5–0.7
Cellulose (% of TS)	8–15	10	8–15	10	
Iron (not as sulphide)	2–4	2.5	3–8	4	
Silica (SiO_2, % of TS)	15–20		10–20		
Alkalinity (kg/l as $CaCO_3$)	0.5–1.5	0.6	2.5–3.5		0.58–1.1
Organic acids (kg/l as Hac)	0.2–2	0.5	0–0.6	3	1.1–1.7
Energy content (MJ/kg)	23–29	25	9–14	12	19–23

2. Criteria for the European Union

As early as 1986, the Council of the European Union promulgated the Directive: "*on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC)*" [1]. The aim of the Directive is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and people, while encouraging its proper use. To this end, it sets out the requirements regarding pollutant limits, operational standards, management practices, sampling and analysis methods, recordkeeping (e.g. the quantities and properties of sludge produced) and, periodical reporting. The Directive prohibits the use of untreated sludge on agricultural land unless it is injected into the soil under specific conditions.

Directive sets limit values for seven heavy metals (cadmium, copper, nickel, lead, zinc, mercury and chromium), both in soil and in sludge itself. It describes limit values for concentrations of heavy metals in soil to which sludge is applied, concentrations of heavy metals in sludge, and the maximum annual quantities of such heavy metals which may be introduced into soil (Tables 3, 4 and 5).

Table 3. Limit values for concentrations of heavy metals in soil [1]
Tabela 3. Dopuszczalne stężenia metali ciężkich w glebie [1]

Metals	mg/kg of dry matter
Cadmium	1 to 3
Copper	50 to 140
Nickel	30 to 75
Lead	50 to 300
Zinc	150 to 300
Mercury	1 to 1.5
Chromium	–

Table 4. Limit values for heavy-metal concentrations in sludge used in agriculture [1]
Tabela 4. Dopuszczalne stężenia metali ciężkich w osadach ściekowych wykorzystywanych w rolnictwie [1]

Metals	mg/kg of dry matter
Cadmium	20 to 40
Copper	1 000 to 1 750
Nickel	300 to 400
Lead	750 to 1 200
Zinc	2 500 to 4 000
Mercury	16 to 25
Chromium	–

Table 5. Limit values for amounts of heavy metals which may be added annually to agricultural land, based on a 10-year average [1]
Tabela 5. Dopuszczalne stężenia metali ciężkich, jakie można wprowadzać w ciągu roku do gleby, w oparciu o 10-letnią średnią [1]

Metals	kg/ha/yr
Cadmium	0.15
Copper	12
Nickel	3
Lead	15
Zinc	30
Mercury	0.1
Chromium	–

The current Sewage Sludge Directive addresses both pathogen reduction and the potential for accumulation of persistent pollutants in soils but sets no limits for organic contaminants. The Directive establishes limit values for seven heavy metals (cadmium, copper, nickel, lead, zinc, mercury and chromium), both in soil and in sludge itself. It specifies general land use, harvesting and grazing restrictions to provide protection against health risks from residual pathogens. The Directive requires all sludge to be treated before being applied to agricultural land, but allows the injection of untreated sludge into the soil under specific conditions. While it calls for the use of treated sludge, the Directive does not specify treatment processes.

The Member States can apply stricter restrictions than those determined in Directive 86/278/ EEC and this is observed in several cases. Specifically, 16 out of the 27 EU countries have set more rigorous national standards for heavy metals concentrations in sludge, whereas 10 out of 27 countries have set stricter limit values for the concentrations of heavy metals in soil. There is a wide variation in national limit values for heavy metals, even between similar geographical areas, such as the Nordic or Baltic countries. Nordic countries (Finland, Sweden, Denmark and Netherlands) have set the lowest limit values. On the other hand, except of France, Malta and Slovenia, Mediterranean countries have adopted the limit values proposed by the EU Directive.

Apart from heavy metals included in the EU Directive 86/278, several countries have set limit values for chromium as well as for other categories of pollutants commonly detected in sludge such as pathogens and organic micropollutants. Limit values for total chromium in sludge have been set by 19 out of the 27 countries, while different legislation on this matter is observed in different parts of Belgium. The limit values of total Cr range from 40 mg/kg dry matter (Slovenia) to 1750 mg/kg dry matter (Luxembourg).

So far, except for Hungary which has set a limit value of 1 mg/kg for Cr(VI), no limit values have been set for this chromium species by other European countries, despite the fact that it is much more toxic than total chromium [18].

3. Criteria for the USA

The US EPA introduced regulations in 1993 [9,17] that established minimum standards that must be met if sludges are to be land-applied. The regulations include concentration limits for nine metals and for pathogens, and requirements for the reduction of flies and rodents attraction. The regulations establish Class A sludges, which have been treated to total elimination of pathogens (disease-causing organisms), and Class B, in which pathogens have been reduced but are still present. Under the federal 503 rules certain site restrictions apply to Class B use, but no individual site permits are required for its use.

The federal regulations also establish standards for nine contaminants (see Table 6).

The standards include the so-called 'exceptional quality' (EQ) sludges, which meet certain concentration limits (no more than X parts per million of any of the nine regulated contaminants) as well as pathogen and fly and rodent reduction. With regard to metal concentrations, sludges and sludge products that fail to meet one or more of those 'EQ' pollutant concentrations but which fall below a higher ceiling concentration may be applied, but the applicator is directed to keep track of the total amount of each metal applied and cease application when a regulatory cumulative pollutant loading limit is reached. Sludge products that fail to meet one or more of the 'EQ' pollutant concentrations but which fall below the ceiling concentration may still be as long as information on the acceptable annual pollutant loading rate (APLR) is reached.

Table 6. Pollutants limits for all land applied sewage sludge [9]
Tabela 6. Limity zanieczyszczeń osadów ściekowych stosowanych na grunty[9]

Pollutant	Ceiling Concentration Limits for All Biosolids Applied to Land (milligrams per kilogram)[2]	Pollutant Concentration Limits for EQ and PC Biosolids (milligrams per kilogram)[2]	Cumulative Pollutant Loading Rate Limits for CPLR Biosolids (kilograms per hectare)	Annual Pollutant Loading Rate Limits for APLR Biosolids (kilograms per hectare per 365-day period)
Arsenic	75	41	41	2.0
Cadmium	85	39	39	1.9
Chromium	3,000	1,200	3,000	150
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum[b]	75	–	–	–
Nickel	420	420	420	21
Selenium	100	36	100	5.0
Zinc	7,500	2,800	2,800	140
Applies to:	All biosolids that are land applied	Bulk biosolids and bagged biosolids[c]	Bulk biosolids	Bagged biosolids[c]

[a] Dry-weight basis
[b] As a result of the February 25, 1994, Amendment to the rule limits for molybdenum were deleted from the Part 503 rule pending EPA reconsideration.
[c] Bagged biosolids are sold or given away in a bag or other container.

4. Criteria for China

In China, the first regulation (Control Standards for Pollutants in Sludges from Agricultural Use) regarding land application of sewage sludge was established in l984 by the Ministry of Urban-Rural Construction and Environmental Protection (MURCEP). The regulation set limits on ten pollutants for sewage sludge used in agriculture. The maximum allowable concentrations of pollutants in sludges that are applied to land are presented in Table 6.

In addition, the regulation establishes other requirements:

- annual loading rate of sludge application should not exceed 30 ton/ha,
- if the content of any inorganic chemical contained in sewage sludges is close to the limit value shown in Table 7, the waste cannot be applied to the same site for more than 20 years,
- sewage sludges should not be used on sandy soil, land with high ground water level, or conservation area for water resources,
- before land application, sludge must be composted or digested,
- sludge should not be employed on vegetable field or grass lands used for grazing within 1 year of application,
- when sewage sludge is applied to acid soil, the soil should be treated with lime,
- sludge loading rate should be reduced if the content of more than one chemical in sludge reaches the limits,
- if crop growth is affected negatively or harmful chemical content in crop excesses any standard, sludge application should be stopped.

There have been no regulations for pathogen control for sludge land application.

Table 7. Control standards for pollutants in sludges used in agriculture [3]
Tabela 7. Standardowe stężenia zanieczyszczeń w osadach ściekowych stosowanych w rolnictwie [3]

Parameters	Limit values [mg·kg^{-1}d.m.]	
	pH < 6.5	pH > 6.5
Cadmium	5	50
Mercury	5	15
Lead	300	1000
Chromium	600	1000
Boron	150	150
Copper	250	500
Zinc	500	1000
Nickel	100	200
Mineral oil	3000	3000
Benzo[a]pyrene	3	3

5. Criteria for Poland

Sewage sludge produced in wastewater treatment plants requires neutralization not only for practical, but also legal reasons. If possible, processed sludge should return to the natural environment mainly due to the content of valuable fertilizing components such as nitrogen or phosphorus, responsible for biomass growth. Agricultural use is recommended for small and medium treatment plants. For large treatment plants, it is impossible to use sludge in agriculture, as it contains exceeded concentrations of heavy metals.

In the Polish legal system, there is a range of regulations pertaining to sludge management. The basic regulation concerning waste management is the Act on waste of 14th December 2012 (Official Journal, Dz. U., 2013, item 21) and several regulations which determine the management of sewage sludge in a detailed way. The most important ones include: Regulation of the Polish Minister of Environment of 27th September 2001 on the Waste Catalogue (Official Journal, Dz.U., 2001, No. 112, item 1206); in the case of thermal processing of waste – Regulation of the Polish Minister of Economy of 21st March 2002 on conditions of thermal processing of waste (Official Journal, Dz.U., 2002, No. 37, item

339); and the Regulation of the Polish Minister of Economy of 8th January 2013 on the criteria and procedures of *waste* approval for *storage* at a *waste storage* facility of particular type (Official Journal, Dz.U., 2013, item 38).

One of the most important legal acts regulating sewage sludge management is the Regulation of the Polish Minister of Environment of 13th July 2010 on municipal sewage sludge (Official Journal, Dz.U., 2010, No. 137, item 924). This act contains transposed legal regulations of the European Union. It specifies the conditions which are to be met while employing municipal sewage sludge in agriculture as well as land reclamation, including agricultural lands, lands for cultivation of plants used in compost production, feed production, and plants not intended for human consumption. Similarly, as in other countries, regulations found in this act set the limit values for concentrations of seven heavy metals found in sewage sludge (see Table 8).

Table 8. Limit values for concentrations of heavy metals in municipal sewage sludge [15]
Tabela 8. Wartości graniczne stężeń metali ciężkich w komunalnych osadach ściekowych [15]

Metals	Heavy metal content [mg·kg^{-1}d.m]	
	in agriculture and the reclamation of lands for agricultural purposes	in the reclamation of lands for non-agricultural purposes
Cadmium	20	25
Copper	1000	1200
Nickel	300	400
Lead	750	1000
Zinc	2500	3500
Mercury	16	20
Chromium	500	1000

8. Conclusions

Sewage sludge is a sustainable source of phosphorus and potassium compounds for the growth of biomass. Their application on cultivated land could be beneficial on condition that the level of pollution does not exceed the acceptable level, in particular with regard to heavy metals.

Taking into account their possible negative impact on the environment, strict regulations on the content of pollutants in sewage sludge, especially heavy metals, have been established in all the discussed regions.

Bearing in mind both the advantages of the use of sewage sludge to fertilize crops and the possible risks arising from contaminants, a number of countries introduced strict regulations governing the use of sewage sludge to fertilize soil.

Taking into consideration the example of the European Union, the U.S., Poland and China, it can be concluded on the basis of analysis of legal regulations in this regard that the use of sewage sludge to fertilize crops is controlled in an appropriate way in both the developed as well as the developing countries.

References

1. Commission of European Communities. Council Directive 86/278/EEC of 4th July 1986 on the protection of the environmental, and in particular of the soil, when sewage sludge is used in agriculture.
2. **Ecimovic T., Haw R, Kondrashin I., Weiler R, Gutierrez F., Vivanco et al.:** *Philosophy of the Sustainable Development and the Sustainable Future of Humankind the Survival of Humanity*. Problemy Ekorozwoju – Problems of Sustainable Development, 9(2), 7–25 (2014).
3. GB4284-84, Control standards for pollutants standards for pollutants in sewage sludge from agricultural use, 1984.
4. **Kelessidis A., Stasinakis A.S.:** *Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries*. Waste Management, 12, 1, 201–216, 2012.
5. **Kelessidis A., Stasinakis A.S.:** *Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries*. Waste Management, 32, 6, 1186–1195, 2012.
6. **Konstańczak S.:** *Theory of Sustainable Development and Social Practice*. Problemy Ekorozwoju – Problems of Sustainable Development. 9, 1, 37–46, 2014.

7. **Konarski W.:** *Mineral Energy Sources and Political Activities: Introduction to Mutual Dependencies and Their Selected Exemplification*.Problemy Ekorozwoju – Problems of Sustianable Development, 9, 1, 63–70, 2014.
8. **Krajewski P.:** *Food Safety and Sustainable Development*. Problemy Ekorozwoju – Problems of Sustianable Development. 9, 2, 79–86, 2014.
9. Land Aplication of sewage Sludge, EPA/831-B-93-002b, December 1994.
10. Metcalf and Eddy, I. Wastewater Engineering: Treatment and Reuse. Fourth Edition, McGraw-Hill Higher Education, New York 2003.
11. **Pawłowska M., Pawłowski L.:** *Method for elimination of mobile fraction of heavy metal ions in sewage sludge*. Patent nr EP08165555.7 z dnia 2008.09.05.
12. **Pawłowski L., Pawłowski A.:** *Method for producing fuel from sewage sludge*. Patent nr EP09174096.9 z dnia 2009.10.26.
13. **Pawłowska M., Siepak J., Pawłowski L., Pleczyński J.:** *Method for sewage sludge utilisation for intensification of biogas production in refuse collection depot*. Patent nr EP08165556.5 z dnia 2008.09.05.
14. **Piekarski J., Kogut P., Kaczmarek F., Dąbrowski T.:** *Biogazownie utylizacyjne jako propozycja utylizacji osadów ściekowych w odniesieniu do ustawodawstwa polskiego*. Rocznik Ochrony Środowiska, Tom 14 (2012).
15. Regulation of the Polish Minister of Environment of 13th July 2010 on municipal sewage sludge (Official Journal, Dz. U., 2010, No. 137, item 924).
16. **Singh R.P., Agrawal M.:** *Potential benefits and risks of land application of sewage sludge*. Waste Management 28, 347–358 (2008).
17. Standards for the use or disposal of sewage sludge, 40 CFR Part 503.
18. **Stasinakis A.S., Thomaidis N.S.:** *Fate and biotransformation of metal and metalloid species in biological wastewater treatment processes*. Critical Reviews in Environmental Science and Technology. 40, 4, 307–364 (2010).
19. **Wall G.:** *Exergy, Life and Sustainable Development*, *Egzergia, życie i rozwój zrównoważony*. Problemy Ekorozwoju – Problems of Sustianable Development. 8, 1, 27–41 (2013).
20. **Wang X., Chen T., Ge Y., Jia Y.:** *Studies on land application of sewage sludge and its limiting factors*. J Hazard Mater. 160, 554–558 (2008).
21. **Zhang Y., Sheng Li**: *The Impact of Environmental Preferences on Public Supporting for the River Ecosystem Restoration Program in China,* Problemy Ekorozwoju – Problems of Sustianable Development. 9, 2, 55–64 (2014).
22. **Zhine W., Meijun F., Ikerd J.:** *Beyond the Dilemma Facing China's Agriculture – Toward a Chinese Constructive Postmodern Agriculture*. Problemy Ekorozwoju. Problems of Sustainable Development. 8 1, 43–56 (2013).

Kryteria zrównoważonego usuwania osadów ściekowych

Streszczenie

Osady ściekowe są stanowią trwałe źródło związków fosforu i potasu niezbędnych do wzrostu biomasy. Od ich dostępności dla roślin zależy produkcja żywności dla stale wzrastającej liczby ludności. Do gleby dostarczane są związki fosforu i potasu w postaci soli pozyskiwanych jako kopaliny. Problem jednak stanowią szybko wyczerpujące się zasoby minerałów, z których pozyskiwane są wyżej wymienione pierwiastki do produkcji nawozów rolniczych. W przyszłości ich brak może pogorszyć jakość gleb, co zmniejszy skalę produkcji rolnej. Oznacza to, że podstawowy paradygmat zrównoważonego rozwoju mówiący o konieczności postępowania takiego, aby zapewnić niezbędne środki do życia obecnym pokoleniom, nie pozbawi przyszłych pokoleń możliwości zabezpieczenia ich potrzeb. Paradygmat ten nakazuje podjęcie wszelkich działań zdążających do ograniczania eksploatacji naturalnych ich zasobów. Poszukując innych źródeł zwrócono uwagę na osady ściekowe pochodzące z biologicznych oczyszczalni ścieków. Osady te zawierają związki fosforu i potasu, które po odpowiedniej obróbce mogą przyczynić się do spowolnienia zużycia naturalnych rezerw fosforu i potasu. Zastosowanie osadów ściekowych na uprawianej ziemi, może być korzystne pod warunkiem, że poziom zanieczyszczeń m.in. metalami ciężkimi nie przekracza dopuszczalnego poziomu. Biorąc pod uwagę ich możliwy negatywny wpływ na środowisko naturalne oraz surowe przepisy dotyczące zawartości zanieczyszczeń w osadach, metale ciężkie zostały uwzględnione w prawodawstwie omawianych regionów.

Biorąc pod uwagę zalety wnikające z wykorzystania osadów ściekowych do nawożenia upraw i możliwych zagrożeń wynikających z obecności w osadach ściekowych niepożądanych zanieczyszczeń, wiele krajów wprowadziło surowe przepisy regulujące wykorzystanie osadów do nawożenia gleby. Biorąc pod uwagę przykład Europejskiej, USA, Polski i Chin można stwierdzić na podstawie analizy regulacji prawnych w tym zakresie, że stosowanie osadów ściekowych do nawożenia gleb jest w pełni kontrolowane zarówno w krajach rozwiniętych jak również w krajach rozwijających się.

Słowa kluczowe:
zrównoważony rozwój, fosfor, potas, osady ściekowe, uwarunkowania prawne

Keywords:
sustainable development, phosphorus, potassium, sewage sludge,
legal conditions