CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXVII, z. 67, 2020, s. 19-32, DOI:10.7862/rb.2020.2

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ASSESSMENT OF THE POSSIBILITIES OF AGRICULTURAL USE OF SEWAGE SLUDGE FROM SMALL, MEDIUM AND LARGE WASTEWATER TREATMENT PLANTS

The management of sewage sludge, generated at various stages of wastewater treatment, is still a significant problem. One of the possibilities of using sewage sludge, which is a valuable source of nutrients (carbon, nitrogen, phosphorus), is its use for agricultural purposes. Sludge can be used for fertilising when it meets the requirements with regard to the content of heavy metals, the number of eggs of intestinal parasites and *Salmonella* bacteria, and when the amount of organic substances and fertilising components is sufficient. That is why it is so important to know exactly the characteristics of sewage sludge. This allows determination of whether it can be used as fertiliser in agriculture. The study assesses the agricultural use of sewage sludge from three mechanical and biological wastewater treatment plants of different PE, produced in 2016–2018. The analysis was carried out on the basis of the physicochemical parameters of the sludge. Particular attention was paid to the fertilisation and sanitary properties, as well as the presence of heavy metals, which were largely influenced by such factors as: the size of the wastewater treatment plant, the method of sewage sludge treatment and sludge management, and the nature of the catchment area. The concentrations of particular substances in sludge from wastewater treatment plants differed from one another, and sometimes these were very large differences. The conducted analysis showed that sewage sludge, from both small and large wastewater treatment plants, has a significant potential as agricultural fertiliser due to the presence of minerals such as nitrogen, phosphorus and calcium.

Keywords: municipal sewage sludge, heavy metals in sludge, fertilisation properties of sludge, sanitary properties, wastewater treatment plant PE

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1. Introduction

1.1. Legal conditions of the agricultural use of sewage sludge

The supreme legal act in Poland dealing with broadly understood waste management is the Act of 14 December 2012 on waste. According to this act, the term municipal sewage sludge is understood as sludge from wastewater treatment plants, more precisely from fermentation chambers and other installations for the treatment of municipal sewage and other sewage with a composition similar to that of municipal sewage [1]. In accordance with the Regulation of the Minister of Climate of 2 January 2020 on the waste catalogue, stabilised municipal sewage sludge has the code 19 08 05 [2].

The use of sewage sludge in agriculture, understood as the cultivation of all agricultural crops placed on the market, including crops intended for the production of animal feed, is possible when it is stabilised and properly prepared (subjected to, for example, biological, chemical, thermal or other treatment) depending on its intended use and method of application, thanks to which it does not pose a threat to the environment and people, and is less susceptible to decay [1].

Relevant legal acts regulate the prohibition of agricultural use of sewage sludge (Tab. 1).

Table 1. Criteria limiting the agricultural use of sewage sludge, based on [1, 3]

Criterion	Characteristics
Type of land / soil on which sludge cannot be used	– an area of indirect protection of water intakes or a protected area of inland water reservoirs, – a 50 m wide strip of land directly adjacent to the banks of lakes and watercourses, – soil with high permeability, – an area with an incline >10%, – an area where: the distance from a water intake, a residential house or a food production plant is less than 100 m, fruit plants and vegetables grow, except for fruit trees, cultivation will be carried out under covers, – land used for pastures and meadows.
Heavy metal content	Use in agriculture and for land reclamation for agricultural purposes: – 20 mg Cd/kg DM, 1000 mg Cu/kg DM, 300 mg Ni/kg DM, 750 mg Pb/kg DM, 2500 mg Zn/kg DM, 16 mg Hg/kg DM, 500 mg Cr/kg DM.
Microbiological properties of sludge	Use in agriculture and for land reclamation for agricultural purposes: – presence of bacteria of the genus *Salmonella*: not isolated in a representative sample of sludge weighing 100 g, – total number of live eggs of intestinal parasites *Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.* in 1 kg of dry mass: 0.

The most important executive act for the Law on waste regulating the use of sewage sludge in agriculture and other branches of the economy is the Regulation of the Minister of the Environment of February 6, 2015 on municipal sewage sludge, which specifies the principles of its use and dosage, as well as methodology, scope and frequency of testing the sludges and the land on which they are to be applied [3]. Example tests with reference methods are carried out at a frequency depending on the size of the wastewater treatment plant, expressed in population equivalent (PE) and amount to once every six months for PE <10 000, once every four months for 10 000 < PE < 100 000 and once every two months for PE > 100 000. In turn, the following parameters of sewage sludge are tested: pH, dry mass content, organic matter, total nitrogen, including ammonium nitrogen, calcium and magnesium, total phosphorus, heavy metals, as well as the presence of pathogenic bacteria of the genus *Salmonella* and the number of live eggs of intestinal parasites [3]. The requirements and principles contained in this regulation are in line with the Council Directive 86/278/EEC [4].

1.2. Fertilisation properties of sewage sludge

The use of sewage sludge in agriculture is justified due to its fertilisation properties, and thus the possibility of improving the physical and chemical properties of soil, e.g. increasing the degree of infiltration. The use of sewage sludge as fertiliser significantly increases the amount of humus in the soil and is a very valuable source of nutrients, therefore its use may replace natural fertilisation or constitute supplementary fertilisation [5, 6]. Calcium and magnesium can also contribute to the improvement of soil fertility, and their presence in sludges allows soil to be enriched with these elements, the latter of which is currently a deficient component [6, 7]. Sewage sludge is also rich in phosphorus. Table 2 presents the content of particular components in sewage sludge depending on the type.

Table 2. The composition of sewage sludge depending on the type, based on [8]

Parameter	Unit	Type of sludge			
		Raw sludge - primary sludge	**Raw sludge – secondary sludge (activated sludge)**	**Well-digested sludge**	**Very well-digested sludge**
Dry matter	[%]	5–10	0.5–3.0	4–12	4–12
Total nitrogen	[%]	2–7	2–10	0.5–3.0	0.5–2.5
Total phosphorus	[%]	0.4–3.0	0.9–1.5	0.3–0.8	0.3–0.8
Potassium	[%]	0.2–0.7	0.1–0.8	0.1–0.3	0.1–0.3

It should be emphasised that the composition of sewage sludge is variable and depends on the type and amount of wastewater introduced to the sewage system, as well as on the method of its treatment [6, 9].

When considering the possibility of using municipal sludge for agricultural purposes, mainly due to its fertilisation properties, one should always pay attention to its heavy metal content. For example, the presence of nickel is dangerous for plants because it adversely affects metabolism, which inhibits the growth of their roots, and may also contribute to leaf chlorosis. Also, a small amount of cadmium adversely affects plants, leading to browning and leaf chlorosis. A high concentration of copper and zinc can also have a negative effect on plant development, despite the fact that they are essential nutrients. The presence of lead in their tissues may also have a negative impact on the development of plants, causing disorders in photosynthesis and cell division and sometimes the disturbance of water use [10].

Thanks to the very good fertilisation properties of sewage sludge, it is used, for example, for fertilising land intended for the cultivation of plants used in the production of compost. This method of use is based on single and intensive soil fertilisation. In the following years, plants with high energy values, such as willows, poplars, cereals, rape, are constantly cultivated on such a substrate and periodically the soil is fertilised with sewage sludge [11].

2. Materials and methods

In order to assess the agricultural use of sewage sludge, three municipal wastewater treatment plants were selected, located in the Podkarpackie Voivodeship, where sludge is formed in subsequent stages of wastewater treatment.

The largest of the wastewater treatment plants under study (WWTP A) is a facility designed for mechanical and biological wastewater treatment, for which the value of the population equivalent is equal to 141 960 – which qualifies this facility as a large wastewater treatment plant. In the mechanical part of this treatment plant, wastewater is treated on automatic gratings, in two-chamber horizontal sand traps and in primary settling tanks. In turn, in the biological part, the classic Bardenpho system is used with predenitrification of recirculated sludge and secondary settling tanks after biological reactors. As a result of mechanical and biological wastewater treatment processes, sewage sludge is produced in the treatment plant, which is directed to equipment enabling its processing and biogas production. The thickening process is carried out in gravity thickeners for primary sludge and in mechanical thickeners for secondary sludge. The thickened sludge undergoes an anaerobic stabilisation process, which is carried out in separate fermentation chambers with a total capacity of 5 000 m^3. Then the sludge is subjected to the dewatering process on belt sieves. Due to the size of the wastewater treatment plant, the frequency of tests of the generated sludges is 6 times a year.

The next of the selected wastewater treatment plants (WWTP B) is a facility with a size of 16 876 PE, which also carries out mechanical and biological wastewater treatment. For the mechanical treatment of wastewater, this treatment plant uses a stepped grate, vertical sand traps and an Imhoff primary settling tank, in which primary sludge fermentation also takes place. Mechanically treated sewage is sent to biological treatment in sequencing batch reactors. These reactors work on technology ensuring the process of biological dephosphatation, denitrification, nitrification and simultaneous oxygen stabilisation of excess activated sludge and do not require the use of secondary settling tanks. In the biological treatment process, a reagent is added to the wastewater to assist in the simultaneous chemical precipitation of phosphorus. Primary sludge after the anaerobic digestion process in the Imhoff settling tank and excess sludge stabilised in bioreactors is gravitationally discharged to gravity thickeners. From the thickeners, the mixed sludge flows into the mixed sludge tank, from where it is pumped to a dewatering press. The dewatered sludge is subjected to hygienisation by mixing with lime and stored in a covered sludge storage facility. For this plant, the frequency of sludge testing is 3 times a year.

The smallest of the selected wastewater treatment plants (WWTP C) is a facility with the size of 1 328 PE, which is designed for mechanical and biological wastewater treatment. In the mechanical part, purification takes place on a sand trap. In turn, the removal of biogenic compounds is carried out by the activated sludge method in a sequencing batch reactor. Excess sludge, as part of the activated sludge separated from the treated wastewater in the sedimentation phase, is discharged to a separate oxygen stabilisation tank. In the stabilisation tank, a polyelectrolyte is added to the sludge in order to increase the efficiency of the subsequent sludge treatment process, i.e. dewatering and calcium for the purpose of hygienisation. After the stabilisation process, the sludge is discharged to a DRAIMAD dewatering device. The sludge prepared in this way goes to a covered sludge landfill. Due to the size of the wastewater treatment plant, it is necessary to test stabilised sewage sludge twice a year.

The assessment of the possibility of agricultural use of sewage sludge was carried out on the basis of data for a period of three years (from 2016 to 2018) provided by the operators of the particular wastewater treatment plants and in relation to the legal act, which is the Regulation of the Minister of the Environment of February 6, 2015 on municipal sewage sludge. The fertilisation properties of the sludges were analysed (the content of organic substances, total nitrogen and phosphorus, calcium and magnesium), the content of heavy metals in the sludges (lead, chromium, copper, nickel, cadmium, zinc and mercury) and the presence of *Salmonella* in 100 g of sludge, as well as the total number of live eggs of intestinal parasites *Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.* per 1 kg of dry mass. For particular parameters, basic descriptive statistics were determined, i.e. mean, minimum, maximum and standard deviation.

3. Research results and discussion

3.1. Assessment of fertilisation properties

One of the parameters allowing assessment of the fertilisation properties of sewage sludge is its organic matter content (Fig. 1). The sludges subjected to assessment showed differentiation in terms of this parameter. The highest mean values of organic matter content were recorded in sludges produced in the largest wastewater treatment plant (WWTP A). These sludges were characterised by a similar average annual concentration of organic matter in subsequent years, which varied from 66.62 to 68.35% DM. The dry mass of these sludges oscillated between 16.4 and 25.7%. On the other hand, sludges produced in WWTP B were characterised by a very variable concentration of organic matter in dry mass (dry mass ranged from 18.1 to 30.0%). The lowest value of this parameter was recorded in April 2016 (24.60% DM) and the highest in June 2018 (73.20% DM), while the mean values ranged from 45.40 to 59.43% DM. On the other hand, the average annual content of organic matter in sludges from WWTP C oscillated in the range of 46.70–55.85% DM (dry mass was in the range of 16.2–25.3%).

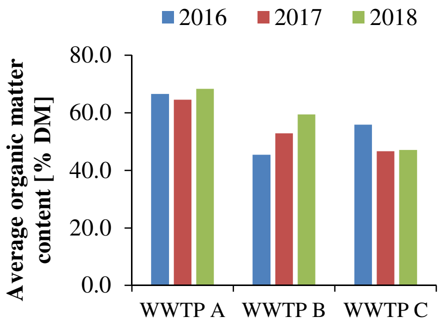

Fig. 1. Average organic matter content in sewage sludge from wastewater treatment plants: A, B and C

The content of organic matter in sludge from the analysed treatment plants is comparable with the literature. Kazanowska and Szaciło [12] report that the value of this parameter in sludge from the Suwałki wastewater treatment plant (the PE of this treatment plant is comparable to that of WWTP A) oscillated in the range of 62.70–72.00% DM. In turn, Wiater and Butarewicz [11] showed that the content of the analysed parameter in sludges from the wastewater treatment plant in Białystok in 2011–2013 amounted to an average of 56% DM.

The content of one of the most important fertilising components, i.e. total nitrogen, in sewage sludge from the WWTP A plant varied in the range of 4.54–6.14% DM. In the case of the WWTP B wastewater treatment plant, the total nitrogen content in the sewage sludge was lower than in the case of the above-mentioned wastewater treatment plant and was at the level of 2.65–5.04% DM. However, the content of this component in sewage sludge from the smallest wastewater treatment plant (WWTP C) was within the range of 2.66–4.60%. Mean values of total nitrogen (TN) content in particular sludges are presented in Fig. 2. Based on the literature, examples of average content of this element in sludges are 3.72% DM (wastewater treatment plant in Recz, data from 2010–2011) [13], or 3.89% DM (facility located in the Kuyavian-Pomeranian Voivodeship, data for 2015) [14].

The average content of total phosphorus in particular years in sludges from the largest of the analysed wastewater treatment plants ranged from 2.48 to 2.67% DM and was the highest among the facilities under consideration. In turn, the lowest values of the discussed macroelement, in the range from 1.03 to 1.17% DM, were recorded in sludges from the medium-sized wastewater treatment plant. The average content of total phosphorus in the dry mass of sludge in the smallest wastewater treatment plant ranged from 1.65 to 2.04% (Fig. 3). Literature data on phosphorus content in sludges are very divergent. Example values are 1.71% DM (wastewater treatment plant with a PE equal to 25 725) [15], 2.87–3.99% DM (wastewater treatment plant with a PE comparable to that of WWTP A) [12], or 0.015% DM (wastewater treatment plant with a PE comparable to that of WWTP C) [13].

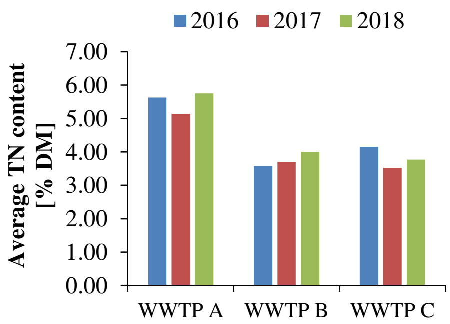

Fig. 2. Average total nitrogen content in sewage sludge from wastewater treatment plants: A, B and C

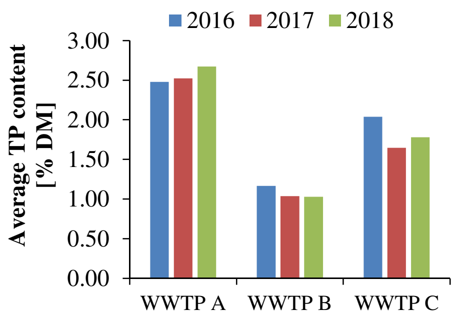

Fig. 3. Average total phosphorus content in sewage sludge from wastewater treatment plants: A, B and C

The calcium content of sewage sludge depends mainly on whether or not the sludge material is hygienised. Average annual amount of calcium in the years 2016–2018 in sewage sludge from WWTP A ranged from 3.01 to 3.13% DM. According to available information, the collected sludges were not limed for hygienisation purposes. In turn, sludge produced in WWTP B was characterised by a much higher average annual concentration of calcium in dry mass (from 9.90 to 16.13% DM) compared to the WWTP A treatment plant.

In this case, high levels of this element were caused by the sludge hygienisation process. The average annual calcium content in sludge from WWTP C fluctuated in the range of 3.38–4.77% DM (Fig. 4). Higher values of this parameter in sludges from WWTP C, compared to the results for sludges from WWTP A, result from the use of calcium for sludge hygienisation, which is added to the sludge stabilisation tank. The direct hygienisation process influenced the pH of the sludge – in the case of sludge from WWTP B this parameter oscillated between 7.8 and 12.6 (average 11.8). The pH of sludge from other wastewater treatment plants was lower, i.e. from 7.2 to 8.2 (average 7.7) for WWTP A and from 6.9 to 8.6 (average 7.7) for WWTP C.

The concentration of magnesium in sludge from the largest wastewater treatment plant was within a range from 0.23 to 0.59% DM. In the case of the medium-sized wastewater treatment plant, the content of this element ranged from 0.37 to 0.97% DM. On the other hand, the amount of magnesium in sludge from the smallest wastewater treatment plant was in a wide range from 0.3 to 1.3% DM. The average content of this element in sludges in consecutive years is shown in Fig. 5.

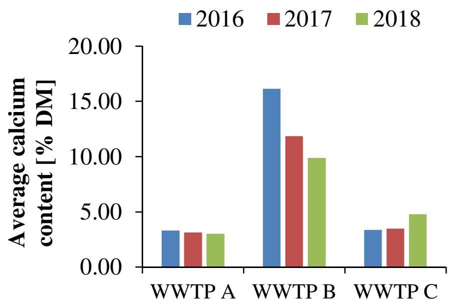

Fig. 4. Average total calcium content in sewage sludge from wastewater treatment plants: A, B and C

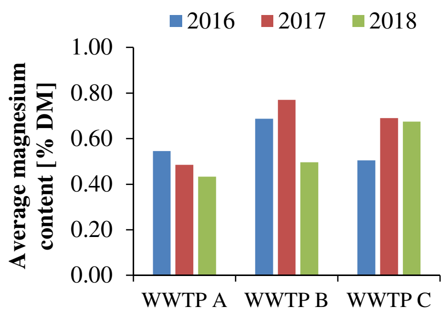

Fig. 5. Average total magnesium content in sewage sludge from wastewater treatment plants: A, B and C

3.2. The content of heavy metals in sewage sludge

The content of heavy metals in the sludge under assessment varied both between the particular treatment plants and in many cases in the subsequent years analysed (Tab. 3).

The highest lead content was recorded in sewage sludge from the WWTP A treatment plant – the maximum value of 49 mg Pb/kg DM was recorded in October 2017. In the case of sludge from WWTP B, the average lead content was lower than that of WWTP A. The lowest value of this metal was recorded six times and it was 15 mg Pb/kg DM, while the maximum value was 41 mg Pb/kg DM. On the other hand, the lead content in sewage sludge from WWTP C oscillated between 22 and 38 mg Pb/kg DM.

Table 3. Values of selected descriptive statistics for content of heavy metals in sewage sludge noted in the 2016–2018 period

Parameter	Year	Metal						
		Pb [mg/kg]	Cr [mg/kg]	Cu [mg/kg]	Ni [mg/kg]	Cd [mg/kg]	Zn [mg/kg]	Hg [mg/kg]
WWTP A								
Average	2016	32.5	82.7	173.7	110.8	2.0	1 002.3	0.579
	2017	38.2	75.2	191.2	64.7	2.8	946.3	0.563
	2018	27.3	59.0	169.5	77.0	12.7	1 004.5	0.785
Minimum	2016	21.0	57.0	142.0	47.0	1.1	860.0	0.448
	2017	29.0	36.0	163.0	30.0	1.7	840.0	0.326
	2018	18.0	45.0	123.0	30.0	0.0	915.0	0.417
Maximum	2016	41.0	110.0	196.0	292.0	3.7	1 346.0	0.769
	2017	49.0	93.0	220.0	117.0	3.6	1 132.0	0.708
	2018	37.0	84.0	209.0	117.0	39.0	1 090.0	1.810
SD	2016	8.8	19.7	19.8	92.9	1.0	175.9	0.118
	2017	8.1	20.9	20.2	30.0	0.8	115.8	0.140
	2018	7.2	15.1	28.4	27.8	14.3	71.0	0.516
WWTP B								
Average	2016	19.7	24.0	124.7	31.3	1.4	694.0	0.361
	2017	17.5	28.0	129.3	33.3	1.1	930.3	0.382
	2018	23.7	38.3	139.7	31.0	2.1	1 003.3	0.177
Minimum	2016	15.0	15.0	83.0	26.0	1.0	572.0	0.144
	2017	15.0	24.0	109.0	32.0	1.0	522.0	0.202
	2018	15.0	20.0	129.0	12.0	1.0	904.0	0.107
Maximum	2016	29.0	41.0	154.0	36.0	2.2	906.0	0.571
	2017	20.0	33.0	141.0	34.0	1.4	1 560.0	0.631
	2018	41.0	67.0	160.0	46.0	3.9	1 095.0	0.214
SD	2016	8.1	14.7	37.1	5.0	0.7	184.3	0.214
	2017	3.5	4.6	17.7	1.2	0.2	553.3	0.223
	2018	15.0	25.2	17.6	17.4	1.6	95.7	0.060
WWTP C								
Average	2016	30.0	33.0	175.0	27.0	1.8	1 440.0	0.343
	2017	28.0	78.0	189.0	55.0	1.3	1 407.0	0.403
	2018	26.5	60.0	164.5	72.5	1.4	1 315.0	0.297
Minimum	2016	22.0	18.0	170.0	21.0	1.5	1 424.0	0.341
	2017	26.0	51.0	180.0	34.0	1.1	1 398.0	0.400
	2018	23.0	44.0	131.0	33.0	1.0	1 200.0	0.149
Maximum	2016	38.0	48.0	180.0	33.0	2.1	1 456.0	0.345
	2017	30.0	105.0	198.0	76.0	1.6	1 416.0	0.405
	2018	30.0	76.0	198.0	112.0	1.7	1 430.0	0.444
SD	2016	11.3	21.2	7.1	8.5	0.4	22.6	0.003
	2017	2.8	38.2	12.7	29.7	0.3	12.7	0.004
	2018	4.9	22.6	47.4	55.9	0.5	162.6	0.209

The amount of chromium in sewage sludge from the WWTP A treatment plant oscillated in the range of 36–110 mg Cr/kg DM. The content of this metal in sludges from WWTP C was at a comparable level, as it was in the range from 18 to 105 mg Cr/kg DM. On the other hand, the content of this element in sludge from the WWTP B wastewater treatment plant was much lower – it varied in the range of 15–67 mg Cr/kg DM. In the case of chromium content, the sludges showed differentiation (Fig. 6).

Sludges produced in WWTP A and WWTP C were characterised by a higher content of copper – the values fluctuated respectively in the range of 123–220 mg Cu/kg DM and 131–198 mg Cu/kg DM. On the other hand, the content of this metal in sludges produced in WWTP B ranged from 83 to 160 mg Cu/kg DM.

The analysis of sewage sludge in terms of nickel content showed that sludge from the largest treatment plant was characterised by the highest content of this element – the maximum obtained value was 292 mg Ni/kg DM. In the case of sludge from the medium and small wastewater treatment plants, the maximum nickel concentration was 46 and 112 mg Ni/kg DM, respectively. The differences in the average content of this element in sludges in subsequent years are shown in Fig. 7.

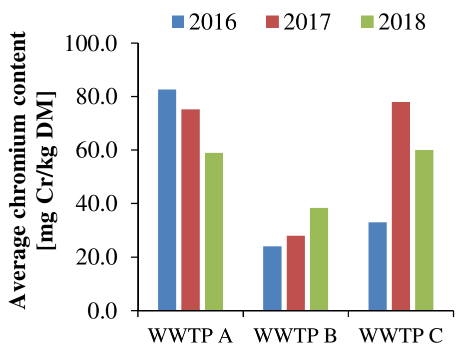

Fig. 6. Average chromium content in sewage sludge from wastewater treatment plants: A, B and C

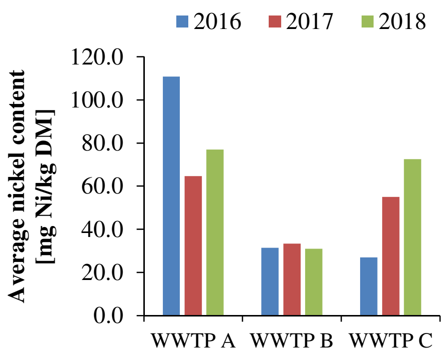

Fig. 7. Average nickiel content in sewage sludge from wastewater treatment plants: A, B and C

The average annual content of cadmium in sewage sludge from WWTP A ranged from 2.0 to 12.7 mg Cd/kg DM. In the case of WWTP B and WWTP C, the value was 1.1–2.1 mg Cd/kg DM and 1.3–1.8 mg Cd/kg DM, respectively. In the case of sludge from the largest treatment plant, the maximum content of this metal was recorded at the level of 39 mg Cd/kg DM (October 2018) and this was over 10 times higher than the remaining results. The average cadmium content in the sludges is presented in Fig. 8.

The zinc content in sludge from the WWTP A wastewater treatment plant fluctuated in the range from 840 to 1 346 mg Zn/kg DM. The zinc content in sludge from the WWTP B wastewater treatment plant was from 522 to 1 560 mg Zn/kg DM. On the other hand, in the WWTP C treatment plant, the content of this element ranged from 1 200 to 1 456 mg Zn/kg DM.

The last metal analysed is mercury. The average content of this metal in sewage sludge from the largest treatment plant was 0.643 mg Hg/kg DM. The data analysis shows that the average amount of mercury in sewage sludge from the medium-sized treatment plant was 0.307 mg Hg/kg DM. However, in the case of the smallest wastewater treatment plant, the amount was 0.347 mg Hg/kg DM. Average contents of this element in sludges are presented in Fig. 9.

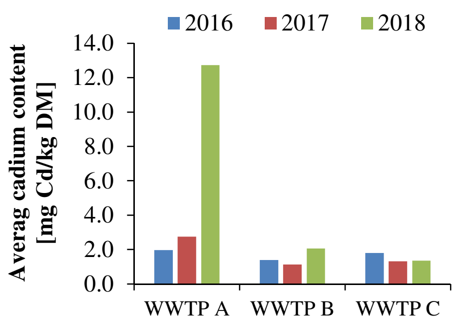

Fig. 8. Average cadium content in sewage sludge from wastewater treatment plants: A, B and C

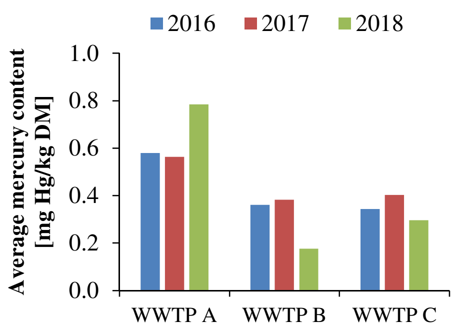

Fig. 9. Average mercury content in sewage sludge from wastewater treatment plants: A, B and C

The analysis of the data provided showed that in almost all cases the sewage sludge, in terms of heavy metal content, met the requirements of the Regulation of the Minister of the Environment of February 6, 2015 on municipal sewage sludge [3]. The exception was the amount of cadmium in October 2018 in sewage sludge from the WWTP A treatment plant. This value exceeds by almost twice the permissible concentration for agricultural use of sewage sludge – amounting to 20 mg Cd/kg DM. Moreover, the content of metals in the assessed sludges falls within the ranges indicated in the literature. Czekała [16] states that the content of heavy metals in sludges fluctuates in the following ranges: 5.0–2 970.0 mg Pb/kg DM; 3.2–8 500.0 mg Cr/kg DM; 3.0–1 840.0 mg Cu/kg DM; 1.7–830.0 mg Ni/kg DM; 0.2–56.2 mg Cd/kg DM; 126.0–4 640.0 mg Zn/kg DM and 0.003–7.55 mg Hg/kg DM.

3.3. Microbiological properties of sewage sludge

The evaluation of the microbiological properties of sludges from WWTP A showed that live eggs of intestinal parasites *Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.* were isolated four times in the analysed years. These were tests in February, April and August 2017 and August 2016. However, tests for the presence of pathogenic bacteria of the genus *Salmonella* in 100 g of sludge showed that in February 2016 and 2017 sewage sludge contained 130 and 110 such bacteria, respectively. Also, live eggs of intestinal parasites *Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.* were isolated twice (in April 2016 and 2017) in sludges from WWTP C. In turn, tests for the presence of pathogenic bacteria of the genus *Salmonella* in 100 g of sludge showed that there were no such bacteria in any sludge sample from WWTP C. Only sludges from WWTP B met the legal requirements each time for microbiological properties – live eggs of intestinal parasites *Ascaris sp.*, *Trichuris sp.*, *Toxocara sp.* and pathogenic bacteria of the genus *Salmonella* in 100 g of sludge were not isolated from any sludge samples, which confirms the legitimacy of sludge hygienisation with calcium.

4. Conclusions

The assessment of particular parameters of municipal sewage sludge from selected wastewater treatment plants, in terms of the possibility of its agricultural use, showed that:

- the proportion of organic matter in the sludge depends on the size of the treatment plant – the higher the PE of the wastewater treatment plant, the higher its content in the sludge, while the phosphorus content in the sludge seems to be independent of the size of the facility,
- sludge hygienisation after the process of aerobic or anaerobic stabilisation contributes to an increase in the proportion of calcium in the dry mass of sludge,
- the size of the wastewater treatment plant definitely influenced the heavy metal content in the sludges – much higher levels of lead, chromium, nickel, cadmium and mercury were recorded in the sludges from the largest wastewater treatment plant,
- the lowest concentrations of metals were recorded in sludges from the medium-sized wastewater treatment plant – the area of this facility and the wastewater catchment area are in forest and spa areas,
- appropriate sanitary properties were obtained only in sludge taken from the medium-sized wastewater treatment plant – which results from direct hygienisation of the sludge with calcium, for the remaining wastewater treatment plants the limits for sanitary properties were exceeded.

To sum up, the differences between the sludges in the content of fertilising substances, heavy metals and microbiological composition are influenced by such factors as: the size of the wastewater treatment plant, the method of wastewater treatment, the manner of sludge management (especially the adopted solution in the field of stabilisation and hygienisation of sludge) and the nature of the catchment area. Some batches of the tested sludge did not meet the relevant requirements; however, it should be remembered that the properties of the sludge in a wastewater treatment plant depend on many factors, and deviations from the norm for one batch of sludge do not exclude the agricultural use of other batches. Finally, it is concluded that sewage sludge, regardless of the size of the treatment plant, is a material that can be used very often for fertilisation in agriculture.

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Przesłano do redakcji: 30.09.2020 r.