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Accumulation of Cadmium, Chromium and Nickel in the Process of Stormwater Treatment

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1. Introduction

Among the most problematic pollutants of rainwater, acidifying compounds (Pokrývková et al. 2016) and suspension with other absorbed components (e.g. organic compounds, biogenes or heavy metals) are often mentioned (Wakida et al. 2014, Wojciechowska et al. 2017). According to Królikowski et al. (2006) rain runoffs from urbanized areas can contain 3,000 mg·dm^{-3} of suspensions on average, which gives 3 Mg of sediment per 1,000 m^3 of liquid. In turn, Dąbrowski (2001) reports that rainwater is able to collect up to 2.3 Mg of suspension from one hectare of the sealed area of the urban catchment. This amount of sediment sometimes complicates the operation and exploitation of rainwater management systems (sewage system, natural and artificial receivers). Reduction of the throughput or dropping of the active capacity of particular facilities may be mentioned (Sawicka-Siarkiewicz & Błaszczyk 2007, Zubala 2013). Another important issue is the strong affinity of suspensions and heavy metals. Metal compounds are characterised by very high durability and the ability to accumulate in the environment, even if they are introduced periodically in small doses. They easily go to trophic chains. Some heavy metals in trace amounts are vital to life, but their excessive concentration has negative effects on plant, animal and human health (Giri & Singh 2015, Kabata-Pendias & Mukherjee 2007). For this reason, particular attention should be paid to the process of capturing and the safe disposal of rainwater suspensions, and indirectly other pollutants.

Contemporary studies in the vast majority of cases concern sludge released in small rainwater management facilities, e.g. separators, settlers, infiltration wells, infiltration basins, retention and infiltration tanks (Tran & Kang 2013, Zubala & Patro 2015). They collect rain runoffs from small areas (small settlements, car parks, fuel stations, road sections) and are located in their immediate vicinity. Complex multi-hectare systems, serving much larger areas (large residential quarters, industrial areas) and performing multiple functions at the same time, are unfortunately rarely used. This stems from the significant implementation costs and spatial restrictions within the agglomeration. Their effectiveness, including the quantity and quality of retained sediments, is poorly recognised. Only a few research papers include the evaluations of technical and operational parameters and the reasonability of using such systems. Unfortunately, the lack of proper knowledge and legal regulations results in improper handling of rainwater sludge; for example, depositing them in random and unprotected places without qualitative analysis.

The aim of this article is to assess the degree of accumulation of cadmium (Cd), chromium (Cr) and nickel (Ni) in sludge of a municipal stormwater treatment plant and to identify possible dangers resulting from this fact. The research facility is located in Puławy (south-eastern Poland). It receives outflows from an area of about 500 hectares of the city and is characterised by high throughput, retention capacity and innovative implemented technology. Due to the nature of drained surfaces, the considerable size of the treatment plant, the location of the individual devices, the variable hydraulic load and periods of rainwater retention (sedimentation time), a diversified concentration of pollutants in sediments in the subsequent stages of purification should be expected.

2. Material and methods

2.1. The study area

Puławy is located on the right bank of the Vistula river in its middle course. This area is characterised by a large diversity of geomorphological and geological forms. There are both slopes and loess gorges, as well as sandy and clayey glacial moraines. Limestone outcrops or inland dunes are also visible (Kondracki 2000). In the study area there are 165 days with precipitation during the year. The average total annual precipitation is about 570 mm. Their maximum heights are recorded in July. The average annual air temperature reaches 8°C. The time of snow cover does not exceed 60 days and the growing season lasts 220 days (Kaszewski 2008).

The municipality of Puławy covers an area of about 50 km^2 and has a population of nearly 50 thousand. The ring water supply system spans almost 98%, and the separate drainage system – 96% of the total population. Underground water intakes as well as a modern mechanical and biological wastewater treatment plant are utilised here. Around 330 business entities in the industrial sector and 460 in the construction sector are registered in the city. The chemical industry represented by Zakłady Azotowe S.A. (nitrogen plants) is growing rapidly. National road no. 12 and regional roads no. 801 and 824 run through Puławy (UMP 2004, US 2016).

In the 1990s, a stormwater treatment plant was built in the south-western part of the city. The facility is located on the lower floodplain of the Vistula river (1 km from the river bed) in the immediate vicinity of its oxbow. The adjacent area is characterised by a large variety of land use forms. There are large areas of arable fields, a single-family housing estate, poorly developed lands with old buildings and a Roman Catholic cemetery.

2.2. Characteristic of stormwater treatment plant

The main elements of analysed technological line are screen chambers (2 pc.), grit chambers (2 pc.), a settler (1 pc.) and a retention pond (1 pc.) (Fig. 1). In the treatment plant there is only gravity flow - possible because of preserving the appropriate slopes and differences in bottom elevation of the individual devices. During the flow, physical, chemical and biological processes of self-cleaning occur - characteristic for aquatic and wetland ecosystems. Among them, straining, filtration, sedimentation, sorption, mixing, dilution, oxidation, reduction and biological decomposition can be mentioned (Braskerud 2001, Herrmann 2012). The receiver of treated sewage is the oxbow of the Vistula.

The municipal stormwater drainage system consists of two main interceptors of 1.4 and 1.6 m diameters and smaller side channels with necessary elements of utilities. Interceptor 2 drains nearly twice the area of interceptor 1. The drainage system spans most urbanized areas – among others, the main street of the city, residential districts with a predominance of multi-family buildings, and areas of services, education and sports.

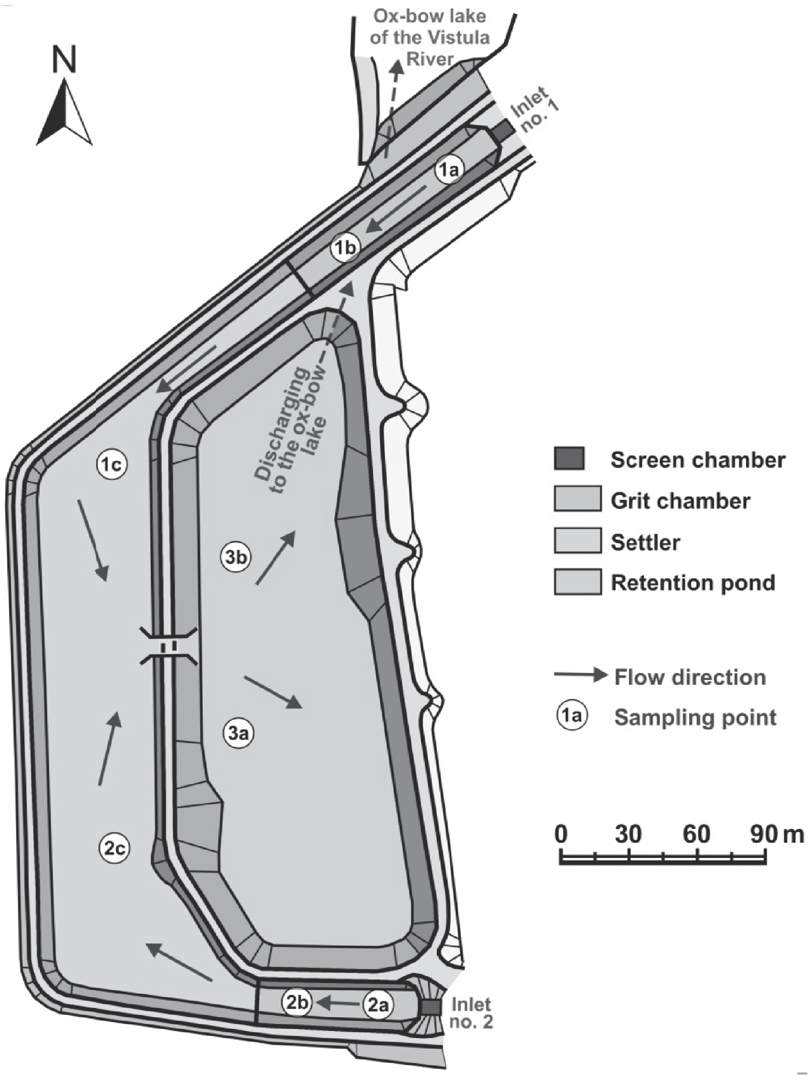

Fig. 1. Scheme of the stormwater treatment plant in Puławy
Rys. 1. Schemat oczyszczalni ścieków deszczowych w Puławach

Both main interceptors carry rainwater sewage to separate inlet chambers of the treatment plant. In each flat, screens with a clearness of 8 cm were installed (Fig. 2). The purpose of the screens is to stop larger solid effluents in the process of straining (e.g. municipal waste that accidentally gets into the drainage). The other elements of the treatment plant are two parallel grit chambers, 100 and 70 m long. They have the same width (10 m) and active depth (1 m). Designed speeds of sewage flow are approximately 0.4 $m \cdot s^{-1}$ (grit chamber 1) and 0.2 $m \cdot s^{-1}$ (grit chamber 2). Hydraulic conditions allow for sedimentation of heavy suspensions - mainly mineral fraction. The grit chambers are separated from the settler by overflows equipped with weirs.

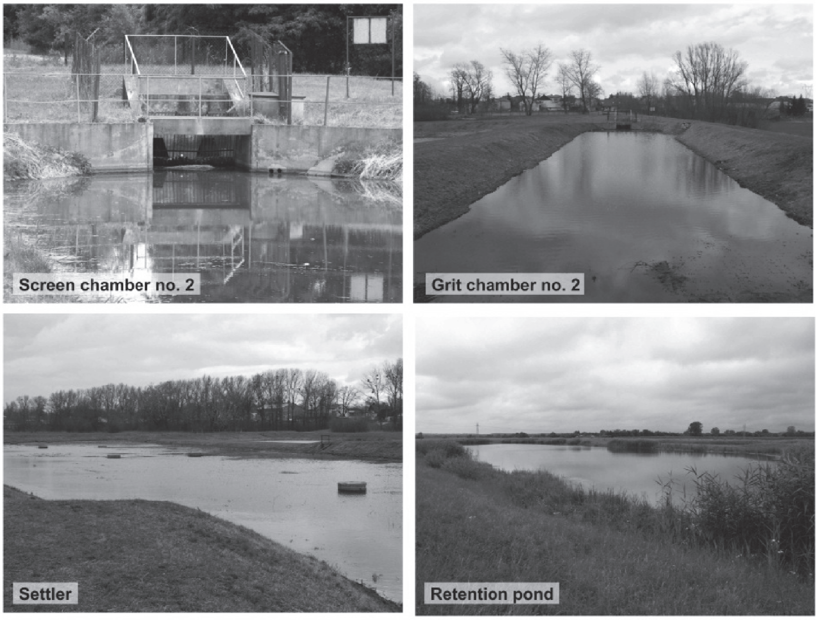

Fig. 2. Basic devices of the stormwater treatment plant
Rys. 2. Podstawowe urządzenia oczyszczalni ścieków deszczowych

In the settler, wastewater flowing from opposite directions mixes. The length of the main part of the settler is 190 m, and the width 46 m. The working depth does not exceed 1.2 m. The bottom of the settler is levelled, which guarantees slow flow and allows stopping light suspensions (mineral and organic fractions). The last facility of the treatment plant is the retention pond (Fig. 2), where sewage gets through the culvert with weirs. The surface of the reservoir is 1.5 ha, and the total capacity reaches 38,100 m^3. The lower layer is kept permanently, powered by groundwater. The upper retention layer is discharged to the oxbow lake of the Vistula. For this purpose, the culverts with weirs and two channels under the bottom of grit chamber 1 are used.

The bottoms of both the grit chambers and the settler were reinforced with openwork concrete slabs. Underneath there is a drainage that intercepts potential percolation, which reduces the risk of contamination of groundwater. It also enables rapid drainage of the grit chambers and settler, and then cleaning from accumulated sludge. The retention pond is a typical earth structure formed by adapting the end part of the oxbow lake. Like other devices, it was not sealed. It does not have its own drainage and technical reinforcements. In order to protect the adjacent farmlands against flooding, a band-shaped trench was constructed around the treatment plant. In the settler and at the base of dikes of the grit chambers and the retention pond, water-loving vegetation appears spontaneously. It is periodically mowed and removed from the area of the stormwater treatment plant.

2.3. Sediments sampling

Sewage sludge was collected using a sediment core sampler, type Beeker, by Eijkelkamp in the autumn of 2007 and 2015. The material of intact structure was taken from the bottom of particular stormwater treatment facilities from the 0-10 cm layer. This took place the year after the removal of sludge from the grit chambers and the settler, as part of routine operational activities. Due to a small amount of suspensions accumulated in the retention pond its bottom was not cleaned during the study period.

The exact locations of points of sediments sampling are showed in Figure 1:

- grit chamber 1 – 15 m behind the screen chamber (sample 1a) and 3/4 of its length – 75 m (sample 1b),
- grit chamber 2 – 15 m behind the screen chamber (sample 2a) and 3/4 of its length – 55 m (sample 2b),
- settler – 100 m behind grit chambers – half the distance between baffles separating grit chambers from the settler and the culvert of retention reservoir (samples 1c and 2c),
- retention pond – 30 m from the culvert connecting the pond with the settler (samples 3a and 3b).

2.4. Methods of analysis

The analyses were carried out in the certified Central Laboratory of Agroecology of the University of Life Sciences in Lublin. During laboratory work, the sludge samples were homogenised and dried at 105°C. Then, 0.5 g samples were mineralised in a microwave digestion at 210°C (Mars Xpress). The ash was digested in 10 ml of concentrated nitric acid (V), and then distilled water was added to the solution to obtain a final volume of 50 cm^3. The cadmium content (Cd) was determined in plasma using a quadrupole mass spectrometer and an ion detector (Varian 820-MS). Chromium (Cr) and nickel (Ni) contents were determined using the method of atomic absorption spectrometry in acetylene-air flame (Varian SpektrAA 280-FS). The analyses were repeated three times and the obtained data was averaged. The results were checked using the RTC reference material (Trace Metals – Wet Sewage Sludge CRM018-50G). The basic measurement conditions have also been determined. These include, among others: precision – 4% (Cd), 5% (Cr), 6% (Ni); recovery – 98% (Cd), 102% (Cr), 103% (Ni); expanded uncertainty – 9% (Cd), 11% (Cr), 14% (Ni).

To assess the degree of accumulation of heavy metals in sewage sludge, the characteristic and average values of analysed indicators were taken into account - both for each checkpoint and each device of the treatment plant. The percentage differences in pollutant concentrations between chosen positions were evaluated. The obtained data was compared with the data available in the scientific papers.

3. Research results and discussion

The contents of trace metals (Cd, Cr, Ni) in sludge of the stormwater treatment plant in Puławy are characterised by relatively large diversity. In the case of Cd and Cr the highest average concentrations were recorded in grit chamber 1 – successively 0.227 and 21.4 $mg \cdot kg^{-1}$, and the lowest in the retention pond – respectively 0.005 and 4.5 $mg \cdot kg^{-1}$. The highest average content of Ni was in sediments of the settler – 20.5 $mg \cdot kg^{-1}$, and the lowest in grit chamber 2 – 14.3 $mg \cdot kg^{-1}$. Sediments in grit chamber 1 were more polluted than in grit chamber 2, which specifically concerns Cd. Differences in average concentrations of metals between these devices ranged from 0.9% (Cr) to 93.1% (Cd). Comparing the quality of sludge near raw sewage inlets (checkpoints 1a and 2a), similar regularity can be observed, but only in the case of Cd and Ni. In point 2a the average content of Cr was significantly higher than in point 1a (table 1).

Table 1. Percentage differences between average concentrations of trace metals in particular observation posts ("-" – decrease, "+" – increase)
Tabela 1. Różnice procentowe pomiędzy średnimi zawartościami metali śladowych na poszczególnych stanowiskach obserwacyjnych badanej oczyszczalni („-” – spadek; „+” – wzrost)

Variable	Sampling points (comparison)							
	1a-2a	1a-1b	1b-1c	2a-2b	2b-2c	grit chambers-settler	settler-pond	grit chambers-pond
Cd	-92.9	+33.2	+2.8	+23.5	+285.7	+37.2	-97.5	-96.6
Cr	+239.5	+328.4	-62.8	-45.8	-33.6	-46.5	-60.5	-78.9
Ni	-2.6	+32.2	+8.5	-6.8	+39.9	+28.1	-11.2	+13.8

High differences of metal concentrations were also found within the grit chambers. Analysing data in points a and b, an increase in the concentration of pollutants in sediments of grit chambers 1 with the distance from the inlet of the treatment plant can be seen. In point 1b the maximum concentrations of Cd (0.461 $mg \cdot kg^{-1}$) and Cr (62.1 $mg \cdot kg^{-1}$) were recorded. In sediments of grit chamber 2 similar trends were observed only in the case of Cd. The cause of these phenomena may be different hydraulic conditions prevailing in different zones of grit chambers, and in particular, the rates of sewage flow. They decrease with the distance from the inlets. As a result, there is an opportunity for sedimentation of increasingly lighter fractions of suspension. The smallest fraction is retained in the settler whose bottom is levelled and the speed of wastewater flow is the smallest. The average accumulations of Cd and Ni in sediments of the settler were 37.2% and 28.1% higher than the average values for the grit chambers. In turn, the content of Cr decreased by 46.5% when moving from the grit chambers to the settler. In checkpoint 1c of the settler, the maximum values of Cd (0.461 $mg \cdot kg^{-1}$) and of Ni (22.4 $mg \cdot kg^{-1}$) were recorded. The strong impact of sewage supply from the side of grit chamber 1 on the quality of sludge in the settler was noticed. In point 1c, the average concentrations of Cd, Cr and Ni were higher by 75.2, 23.3 and 11.5% respectively than in point 2c, adjacent to grit chamber 2. More pollutant loads brought to the northern part of the treatment plant are probably related to the character of the drained area by interceptor 1. There are more pollutant sources than in the basin of interceptor 2. A significant share of roads (including the main street of the city), high intensity of road traffic, and high density of diverse technical infrastructure can be mentioned. Studies of other authors have shown that transport (including transport routes) is a supplier of large quantities of suspensions, as the result of corrosion, abrasion of vehicle components and road pavements (Hjortenkrans et al. 2006, Mangani et al. 2005). The existence of a correlation between the way of catchment management and the quality of outflowing rainwater is also indicated by Goonetilleke et al. (2005) and Zubala (2018).

During the study, a significant decrease of pollutant accumulation in sludge in the passage from the settler to the retention pond (the last facility of the treatment plant) was observed. In the case of particular metals it amounts to 97.5% (Cd), 60.5% (Cr) and 11.2% (Ni) on average (table 1). The relatively low content of metals in the pond may indicate that they are well bonded to suspension particles, which are largely retained in the grit chambers and the settler. The existence of relationships between the types (including particle size), the concentrations of suspensions and the level of trace metal pollution has been demonstrated. Gunawardana et al. (2014) and Zhu et al. (2008), examining suspensions deposited on roads, have shown that metals are most often transported with finer and slower sedimenting fractions. This could explain the increased concentrations of some metals in the settler of the treatment plant.

Taking into account the average contents of metals, it was noted that the studied sediments in 2007 were characterised, in the majority of cases, by a higher degree of pollution than in 2015. The exception is grit chamber 2, where a significant increase in the contents of Cr and small increase of Ni were recorded. This is probably due to major changes in the management of catchment 2, which have occurred for the last few years (technical infrastructure expansion) and the emergence of new sources of pollution.

In comparison with results obtained by other authors, the degree of accumulation of trace metals in the sludge of the treatment plant in

Puławy is not very high (table 2). Their presence in the research area is probably related to the functioning of road transport and burning of fuels for energy purposes. A certain pool of metals can be released from various components of the technical infrastructure (Petrucci et al. 2014, Wojciechowska et al. 2017). Due to the lack of data in specialist literature on complex urban systems (combination of technical and semi-natural elements), the degree of pollution of analysed sediments was compared with the accumulation of metals in the ponds and wetlands rainwater management systems.

Table 2. Comparison of average concentrations of metals in sludge of the treatment plant in Puławy (own studies) with average accumulation in other tank-type stormwater management systems (literature data)
Tabela 2. Porównanie średnich stężeń metali w osadach oczyszczalni w Puławach (badania własne) z przeciętną akumulacją w innych zbiornikowych systemach zagospodarowania wód deszczowych (dane literaturowe)

Variable ($mg \cdot kg^{-1}$)	Treatment plant in Puławy				Literature data			
	Grit chamber 1	Grit chamber 2	Settler	Retention pond	Wetlands, ponds [a]	Detention pond [b]	Drainage system ponds [c]	Wet detention ponds [d]
Cd	0.277	0.019	0.203	0.005	2.000	0.431	0.285	0.150
Cr	21.4	21.2	11.4	4.5	41.0	25.7	85.9	1.7
Ni	17.7	14.3	20.5	18.2	30.0	38.7	69.8	0.7

[a] Allinson et al. (2015), [b] Färm (2002), [c] Heal et al. (2006), [d] Mallin et al. (2002)

Depending on the checkpoint, in the metal pool definitely dominate Cr and Ni (advantage of one or second element), while the percentage of Cd, considered as one of the most ecotoxic pollutions, is minor. Similar proportions in the contents of trace metals in rain sludge have been shown by authors of other articles (table 2). The highest pollution is observed in rainwater runoffs from large agglomerations, industrial areas or roads with greater traffic. For example, in the sludge of the rainwater management system of the metropolitan area of Melbourne (Australia) (Allinson et al. 2015), mean concentrations of Cd, Cr and Ni were higher than those of grit chambers in Puławy, respectively: 1,251.4, 92.5 and 87.5%. Most of the rainwater receivers presented in the literature also show high variability of sediment quality.

The direct source of trace metals in rain runoffs from communication routes in the city are motor exhaust gases (Cd, Ni), products of abrasion of tyres and brake discs (Cd, Cr, Ni), products of attrition of pavements and construction materials (Cr, Ni). The analysed metals can also be released from painted and varnished surfaces (components of pigments), galvanic coatings, plastics, metal alloys and impregnated wood. A significant anthropogenic source of Cd, Cr and Ni in the environment is also the burning of fossil fuels and waste (Kabata-Pendias & Mukherjee 2007, Królikowski et al. 2006).

Although no disturbingly high levels of heavy metals were found in the sediments, their quality should be continuously monitored. The city is developing dynamically and it is not possible to exclude the emergence of further potential pollution sources (e.g. increase in sealed surfaces and intensity of road traffic, establishing new production plants and service). Trace metals are characterised by very high durability and an ability to accumulate in the environment. According to the literature data, excessive concentrations of Cd, Cr and Ni are very harmful to living organisms. Plants do not have any metabolic needs towards toxic Cd, but its relatively easy solubility and assimilability show the serious threat to particular links of the food chain (Jayarathne et al. 2017, Zhang et al. 2017). Phytotoxic concentrations of Ni and Cr are varied depending on the species or variety of the plant. Kabata-Pendias & Mukherjee (2007) report that the range of excessive or toxic amounts of Ni in most plant species fluctuates from 10 to 1,000 $mg \cdot kg^{-1}$. According to Wilk & Gworek (2009), the harmful effects of Cr are found at concentrations of 2-20 $mg \cdot kg^{-1}$ dry matter. Plants accumulate Cr in much smaller amounts than Cd and Ni, because its compounds are poorly soluble (Jayarathne et al. 2017).

In the case of plants, dwarfism and chlorosis are usually symptoms of toxic effects. Damage and disturbances in the growth of a root system and metabolic dysfunctions are noted (Wilk & Gworek 2009). Exposure of animals and people to high doses of Cd, Cr and Ni may result in kidney damage, liver failure, skeletal deformity, and tumour growth (kidney, liver, lungs). In some cases, arterial hypertension, anaemia, emphysema, allergy, asthma and reduction of reproductive potential occur (Eisler 1985, Klein 1996, Sunderman 2004).

4. Summary

One of the aspects of the functioning of the stormwater treatment plant is the formation and accumulation of sludge. Its periodic removal and disposal are among the core operational activities. They condition the maintenance of proper hydraulic parameters and should prevent the uncontrolled transfer of pollutants to the environment. The studies have shown that rainwater sludge can be a convenient place to accumulate heavy metals such as cadmium, chromium or nickel. Their concentration, however, is characterised by a considerable variability, evident in the case of comparing particular dates (time variability), as well as plant facilities or checkpoints in specific devices. This is probably due to the variable quality of inflowing stormwater sewage, conditioned by e.g. way and intensity of use of drained areas, transport of various fraction of sludge, weather phenomena, etc. The specific nature of the applied cleaning technology (non-uniform hydraulic loading and period of wastewater retention) and performed operational activities can also be of great importance.

The highest concentrations of studied heavy metals were observed in sediments collected in the northern part of the wastewater treatment plant – powered by rainwater from the main streets of the city. These roads are characterised by heavy traffic. In their neighbourhood, numerous shopping and service facilities with large parking spaces and roofs are located. The least polluted were sediments from the retention pond, from which purified sewage flows to the water receiver. The highest accumulation of metals concerns the points of the treatment plant in which the lightest fractions of suspension are sedimented. In the pool of studied pollutants retained in the grit chambers, Cr has the highest share and ranges from 54% (grit chamber 1) to 60% (grit chamber 2). In turn, in the settler and the retention pond Ni dominates - successively 64 and 80%. In all devices, Cd has the smallest share in the pool of analysed metals (0.02-0.7%).

The quality of the sludge in the stormwater treatment plant should be constantly monitored due to the dynamic development of the city (numerous investments, expansion of technical infrastructure) and the emergence of potential sources of pollution. In the case of increased concentrations of metals, an effective method of neutralization of sediments should be developed and implemented, e.g. using bioremediation processes.

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Akumulacja kadmu, chromu i niklu w procesie oczyszczania ścieków deszczowych

Streszczenie

W pracy dokonano oceny stopnia akumulacji kadmu, chromu i niklu w osadach dużej oczyszczalni ścieków deszczowych. Obiekt zbiera spływy z powierzchni około 500 ha miasta Puławy (południowo-wschodnia Polska) i pod względem innowacyjności, przepustowości oraz pojemności retencyjnej wyróżnia się wśród innych krajowych rozwiązań tego typu. Podstawowymi elementami analizowanego ciągu technologicznego są: kraty, piaskowniki, osadnik i staw retencyjny. W oczyszczalni odbywa się wyłącznie przepływ grawitacyjny – możliwy dzięki zachowaniu odpowiednich spadków i różnic rzędnych den poszczególnych urządzeń. W trakcie przepływu zachodzą fizyczne, chemiczne i biologiczne procesy samooczyszczania. Osady ściekowe pobierano za pomocą próbnika Beeker firmy Eijkelkamp. Materiał o nienaruszonej strukturze pozyskiwano z dna poszczególnych obiektów oczyszczalni z warstwy 0-10 cm. Zawartość kadmu oznaczano w plazmie za pomocą kwadrupolowego selektora mas oraz detektora jonowego. Natomiast zawartość chromu i niklu oznaczano metodą spektrometrii absorpcji atomowej ze wzbudzeniem w pło-

mieniu acetylen-powietrze. Zawartości metali śladowych w osadach cechuje stosunkowo duże zróżnicowanie. Przyczyną mogą być odmienne warunki hydrauliczne panujące w poszczególnych urządzeniach – przede wszystkim prędkości przepływu cieczy. W efekcie następuje sekwencyjna sedymentacja różnych frakcji zawiesiny, a wraz z nią zaadsorbowanych metali. Duże znaczenie może mieć sposób użytkowania powierzchni odwadnianych. Największe stężenia badanych zanieczyszczeń obserwowano w części oczyszczalni zasilanej spływami z głównych ulic miasta. Najmniej zanieczyszczone były osady ze stawu retencyjnego, z którego ścieki oczyszczone odpływają do starorzecza Wisły. W piaskownikach, w puli analizowanych metali największy udział wykazuje Cr (54-60%). Natomiast w osadniku i stawie retencyjnym zdecydowanie dominuje Ni (kolejno 64 i 80%). Udział Cd mieści się w granicach 0,02-0,7%. W porównaniu z wynikami uzyskiwanymi przez innych autorów, stopień akumulacji metali śladowych w osadach nie jest wysoki. Ich obecność w obszarze badań prawdopodobnie wiąże się z funkcjonowaniem transportu drogowego oraz spalaniem paliw w celach energetycznych. Pewna pula metali może uwalniać się z różnych elementów, wchodzących w skład infrastruktury technicznej. Mimo, że nie stwierdzono w badanych osadach niepokojąco wysokich zawartości metali ciężkich, ich jakość powinna być stale monitorowana. Miasto rozwija się dynamicznie i nie można wykluczyć pojawiania się kolejnych potencjalnych źródeł zanieczyszczeń (m.in. wzrost powierzchni uszczelnionych i natężenia ruchu, tworzenie nowych zakładów produkcyjnych i usługowych). W przypadku wzrostu stężeń metali należy opracować i wdrożyć skuteczną metodę neutralizacji osadów, np. z wykorzystaniem procesów bioremediacji.

Abstract

The degree of accumulation of cadmium, chromium and nickel in sludge of a large rainwater treatment plant was assessed in the paper. The facility collects runoffs from an area of about 500 hectares of Puławy (a city in south-eastern Poland) and in terms of innovativeness, throughput and retention capacity stands out among other national solutions of this type. The main elements of analysed technological line are screen chambers, grit chambers, a settler and a retention pond. In the treatment plant there is only gravity flow - possible because of preserving the appropriate slopes and differences in bottom elevation of the individual devices. During the flow, physical, chemical and biological processes of self-cleaning occur. Sewage sludge was collected using a sediment core sampler, type Beeker, by Eijkelkamp. The material of intact structure was taken from the bottom of particular stormwater treatment facilities from the 0-10 cm layer. The cadmium content was determined in plasma using a quadrupole mass spectrometer and an ion detector. Chromium and nickel contents were determined using the method of atomic absorption spectrometry in acetylene-air flame. The trace metal contents in sediments are characterised by relatively large diversity. Different hydraulic conditions prevailing in individual devices – especially speeds of liquid flow – may be the cause. As a result, sequential sedimentation of various fractions of suspension occurs, along with adsorbed metals. The use of drained surfaces may be of great importance. The highest concentrations of pollutants were observed in the part of the treatment plant supplied with runoffs from the main streets of the city. The least polluted was sludge from the retention pond, from which purified sewage flows to the oxbow of the Vistula river. In grit chambers, Cr (54-60%) has the highest share in the pool of analysed metals. In contrast, the settler and the retention pond are dominated by Ni (respectively 64 and 80%). The contribution of Cd is in the range of 0.02-0.7%. In comparison with results obtained by other authors, the degree of accumulation of trace metals in the sludge is not very high. Their presence in the research area is probably related to the functioning of road transport and burning of fuels for energy purposes. A certain pool of metals can be released from various components of the technical infrastructure. Although no disturbingly high levels of heavy metals were found in the sediments, their quality should be continuously monitored. The city is developing dynamically and it is not possible to exclude the emergence of further potential pollution sources (e.g. increase in sealed surfaces and intensity of road traffic, establishing new production plants and service). In the case of increased concentrations of metals, an effective method of neutralization of sediments should be developed and implemented, e.g. using bioremediation processes.

Słowa kluczowe:
woda deszczowa, osady, zanieczyszczenia, metale śladowe, oczyszczalnia

Keywords:
rainwater, sludge, pollutants, trace metals, treatment plant