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Conditions of agricultural and natural use of sewage sludge in rural areas

Steady increase in sludge quantity emerging from municipal sewage treatment plants and shortcoming in managing sludge cause that problems of sludge management require urgent solution. The final stage of sewage sludge disposal should be its agricultural or natural utilization. This is possible if the sludge complies with qualitative requirements (stabilization, decontamination, composting). In the report there will be presented the analysis and estimation of possibilities of agricultural or natural use of sewage sludge as organic fertilizers.

Municipal sewage sludge, produced in sewage treatment plants, is not a fertilizer and can not be treated like natural fertilizer e.g. manure. It can be used in agriculture in processed and not processed form and on condition that it is stabilized and fulfills requirements in permissible levels of heavy metals and sanitary indicators and included definite quantities of organic matter and fertilize compounds of nitrogen, phosphorus and potassium. It can be treated as organic fertilizers according to the act on fertilizers and manuring. The additional point of consideration is the problem connected with sewage sludge in relation to special planning and managing. The important role plays possibility of disposing proper base of areas, fields in it (agricultural and green grounds) fulfilling particular requirements as far as the content of heavy metals is concerned taking into consideration ecological and physiographic condition. Therefore on every step of studying water - sewage and sewage sludge management in the variant expression it is essential to carry out recognition and listing of areas e.g. in the form of multiaspect survey.

The starting point for consideration concerning processing and possible managing of sewage sludge for agricultural or natural aims is recognition of range of conditions connected with it. The law regulations mentioned before are uppermost and stating quantity and quality characterization of sewage sludge made in sewage treatment plants yearly as well. In the article the quality characterization of sewage sludge made in sewage treatment plants serving rural settlement units and small cities from the point of view of fertilizing compounds contents (N, P, K) and heavy metals will be included. Precise knowledge of sewage sludge characteristic is the basis of choice as far as proper way of its processing, usage and management is concerned. The next criteria of dealing with sewage sludge will be preparation of sewage sludge preceding their agricultural or natural use.

Particularly there will be discussed law essentials including quality requirements of sewage sludge and areas characterization, on which they would be used, stating annual doses of sludge used in an agricultural or natural way with taking into consideration needs of plants, the degree of plants demand for nitrogen from this source, the content of nitrogen in sludge or composts made on their basis and fertilization equivalent of nitrogen in relation to mineral fertilizers.

Keywords: **sewage, sewage sludge, agricultural and natural use of sewage sludge**

Introduction

The starting point for considerations on the treatment and any possible use of sewage sludge for agricultural or natural purposes is to identify a number of conditions associated with it. At first the legal bases are considered, which in the national conditions provide opportunities for above-mentioned treatment of sewage sludge. Another factor is determination of the quantity and quality of sewage sludge produced annually in sewage treatment plants, in particular the content of biogenic elements (N, P, K) and indicators of pollution, which are contraindication of using sludge in agriculture. An important role in these considerations is played by availability of disposing of land, including fields, that meet certain environmental and agricultural requirements, on which you can use sewage sludge for agricultural or natural purposes or the so-called development of agricultural space production. We should not ignore aspects which allow for an analysis of a number of considerations mentioned above, in the form of environmental impact assessments, and focused on the economic efficiency of investments, which include ecological, environmental and economic aspects.

1. The legal basis for the sewage sludge management in rural and suburban areas

The legislature and regulations concerning the management of sewage sludge are characterized by great diversity in terms of formal and substantive, relating to procedures, policies of sewage sludge treatment. They are mandatory, but also contain a number of limitations, recommendations and proposals relating directly to sewage sludge, the environment in which they are to be developed and the relationship between producer and receiver deposits, together with the principles of their use for agriculture or natural purposes.

Sludge in its natural form is regulated by law, waste act [1] and act of environment protection law [2], as well as additional specific requirements, defined in the Regulation of the Minister of Environment on municipal sewage sludge [3]. The act of 27 April 2001 on waste classifies sewage sludge as waste. The term - sewage sludge means sludge from the sewage treatment plants from fermentative chambers and other installations for municipal sewage treatment and other waste with a composition similar to the composition of municipal sewage. Acknowledgment for it is a formal classification of sludge contained in the catalog of waste [4]. Sewage sludge from municipal sewage treatment plants belongs to group 19 (wastes from the installations and facilities which serve as waste management, waste water treatment plants and drinking water treatment and water for industrial purposes), subgroup 19 08 (wastes from sewage treatment plants not otherwise specified) and has generic code 19 08 05, which defines the stabilized sludge. Stabilized sewage sludge, that is, the sludge which meets the criteria of mineralization of about 50% content of organic matter is not considered as hazardous waste. Conditions relating to the application of sewage sludge and excluding such opportunities were formu-

lated in art. 43 of the waste act. Detailed information in this regard is shown in [5-7].

Municipal sewage sludge may be used if it is stabilized and prepared appropriately to the purpose and manner of its use, in particular by subjecting it to biological thermal treatment or other process as that reduce susceptibility to uncontrolled decay of sludge and eliminate the risk to the environment or human health.

The primary responsibility of the producer is to obtain permission to produce waste, regardless of whether the sludge is waste produced in municipal or industrial wastewater treatment plants. Waste producer or manager of the sewage treatment plant is required to provide information how to use and the possible application of sewage sludge farm. The obligation to obtain authorization or only approval information about the production and methods of use of sludge sent to the authorities depends on the category and quantity of sludge. The waste act [1] emphasizes that the institution of control in all respects connected with the production and use of sludge is the Environmental Protection Inspection. A license or approval for sludge management program can be obtained from the district governor. In the case of finding by the Environmental Protection Inspection any misuse of a license or perceiving other legal problems, it may prohibit the activity. The authorities issuing a permit or approval of sludge management program do not have direct supervisory role, but are those that can fulfil these functions and are kept informed of the decisions of other bodies. Control powers are only eligible for the Inspection of Environmental Protection [8].

Detailed requirements for the possible use of municipal sewage sludge is given in the regulation of Minister of Environment of 13 July 2010 [3]. Regulation in §1 defines the conditions that must be met in the use of municipal sewage sludge, sewage sludge dose levels that can be used on land and the scope, frequency and reference methods of research of these deposits and the land on which sludge is to be used.

In relation to the waste act, in the regulation mentioned above additional requirements that must be met in case of natural or agricultural use were formulated. In such cases, the sludge should not exceed the permissible heavy metal content, the number of which is given in Annex 1 to this regulation (§2, point 1). Furthermore, the legislator formulated a general requirement, according to which the use of sewage sludge can not cause a nuisance to humans, animals and the environment, in particular, can not cause a deterioration in the quality of surface water and groundwater. The sewage sludge used in agriculture and for reclamation of land for farming is not allowed to contain *Salmonella* bacteria. The number of live eggs of intestinal parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp. in kg dry matter (d.m.) found in these sludge is limited to 0 in the case of agricultural use and maximum up to 300 units in the case of the use of sludge:

– on land to the specific needs of waste management plans, planning waste management or decision about requirements on building and land development,
– for crops not intended for consumption or for production of animal feed.

According to § 3 section 5 permissible doses of sewage sludge are [3]:
- in agriculture and land reclamation for agricultural purposes - 3 Mg d.m./ha/year;
- for land reclamation for non-agricultural land and to adapt to the specific needs of the planning or decision on building and land development, the cultivation of plants for the production of compost, the cultivation of crops not intended for consumption or for animal feed - 15 Mg d.m./ha/year.

Subsequently, the requirements of such multiple dosing of sewage sludge are given.

Permissible contents of heavy metals in municipal sewage sludge are varied for each type of metal depending on the capabilities of sludge. The regulation also requires evaluation of the quality of land, on which a sludge would be used, according to the specific needs. This applies to 25 cm soil layer. This provision is reflected in Annex 2 of the mentioned above regulation. Also in this case the limiting values of heavy metals in the surface soil layer (0-25 cm) in the application of municipal sewage sludge for agricultural purposes, natural or reclamation are distinguished for each heavy metal depending on the type of soil: light, medium and heavy. Annex 3 lists the requirements as before, but with the use of sewage sludge for the purposes of natural and waste management planning. In summary it can be stated that the basis of agricultural or natural application of sewage sludge is fulfilment of quality requirements in scope of acceptable concentration of heavy metals and also fulfilment of sanitary requirements including pathogens, as well as quality requirements of soil, on which sludge will be used in agricultural, natural and for planning purposes. It is also noted to determine the annual doses of municipal sewage sludge by dry weight of cargo in Mg/ha/year or times of the load in long-term intervals. The criterion about the fertilizing value of sludge, in particular, leading biogenic element, which is nitrogen, with checking the load of total phosphorus contained in the applied dose has not been developed. A number of requirements that may be relevant in other cases, such as contamination of PAH, PCB etc. in sewage flowing into medium or large municipal wastewater treatment plants have been omitted.

2. Characteristics of sewage sludge from sewage treatment plants on non-urban areas

The amount and composition of sewage sludge produced in the sewage disposal process depends on many factors, most important of which are:
- the characteristics and quantity of waste water;
- technology of the disposal of sewage and sludge treatment and, in particular, the method of stability;
- the type of sewage system.

Characteristic features of sewage sludge are:
– large hydration,
– high share of organic compounds in the dry weight of sludge, including ones susceptible to biodegradation,
– a significant amount of biogenic compounds (nitrogen, phosphorus, potassium),
– the occurrence of heavy metals and micronutrients,
– a large share of dangerous pathogens, including the eggs of worms and eggs of gastrointestinal parasites, bacteria and viruses,
– the occurrence of toxic compounds.

Sewage sludge generated in the rural and suburban sewage treatment plants differ significantly from the sewage sludge produced in medium and large municipal wastewater treatment plants. In particular, it relates to heavy metals, toxic substances and pathogens. This is mainly due to the participation of wastewater from the industry and services sewage discharged to the wastewater system.

The national and foreign literature presents a lot of data in the field of qualitative and quantitative characteristics of the sewage sludge, with special emphasis on sludge created in urban areas. This indicates the possibility of calculating the amount of sludge, depending on the equivalent resident (MR). According to the Nordic countries data, this quantity is as follows:
– initial sludge - 0.8 dm^3/MR at 6% dry matter content in the sludge,
– secondary sludge - 1.5 dm^3/MR at 2% of d.m. in the sludge,
– sludge after chemical precipitation - 1.2 dm^3/MR at 2% of d.m. in the sludge of hydration equal 97% [9].

The amount of sludge can also be taken starting from the number of plants. The average quantity of sludge produced from 1000 m^3/d sewage stands at 247 kg d.m./d and 27.7 kg d.m./Mk·y [10]. However, for the study work it is proposed to adopt the quantitative indicators shown in Table 1.

Table 1. **Quantitative indicators of sewage sludge**

Unit of quantitative indicators of sewage sludge	Values of indicators according to literature data	Values of indicators calculated on the basis of GUS data for 2010 [11]
g d.m. of sludge/m^3 of sewage	450 [12] 247 [13]	424
g d.m. of sludge/M·d	70 [12] 50 [14]	60
g d.m./kg BZT_5	800 [12]	about 930

With regard to the qualitative characteristics stabilized sludge have important meaning, which is required for agricultural or natural development. The analysis of literature data and own research [15] shows that the sludge in relation to biogenic compounds content have characteristics shown in Table 2.

Table 2. **The content of some ingredients in sludge**

Type of sewage sludge	Content of components, % in d.m.		
	Nitrogen	Phosphorus	Potassium
Unstabilized sludge (raw)	2÷7	0÷3	0.1÷0.8
Stabilized sludge	0.5÷3.5	0.8÷2.6	0.1÷0.3

For the particular sewage treatment plant it is recommended, if possible, to carry out quantitative and qualitative research at any stage of separation of sludge and treatment. This data should be considered with caution at the stage of preliminary studies and plans for waste management. In order to verify the data taken further testing of quantitative and qualitative sediment is recommended. It is important that research covers the following parameters: pH, dry matter, organic matter, total phosphorus, calcium, magnesium, ammonia nitrogen, total nitrogen, heavy metals, pathogenic bacteria of the genus *Salmonella*, the eggs of intestinal parasites *Ascaris*, *Toxocara*, *Trichuris*, which is very desirable in the case of stabilized and hygienisated sludge.

3. Methodological bases related to agriculture or natural use of sewage sludge

Reports of the literature [16, 17] confirm the possibility of using sewage sludge for growing plants for the production of compost, to cultivation of non-comestible plants or reclamation of degraded land.

The Decree of the Ministry of Environment on municipal sewage sludge [3] states the maximum annual dose of sewage sludge used for agricultural purposes and for reclamation, but methodological bases for determining these levels are not formulated. It is proposed that the basis for determining dosage was the balance of demand of sludge of plants to nitrogen and the level of covering needs of the plants from this source according to the criterion of fertilization:

– the maximum (about 75÷100% coverage needs of the plants),
– optimal (about 50÷60% coverage needs of the plants from sewage sludge, the rest by mineral fertilization),
– extensive (about 30% coverage needs of the plants from the sediment, the rest by mineral fertilization).

The second factor, which seems more reasonable in terms of ecology, is acceptance of phosphorus balance as the basis of fertilization and not nitrogen, at which the dose of sewage sludge is lower than in the case of criterion of demand for nitrogen. In addition phosphorus fertilizer equivalent, according to the experience of learning and practice [18] is 1, in the case of nitrogen from 0.3 to 0.7 and is dependent on the type of soils, seasons, crops, etc. This means that one can more precisely customize dose of sewage sludge by the balance of the content of phos-

phorus, treating sewage sludge as organic fertilizer [19], a medium rich in this element, and without fear of exceeding its deposits in the soil.

Fertilizing rates of sewage sludge and composts produced from sewage sludge are proposed to be determined from the following formula:

$$D = \frac{Z_N \cdot \alpha_N \cdot 10^{-3}}{S_{uN} \cdot R_{uN}}$$

where:

D - dose of sludge or compost, Mg d.m./ha,
Z_N - crops demand for nitrogen, kg N_{total}/ha·year,
α_N - the degree of covering the demand for nitrogen,
S_{uN} - nitrogen content (pure component of nitrogen - N), kg/kg d.m. of sludge,
R_{uN} - the equivalent of fertilizer nitrogen in sewage sludge or composts, depending on soil type, time of fertilization, in the range of 0.25÷0.50, an average of 0.3÷0.4. In the case of manure R_{uN} - is in the range 0.25÷0.60 and sewage 0.55÷0.85 [19, 20].

Crops demand for nitrogen is recommended to be taken in the range of 70÷240 kg N/ha·y for which the level of organic fertilization indicates the latest emerging trends as recommended by agronomic application rates.

Coverage needs of the plants for nitrogen and phosphorus are also recommended to be taken as 0.1÷0.3 [19-21].

The full algorithm for calculating doses of sewage sludge is presented in [7].

Taking as its starting point the above-mentioned formula for determining the dose of sludge, the calculations were performed for selected field crops. In the practice it is accepted that:

– for cereals $Z_N \approx$ 100 to 150 kg N/ha·y,
– for root crops $Z_N \approx$ 120 to 140 kg N/ha·y,
– for pasture $Z_N \approx$ 150 to 240 kg N/ha·y, an average of 180 to 200 kg N/ha·y,
– for beet $Z_N >$ 240 kg N/ha·y.

For the output mentioned above the level of demand for nitrogen degree coverage of nitrogen needs α_N from this source was assumed as 0.3; 0.5; 1.0 for the nitrogen content of sludge, or composts made of sewage sludge in the range of 1, 2, 3% N_{total} in kg d.m. of sludge. Calculated annual dose of sludge in the Mg d.m./ha, have been summarized in Table 3.

This data is related to the nitrogen content in sewage sludge of 1% in dry matter of sludge. At higher nitrogen content in the sewage sludge specified dose will be correspondingly less inversely proportional to the times of the total nitrogen content in sludge, for example at the content of 2% in dry mass N_{total} doses will be twice smaller.

The table below shows that for given initial conditions, the degree of soil fertilizing cover demand with sewage sludge for agricultural and land reclamation for agricultural purposes reduces the dose to 3 Mg d.m./ha·y, up to 6 Mg d.m./ha for

2 years and up to 9 Mg d.m./ha every third year. The coverage of the needs of the dose of 3 Mg d.m./ha·y is therefore important. In order to determine degree coverage needs of plants of nitrogen, with mentioned above assumptions transforming the relationship α_N was determined. At a nitrogen concentration of 1% in kg d.m., the degree of coverage needs will be within the range 6÷9%, for the assumed nitrogen concentration of 2% in kg d.m. degree coverage is 12÷18% and 3% concentration in kg d.m. - 18÷27%. The dose used for the required maximum of 3 Mg d.m. results in extensive fertilization of about 0.3. However, in the case of maximum dose, for the purposes of natural, reclamation of non-agricultural purposes and the objectives of planning, of 15 Mg d.m./ha·y it will cover the needs of any plants, including grasses, in the range 0.5÷1, corresponding to the optimal or full fertilization.

Table 3. **The annual dose of sewage sludge (according to the authors' suggestions)**

Degree coverage of nitrogen needs α_N	Crops demand of nitrogen, Z_N kg N_{total}/ha·y	Calculated dose of sludge D Mg d.m./ha	Maximum dose, according to regulation, Mg d.m./ha	
			Agricultural purpose	Natural purpose
0.3	100	10	3	15
	120	12		
	150	15		
0.5	100	16.7	3	15
	120	20		
	150	25		
1.0	100	33.4	3	15
	120	40		
	150	50		

The impact of sewage sludge on soil with a maximum permissible concentrations of heavy metals in sludge and in the soil and using a maximum dose of sludge according to the requirements of regulation [3] is important. For example, assuming a maximum content of cadmium in sewage sludge in the amount of 20 mg/kg d.m. of sludge at the considered dose of sludge about 3 Mg d.m./ha·y, the charge introduced into the soil during the year on the area of 1 ha will be 60 000 mg Cd/ha·y. Assuming that the soil is not contaminated with cadmium, charge per unit which is added to the soil, due to its content in the sludge, to the medium soil would be 0.00923 mg Cd/kg d.m. soil. This represents approximately 0.46% of normative values for the maximum permissible content of the metal in medium soil, which is 2 mg Cd/kg d.m. of soil and about 0.23% of the other criteria under the regulation [22], where the allowable level of cadmium contamination of agricultural land is set at 4 mg/kg d.m. of soils. For considerations we adopted cadmium, because in addition to lead and mercury it is the most toxic metal [23]. In turn, along with zinc

and molybdenum it is one of the most mobile elements but the least busy are chromium, nickel and lead [24].

Taking the above-mentioned conditions into account it can be stated that the soil will not be contaminated with cadmium over the acceptable normative value. The achievement of this magnitude in the case of agricultural land at 2 mg Cd/kg d.m. of land may occur after about 200 years of introducing sewage sludge into the soil, which results from the calculations carried out by the authors. In soil contaminated with cadmium in the amounts such as 1 mg Cd/kg d.m. of soil and sewage sludge in the application of the same characteristics, the achievement of the limit value would be possible after a period of 100 years. In fact, this period will be longer, due to the fact that cadmium is extracted from soil by plants.

Summary and conclusions

The paper presents selected problems of agricultural or natural utilization of municipal sewage sludge. The presented analysis points to the need of amending the regulation on municipal sewage sludge, taking into account the criteria in the application of admitted dose of sewage sludge, taking into consideration fertilizing factors, especially nitrogen. Fully justified is to take into account the requirements of the act on fertilizers and fertilization, in particular the requirements in the relevant legislation. Cooperation of two ministries, the Ministry of the Environment and the Ministry of Agriculture seems logical.

After the analysis of series of conditions relating to quantitative and qualitative characteristics of the sludge in the existing legal order, a natural or agricultural utilization of sewage sludge produced in rural and suburban sewage treatment plants seems possible. This would allow the recycling of valuable components such as organic matter, nitrogen, phosphorus [25] and a number of macro- and micronutrients for the benefit of vegetation.

National conditions allow for agricultural or natural usage of sewage sludge from wastewater treatment plants in rural areas through their use in the early spring and late autumn during the year and in a wider time frame in case of their natural use. Natural or agricultural use of sewage sludge is conditioned by pre-treatment involving stabilization and sludge hygienisation with the desired pre-composting process.

Taking into account the forecast balance of sewage sludge of approximately 662 000 tones of dry matter in 2015 [13], it is expected that nearly 30% of this amount will come from rural areas and small towns and cities. Knowing the characteristics of sewage sludge from objects mentioned above it can be assumed that it can be used for agricultural, natural, reclamation of agricultural and non-agricultural purposes. Environmentally friendly approach to treatment of sewage sludge directs its agricultural use also based on the balance of phosphorus.

1. The basis for determining the doses of sewage sludge as a guiding criterion is the balance of fertilizer needs of plants in meeting the quality criteria as fertilizers and heavy metals in soils or ground, planned to be fertilized with sludge.
2. Using doses determined in this paper it can be assumed that sludge is a substitute for phosphorus fertilizer with low content of fertilizing element. Realistically the dose of sewage sludge provides extensive fertilization. It is necessary then to fertilize soil more to cover the full needs of the plants for natural fertilizers (manure, urine manure) and mineral or mixed fertilizers.

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Uwarunkowania rolniczego i przyrodniczego wykorzystania osadów ściekowych na terenach wiejskich

Stały wzrost ilości osadów powstających w komunalnych oczyszczalniach ścieków oraz niedociągnięcia w zakresie ich zagospodarowania powodują, że problemy gospodarki osadowej wymagają pilnego rozwiązania. Końcowym etapem unieszkodliwiania komunalnych osadów ściekowych powinno być ich rolnicze bądź przyrodnicze wykorzystanie, oczywiście po spełnieniu przez nie wymagań jakościowych (osady ustabilizowane, odkażone, przekompostowane). W artykule zostanie przedstawiona analiza i ocena możliwości rolniczego bądź przyrodniczego wykorzystania osadów ściekowych jako nawozów organicznych.

Komunalne osady ściekowe, powstające w oczyszczalniach ścieków, nie są nawozami i nie mogą być traktowane jak nawozy naturalne, np. obornik. Mogą być stosowane w rolnictwie w formie przetworzonej i nieprzetworzonej pod warunkiem, że są ustabilizowane i spełniają wymagania dopuszczalnych poziomów metali ciężkich oraz wskaźników sanitarnych, a także zawierają określone ilości substancji organicznych oraz związków nawożących azotu, fosforu i potasu. Mogą być wówczas traktowane jako nawozy organiczne zgodnie z ustawą o nawozach i nawożeniu. Dodatkowym punktem rozważań jest problematyka wykorzystania osadów ściekowych w odniesieniu do planowania i zagospodarowania przestrzennego. Istotną rolę odgrywa możliwość dysponowania odpowiednim zapleczem terenów, w tym pól (gruntów ornych i użytków zielonych) spełniających określone wymagania ze względu na zawartość metali ciężkich z uwzględnieniem uwarunkowań ekologicznych i fizjograficznych. Zatem na każdym etapie opracowywania gospodarki wodno-ściekowej i osadami ściekowymi w ujęciu wariantowym konieczne jest przeprowadzenie rozpoznania i inwentaryzacji terenów np. w formie wieloaspektowej ankiety.

Punktem wyjścia do rozważań dotyczących przeróbki i ewentualnego zagospodarowania osadów ściekowych w celach rolniczych bądź przyrodniczych jest rozpoznanie szeregu uwarunkowań z tym związanych. Na pierwszy plan wysuwają się wspomniane podstawy prawne oraz określenie charakterystyki ilościowej i jakościowej osadów ściekowych powstających w ciągu roku w oczyszczalni ścieków. W pracy zawarto zatem charakterystykę jakościową osadów ściekowych powstających w oczyszczalniach obsługujących wiejskie jednostki osadnicze i małe miasta z punktu widzenia zawartości związków nawożących (N, P, K) oraz metali ciężkich. Bardzo dokładne poznanie charakterystyki osadów jest podstawą wyboru odpowiedniego sposobu ich przeróbki, wykorzystania lub zagospodarowania. Kolejnymi kryteriami wyboru sposobu postępowania z osadami będzie przygotowanie osadów ściekowych poprzedzające ich rolnicze bądź przyrodnicze wykorzystanie. W szczególności omówione zostanie określenie rocznych dawek osadów ściekowych wykorzystywanych rolniczo bądź przyrodniczo z uwzględnieniem potrzeb roślin, stopnia pokrycia potrzeb roślin na azot z tego źródła, zawartości azotu w osadach bądź kompostach tworzonych na ich bazie oraz równoważnika nawozowego azotu w odniesieniu do nawozów mineralnych.

Słowa kluczowe: **ścieki, osady ściekowe, rolnicze i przyrodnicze wykorzystanie osadów ściekowych**