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Research Article

ASSESSMENT OF POSSIBILITY OF AGRICULTURAL USE OF MUNICIPAL SEWAGE SLUDGE GENERATED IN SELECTED SMALL SEWAGE TREATMENT PLANTS FROM KRAKÓW DISTRICT

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ABSTRACT
The paper presents the findings from research on physical chemical parameters as well as on microbiological-parasitological municipal sewage sludge from one medium-sized and three small municipal sewage treatment plants from the area of Kraków district. The research was conducted in the years 2007-2012 and aimed at estimating the possibility of agricultural use of the studied sludge. The analyzed sludge turned out to be rich in fertilizing elements, i.e. organic substance, nitrogen, phosphorus, calcium and magnesium. Contents of heavy metals in the analyzed sludge were distinctly lower than the permissible contents in sludge used in agriculture. However, due to frequent occurrence of bacteria from *Salmonella* group in the studied sludge, its agricultural use may be limited. Relatively high variability in the determined parameters makes it necessary to monitor continuously the sludge coming from particular lots and sewage treatment plants.

Keywords: municipal sewage sludge, agricultural use of sludge, heavy metals, micro and macroelements.

INTRODUCTION

In the last dozen or so years a systematic increase in mass of sewage sludge created in Poland has been observed. However, it is worth highlighting that the amount of sludge generated in industrial treatment plants is decreasing from year to year (an over 50 percent drop in the last 10 years), while the amount of municipal sewage sludge is increasing regularly (in an analogous period the amount increased by 46.4%). An increased share of sludge of municipal origin in the total mass of created sewage sludge appears to be beneficial, since sludge is generally a rich source of fertilizing elements and contains fewer pollutants than industrial sludge [Wilk, Gworek 2009], which increases the possibility of its management. 526.7 thousand Mg d.m. of sludge in municipal treatment plants in Poland were generated in 2010 [Ochrona Środowiska/ Environment 2011]. It is estimated that approximately 726 thousand Mg d.m. of municipal sewage sludge will be generated in 2018, and in 2022 this number will reach 746 thousand Mg d.m. [Krajowy plan 2010].

Sewage sludge can be managed in several different manners. Information gathered by GUS (Central Statistical Office) [Ochrona Środowiska/ Environment 2011] shows that the currently dominant manner of handling municipal sewage sludge in Poland is its disposal (just under 60%), and, in lesser degree, using sewage in agriculture and in reclamation of areas (in total slightly over 30%). Only a small amount of generated sludge is thermally processed (below 4%), although a slow increase in share of this utilization method in the total mass of generated sludge can be observed over the last few years.

According to regulations of "The National Waste Management Plan 2014" [2010], the following, among other things, should be carried out within the next 10 years in Poland: limitation of municipal sewage sludge disposal; increase of the amount of sludge thermally treated and processed before introduction to the environment. In addition, actions should be undertaken to maximize utilization of biogenic substances contained in sludge, but on the condition that all requirements concerning environmental safety are kept. Therefore, due to organizational/financial reasons, which are connected with insufficient area of lands fit for managing high amount of municipal sewage sludge around the biggest cities, and due to high probability of contaminating these lands with toxic substances (they limit the possibility of natural use), most national agglomerations decided to build thermal sludge processing plants [Pająk 2010]. However, in case of small and medium-sized sewage treatment plants, natural management of sewage sludge appears to be a definitely cheaper and easier way [Werle 2012, Bień et al. 2011]. All the more so because sewage, when used for fertilization, can be an alternative to natural fertilizers as it influences the improvement of unfavorable balance of organic substance in soils of our climatic zone [Turski 1996].

Research studies carried out in the years 2007–2012 aimed at estimating the possibility of natural use of sewage sludge generated in municipal sewage treatment plants located in small towns in Kraków district.

MATERIALS AND METHODS

Three small treatment plants (Pomiltek) located in a rural commune of Zabierzów, in a village head's offices of Balice, Niegoszowice (both with flow capacity of 800 $m^3 \cdot d^{-1}$) and Zelków (flow capacity of 150 $m^3 \cdot d^{-1}$) were chosen for the research, along with one treatment plant which now serves over 15 000 people who live in the city of Krzeszowice and in adjacent towns (municipal-rural commune of Krzeszowice) and which has a flow capacity of 7000 $m^3 \cdot d^{-1}$. In 2011, in total 106 Mg d.m. of sewage sludge was generated in the discussed sewage treatment plants from the commune of Zabierzów, whereas the central sewage treatment plant in Krzeszowice generated 468 Mg d.m. The amount of sludge generated in Krzeszowice is going to increase considerably in the future as a result of implementation of an investment project within the framework of the Cohesion Fund (2007–2013). This project involves modernization of the central sewage treatment plant in Krzeszowice, theconstruction of a sewerage treatment plants in the next towns of the commune (inhabited by approximately 10 000 residents), and the sewage system is to be connected to the rebuilt treatment plant. A consistent increase in mass of the generated sludge is expected in future also in the structures from the commune of Zabierzów, on account of intensive development of these towns and new connections to the sewerage system which are connected with the development. It is estimated that with full loading of the three treatment plants the annual production of sewage sludge may amount to 210 Mg d.m.

Two representative sewage sludge samples were collected from the treatment plants considered in the research in June and December every year in the years 2007–2012, except the last year 2012, where only sludge collected in June were examined. In total, 44 samples were examined. Samples for sanitary and physical chemical analyses were collected into separate containers. After being transported to the laboratory, the sludge was homogenized and was immediately subjected to a sanitary-microbiological analysis (for the presence of bacteria from the *Salmonella* group as well as number of *Ascaris*, *Trichuris* and *Toxocara* parasites). The material for analyses of physico-chemical parameters was stored until the time of the analyses. The material was stored fresh in closed glass containers, at a temperature of 2–5°C. The analyses were conducted using methods which are adopted in Poland as reference methods for studies on municipal sewage sludge [Regulation 2010]. The following were determined in the sludge: pH (potentiometrically) and contents of dry matter (by weight), organic substance (residue after ignition), total nitrogen (using Kjeldahl method) and ammonia nitrogen (by distillation). In order to determine the content of the remaining mineral components, the sludge samples, after incineration at a temperature of 450°C, were digested in a mixture of concentrated acids: nitric and perchloric 3:2. The content of elements in the obtained filtrate was determined an atomic absorption spectrophotometer (AAS) or an inductively coupled plasma atomic emission spectrometer (ICP-AES). Mercury content was determined by spectrometry using AMA 254 analyzer.

The analyses were conducted in two replications and were repeated whenever the relative error of determination was higher than 5%. A statistical elaboration of the obtained results was done with the use of a Microsoft Excel 2007 spreadsheet.

ANALYSIS OF RESULTS AND DISCUSSION

Results obtained from research conducted for 5 years are presented in a cumulative form as selected statistical parameters. Municipal sewage sludge from the studied treatment plants of Kraków district were characterized by relatively low variability of both pH and organic matter content, whereas dry matter content in the sludge was more distinctly diversified (Tab. 1).

Mean pH values of sludge from particular treatment plants were between 7.21 (sludge from Krzeszowice) and 7.59 (sludge from Balice) and were close to the results obtained form sludge from the Warmia-Mazury Province [Mazur, Mokra 2011], but they were slightly higher than the mean pH = 6.79 of sewage sludge coming from 43 treatment plants located in various places in Poland [Siebielec, Stuczyński 2008] as well as from the Płock district (pH = 6.76) [Bauman-Kaszubska, Sikorski 2011]. With an exception of one sample from Niegoszowice, the sludge had high organic matter content, usually oscillating at a level of 500-600 g·kg^{-1} d.m., which makes it a valuable material with regard to humus-forming value [Mazur, Mokra 2011]. Dry matter content in the analyzed materials fluctuated within a range between 94.8 and 589.2 g·kg^{-1}, and it did not differ from amounts determined in sludge from different towns [Siebielec, Stuczyński 2008, Bauman-Kaszubska, Sikorski 2011, Mazur, Mokra 2011]. In most cases sludge consistency allowed for its application in soil without additional treatment. Sludge coming from treatment plants equipped with devices for its dehydration (Balice and Krzeszowice) had considerably higher stability of dry matter content in comparison to the remaining sludge, which was dehydrated only on the experimental plots.

Table 1. Basic physico-chemical properties and microbiological and parasitological characteristics of sewage sludge from selected small sewage treatment plants from Krakow District in 2007–2012

Parameter		Treatment plant			
		Balice	Krzeszowice	Niegoszowice	Zelków
pH	minimum	7.07	6.76	6.72	6.20
	maximum	8.10	7.96	8.56	7.76
	mean	7.59	7.21	7.48	7.25
	median	7.50	7.12	7.23	7.34
	V %*	4.5	5.2	7.8	6.3
Dry matter [g·kg^{-1}]	minimum	104.1	162.2	127.8	94.8
	maximum	209.0	324.0	589.2	366.0
	mean	153.9	198.2	222.2	162.9
	median	140.2	190.0	157.7	154.2
	V %	25.3	22.0	64.5	44.2
Organic matter [g·kg^{-1} s.m./d.m.]	minimum	511.0	470.0	257.8	574.0
	maximum	724.4	612.0	683.3	710.9
	mean	613.9	543.4	565.6	643.6
	median	634.5	539.0	604.0	645.0
	V %	12.2	8.7	22.4	6.5
Salmonella sp.	isoleted	8	8	7	5
	not isoleted	3	3	4	6
Parasite eggs (*Ascaris* sp.. *Trichuris* sp.. *Toxocara* sp.)	isoleted	0	0	0	0
	not isoleted	11	11	11	11

*V% – coefficient of variation.

Results of sanitary-microbiological analyses presented in Table 1 showed that methods of sludge hygienization which are used in the treatment plants are fallible, because in over 60% of the examined samples bacteria from the *Salmonella* group were stated. According to Polish law [Regulation 2010], which makes sludge use in agriculture and for land reclamation for agricultural purposes impossible. Lots of bacteriologically contaminated sludge might be used only for other purposes, among other things in adjusting lands to meet specific needs resulting from waste management plans, local zoning plans, and in cultivating plants for production of composts or not designated for consumption and fodder production. In the examined sludge, living eggs of intestinal parasites were not found in any case.

Content of macroelements in sewage sludge used for natural purposes is not standardized, but its proper content is one of important elements advocating the use of that kind of waste as fertilizers. The studied sewage sludge turned out to be materials which usually contained considerable amounts of nitrogen, phosphorus, calcium (Table 2). In relation to plant nutritional needs, potassium content was low, but that is a characteristic feature for municipal sewage sludge, caused by good solubility of mineral compounds of that element [Skorbiłowicz 2002].

Mean contents of total nitrogen in the sludge from particular treatment plants were diversified and amounted between 40.7 and 49.9 $g \cdot kg^{-1}$ d.m. (Table 2). In extreme cases, while comparing results of individual determinations in samples from the same object, differences between them reached even more than 300% (Niegoszowice treatment plant). When confronting the obtained results with total nitrogen content in sludge from other regions of Poland [Maćkowiak 2000, Siebielec, Stuczyński 2008, Mazur, Mokra 2011], it was established that sludge from Krakow district is richer in that element. However, such high ni-

Table 2. Content of macroelements [$g \cdot kg^{-1}$ d.m.] in sewage sludge from selected small sewage treatment plants from Krakow District in 2007–2012

Parameter	N	$N\text{-}NH_4$	P	K	Ca	Mg
Treatment plant Balice						
minimum	30.0	1.0	7.3	2.6	26.1	3.9
maximum	66.8	16.0	27.3	4.5	65.7	6.1
mean	49.0	8.3	14.5	3.4	44.7	4.9
median	45.5	8.1	13.6	3.3	40.7	5.0
V %*	26.0	64.3	37.5	18.0	29.4	13.1
Treatment plant Krzeszowice						
minimum	21.9	0.4	11.0	0.6	23.7	2.7
maximum	51.3	6.5	40.1	4.0	56.5	8.0
mean	40.7	2.8	20.3	2.7	39.4	6.1
median	40.0	2.3	19.9	2.9	39.3	6.2
V %	20.2	68.4	35.9	40.1	21.8	23.0
Treatment plant Niegoszowice						
minimum	15.0	0.3	5.7	2.5	25.0	4.2
maximum	57.7	17.5	21.4	5.1	82.6	6.6
mean	44.7	7.3	16.1	3.8	45.9	5.5
median	45.2	7.5	18.2	3.8	47.1	5.7
V %	26.3	68.9	29.2	18.8	38.4	14.6
Treatment plant Zelków						
minimum	38.7	2.4	9.0	0.9	26.3	3.8
maximum	61.8	9.8	35.0	5.5	49.3	6.4
mean	49.9	4.9	16.6	3.2	36.9	4.7
median	51.5	4.3	14.8	3.5	38.7	4.4
V %	16.9	50.6	45.0	39.6	21.4	15.6

*V% – coefficient of variation.

trogen contents might be the reason of limitation of the amount of utilized sludge, because, according to guidelines of Code of Good Agricultural Practice [2004], the annual nitrogen dose in a fertilizer should not exceed 170 kg·ha^{-1}. Thus, for example, when using 9 Mg d.m.·ha^{-1}, which is the maximum permissible sludge dose for once in 3 years [Regulation 2010], nitrogen content in the used sludge cannot exceed 19 g·kg^{-1} d.m. With relation to the above, in order to follow the guidelines of Code of Good Agricultural Practice [2004], soil fertilization with the studied sludge would require adequate dose reduction or its more frequent application.

Phosphorus content in the discussed sludge was less stable than nitrogen content. The calculated variation coefficients most often exceeded 30% (Table 2). Mean phosphorus contents were within a range between 14.5 and 20.3 g·kg^{-1} d.m., depending on treatment plant. They were slightly lower compared to the contents provided by other authors [Bauman-Kaszubska, Sikorski 2011, Mazur, Mokra 2011], yet high enough to introduce 130 kg P·ha^{-1} to soil using 9 Mg d.m. of the sludge from Balice, which had the lowest mean phosphorus content. Phosphorus applied in such amounts will be used directly by cultivated plants only in part, instead it will accumulate mainly in the soil surface layer, forming an important share in supplying plants in succeeding years.

As it has been already mentioned, the studied sludge had a relatively low potassium content, but that content did not deviate from the amounts determined in such materials [Maćkowiak 2000, Siebielec, Stuczyński 2008]. In respect of richness in potassium, the fertilizing value of sewage sludge should be regarded as not high, since even if the maximum permissible dose is applied, approximately 30 kg K·ha^{-1} can be delivered to plants, which generally constitutes tens of percent of nutrient requirements of a cultivated plant. Therefore, in order to use the studied sludge in fertilization, it must be kept in mind to carry out supplementary fertilization with potassium.

Calcium and magnesium content in sewage sludge depends on the character of sewage flowing in, and, in addition, calcium content depends also on the manner of sewage sludge hygienization. These elements, introduced to soil, have beneficial influence on soil reaction, and they are also important nutrients for plants. Mean calcium content in the analyzed sludge was most often higher or comparable, whereas mean magnesium content was about twice higher compared to the amounts of these elements that were determined in sewage sludge coming from other treatment plants from Poland [Siebielec, Stuczyński 2008, Mazur, Mokra 2011]. By fertilizing soil with 9 Mg dry matter of the discussed sludge, on average 375 kg Ca and 48 kg Mg will be introduced, which should satisfy the nutrient requirements of plants for these elements and slightly influence the increase in soil pH.

The results of the determinations (conducted within five years) of heavy metals content in the sludge from treatment plants from Kraków district are presented in Table 3. Recorded amounts of metals can be generally considered as small. In the monitored group of sewage sludge there was no case of exceeding the permissible contents of heavy metals in municipal sewage sludge used in agriculture as well as for land reclamation for agricultural purposes [Regulation 2010]. Mean zinc content in the sludge was 54%, mean cadmium and copper contents were approximately 20%, and mean contents of the remaining metals did not even reach ten percent of their maximum permissible values. The determined contents of trace metals were considerably lower than contents stated in municipal sludge by Siebielec and Stuczyński [2008]. Mercury (mean V = 64%) turned out to be the element which was characterized by the highest variation, whereas contents of zinc (mean V = 19%) and nickel (mean V = 21%) were the most stable. When analyzing the variation in sludge composition in individual treatment plants, the lowest fluctuations in contents of trace metal were found in the sludge samples from Krzeszowice, which is indicative of a higher uniformity of sewage flowing into this plant.

Municipal sewage sludge from Krzeszowice contained approximately three times more cadmium and lead as well as almost twice more zinc compared to their amounts in the sludge from the remaining treatment plants. The cause of this phenomenon is surely the fact that this treatment plant takes sewage with a higher share of industrial sewage than the remaining three facilities, which convert sewage from rural areas. Content of the remaining metals in the sludge from all treatment plants was at a similar level, even though there were some individual samples containing considerably higher amounts than other samples. For instance, the sludge from Balice, which was collected in June 2011, contained as much as 619 mg Cu·kg^{-1} d.m., whereas the content of this element

Table 3. Content of heavy metals [mg·kg^{-1} d.m.] in sewage sludge from selected small sewage treatment plants from Krakow District in 2007–2012

Parameter	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Treatment plant Balice							
minimum	0.70	16.7	92.2	0.24	7.8	15.6	580.4
maximum	2.31	27.6	619.0	2.04	16.4	42.5	1122.7
mean	1.33	22.9	173.7	0.67	13.0	25.7	773.2
median	1.26	22.9	127.6	0.52	12.8	25.0	747.8
V %*	39.7	14.7	86.4	81.8	20.0	29.8	20.6
Treatment plant Krzeszowice							
minimum	3.33	24.2	130.8	0.29	14.6	18.6	1194.2
maximum	5.84	56.6	218.6	2.23	23.1	113.0	1598.2
średnia/mean	4.32	34.8	158.5	0.87	18.8	77.1	1355.6
median	4.24	33.4	155.1	0.72	19.3	82.0	1306.7
V %	19.4	26.4	15.5	63.5	14.9	29.6	11.0
Treatment plant Niegoszowice							
minimum	0.72	22.3	71.8	0.12	14.6	15.2	506.7
maximum	2.11	69.3	193.8	1.11	43.0	40.0	1024.0
mean	1.31	37.1	122.4	0.45	21.6	25.9	810.1
median	1.19	32.7	113.0	0.37	20.6	25.0	827.3
V %	34.7	43.1	27.3	69.7	36.5	30.3	20.0
Treatment plant Zelków							
minimum	1.38	18.8	137.2	0.13	11.7	21.1	750.5
maximum	3.11	55.1	350.5	0.73	19.9	41.7	1642.6
mean	1.95	30.9	205.1	0.44	17.3	28.5	1028.5
mediana/median	1,77	28,8	184,7	0,44	17,0	27,7	954,5
V %	28,1	32,7	30,8	42,5	14,0	19,0	25,1

*V% – coefficient of variation.

in the remaining samples most often oscillated between 100 and 200 mg Cu·kg^{-1} d.m.

The carried out research showed that, in respect to chemical composition, the monitored municipal sewage sludge meets all requirements which are now binding in Poland. When used in soil, it can be a rich source of organic matter as well as macro- and microelements, and the content of pollutants is at a relatively low level. Contamination with bacteria from the *Salmonella* group, which was observed in more than sixty percent of the examined samples, seriously limited the perspective of their use in agriculture. However, this situation can be significantly corrected by improving sludge hygienization processes in the discussed treatment plants. In order to manage municipal sewage sludge for agricultural purposes, it should be kept in mind that apart from having sludge fit for such a way of management, access to sufficient number of areas which could meet all legal requirements [Act 2001, Regulation 2010] that are set for such lands (regarding e.g. reaction, heavy metals content in a 0–20 cm layer, appropriate distance from water bodies, water intakes or homesteads) is necessary.

CONCLUSIONS

1. Municipal sewage sludge from Kraków district is characterized by a high content of fertilizing elements, i.e. organic substance, nitrogen, phosphorus, calcium and magnesium, as well as by relatively low heavy metals contents, which predestines the sludge to be used in agriculture for fertilizing purposes.
2. Due to frequent occurrence of bacteria from the *Salmonella* group in the studied sludge, its agricultural use may be limited. In order to reduce the amount of microbiologically contaminated sludge, an improvement of the hitherto used hygienization methods is necessary.

3. Relatively high variation in the determined physical and chemical, microbiological-parasitological parameters makes it necessary to continuously monitor the sludge coming from particular lots and sewage treatment plants.

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