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Review of possibilities of using sandy waste obtained in wastewater treatment plants as an alternative raw material in construction[1]

Przegląd możliwości wykorzystania odpadów piaszczystych odzyskiwanych w oczyszczalniach ścieków jako surowca alternatywnego w budownictwie

Abstract

Sand is a globally mined natural resource. It is applied, among others, in construction, because sand is one of the main components of concrete mixtures and a material used in earthworks. The aim of the manuscript is to organize the state of knowledge regarding the management of sandy waste generated in wastewater treatment plants and to indicate the possibilities of using this waste as an alternative raw material in construction applications. The main thesis is the claim that sand recovered in wastewater treatment plants, perceived as waste, can be an alternative for the global economy to obtain a significant amount of raw material for various uses in construction and to replace natural raw materials extracted for industry. The paper presents data on natural sand resources and its use, the effects of uncontrolled exploitation of the worlds sand resources and the potential of the Polish sand resource base. Particular attention was paid to the review of the possibilities of using sandy waste generated in wastewater treatment plants as an alternative raw material for natural sand resources. The practical applications of sand obtained in the processes used in wastewater treatment plants were also presented.

Keywords:
sand, mineral waste, sandy waste generated in wastewater treatment plants, circular economy, natural resources

Streszczenie

Piasek jest globalnie wydobywanym zasobem naturalnym. Stosuje się go m.in. w budownictwie, ponieważ piasek jest jednym z głównych składników mieszanek betonowych oraz materiałem wykorzystywanym w robotach ziemnych. Celem artykułu jest uporządkowanie stanu wiedzy dotyczącego zagospodarowania odpadów piaszczystych powstających w oczyszczalniach ścieków i wskazanie możliwości wykorzystania tych odpadów jako surowca alternatywnego w zastosowaniach budowlanych. Główną tezę stanowi twierdzenie, że piasek odzyskiwany w oczyszczalniach ścieków, postrzegany jako odpad, może być alternatywą dla światowej gospodarki na pozyskanie znacznej ilości surowca do różnych zastosowań w budownictwie i zastąpienia nim surowców naturalnych wydobywanych dla przemysłu. W pracy przedstawiono dane dotyczące zasobów piasku naturalnego i jego wykorzystania, skutki niekontrolowanej eksploatacji światowych zasobów piasku oraz potencjał polskiej bazy zasobowej piasku. Szczególną uwagę poświęcono przeglądowi możliwości wykorzystania odpadów piaszczystych powstających w oczyszczalniach ścieków jako alternatywnego surowca dla piasku naturalnego. Przedstawiono również dotychczasowe, praktyczne zastosowania piasku uzyskanego w procesach stosowanych w oczyszczalniach ścieków.

Słowa kluczowe:
piasek, odpady mineralne, odpady piaszczyste powstające w oczyszczalniach ścieków, gospodarka o obiegu zamkniętym, zasoby naturalne

JEL: L74, Q01, Q34, Q53

Introduction

The circular economy is a model of economic development based on the assumption that all elements of the production chain (raw materials/resources, products and materials) are maximized, i.e. remain in circulation as long as possible. On the other hand, the amount of generated waste is minimized and it is managed in accordance with the waste management hierarchy (waste prevention, preparation for reuse, recycling, other recovery methods, disposal).

The main goal of the circular economy is to reduce the burden on the environment caused by negative human activity. Rapid globalization, industrialization and consumerism, as well as global population growth, place an excessive burden on the ecosystem, ruining its natural ability to renew and return to a state of equilibrium. Therefore, it is crucial to use natural resources wisely, maximize the recovery of secondary raw materials and recycle waste that can replace materials obtained from natural resources (Karło et al., 2018; Ngan et al., 2019; Torres et al., 2021).

Sand as a product has become a globalized commodity, and its overexploitation around the world degrades the environment, threatens communities, causes scarcity and creates conflict every day (Leal Filho et al., 2021; Bendixen et al., 2021). In order to alleviate the symptoms of the global sand crisis affecting more and more countries in the world, opportunities for a circular economy should be considered in the water and wastewater sector, already during the first stage of wastewater treatment or in the process of sludge treatment from cleaning sewage collectors while recovering a valuable raw material, which is sand (Szulc, 2018; Karło et al., 2018).

The reuse of sand from technological processes used in wastewater treatment plants, as part of the circular economy, has favorable legal, economic and ecological aspects (respectively: reducing the amount of landfilled waste, reducing the costs of its disposal, and protecting natural sand resources). The results of transforming sandy waste into a full-value product will constitute an added value for the economy, and the sandy waste will no longer function in the consciousness of society as waste – instead, it will begin to be perceived as a raw material.

Global natural resources of sand

Sand is fundamentally important for human development and is the second most used natural resource after water. It plays crucial role in the economy, being used in many areas: as a material for earthworks, an ingredient for the production of concrete or other products used in construction, as well as in the production of glass and electronics. Sand is needed to filter water and huge amounts are used for land reclamation projects, shale gas extraction and beach regeneration programs (Torres et al., 2017; Hall, 2020).

There is a view that there are endless amounts of sand on Earth for practical use, but given the current period of rapid acceleration in the extraction and use of resources, this claim requires critical analysis. The world's natural resources of sand are estimated at 12,000 billion tonnes, and 125,000 billion tonnes of rock can be crushed into sand and gravel (Sverdrup et al., 2017). Over the period 1900–2010, the global amount of natural resources used in construction increased 23 times. Sand and gravel constituted the main part of these raw materials, in 2010: 79%, or by weight: 28.6 billion tonnes (Torres et al., 2017). In 2014, the annual consumption of sand was estimated at around 53 billion tonnes, which corresponds to the consumption of 20 kg of sand per day by every person on Earth (Hall, 2020). Currently, sand and gravel are the most extracted natural resources in the world. Their extraction was ahead of fossil fuels and biomass (Torres et al., 2017). Moreover, scientists estimate that the extraction of sand takes place more than three times faster than nature can restore its deposits (Hall, 2020).

The enormous global demand resulting from the expansion of cities, combined with unlimited mining, creates the perfect conditions for sand shortages. The papers (Leal Filho et al., 2021; Bendixen et al., 2021; Torres et al., 2017; Hall, 2020; Sverdrup et al., 2017) describe global socio-political, economic and environmental problems resulting from the uncontrolled exploitation of the world's sand resources. These include: a drastic understatement or a complete lack of reliable statistics on the world's sand extraction and use, national shortages of access to sand resources, development of organized crime involving the illegal extraction and trade of sand, international disputes, changes in the rivers structure and coastal ecosystems, increase in the amount of suspended sediments and erosion, threats resulting from climate change (lack of flood protection), impact on drinking water supply and lowering the productivity of food sources, epidemiological threats among the population. The lack of international law (strategies) regulating sand extraction, use and trade was also noted.

The potential of the national sand resource base

In 2021, Poland's national natural resources of sand were estimated at approximately 9.7 billion tonnes. Additionally, about 9.5 billion tonnes were sand and gravel. In 2021, the extraction of sand and gravel from deposits was estimated at about 0.19 billion tonnes, i.e., about 1% of the national resources. It corresponded to the daily consumption of over 13 kg of sand and gravel by everyone living in Poland (Miśkiewicz et al., 2022). Currently, the natural aggregates industry is able to meet the needs of the national economy without the need to import. However, it must be borne in mind that economic development is closely related to the building structures' construction, modernization and renovation (Szczygielska, 2015). In 2021, there was an increase in the consumption of sand and gravel aggregates in infrastructure and cubature construction as well as in the production of concrete (including ready-mixed concrete) and concrete products. Currently, a significant part of aggregates is allocated for infrastructural investments. In the perspective of several or several dozen years, a greater share of aggregates in the production of ready-mixed concrete and concrete products in cubature construction is forecast (Miśkiewicz et al., 2022). Poland owns of a rich raw material base for aggregates production, however, there is a great difficulty in the uneven distribution of deposits in individual regions of the country (Szczygielska, 2015). According to W. Miśkiewicz et al. (2022), the shortage of sand aggregates can now be observed in the southern voivodships. In contrast, the shortage of sand-gravel aggregates (currently defined as particularly sought after) is primarily felt in the central voivodships. The seemingly safe situation of the domestic raw material base may deteriorate, because, due to the environmental restrictions forecasted in the future and limited access to deposits, a decrease in aggregate production is expected. Therefore, meeting the needs which are a condition of the country's economic development will become a significant challenge for producers of building materials (Szczygielska, 2015).

The solution to this problem could be the use of aggregates alternative to natural aggregates, namely, secondary aggregates defined as aggregates of mineral origin, obtained as a result of an industrial process involving thermal or other modification of their properties. These include waste materials from the following industries: metallurgical (e.g. granulated blast-furnace slag), mining (e.g. burnt shale) or energy (e.g. fly ashes). The growing interest in these aggregates in the construction industry is mainly observed in situations where the location of significant infrastructure investments is close to the potential resource base for their production. Usually, they are cheaper than natural aggregates, and at the same time have similar physical and mechanical properties. The transformation of waste into a product also reduces the fees associated with its storage. In addition to economic benefits, it is worth remembering about environmental benefits, e.g., saving natural resources (minerals) for the production of aggregates, reducing pollutant emissions related to their transport, reducing the amount of waste disposed of in landfills or recovery of land occupied by landfills. Alternative aggregates, depending on their quality and origin, can be used in many branches of construction, such as aggregate for concrete, supplementary aggregate for other types of soil, filling material, backfills for engineering structures or material for embankments construction, land macro-levelling, land reclamation, etc. (Machniak et al., 2014).

Sandy waste recovered in wastewater treatment plants in the circular economy

Wastewater treatment plants as elements of the circular economy

Wastewater treatment plants are unique production plants that generate waste streams that are products of various technological processes. Wastewater treatment plants are a suitable example of facilities where the goals of the circular economy can be effectively implemented, e.g., by recovering natural resources (Karło et al., 2018; Chrispim et al., 2020; Papa et al., 2017; Hernández-Chover et al., 2023).

The increase in the total amount of wastewater to be treated and, consequently, the increase in the amount of waste generated in wastewater treatment plants (Table 1) results from the development of municipal wastewater collection and treatment systems (expansion of the water supply and sewage network and commissioning of new and modernization of existing wastewater treatment plants).

A fundamental problem for wastewater treatment plants is the proper management of waste generated in them. Efforts are made to reduce the nuisance of waste for the environment and human health, and to manage resources as efficiently as possible. The main challenge in waste management for the coming years is in the

Table 1
Industrial waste generated in Poland, classified into the group "water supply, sewerage, waste management and remediation activities"

Year	2017	2018	2019	2020	2021
Amount of waste (in thousands of tonnes)	4,799	5,174	5,355	5,465	6,100

Source: own study based on Statistics Poland, 2018; 2019; 2020; 2021; 2022.

transition to a circular economy: minimizing the amount of waste generated and applying the waste hierarchy, in which one of the main postulates is the use of waste as a resource through recycling processes. This approach is in line with the current objectives of the European Union directive on waste management, and the waste management hierarchy has been included in the 12. goal of 17 Sustainable Development Goals of the 2030 Agenda for Sustainable Development under the name "Responsible consumption and production" (Pires et al., 2019). According to Obwieszczenie (2022), recycling is a process by which waste is reprocessed into products, materials or substances and used for the original or other purposes.

Classification of sandy waste generated in wastewater treatment plants

In accordance with the provisions of law (Obwieszczenie, 2022), waste is any substance or object the holder discards or intends or is required to discard. In Poland, each waste has been assigned a code clearly indicating the way of its generation and disposal (Szulc, 2018; Rozporządzenie, 2020).

In the wastewater technology, the term sand removed in the processes used in a wastewater treatment plant (Figure 1) is a mixture of all kinds of mineral impurities, which includes: sand, gravel, pebbles, but also organic impurities such as seeds or fragments of egg shells, etc. (Szulc, 2018; Stahl, 1997).

Figure1
Waste recovered in the wastewater treatment plant, which is a mixture of mineral, organic and anthropogenic parts

Source: photo by J. Kostrzewa.

Mineral waste, also called sandy waste due to the dominant content of the sand fraction, can be obtained in wastewater treatment plants (Bieniowski et al., 2020):

- from grit chambers, devices belonging to the first stage of wastewater treatment, i.e., mechanical treatment (waste code: 19 08 02 – the content of grit chambers);
- from special nodes (located on the wastewater treatment plant site) to receive sludge from cleaning sewage collectors (waste code: 20 03 06 – waste from sewer chambers and waste code: 20 03 03 – waste from cleaning streets and squares).

In grit chambers (Figure 2), sands, gravels and other mineral solid particles as well as suspended solids of other origins, which have not previously been retained on the screens, fall to the bottom of the tanks. Hence, they are collected using mechanical devices and finally sent to the storage tank. The role of grit chambers is primarily to protect against damage to subsequent elements of the technological line of the wastewater treatment plant (including protection of pipelines against loss of patency, protection of devices in sewage aeration chambers and anaerobic digestion chambers, as well as protection against the reduction of their active capacity through the accumulation of mineral suspension) and protection of mechanical elements of pumps and centrifuges against abrasion, and thus extending the service life of devices, which directly reduces the cost of their maintenance. Average annual maintenance costs can represent 15% to 25% of the total operating costs of a wastewater treatment plant, with the cost of mechanical equipment accounting for up to 6% of maintenance costs (Kolosovska et al., 2022). Hence, grit chambers are objects that play a significant role in the proper functioning of the entire wastewater treatment plant (Stahl, 1997; Kolosovska et al., 2022; Mateo Pérez et al., 2020; Karło et al., 2018; Biedrzycka, 2021; Wilson, 1985; Huang et al., 2021).

In many wastewater treatment plants, the sand recovery system is modernized with sand separator nodes (Figure 3). The purpose of using such nodes is to receive contaminated sand pulp from grit chambers, to rinse and separate organic and mineral parts. This solution improves the final parameters of sandy waste, minimizing or practically completely removing the odour from the waste, reducing the content of organic substances in the waste (even to a level below 2%) and reducing the hydration of the waste. With the use of such systems, the waste from the sand separators is discharged to a storage tank or a place of temporary storage (Biedrzycka, 2021; Szulc, 2018). Considering application of sandy waste recovered in wastewater treatment plants in construction, it

Figure 2
Grit chambers

Source: Biedrzycka, 2021.

Figure 3
Sand separator nodes

Source: Biedrzycka, 2021.

seems necessary to use a sand separator system as an element of the technological process of wastewater treatment. A significant amount of organic substances in the waste could adversely affect its properties, worsening the parameters of compaction and shear strength, or increasing compressibility. In addition, it could also be responsible for increasing the putrefaction of waste through the development of biological microorganisms and cause a biohazard.

Taking sludge from cleaning sewage collectors in special nodes is possible thanks to the company's possession of specialized trucks (Figure 4), which ensure the removal of sludge remaining in the sewage system by using high water pressure and the use of various types of heads and nozzles. This waste is deposited in the chamber of a specialist truck, which transports it to the wastewater treatment plant to the service station. Removal of this type of waste from the network is necessary and extremely important because it reduces the costs of works carried out by water supply companies (removing network failures and blockages) and ensures the maintenance of appropriate installation efficiency (Sikorska, 2019).

From the technological point of view, sandy waste from cleaning sewage collectors is similar in its particle size fraction to waste collected in grit chambers – waste code: 19 08 02 or minerals, such as sand and stones – waste code: 19 12 09 (Bieniowski et al., 2020).

Sandy waste generated in wastewater treatment plants could also be classified as man-made soils, because their solid phase was created as a result of human existence and activity. The grain-size distribution curves of sandy waste samples prepared on the basis of own research with grain-size distribution curves presented by M. Beniowski et al. (2020), along with information on dry organic matter characterizing a given sample, are shown in Figure 5.

The percentage content of individual soil fractions, in accordance with the PN-86/B-02480 standard, is presented in Table 2. Additionally, the dimensions of equivalent diameters read from the grain-size distribution curves are included.

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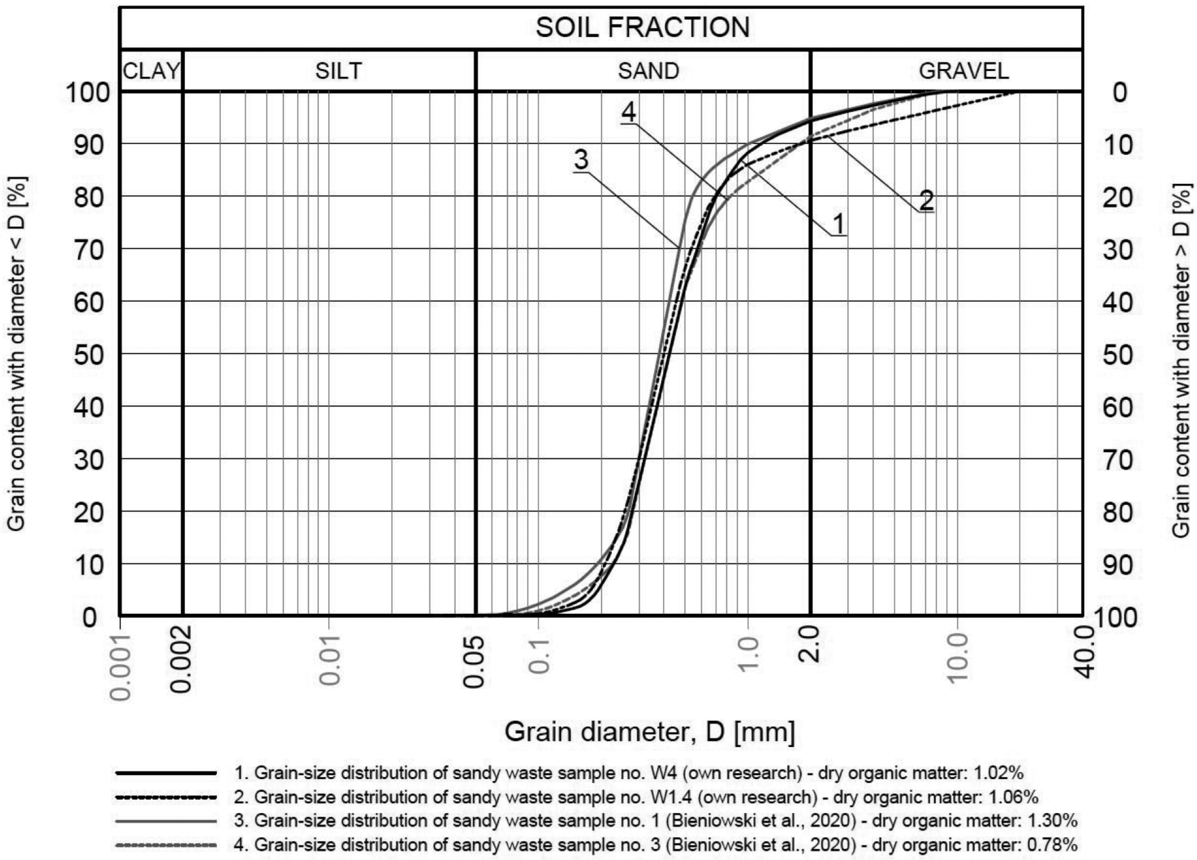
The gravel fraction of each sample does not exceed 10%, while the equivalent diameter d_{90} – 2 mm, and the equivalent diameter d_{50} is in the range of 0.50 mm ≥ d_{50} > 0.25 mm, thus it follows that sandy

Figure 4
A specialist truck for cleaning the sewage system, FFG Elephant type: (a) general view, (b) sewage collector cleaning

a) b)

Source: Wodociągi Warszawskie, 2022.

Figure 5
The grain-size distribution curves of sandy waste samples along with information on dry organic matter characterizing a given sample (in legend)



Source: own research and samples from Bieniowski et al., 2020.

Table 2

Percentage content of individual soil fractions constituting sandy waste recovered in wastewater treatment plants

Sample name (source)	Soil fraction [%]			Equivalent diameters [mm]	
	gravel	sand	silt + clay	d_{90}	d_{50}
Sandy waste sample no. W4 (own research)	5.69	94.21	0.10	1.10	0.41
Sandy waste sample no. W1.4 (own research)	9.42	90.48	0.10	1.70	0.40
Sandy waste sample no. 1 (Bieniowski et al., 2020)	5.20	94.66	0.14	1.00	0.37
Sandy waste sample no. 3 (Bieniowski et al., 2020)	8.60	91.35	0.05	1.70	0.41

Source: own study; Bieniowski et al., 2020; PN-86/B-02480.

waste recovered in the wastewater treatment plants in terms of grain size correspond to medium sands (PN-86/B-02480).

The content of dry organic matter in a given sample (Figure 5, in legend) does not exceed 2%, hence it can be assumed that sandy waste recovered in a wastewater treatment plants can be treated as mineral soils (PN-86/B-02480).

The low content of organic substances as well as the silt and clay soil fractions determined in the samples of sandy waste as part of the own research indicates a limited impact of these pollutants on the properties of the waste.

Due to the place where the waste is generated, the content of grit chambers (waste code: 19 08 02) belongs to the group of industrial waste related to the economic activity of wastewater treatment plants. On the other hand, waste from sewer chambers (waste code: 20 03 06) and waste from cleaning streets and squares (waste code: 20 03 03) belong to the group of municipal waste generated in inhabited areas and related to human existence (Statistics Poland, 2018; 2019; 2020; 2021; 2022).

In accordance with the regulations (Rozporządzenie, 2020), waste constituting the content of grit chambers (waste code: 19 08 02), waste from sewer chambers (waste code: 20 03 06) and waste from cleaning streets and squares (waste code: 20 03 03) are classified as non-hazardous and inert waste.

Amount of sandy waste generated in a wastewater treatment plants

The amount of sandy waste generated in wastewater treatment plants depends on several factors, e.g. the amount of treated wastewater, the type of wastewater in terms of origin (wastewater from residential estates or industrial zones), the condition of urban infrastructure (the number and character of streets), the need to sprinkle them with sand during winter, season as well as the type and technical condition of the sewage system (Szulc, 2018; Mateo Pérez et al., 2020; Nawrot et al., 2017). Unfortunately, the data from the Statistics Poland still lacks specific figures on the amount of sandy waste generated in the water and sewage sector.

It is estimated that the volume of sandy waste in the stream of wastewater flowing to one wastewater treatment plant in Poland per day is, on average, 0.02–0.04 dm^3 per one equivalent inhabitant and 35–70 dm^3 per 1,000 m^3 of wastewater (Szulc, 2018). In one of the Polish wastewater treatment plants, the amount of sand obtained from wastewater in 2010 was 2,021 tonnes, while in 2019 it already reached the level of 4,265 tonnes (Biedrzycka, 2021).

It seems interesting to predict the amount of sandy waste that reaches the wastewater treatment plant on the basis of a data-based model using the MARS (Multivariate Adaptive Regression Splines) method, implemented in one of the Spanish wastewater treatment plants. It uses data related to the measurement of input parameters in raw water at the mechanical treatment stage (flow rate, pH, raw water temperature, conductivity and ammonia content), as well as data on the amount of sandy waste removed from the wastewater treatment plant and meteorological data (from with particular emphasis on temporary and cumulative rainfall). The results indicate that it is possible to predict changes in trends in the generation of sandy waste as a function of changes in the input variables of wastewater entering the wastewater treatment plant (Mateo Pérez et al., 2020).

The estimated amount of sludge generated in the sewage system facilities can often be biased. The data published in the scientific literature are widely divergent. They relate to the approximate determination of the amount of suspended solids removed annually from the surface of land with various management methods, e.g. the amount of suspended solids discharged from the surface of 1 hectare of city centres per year may be between 0.49 and 4.28 tonnes – on average: 1.59 tonnes, and from industrial areas between 0.45 and 1.70 tonnes – on average: 0.72 tonnes (Nawrot et al., 2017).

Legal regulations regarding the management of sandy waste obtained in Polish wastewater treatment plants

Currently in Poland, there are three ways of dealing with the sandy waste generated in wastewater treatment plants (Bieniowski et al., 2020; Rozporządzenie, 2015):

1. Disposal by processing:
   - in the case of low-quality waste constituting the content of grit chambers (waste code: 19 08 02), exceeding the permissible leaching limits set out in Annex 3 of (Rozporządzenie, 2015): arsenic, barium, cadmium, total chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, zinc, chlorides, fluorides, sulphates, dissolved organic carbon, dissolved solids,
   - in the case of low-quality waste constituting sludge from cleaning sewage collectors: waste from sewer chambers (waste code: 20 03 06) and waste from cleaning streets and squares (waste code: 20 03 03), exceeding the permissible limit values set out in Annex 4 of (Rozporządzenie, 2015): total organic carbon, content of organic substances determined as losses on the ignition, heat of combustion.

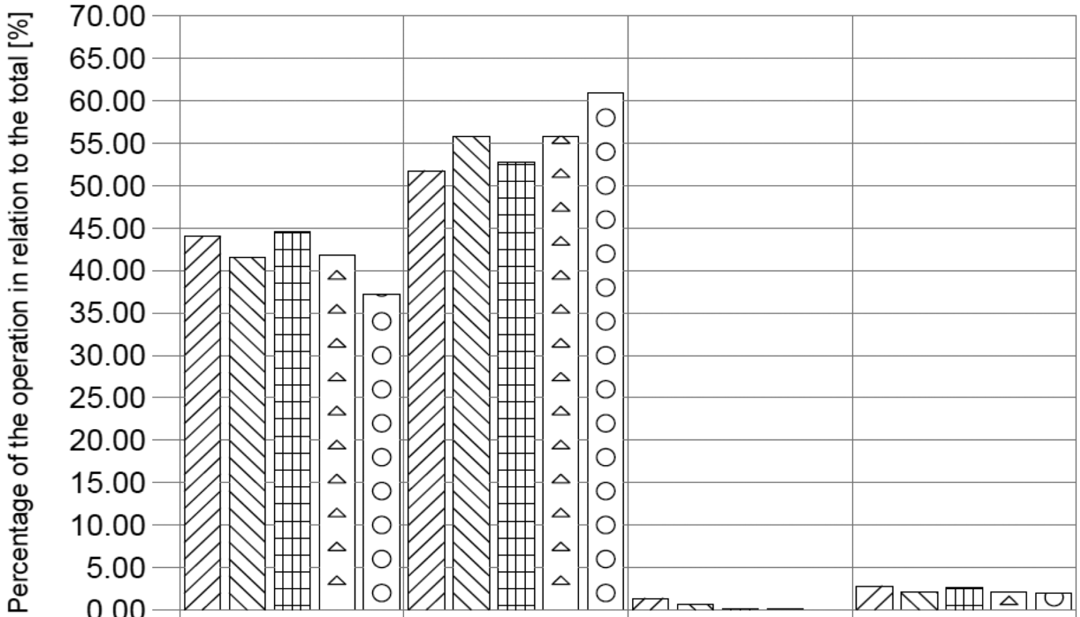
   The waste is entrusted to specialized companies that undertake to process it in accordance with applicable regulations.
2. Disposal by landfilling: in the case of obtaining sandy waste that meets requirements – permissible limit values given in point 1, in accordance with Rozporządzenie (2015), the waste can be transported to a landfill for non-hazardous and inert waste.
3. Change of waste status: efforts can be made to change the waste status.

   The procedure for changing the status of waste, consisting in the use of the concept of a by-product, is generally described in Obwieszczenie (2022):

   "An object or substance, resulting from a manufacturing process not primarily aimed at producing it, is considered a non-waste by-product if the following conditions are cumulatively fulfilled:
   1) further use of the object or substance is certain,
   2) the object or substance can be used directly without further processing other than normal industrial practice,
   3) the object or substance is produced as an integral part of the production process,
   4) the object or substance meets all relevant requirements, including legal requirements, in terms of the product, environmental protection and human life and health, for the specific use of the object or substance, and such use will not lead to general negative impacts on the environment, life or human health,
   5) the object or substance meets the detailed conditions for the recognition of a given object or substance as a by-product, if they have been specified in the provisions of European Union law or the regulations issued on the basis of art. 11 sec. 6 (if the detailed conditions for recognizing an object or substance as a by-product have not been specified in the provisions of European Union law, the minister competent for climate matters may define, by way of a regulation, separately for one or more matters, for some objects or substances, the detailed conditions for recognizing the object or substance as a by-product, taking into account the protection of the environment and human life or health)."

The first two options for dealing with sandy waste generated in wastewater treatment plants are widely used but generate costs and are related to administrative procedures for waste management (Bieniowski et al., 2020). According to the information available, the costs of processing sandy waste in 2021 amounted to PLN 700/tonne (Biedrzycka, 2021), while the landfill costs in 2019 amounted to PLN 170/tonne (Sikorska, 2019). The action, within the third option, consisting in changing the status of waste, allows the use of sand recovered in the wastewater treatment plants as a full-value product in construction solutions (Szulc, 2018), potentially leading, in effect, to a reduction in the amount of waste for disposal (Mielke et al., 2001). From the above provisions (Obwieszczenie, 2022), it can be concluded that finding a use for sandy waste obtained in wastewater treatment plants, while documenting that such use does not threaten the safety of the environment, human life or health, is sufficient to change the waste status to a full-value product. However, it should be noted that sandy waste obtained in wastewater treatment plants are still relatively new, insufficiently recognized materials. Currently, there are no legal regulations (standards, guidelines or technical approvals) describing the possibilities of using them in the construction industry. Sandy waste recovered in wastewater treatment plants are most often compared to soils or aggregates. The assessment of their suitability for engineering purposes should be preceded by appropriate tests confirming the

Figure 6
Generated industrial waste in the category "water supply, sewerage, waste management and remediation activities" in 2017–2021



	Recovered	Disposed	Transfered to other recipients	Temporarily stored
2017	44.01	51.78	1.38	2.83
2018	41.50	55.76	0.64	2.11
2019	44.58	52.72	0.13	2.60
2020	41.88	55.86	0.09	2.16
2021	37.15	60.90	0.02	1.95

Source: own study based on: Statistics Poland, 2018; 2019; 2020; 2021; 2022.

possibility of their use, depending on the place, method of manage and the role of the building, also taking into account the relevant physical and mechanical parameters as well as chemical and microbiological properties of the waste.

So far, sand recovered in wastewater treatment plants has been used as material for renovation and construction works of the municipal sewage system and as a ballast for construction works carried out on the wastewater treatment plant site (Karło et al., 2018). It was also used as a material for road construction and for use in civil engineering (Mielke et al., 2001). Recovered sand was supplemented as fine aggregate in the production of concrete mixture and used for the construction of road concrete pavement (Oczyszczalnia Ścieków "WARTA" S.A. w Częstochowie, n.d.) or as an aggregate in the production of concrete for non-structural purposes (Borges et al., 2015). It was also used as material for land reclamation, e.g., at the treatment plant in Berlin, after rinsing (Michałkiewicz et al., 2017) or as material constituting the insulating layers in municipal landfills, as well as for minor repairs of technological roads and internal roads on the site of the wastewater treatment plant and in landfills (Szulc, 2018).

There is often a lack of comprehensive waste recovery data from wastewater treatment in developing countries. Quantification of the detailed status of waste management in wastewater treatment plants remains a current challenge (Chrispim et al., 2020; Papa et al., 2017). This is also the case in Poland. Despite the known methods of dealing with sandy waste generated in wastewater treatment plants (disposal by processing, disposal by landfilling and change of waste status), there is still a lack of specific figures on the amount of sandy waste subjected to these operations. Currently, only general data on industrial waste generated in the category: "water supply, sewerage, waste management and remediation activities" are available, along with the possibilities of their management (Figure 6).

Conclusions

1. Considering the lack of access to natural resources of sand in some countries, it may turn out that this fraction's only available construction material in the future will be the sandy waste generated in wastewater treatment plants.
2. Due to the crucial demand for sand and gravel aggregates in infrastructure and cubature construction, as well as for the production of concrete and concrete products, it seems necessary to carry out the process of selecting aggregates in terms of their use as well as the place and purpose of building structures. Replacing natural sand with sand recovered in wastewater treatment plants could have significant potential in many infrastructure construction applications, and thus have a real impact on saving natural resources of sand for other purposes, and reducing the costs of construction, modernization or renovation of structures using alternative sand.
3. In view of the increase in the amount of sandy waste generated by wastewater treatment plants and the costs of their disposal, the possibility of changing the status of this waste and using it as a full-value product in construction applications could have a real impact on decreasing sewage discharge fees for residents.
4. Due to the lack of specific numerical data in the Statistics Poland's reports concerning individual ways of managing sandy waste recovered in wastewater treatment plants, efforts should be taken to create a public catalogue that would make these data available from all wastewater treatment plants. Such a system would enable to forecast the size of the sandy waste resource base and the possibilities of their use within the circular economy.
5. In order to classify sandy waste obtained in wastewater treatment plants as a by-product, it seems necessary to modernize the technological system of wastewater treatment, including the installation of a sand separator system. Such a solution would deprive the waste of a significant amount of organic and anthropogenic pollutants, mainly responsible for chemical and microbiological contamination.
6. The previous uses of sandy waste recovered in wastewater treatment plants as soils or aggregates in construction, comparable to obtain an alternative aggregates from other industries (e.g. metallurgy, mining or energy), together with estimated data showing the amounts of sandy waste generated in wastewater treatment plants, allow to conclude that sand reached in wastewater treatment plants, perceived as waste, can be an alternative for the global economy to get a significant amount of raw material for various applications in the construction and to replace natural raw materials extracted for industry. Therefore, it seems extremely important to introduce guidelines standardizing the use of sandy waste obtained in wastewater treatment plants in construction solutions.

Notes/Przypisy

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Profesor Politechniki Warszawskiej, specjalista z zakresu budownictwa hydrotechnicznego, inżynierii wodnej i środowiska. W latach 2014–2020 kierownik Zakładu Budownictwa Wodnego i Hydrauliki, w latach 2016–2023 dyrektor Centrum Analiz Geo i Hydrotechnicznych Instytutu Badań Stosowanych PW, a obecnie od roku 2020 dziekan Wydziału Instalacji Budowlanych Hydrotechniki i Inżynierii Środowiska. Główne obszary jego zainteresowań naukowych dotyczą problemów geotechnicznych w hydrotechnice i inżynierii środowiska, oceny stanu technicznego obiektów budowlanych, w tym z wykorzystaniem nowoczesnych metod pomiarowych, np. skaningu laserowego, termomonitoringu, pomiarów światłowodowych itp. Jest specjalistą w zakresie modelowania zagadnień filtracji wody w ośrodku gruntowym w obliczeniach i analizie bezpieczeństwa obiektów budowlanych, a także w zakresie analiz oddziaływań głębokich posadowień na obiekty sąsiednie i wodę gruntową w środowisku zurbanizowanym oraz ustalania wartości granicznych dla prowadzonego monitoringu (zarówno na etapie budowy, jak i eksploatacji obiektu).

Dr hab. inż. Agnieszka Dąbska

Inżynier budownictwa lądowego i inżynierii wodnej, specjalizujący się w geotechnice. Jej działalność naukowa obejmuje tematykę właściwości fizycznych i mechanicznych gruntów naturalnych i antropogenicznych, głównie zagęszczalności i przepuszczalności, ich korelacji oraz praktycznego zastosowania w konstrukcjach inżynierskich. Jej główny obszar naukowo-badawczy stanowi problematyka deformacji filtracyjnych piasków oraz odporności filtracyjnej gruntów. W ramach współpracy z otoczeniem społeczno-gospodarczym zajmuje się badaniami laboratoryjnymi i terenowymi gruntów naturalnych i antropogenicznych, problemami współpracy konstrukcji z podłożem gruntowym oraz ocenami i ekspertyzami stanu technicznego konstrukcji budowlanych. Jej działalność naukowa jest również ściśle związana z wdrażaniem normy PN-EN 1997 Eurokod 7 w Polsce.