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CRITICAL ASSESSMENT AND RECOMMENDATIONS FOR SEWAGE SLUDGE MANAGEMENT IN POLAND

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ABSTRACT: The purpose of the article is to demonstrate practices used to supervise the use of sewage sludge for agricultural purposes. The presented research and conclusions are a trend analysis and are not to be used to penalise entities. Sewage sludge, which comes from the illegal dumping of wastewater into municipal wastewater by industrial plants, contains large amounts of heavy metals. Treatment plants transfer the sludge for agricultural use. Regulations specifically restrict the mode and conditions for such use of sludge. Methods: the research was carried out using a proprietary questionnaire, which is a supplement to the reporting questionnaire of the National Urban Wastewater Treatment

Program implemented by the State Water Company "Wody Polskie". Results: The survey was conducted at 208 wastewater treatment plants in Poland. The results show that the majority of wastewater treatment plants do not properly supervise the process of introducing sewage sludge into the soil. They also lack supervision of how much heavy metals from wastewater are introduced into the soil. This means that there is a very high risk of contamination of agricultural soils. The results obtained could initiate a detailed analysis of this phenomenon in Poland. A comprehensive study of the scale of the practice and its current effects is required to determine the actual condition of soil treated with sewage sludge.

KEYWORDS: sewage sludge, metals fractions, wastewater treatment plants

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Introduction

Climate change, air pollution, global warming, and other adverse global phenomena have become well-known to the public, largely due to the efforts of non-governmental organisations and the media. On the contrary, the issue of high concentrations of heavy metals in municipal sludge remains largely unknown to the public, resulting in a lack of societal pressure on businesses, treatment plants, and lawmakers to adequately oversee these phenomena. Of particular concern is the poorly supervised process of discharging these substances into the environment, notably into soils used for growing plants for human and livestock consumption. This leads to direct (through plants) and indirect (through animals fed on these plants) ingestion of hazardous substances, introducing them into our bodies.

Municipal sewage sludge is the sludge from a wastewater treatment plant. It comes from fermentation chambers and other installations used for the treatment of municipal sewage. Other sewage with a composition similar to that of municipal sewage is also treated as municipal sludge. The sludge generated in the course of wastewater treatment should be treated and then properly used, managed, conditioned, or disposed of. Municipal sewage sludge management is subject to a hierarchy of waste management and is regulated by relevant provisions of law. Municipal sewage sludge can be reused if it is stabilised and prepared according to the purpose and method of its use. This includes biological, chemical, or thermal treatment, which reduces its susceptibility to rot and eliminates environmental or human life and health hazards (Cieslik et al., 2015; Kacprzak et al., 2017; Przydatek & Wota, 2020; Borek & Romaniuk, 2020; Wojcieszczak et al., 2023; Czekala et al., 2023). In recent years, there has been increased interest in the use of ash from sewage sludge incineration for the manufacture of concrete (Sikora et al., 2019), as well as sewage sludge organic matter for the production of lightweight aggregate used in construction (Góralczyk et al., 2009; Franus et al., 2020).

It could seem that the existing legislation defines all possible conditions, restrictions, and recommendations for managing sludge in such a way that it is environmentally safe. However, practice shows and studies confirm that despite legal requirements, sludge producers do not properly supervise what happens to the sludge after it is released to recipients (Spinosa et al., 2011).

During expert panels with employees of wastewater treatment plants, a significant problem was revealed. In cities and minor municipalities, companies connected to the municipal sewage network discharge untreated sewage into municipal industrial wastewater collectors. In many cases, treatment plants cannot cope with such contaminated municipal wastewater and dilute it to avoid the destruction of the biological substance in technological installations. When the sludge is concentrated and dehumidified, hazardous substances are re-concentrated, and in this form, the sludge goes to the landfill.

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The main problem is that domestic wastewater treated in treatment plants contains very significant amounts of heavy metals (Ignatowicz, 2017; Mulchandani & Westerhoff, 2016; Dahiya et al., 2022; Barwicki et al., 2022; Derehajlo et al., 2023). The origin of these pollutants is industrial, not residential. Expert panels conducted with representatives of wastewater treatment plants and scientists identified potential and suspected sources of heavy metals that pollute wastewater. These are most often industrial plants located within the agglomeration, which, in certain situations, discharge pollutants accumulated over a period of time into the sewage collectors of the municipal network.

Discussions and analyses conducted during expert panels showed low awareness of the strategic importance of the problem among residents, representatives of local government, companies supplying water to customers, companies dealing with sewage treatment, and entrepreneurs operating in the catchment area.

The main goal of the article is to indicate the risks associated with the lack of awareness among entrepreneurs, the public, and officials supervising the work of wastewater treatment plants concerning the consequences of improper supervision over the disposal of sewage sludge produced in urban agglomerations. The additional goal is also to show the scale of the phenomenon together with its perception by society and entities dealing with sewage treatment and sludge processing.

The authors of the article, based on the analysis of legal conditions and data obtained from 208 municipal wastewater treatment plants in Poland, note the following important aspects of the described problems:

- there is a need for continuous supervision of the control of the various methods of sludge disposal used,
- there is a need to develop recommendations on how to register the sludge.

We show that there are risks associated with a free interpretation of the regulations on the use of sludge, as well as the use of methods of control and supervision of their use. Secondly, the existing provisions create certain gaps in the chain of use of sewage sludge that can be used for agricultural purposes, which should not be the case due to the high content of heavy metals in the sludge.

Literature review

The topic of sewage sludge (SS) is developing dynamically, which is reflected in the constantly growing number of publications on this topic. The main theme in the articles is the management or use of sewage sludge. Due to the increase in the amount of SS produced, it is necessary to manage it appropriately in accordance with the applicable state and European regulations, as well as EU recommendations (Szpilko & Ejdys, 2022). The direction of SS development is significantly influenced by legal requirements and restrictions (Hawrylik et al., 2022).

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For example, one of the requirements is a total ban on the storage of high-calorie SS in landfills (combustion heat above 6 MJ/kg of dry matter) and the maximum use of its fertiliser potential (Szołdrowska & Smol, 2022; Czekala et al., 2023).

After appropriate treatment, i.e., concentration, stabilisation, dehydration, drying and incineration, sewage sludge can be used in different ways (Krasowska et al., 2023). It can be used, among others, as organic fertiliser in agriculture (Przydatek & Wota, 2020). In the literature on the subject, research on this issue focuses on the assessment of the fertiliser potential of sewage sludge, its impact on soil properties, the effectiveness of use in various crops, as well as aspects related to environmental protection and human health.

Zamotaev et al. (2022) presented an overview of contemporary concepts of technogenesis and soil formation in liquidated wastewater treatment plants of former sugar plants, as well as trends in changes in soil properties under the influence of the use of waste in agriculture as organic fertilisers in various natural areas. Raček et al. (2022) and Fachini and de Figueiredo (2022) presented the results of the preparation and characterisation of the dried municipal sewage sludge and the so-called solid carbonaceous product, the outcome of its further processing by slow microwave pyrolysis/torrefaction. The research aims to determine the possibility of using these products for combustion in energy production, agriculture, and blue-green infrastructure.

According to Dahiya et al. (2022), the use of sewage sludge in agricultural soils is an alternative to expensive artificial fertilisers, which plays an important role in improving the physicochemical and biological properties of soils in various ways. However, the effect of sewage sludge on soil biological properties is based on the concentration of organic carbon and metals, which directly affect the beneficial flora and fauna of the soil, as well as plants. In their publication, Dahiya et al. (2022) focused on the long-term impact of sewage sludge and heavy metal accumulation on soil fertility and the impact on soil microbial diversity. He also discussed plant bioavailability and various methods of removing metals from contaminated soil for possible use in agriculture.

Moreover, Almeida et al. (2021) assessed the impact of the use of sewage and sewage sludge on soil properties in an irrigated maise plantation in the north-eastern semi-desert region of Brazil in an experimental reuse unit. Two experimental plots with sewage and sludge treatment and sewage-only irrigation were established. Cocârță et al. (2019), in turn, assessed and documented the agricultural use of sewage sludge from two different sewage treatment plants: the first was a municipal sewage treatment plant, which did not discharge industrial sewage into sewage systems, while the second collected industrial discharges.

Sewage sludge can also be used in processes related to environmental protection, such as reclamation of degraded land, neutralisation of harmful substances, removal of pollutants from groundwater or soil reclamation (Ciuła et al., 2019; Joniec et al., 2019b). Research in this field focuses on assessing the effec-

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tiveness of sewage sludge use in various environmental protection processes and assessing their impact on soil, water, and air quality (Joniec et al., 2019a). For example, Halecki et al. (2022) examined the use of artificial soil substrate in the reclamation of mining waste and its impact on plant metabolic functions. The research was carried out to determine the relationship between the biochemical characteristics of plants and the properties of the plant growth substrate derived from post-flotation coal waste, sewage sludge, crushed stone, and fly ash on the surface of the mine waste landfill. Trees and shrubs were planted on the material and then allowed to grow for eight years. Studies have shown that the plants used, as well as the naturally occurring Taraxacum officinale, were suitable for physio-biochemical evaluation, identification of abandoned areas, and reclamation.

On the other hand, Joniec et al. (2019a) studied a field reclamation experiment established in the former "Jeziórko" Sulphur Mine (Poland). To perform soil reclamation in one application, different combinations of sewage sludge, mineral wool, post-flotation lime, and mineral fertilisers were introduced into degraded soil. Furthermore, the publication of Tymchuk et al. (2021) identified the main problems of the disposal of wastewater in Ukraine. The research discussed the possibility of using a sewage sludge-based substrate for the biological reclamation of affected areas. It determined the quality of sludge from a sewage treatment plant in Lviv. The best composition of the substrate for biological reclamation was determined by bioindication.

Sewage sludge can also be a source of secondary raw materials (Smol & Szołdrowska, 2021). Research on the recycling and recovery of raw materials from sewage waste focuses on technologies such as biogas recovery (Siddiqui et al., 2023; Paranjpe et al., 2020), biological recovery of phosphorus and nitrogen (Boniardi et al., 2022; Saoudi et al., 2022), thermal recovery, metal recovery and the production of fertilisers from sewage sludge (Kominko et al., 2019). The aim of these studies is to reduce the amount of waste that goes to landfills and to obtain added value from raw materials derived from sewage sludge (You et al., 2021).

Sewage sludge management can also include landfilling or utilisation for disposal (Arina & Bendere, 2011). The literature review in this field focuses on the evaluation of various types of sewage sludge storage technologies, such as landfill or compost storage (Bagheri et al., 2023; Grgas et al., 2023). Research also includes evaluating environmental aspects such as greenhouse gas emissions groundwater pollution, and reducing the potential impact on human health and ecosystems (Janas et al., 2018). It can also undergo thermal transformation (Wollmann & Möller, 2022).

In conclusion, the subject matter is very important and adequately included in the literature. However, there is a research gap related to the assessment of the comprehensive management of sewage sludge produced, which requires research both in theoretical and empirical aspects.

Legal considerations

Municipal sewage sludge is sludge from digesters and other installations. They are used to treat municipal wastewater or wastewater with a composition similar to that of municipal wastewater.

The sludge generated in the wastewater treatment process should be treated and then properly utilised, managed or disposed of. Sludge treatment includes the following operations (Act, 2013):

- thickening of raw sludge to achieve a 94-96% solids content,
- decomposition of approximately 50% of the dry weight of organic matter through aerobic or anaerobic stabilisation processes,
- dewatering of stabilised sludge to a final water content of 75-60%, depending on the type of equipment used and further sludge handling,
- final solution to the problem of disposal and use of sludge outside the treatment plant site.

The municipal sewage sludge management process follows the waste hierarchy, which is regulated by Article 17 of the Act on Waste (Act, 2013). According to the regulations, priority should be given to activities that prevent the formation of municipal sewage sludge. Its preparation for reuse (e.g. in agriculture), recycling, and other recovery processes is secondary. According to Article 96(1)(1)-(3) of the Act on Waste, recovery of municipal sewage sludge in agriculture is to use it for:

- The cultivation of all commercially marketed crops, including crops intended for the production of feed.
- The cultivation of crops intended for the production of compost.
- The cultivation of non-food and feed crops.
- Land reclamation, including land for agricultural purposes.

Municipal sewage sludge can be used if it is stabilised and prepared appropriately for the purpose and manner of its use. The preparation is, in particular, biological, chemical, thermal treatment or any other process that eliminates the threat to the environment or human life and health.

In turn, according to Article 96(3) of the Act, when municipal sewage sludge is used in agriculture or for growing crops, the generator is responsible for its use in the environment until the end of the process. This means that transferring the sludge to another entity does not relieve the treatment company of its obligation to supervise the sludge until it is physically disposed of.

The manner in which sludge is introduced into the soil is regulated by the Ordinance of the Minister of the Environment of February 6, 2015, on municipal sewage sludge (Rozporządzenie, 2015), which specifies the doses of sludge that can be used, as well as its quality parameters.

According to the waste management hierarchy specified by the law, one of the methods is recovery (Act, 2013). Appendix No. 1 to this Act specifies 13 recovery methods, as shown in Table 1.

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Table 1. List of recovery processes listed in the Waste Act

R1	Use primarily as a fuel or other means of energy production
R2	Solvent recovery/regeneration
R3	Recycling or recovery of organic substances that are not used as solvents (including composting and other biological processing treatments)
R4	Recycling or recovery of metals and metal compounds
R5	Recycling or recovery of other inorganic materials
R6	Regeneration of acids or bases
R7	Recovery of components used for pollution reduction
R8	Recovery of components from catalysts
R9	Re-refining or other reuse of oils
R10	Land treatment that benefits agriculture or improves the environment
R11	Use of waste obtained from any of the processes listed under R1-R10
R12	Exchange of waste to undergo any of the processes listed in items R1-R11
R13	Storage of waste prior to any of the processes listed in items R1-R12 (except for initial storage at the waste generator)

Source: authors' work based on Act (2013).

The purpose of the R3 method is to recover and prepare the raw material for reuse. This can be done through composting, gasification (semi-combustion) or pyrolysis, which is the combustion of waste under anaerobic conditions or with minimal use of oxygen.

The recovery method R10 consists of treating the waste on the surface of the ground to benefit agriculture or improve the environment (Rozporządzenie, 2015). According to law, stabilised municipal sewage sludge can be used only when the following conditions are met jointly:

- the requirements for municipal sewage sludge, as set forth in the provisions of the Act on Waste (2013) and in the regulations issued pursuant to its Article 96(13) are met,
- the waste is applied in such a manner and in such a quantity that its use will not cause deterioration in the quality of soil, land surface and groundwater, even with long-term use.

According to par. 14.1 of the Ordinance of the Minister of Agriculture and Rural Development on the Implementation of Certain Provisions of the Law on Fertilizers and Fertilization (Rozporządzenie, 2008), the permissible content of contaminants in organic, organic-mineral fertilisers and organic, organic-mineral crop aid products must not exceed:

- for Cr (chromium) – 100 mg/kg dry weight of fertiliser or crop aid,
- for Cd (cadmium) – 5 mg/kg dry weight of fertiliser or crop aid,

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- for Ni (nickel) – 60 mg/kg dry weight of fertiliser or crop aid,
- for Pb (lead) – 140 mg/kg dry weight of fertiliser or crop aid,
- for Hg (mercury) – 2 mg/kg dry weight of fertiliser or crop aid.

Testing a sample for heavy metals allows the use of municipal sewage sludge in agriculture. However, exceeding the permissible content of even one of the heavy metal parameters disqualifies the material for agricultural use.

For municipal sewage sludge to be used, it must be tested for quality, along with the land on which it is to be applied. The tests must be carried out by the sludge generator in testing laboratories in accordance with Sections 5 and 6, Article 147a of the Law on Environmental Protection (Act, 2001) and Article 5(4) of the Law on Conformity Assessment System (Obwieszczenie, 2021), or in a laboratory certified for quality management and for testing municipal sewage sludge.

Soil is tested each time before a batch of municipal sewage sludge is designated for application on land. The permissible dose of municipal sewage sludge is determined in such a way that its application will not cause the values of the permissible amounts of heavy metals in the topsoil layer with a depth of 0-25 cm to be exceeded (Rozporządzenie, 2015).

During another research, the authors learned that sludge generators, i.e. municipal wastewater treatment plants, do not comply with the regulations and sludge is massively used for agricultural purposes without the supervision required by law. Therefore, the authors decided to carry out a study of wastewater treatment plants, the main aspect of which is to find out how they supervise sludge for agricultural purposes.

Research methods and research material

The analysis process and goal achievement were facilitated by surveys conducted from October to December 2022 nationwide. These targeted surveys focused on municipalities with municipal wastewater treatment plants. The authors obtained an address database of 1,867 wastewater treatment plants from the National Urban Wastewater Treatment Program, implemented by the State Water Company "Wody Polskie". Drawing on published reports about the program, we developed a research questionnaire to delve into aspects concerning the supervision of sludge transferred for agricultural use, which were not covered in the original National Program surveys.

The survey was conducted digitally. To maximise the reliability of the results, we directed the digital questionnaire to municipal management teams, requesting them to forward it to the most knowledgeable individuals to complete. Ideally, these respondents were those involved with the reports of the National Urban Wastewater Treatment Program. Out of the municipalities contacted, 208 returned the completed questionnaire.

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The study used an original questionnaire containing, apart from identification data, 6 questions concerning sewage sludge and its management:

1. What is the average amount (mass expressed in tons) of buffer (sludge heaps) for sludge storage?
2. Which entities receive the sludge (farmers, enterprise, self-management, lack of data)?
3. How is the sludge removed (paid, free of charge, no data available)?
4. How is the sludge used (agricultural, R10, R3, D9, D10, composting, incineration, land reclamation, storage, lack of data)?
5. How do you monitor what happens to the waste after it is transferred to another entity?
6. Do you plan to invest in sludge management? If so, what kind of investments are to be made?

After the data collection was completed, the surveys were checked and, if necessary, supplemented with the location of the municipal wastewater treatment plant (municipality, district, voivodeship) and the type of municipality (rural, urban-rural, urban). The number of residents of individual municipalities was supplemented by the Central Statistical Office (GUS) data. The empirical data obtained in this way were evaluated for correctness and then analysed. The results of the survey were prepared using descriptive statistics methods (numbers, percentages). A diagram of data acquisition and analysis is shown in Figure 1.

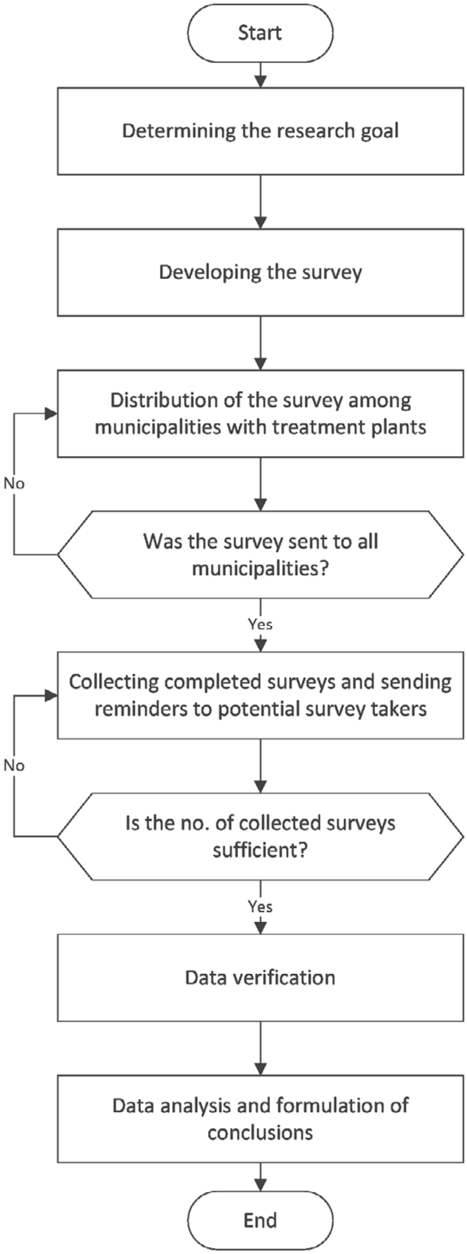

Figure 1. The research implementation plan

Results and discussion

In the surveyed collection of municipal wastewater treatment plants, the majority were found in rural municipalities, with a total of 77 facilities and a total population of 623988 residents. These constituted 25.5% of all rural municipalities in Poland. The study also included municipal wastewater treatment plants located in 75 urban-rural municipalities with 1131300 residents, representing 11.3% of these municipalities in the country. Despite these numbers, the study included municipal wastewater treatment plants in urban municipalities to a lesser extent, with only 56 plants participating. These constituted a mere 3.7% of urban municipalities with a population of 8656829. The locations of the municipal wastewater treatment plants from which the data were obtained are shown in Figure 2.

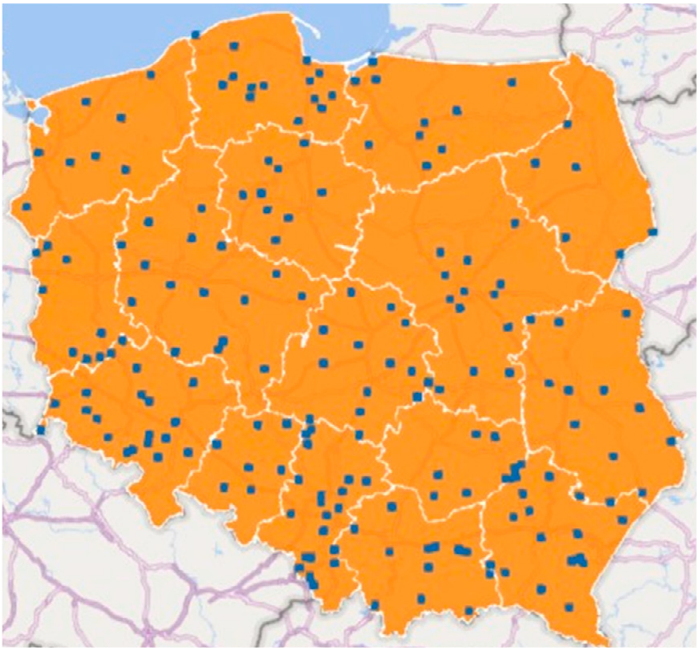

Figure 2. Locations of municipal wastewater treatment plants in Poland

Across the country, an average of 8.4% of municipalities housing municipal wastewater treatment plants participated in the study. However, it is crucial to acknowledge that some wastewater treatment plants serviced multiple municipalities. Figure 3 illustrates the distribution of the examined wastewater treatment plants according to the population size of the municipalities.

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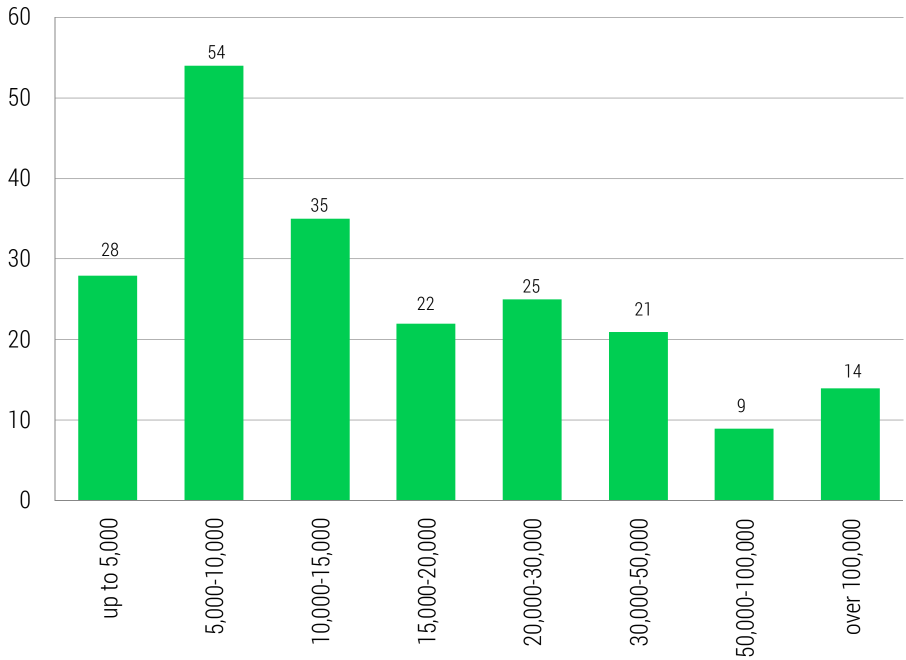

Figure 3. Municipal treatment plants in relation to the number of residents of the municipality

The largest group of wastewater treatment plants was composed of those in which the sludge pile sizes were the smallest (Figure 4), regardless of how large the municipality was. An interesting area is the middle of the graph, in which a relatively large number of centres with a population of 15 000 to 30 000 have large-capacity sludge piles, i.e., from 150t to 1000t. On the one hand, the reason is the largest number of municipalities in terms of the number of residents (Figure 3), but it also proves that large sludge piles are most common. Despite the exploitation of sludge piles of such capacity, municipalities signalled problems with sludge storage and reported the need to expand both the sludge piles themselves and the sludge protection in the city, among others, against the adverse effects of atmospheric conditions (Figure 4).

Studies have shown that a large group of treatment plants avoids providing information on the place of storage of sewage sludge and on ways of their protection against atmospheric conditions. However, despite the lack of information in this area, these treatment plants are aware of the need for proper storage and protection of sludge, as 60% of them declare investments in this area (Figure 5).

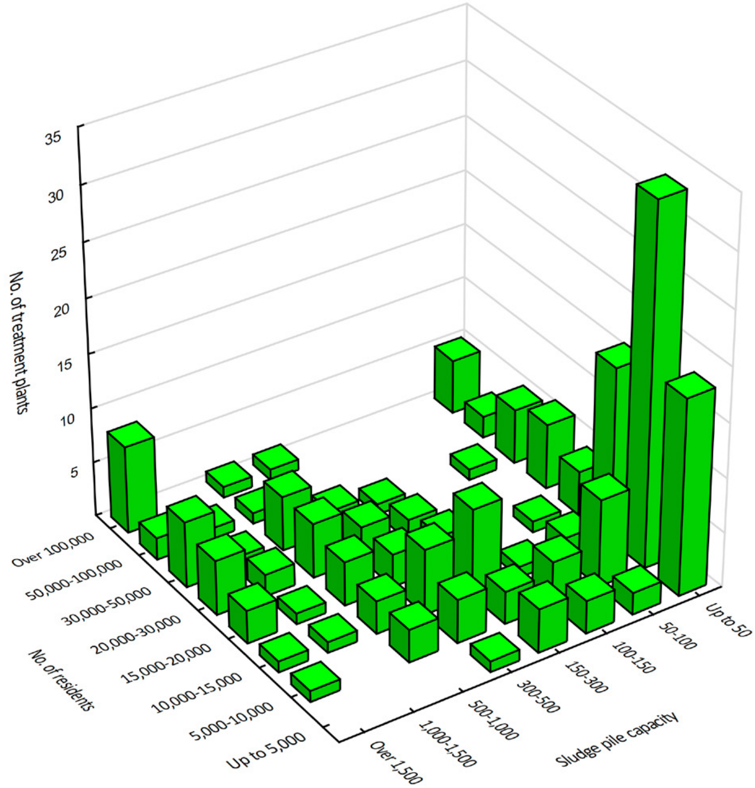

Figure 4. Distribution of buffer sizes (sludge pile capacities) in relation to the size of the agglomeration

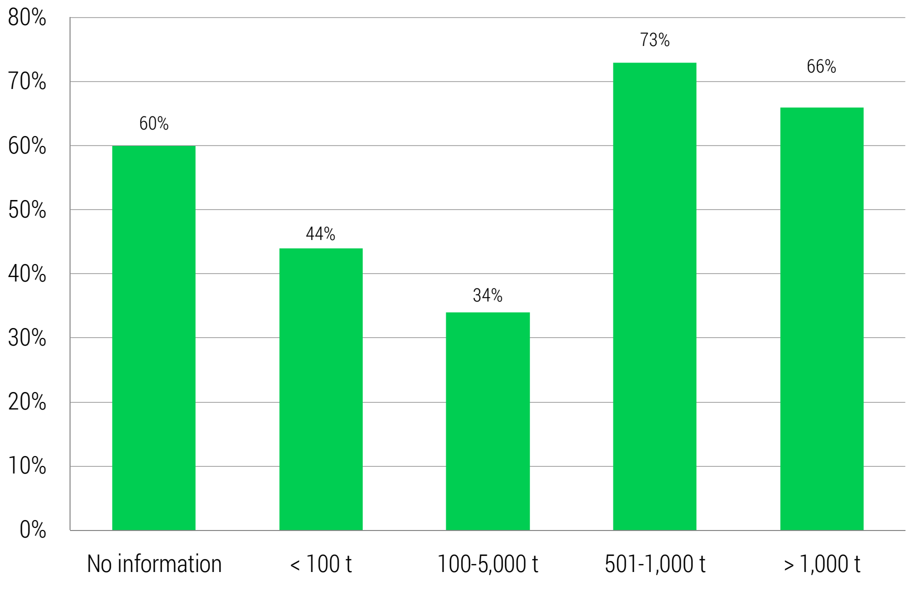

Figure 5. Planned investments in sludge piles and weather protection systems

Municipal treatment plants located in urban municipalities declared the highest amount of sewage sludge per capita (49.5 kg/year). Treatment plants located in rural municipalities declared more than 3.5 times less sludge (Figure 6).

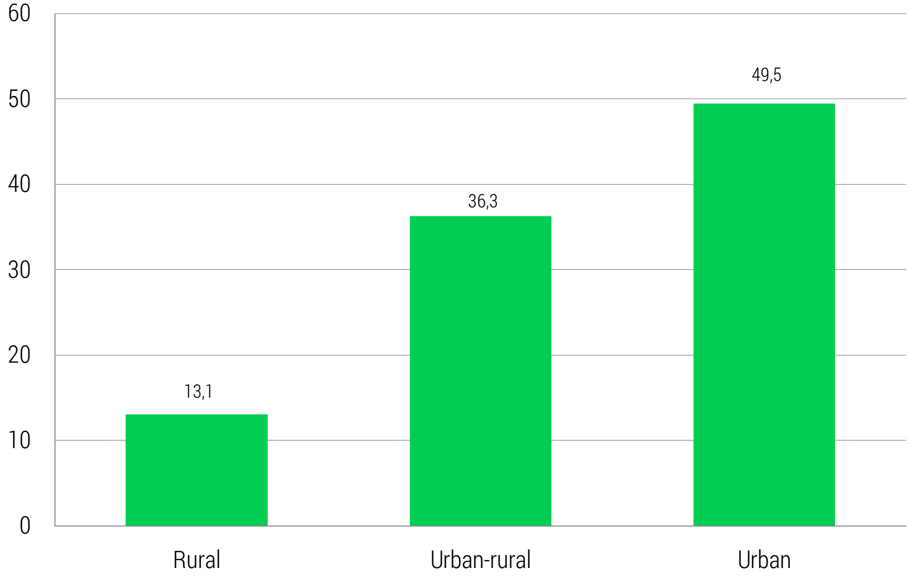

Figure 6. Declared annual sludge per capita in municipalities

By analysing the information on the amount of sludge in the studies of Campo et al. (2021), it was observed that the rural municipalities declared a sludge mass comparable to that of the Piedmont region in Italy, where the sludge mass per capita of the individual treatment plants ranged from 10 to 15kg and was in line with the average values found in the European sewage treatment plants (Bianchini et al., 2016). The question of which municipalities provide the correct data is open, but the results of European research indicate that urban municipalities generate an astonishing amount of sludge because the observed volumes are several times larger than the European averages (Bianchini et al., 2016). This problem requires more detailed research, but also the introduction of a tight sewage sludge management system, starting with its storage and ending with proper management (disposal).

The declared mass of sludge per capita, so large, especially in urban and urban-rural municipalities, requires the appropriate capacity of sludge piles, as well as their proper management. The law provides several possibilities for sewage sludge management, but the results of the research indicate that treatment plants focus on a very narrow range of solutions. It is worrying that the method of sewage sludge management was not reported in 16% of the surveyed treatment plants. The largest number of treatment plants, over ¾, transfer sludge for agricultural purposes or methods related to their introduction into the soil (Figure 7). The research of Koc-Jurczyk and Jurczyk (2021) and Czekała et al. (2023) confirms that most of the municipal sewage sludge is used for agricultural purposes and for the cultivation of plants intended for compost. The agricultural use is in line with the European Green Deal. This method of sludge management seems reasonable, provided that the strict requirements of the regulations are met and on condition that it is in line with current trends.

According to Szołdrowska and Smol (2022), agricultural use of sewage sludge should be a priority, but on condition of meeting appropriate standards. These standards relate primarily to the permissible content of chemical substances and organic and biological agents, as well as procedures related to the transfer of sludge to relevant entities and procedures for the implementation of other activities related to the introduction of sludge into the environment. This is to protect the processes of introducing residues from sewage into the environment in such a way that substances that could cause biological hazards do not enter the soil or water. Unfortunately, the design of the regulations is such that in many situations, it is possible, both for sludge producers and customers, to circumvent them.

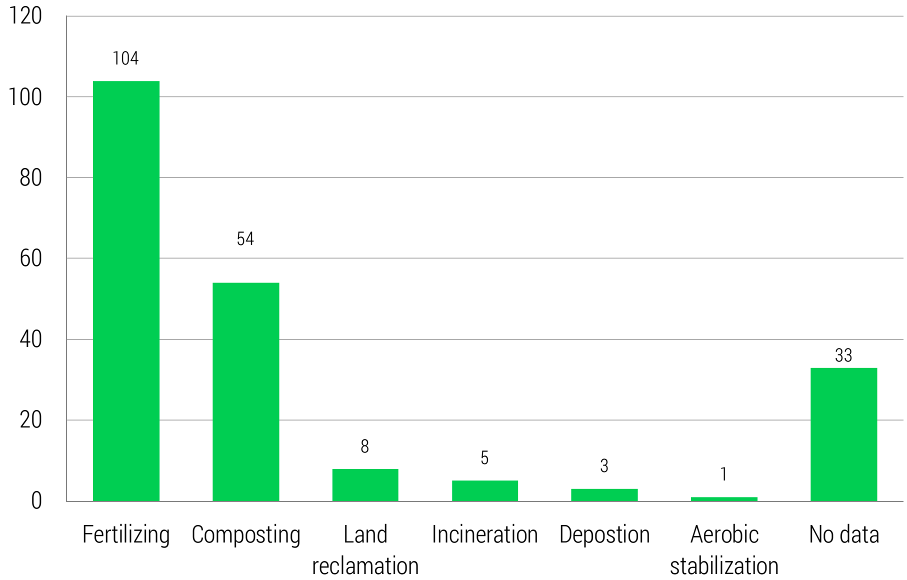

Figure 7. Identified approaches to sewage sludge management

In addition to the above-mentioned risks of agricultural management of municipal sewage sludge, there is a problem of the discomfort of the local community due to unpleasant odours associated with the distribution of sludge on

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the surface of agricultural land, which is what Mukawa et al. (2019) pay attention to in their work. Therefore, in addition to meeting the standards regarding the composition of sludge, the method of their application and proper supervision of this process are important.

The recipients of sludge for agricultural purposes are farmers (38% of recipients) and entrepreneurs (52% of recipients). Both groups exhibit a certain laissez-faire approach to monitoring the effects of the introduction of sludge into the environment, which will be shown in the next graphs. In 57% of cases, disposal of sewage sludge is paid (a fee), and only 18% is free of charge. Despite the attempts to obtain information, 25% of sewage treatment plants refused to provide information on this subject. In most cases, paid waste removal involves enterprises. This is obvious because, for economic operators, a paid removal is a source of their income. Even farmers distribute sludge on their agricultural land partially for a fee, although the vast majority collects it free of charge (Figure 8).

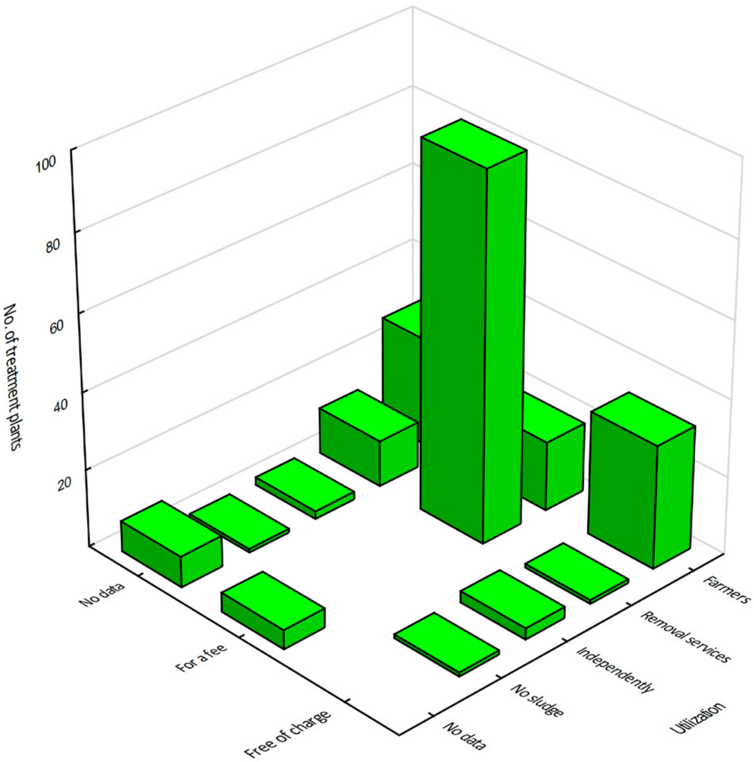

Figure 8. Identified form of settlement for the collection of waste

For agricultural purposes, most sewage sludge is removed to wastewater treatment plants from urban-rural municipalities (Figure 9). For land reclamation, sewage sludge is directed from rural and urban-rural municipalities. Urban municipalities practically did not use sewage sludge for land reclamation.

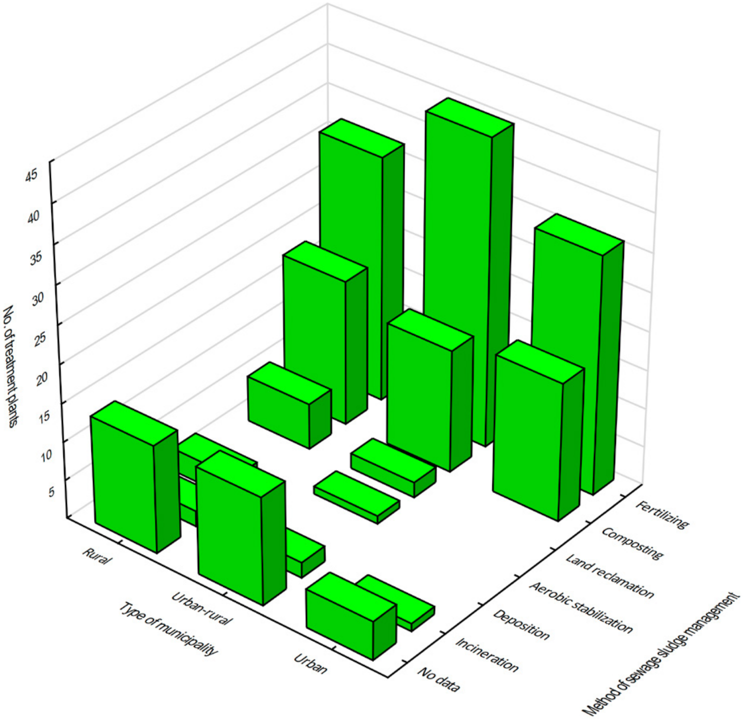

Figure 9. Type of municipality per method of sewage sludge management

Municipalities with a population of between 10,000 and 30,000 were the most numerous groups that had sewage sludge removed for a fee and free of charge for agricultural purposes and composting (Figure 10). In the case of treatment plants in municipalities with more than 100 000 residents, almost all the sludge produced was used for agricultural purposes.

Wastewater treatment plants with the smallest sludge piles (<50 t), in addition to the agricultural management of sewage sludge, have tried to use it also for land reclamation or management through storage, incineration or aerobic stabilization. Wastewater treatment plants with landfill sludge piles of more than 50t burned sewage sludge in small quantities, as they focused on their agricultural management (for fertilising, composting).

Worrying research results were obtained with regard to the monitoring activities carried out by specific treatment plants. A small number of operators producing sewage sludge supervised the use of sludge for agricultural purposes (Figure 11). Such a situation can lead to abuse and the rise of environmental threats or sometimes even endanger food production. Only 7% of the surveyed

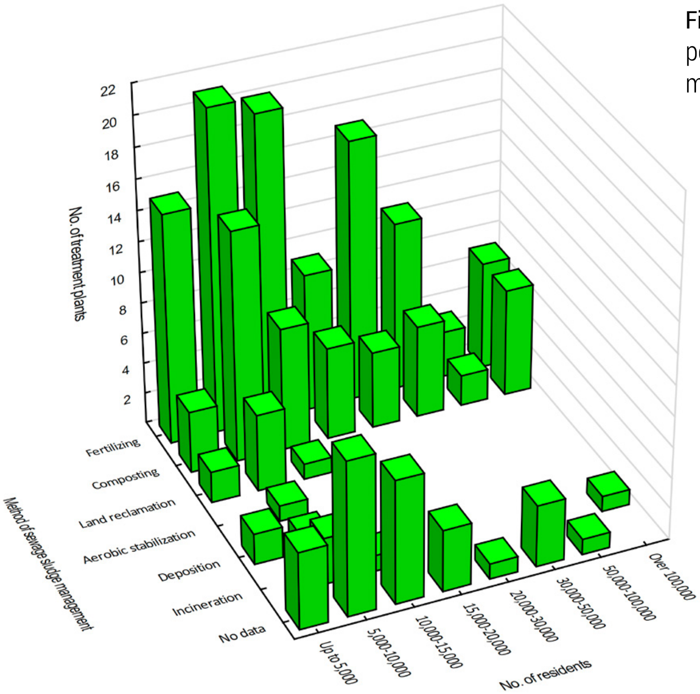

Figure 10. Number of citizens per method of sewage sludge management

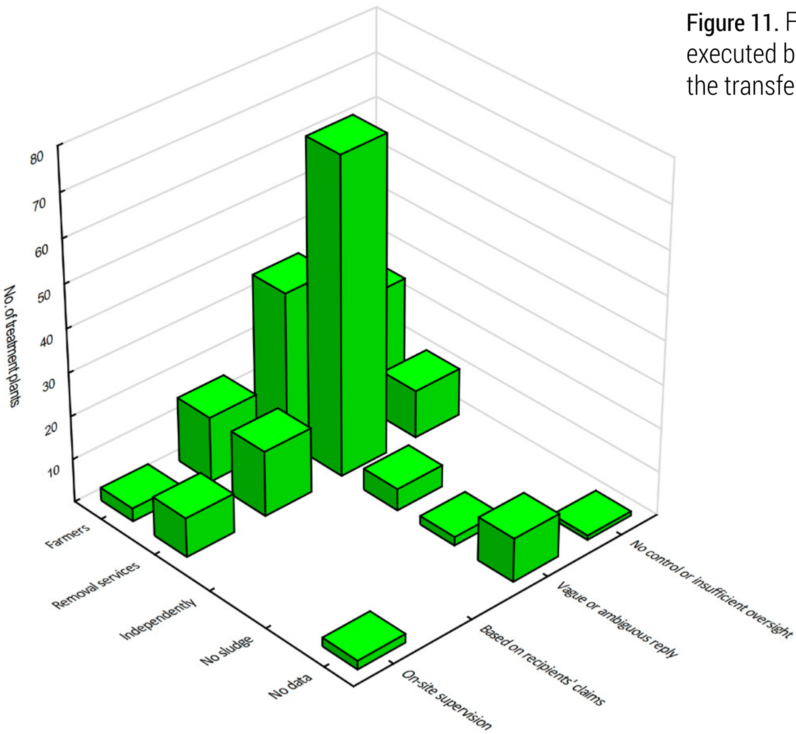

Figure 11. Forms of field control executed by treatment plants after the transfer of sludge to recipients

treatment plants conducted field supervision, but 18% did not carry out any activities in this area, and as many as 61% gave evasive answers. At the same time, 14% do not conduct field supervision but obtain information from the entities to which the sludge was transferred. Answers from respondents were dominated by the following statement: “We do not supervise what happens to the sludge because responsibility for the waste hitherto rests with the recipient”. This, in fact, is illegal because, according to Article 96, par. 3 of the Polish Act on Waste (2013), the responsibility for supervision over sludge after its disposal rests with the producer (the treatment plant) and not the recipient.

There are no major differences between the types of municipalities regarding the approach to post-transfer control issues (Figure 12). In each of the 3 types of municipalities, the frequency distribution of individual kinds of activities is practically the same, with one exception – in the case of rural municipalities, field control occurs several times more often than in urban and urban-rural municipalities, but this could result from the fact that in rural municipalities sludge is transferred for use in agricultural purposes more often, and simultaneously the distances from the sewage treatment plant to the place of sludge distribution are not too large, which facilitates the monitoring process.

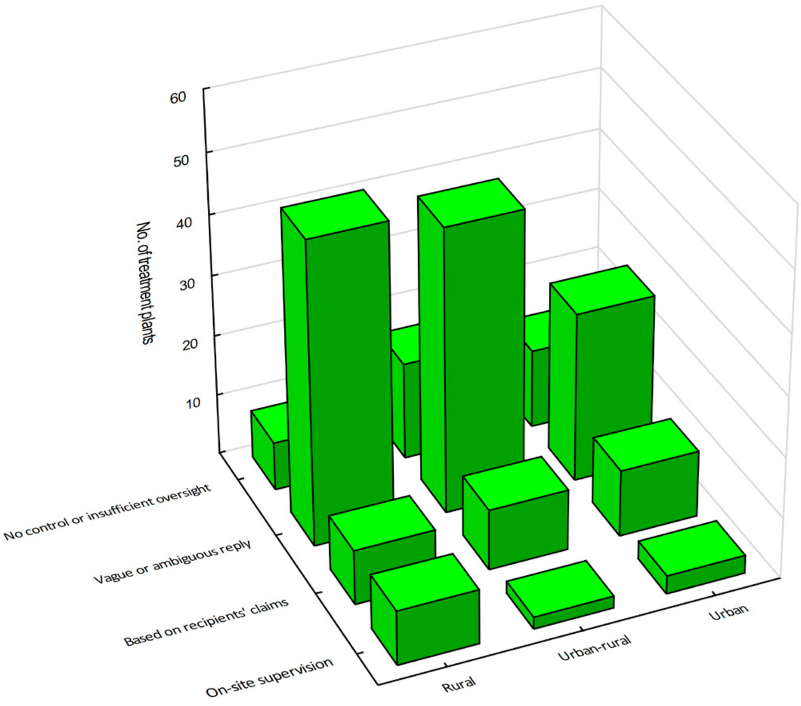

Figure 12. Forms of control executed by treatment plants after the transfer of sludge to recipients, depending on the type of municipality

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Studies show that the size of the agglomeration has a significant impact on the type of control response given. When it comes to control in the field and limiting oneself to receiving assurances of recipients, the size of the municipality does not matter, while as far as avoiding answers and evasive answers are concerned, most of such cases occurred in municipalities with a size from 10 000-30 000 residents. Large municipalities rarely provide such answers, but this is because they transfer their sludge for agricultural purposes less often (Figure 13).

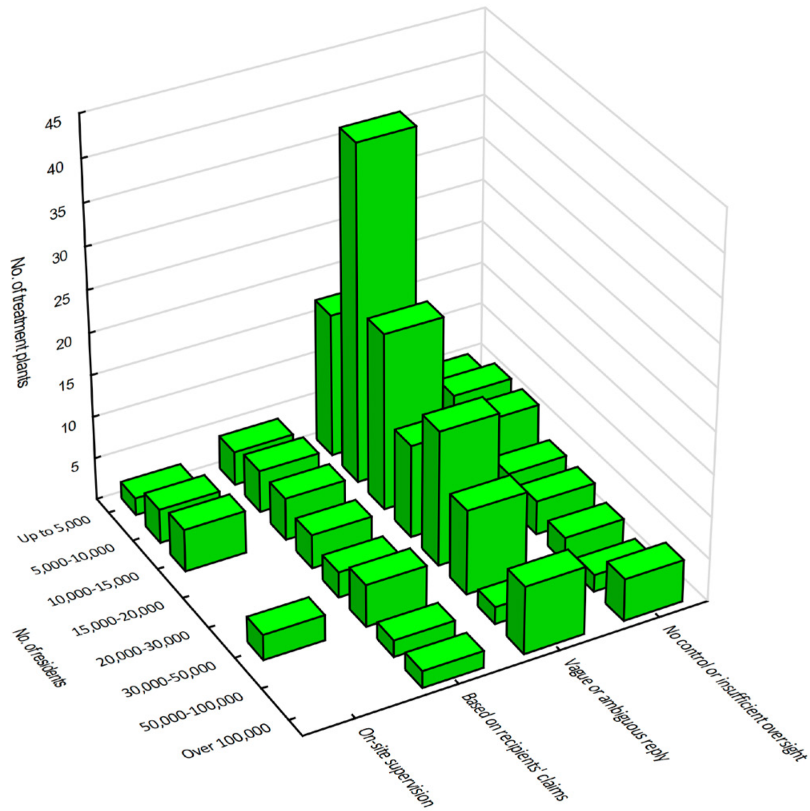

Figure 13. Forms of control executed by treatment plants after the transfer of sludge to recipients, depending on the size of the agglomeration

Conclusions

The research results presented in the paper in the context of the current state of knowledge, after considering the current legal order, enable the formulation of important recommendations for all entities responsible for the management of sewage sludge. By analysing the data presented by municipalities and

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treatment plants, different "approaches" and different cultures of sludge management can be observed. It seems that this problem, especially in terms of the reliability of information on stored sludge, as well as its management methods, is not an important problem for municipalities. These recommendations include both the application and the scientific aspects:

1. Discussions and analyses conducted during expert panels, including the conclusions of the conducted research, showed low awareness of the strategic importance of the problem. "Sustainable sewage management" is lacking among residents, representatives of local government, companies supplying water to customers, companies dealing with sewage treatment, as well as entrepreneurs operating in the catchment area.
2. The research shows that entities responsible for the proper management of sludge do not have precise knowledge of the amount of sewage sludge deposited in their area. The observed dispersion of data on the amount of sludge per capita indicates a varied degree of reliability of the data provided by municipalities. The amount of sewage sludge declared by municipalities should be the result of systematic (monthly) measurements, not an estimated analysis.
3. Research shows that 57% of treatment plants dispose of their sludge for a fee, and 18% do so free of charge. In the case of 25% of treatment plants, such data is missing. Notably, data is missing for 25% of treatment plants, highlighting a significant knowledge gap regarding the further fate of sludge in a quarter of these facilities.
4. The research shows that only 7% of treatment plants control the sludge management methods declared by the recipients in the field, 18% explicitly admit that they do not perform such checks, 61% of treatment plants have given an evasive answer, and 15% accept the assurances of the recipients as reliable. Considering that 76% of the sludge mass, according to the research, is transferred for agricultural purposes, there is concern about such a high carelessness regarding supervision responsibilities.
5. Disturbing conclusions result from the analysis of investment plans of the analysed treatment plants. Only more than half of urban municipalities (65%) plan any investments; in urban-rural municipalities, it is 37%, and in rural municipalities, 45%. In a few cases, the planned investments have a comprehensive and modern character; in others, they are modernisation plans and purchases of individual devices. When analysing surveys, one can get the impression that, in many cases, the data provided are accidental, resulting from the need to provide anything: "It is good to show that we are eco-friendly".
6. The research shows the need for systematic training of personnel responsible for the management of sludge. This applies to local government administration, sewage treatment plants, and logistics companies dealing with the

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collection of sewage from their places of origin. Training should focus primarily on legal obligations and liability for noncompliance.

7. It is necessary to introduce a requirement of possessing equipment for continuous monitoring of the quality of wastewater discharged from the source of its formation directly to the treatment plant. Thanks to this, the wastewater treatment plant would be able to constantly monitor online what the entrepreneur introduces to the sewage network. Companies that mediate in the transfer of sewage should have a system of records enabling the identification of the source if the inspection conducted at the treatment plant determines that the applicable standards have been exceeded.
8. It is necessary to introduce an obligation to systematically check the way wastewater is disposed of in enterprises – performing it without prior notice. The guarantee of prior inspection should be removed from contracts. Each sewage treatment plant should be compulsorily and, without prior notice, inspected at least twice a year in terms of compliance of sludge management with applicable law and reliability of reports. Sludge samples should be kept for inspection for 1 year from the date of collection. The responsible persons should be held criminally liable for the identified infringements.
9. The frequency of reference wastewater checks should be in accordance with the arrangements resulting from Article 86(3)(2) of the Act of Water Law (Act, 2017).
10. Reporting data on the amount and chemical composition of sludge should be mandatory in the case of ongoing collection of sludge from the site of the treatment plant. During the research, it turned out that municipalities of various sizes, but most often the large ones, did not provide data at all. Municipalities with more than one sewage treatment plant should be required to keep collective records of sludge management.
11. It is proposed to introduce the need to monitor compliance with the conditions contained in water permits, including the urgent preparation of implementing regulations in this area.
12. It is suggested that it is necessary to amend the law on domestic sewage disposal, where the basis for charging should be nitrogen and phosphorus loads in the discharged sewage. There should be a system for controlling the frequency of emptying no-outlet storage tanks for liquid waste, as well as household small-scale sewage treatment plants (documentation of how the waste was disposed of).
13. It is reasonable to introduce a legal ban on transferring sewage sludge to farmers that have exceeded the permitted levels of inorganic pollutants.
14. It is necessary to organise social campaigns on residual sludge and sludge piles, their toxicity, and the problem of disposal, together with making data on the results of research and controls available to the public. Violations of the standards resulting from the current regulations should be publicised and stigmatised socially.

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The conducted research confirmed the scale of irregularities, which the authors predicted when undertaking the research. The treatment plants participating in the study (208) accounted for only 15% of all the authors approached with a proposal to complete the survey. It can be expected that the conclusions based on data from the remaining plants would be comparable. The results obtained represent not only a certain scientific value and application value, but also result from a very large amount of work put into collecting and analysing data. According to the authors, the presented results are also of great social importance and should be the subject of analysis of all companies and local government units responsible for this extremely important area of our life and functioning.

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The contribution of the authors

Conception, Z.W. (100%); literature review, K.H. (90%) and B.O. (10%); methodology, Z.W. (20%), J.K. (20%), M.K. (20%), S.K. (20%) and K.H. (20%); acquisition of data, Z.W. (100%); analysis and interpretation of data, Z.W. (20%), J.K. (20%), M.K. (20%), A.M. (20%), and S.K. (20%).

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KRYTYCZNA OCENA I ZALECENIA DLA GOSPODARKI OSADAMI ŚCIEKOWYMI W POLSCE

STRESZCZENIE: Celem artykułu jest przedstawienie praktyk stosowanych w ramach nadzoru nad rolniczym wykorzystaniem osadów ściekowych. Przedstawione badania i wnioski mają charakter analizy trendów i nie powinny być wykorzystywane do karania podmiotów. Osady ściekowe, pochodzące z nielegalnego zrzutu ścieków komunalnych przez zakłady przemysłowe, zawierają duże ilości metali ciężkich. Oczyszczalnie przekazują osad do wykorzystania w rolnictwie. Przepisy wyraźnie ograniczają tryb i warunki takiego wykorzystania osadów ściekowych. Metody: badania przeprowadzono z wykorzystaniem autorskiej ankiety, będącej uzupełnieniem ankiety sprawozdawczej Krajowego Programu Oczyszczania Ścieków Komunalnych realizowanego przez Państwowe Gospodarstwo Wodne „Wody Polskie". Wyniki: Badanie przeprowadzono w 208 oczyszczalniach ścieków w Polsce. Wyniki pokazują, że większość oczyszczalni ścieków nie prowadzi właściwego nadzoru nad procesem wprowadzania osadów ściekowych do gleby. Brakuje również nadzoru nad ilością metali ciężkich ze ścieków wprowadzanych do gleby. Oznacza to, że istnieje bardzo duże ryzyko skażenia gleb uprawnych. Uzyskane wyniki mogłyby zapoczątkować szczegółową analizę tego zjawiska w Polsce. Konieczne jest kompleksowe zbadanie skali takich praktyk i ich skutków, aby określić rzeczywisty stan gleby poddanej działaniu osadów ściekowych.

SŁOWA KLUCZOWE: osady ściekowe, frakcje metali, oczyszczalnie ścieków

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