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Variable dynamics of sewage supply to wastewater treatment plant depending on the amount of precipitation water inflowing to sewerage network

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Abstract

The paper analyzes the effect of precipitation water that inflowing to sanitary sewage system as accidental water on the changes in the total amount of treated sewage. The effects of accidental water supply on the total amount of sewage inflowing to treatment plant were analyzed based on mean daily amounts from the investigated periods and mean daily amounts from incidental supplies. The study was conducted in the years 2010–2015. Six characteristic research periods were identified (one per each calendar year), when the amount of sewage in the sanitary sewage system was greater than during dry weather. The analysis of changes in the amount of sewage supplied to the sewerage system in the six investigated periods revealed that the accidental water constituted from 26.8% to 48.4% of total sewage inflowing to the wastewater treatment plant (WWTP). In exceptional situations, during intense rains, the share of precipitation water in the sewerage system would increase up to 75%. Then, the rainwater inflowing the sewerage system caused hydraulic overloading of the WWTP by exceeding its maximum design supply.

Key words: *precipitation, precipitation water, sewerage system, wastewater*

INTRODUCTION

Polish rural and rural-urban communities have recently witnessed a huge increase in the number of new collective sanitary sewage systems [CHMIELOWSKI *et al.* 2016; OBARSKA-PEMPKOWIAK *et al.* 2015; PAWEŁEK 2016]. Sanitary sewage system is only designed for collecting and treating domestic or municipal sewage and it is not a system for discharging precipitation water accumulated during precipitation [KOTOWSKI 2006; SULIGOWSKI 2000; Ustawa… 2001]. In many places people lack awareness regarding proper use of sanitary sewage systems and they connect gutters and building drainage systems to the sanitary sewage system instead of disposing this water within their property [BUTLER, DAVIES 2011; GEIGER, DREISEITL 1999; KARPF, KREBS 2011; SŁYŚ *et al.* 2015]. They often do not know that they violate Polish law [Ustawa… 2001]. Introduction of precipitation water into sewerage systems designed for disposal of domestic or municipal sewage causes multiple operational, technological, and economic problems [FRANZ 2007; KROISS, PRENDL 1996; MICHALSKA, PECHER 2000; PECHER 1999; 2002; WAŁĘGA *et al.* 2014]. Rainwater that inflowing to sewerage systems during intense rains may increase the sewage supply by over 100% as compared to the flow during dry weather [KACZOR 2009]. This causes hydraulic overload of wastewater treatment plants (WWTP). The time the sewage is processed at individual purification steps is then shortened and this negatively affects final performance of the WWTP [ARNOLD *et al.* 2000; BARNARD 2000; BUGAJSKI *et al.* 2016; KACZOR, BUGAJSKI 2007]. Sewage flow exceeding the design limits may wash out the activated sludge from the biological reactor and sedimentation tanks into the receiving water body. In extreme scenario, damming up the sewage in the sewerage system may cause local flooding of basements and cellars and, if appropriate protections systems are lacking, the sewage may be even discharged on WWTP grounds. Biological sewage treatment is severely affected by the supply of snow melt water. It cools the sewage temperature so much that the metabolism of activated sludge microorganisms is restricted or completely inhibited [ARNOLD 2000; KACZOR, BUGAJSKI 2012; KROISS, PRENDL 1996; MICHALSKA, PECHER 2000; WANG *et al.* 2016]. Polish communes equipped with this type of small sewerage systems designed only for disposal of domestic sewage should educate their inhabitants on their proper use to increase ecological awareness of the community and improve local environmental conditions [ILNICKI 2014; MŁYŃSKI *et al.* 2016; ŚWIERK 2016].

MATERIAL AND METHODS

The aim of the study was to determine the changes in sewage supply to the sewerage system during rainy periods.

The research hypothesis assumed that rainfall increased the share of precipitation water in total amount of sewage transported via the sewerage system and might cause hydraulic overloading of the receiving sewage treatment plant. The effects of accidental water supply on the amount of sewage inflowing to WWTP were analyzed based on mean values in the investigated periods and incidental supplies, i.e. daily periods for which intense rainfall was recorded.

The study was conducted in the years 2010–identified (one per each calendar year), when the amount of sewage inflowing to WWTP was greater than during dry weather. The research periods were as follows:

1. From 1 to 30 September 2010,
2. From 1 to 31 July 2011,
3. From 1 to 31 October 2012,
4. From 1 to 31 May 2013,
5. From 1 to 31 March 2014,
6. From 1 to 31 August 2015.

Measured parameters included mean daily volume of sewage inflowing to WWTP and daily amount of precipitation. Data on precipitation height on individual days of the research periods were received from a local Institute of Meteorology and Water Management weather station in Balice. The amount of sewage was measured by means of electromagnetic flowmeter located in the gate valve chamber of the raw sewage pumping station. The flowmeter readings were recorded everyday in the facility operation log.

The share of accidental (precipitation) water UWO in total amount of sewage in the sewerage system was calculated using a formula proposed by KACZOR [2012]:

$$UWO = \frac{Q_d - Q_{bd}}{Q_d} \cdot 100\% \qquad (1)$$

where: UWO = share of accidental water (%), Q_d = daily sewage volume entering the treatment plant, m^3·d^{-1}, Q_{bd} – daily sewage volume flowing to treatment plant in dry weather, m^3·d^{-1}.

The percentage addition of extraneous water DWO flowing into the sewerage system using a formula proposed by PECHER [1999].

$$DWO = \frac{Q_{d.sr.}}{Q_{d.bd.}} \cdot 100\% \qquad (2)$$

where: DWO = addition of accidental water (%), $Q_{d.śr.}$ = daily average of sewage volume entering the treatment plant (m^3·d^{-1}), $Q_{d \cdot bd}$ = daily average of sewage volume flowing to treatment plant in dry weather (m^3·d^{-1}).

Description of the analyzed sewerage system

The analyzed sewerage system serves the villages of Aleksandrowice, Balice, Burów, Brzoskwinia and Kleszczów located within Zabierzów commune, Małopolska region. Total length of the sewerage system is approximately 16 km, and it serves 3829 inhabitants of 1,052 houses. Sewer pipes are made of PCV and their diameters range from 200 to 315 mm. The system discharges also domestic sewage from Balice Airport (daily mean 37 m^3·d^{-1}), National Research Institute of Animal Production (daily mean 56 m^3·d^{-1}), and a military unit of the Polish Armed Forces (daily mean 100 m^3·d^{-1}). The sewage from the sewerage system and the three institutions reach a collective wastewater treatment plant located in Balice. The analyzed sewerage network and WWTP form a sewerage system that according to binding legal regulations is classified as an object with capacity of 2000 to 9999 PE [Rozporządzenie… 2014]. Design specific sewage supply in the sewage treatment plant is:

– $Q_{śr.d.}$ = 800 m^3·d^{-1} (mean daily supply),
– $Q_{śr.h.}$ = 33 m^3·h^{-1} (mean hourly supply),
– $Q_{max.h.}$ = 98 m^3·h^{-1} (maximum hourly supply).

Within six years of the study, the amount of sewage entering the sewerage system increased due to the sewerage network extension and connection of new households. Therefore, the amount of sewage entering the system in dry weather was evaluated individually for each monthly research periods.

RESULTS

Mean daily supply of sewage in the first research period (1–30 September 2010) was 458.1 m^3·d^{-1}, and total daily precipitation was 47.6 mm. Mean daily supply of sewage in dry weather in 2010 was 270 m^3·d^{-1}. Mean daily supply in the investigated period was greater than during dry weather by 188.1 m^3·d^{-1}, which constituted 41.1% of the accidental water UWO share in the analyzed month. In this month, average daily addition of accidental water (DWO) was 169.7%. During this period, an incidental rainfall event of 18.8 mm occurred on 22nd September, and on the next day the sewage supply increased to 990 m^3·d^{-1}. On 23rd September the share of accidental water was 72.7% of total sewage entering the WWTP. Figure 1 shows the amount of sewage reaching the WWTP and precipitation height between 1st and 30th September.

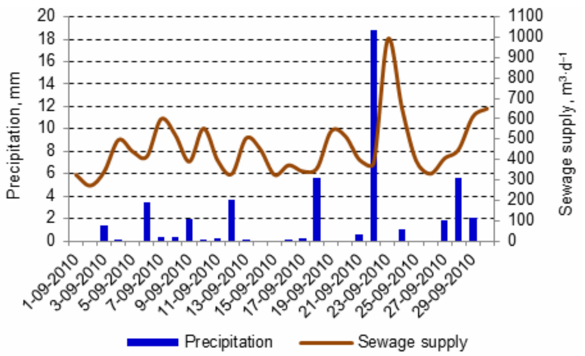

Fig. 1. Effect of precipitation on the increase of sewage amount entering the treatment plant in September 2010; source: own study

Mean daily supply of sewage in the second study period lasting from 1st to 31st July 2011 was 620 m^3·d^{-1}, and total daily precipitation was 191.6 mm. Mean daily sewage supply in dry weather in 2011 was 320 m^3·d^{-1}. In July 2011, mean daily supply of sewage to the sewerage system was by 300 m^3·d^{-1} higher than during dry weather and amounted to 48.8% of accidental water (UWO) share in total amount of sewage in the analyzed period. During this period, average daily addition of accidental water (DWO) was 193.9%. Detailed analysis for two characteristic periods with high rainfall was also prepared for this month. On 19th July a rainfall event of 41.1 mm and on 20th July another one of 24.6 mm occurred, giving a total rainfall of 65.7 mm within two days. The amount of sewage entering the WWTP after this two-day intense rainfall was 1283 m^3·d^{-1}, and was by 963 m^3·d^{-1} greater than the supply during dry weather. On this day, the amount of supplied sewage exceeded maximum allowable capacity of the facility. On 20th July 2011, the share of precipitation wastewater in total amount of supplied sewage was 75.1%. On the next incidental daily period on 24th July, the rainfall height was 24.6 mm. Consequently, sewage supply on the next day increased up to 920 m^3·d^{-1} and was by 600 m^3·d^{-1} greater than dry weather standard. The share of precipitation water in total amount of sewage on this day was 65.2%. Precipitation height and the amount of sewage entering the WWTP in July 2011 are presented in Figure 2.

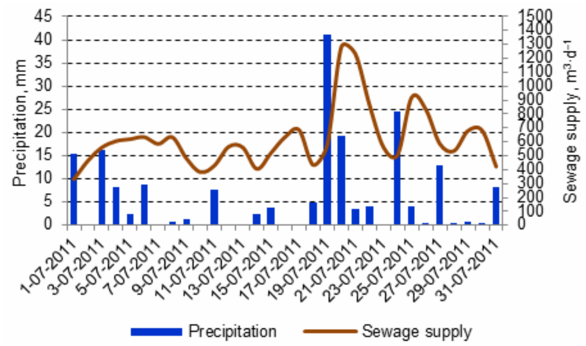

Fig. 2. Effect of precipitation on the increase of sewage amount entering the treatment plant in July 2011; source: own study

In the year 2012, mean daily sewage supply during dry weather was similar to that in 2011 and amounted to 320 m^3·d^{-1}. In October 2012, mean daily sewage supply was 457 m^3·d^{-1}, and total precipitation was 96.7 mm. Mean daily sewage supply in this period was by 137 m^3·d^{-1} greater than during dry weather. The share of precipitation water (UWO) in total amount of sewage this month was 30.5%. During this period, average daily addition of accidental water (DWO) was 143.8%.There were four daily periods with precipitation considerably increasing the amount of sewage entering the WWTP. On 2, 7, 16, and 26–27 October, precipitation ranged from 7.5 to 20.9 mm. For the four analyzed cases, the amount of supplied sewage rose from 320 m^3·d^{-1} to a mean of 633 m^3·d^{-1}, and precipitation water amounted to 47.7% of total sewage entering the WWTP. Precipitation height and the amount of sewage entering the STP in October 2012 are presented in Figure 3.

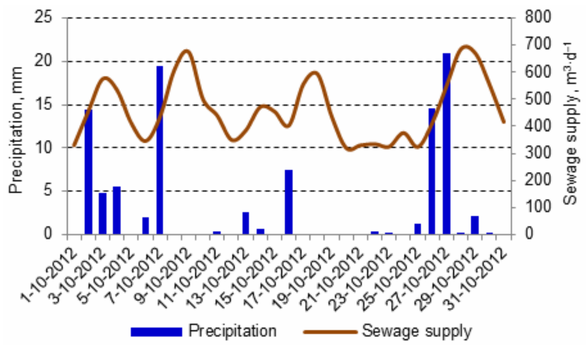

Fig. 3. Effect of precipitation on the increase of sewage amount entering the treatment plant in October 2012; source: own study

Similarly as for two previous years, mean sewage supply in dry weather in May 2013 was the same and amounted to 320 m^3·d^{-1}. Mean daily sewage supply this month was 490 m^3·d^{-1}, and total precipitation was 87.4 mm. Therefore, mean daily sewage supply in

May 2013 was by 170 $m^3 \cdot d^{-1}$ greater that that recorded during dry weather. The share of precipitation water (UWO) in total amount of sewage entering the WWTP in this period was 34.6%. In this time, average daily addition of accidental water (DWO) was 153.0%. On two characteristic days, i.e. 2nd and 30th May 2013, precipitation amounted to 35.3 and 25.0 mm, respectively, and consequently the sewage supply on the following days was 882 and 886 $m^3 \cdot d^{-1}$. On these days the share of precipitation water was nearly 64%. The size of precipitation, and amount of inflowing sewage in May 2013 are shown in Figure 4.

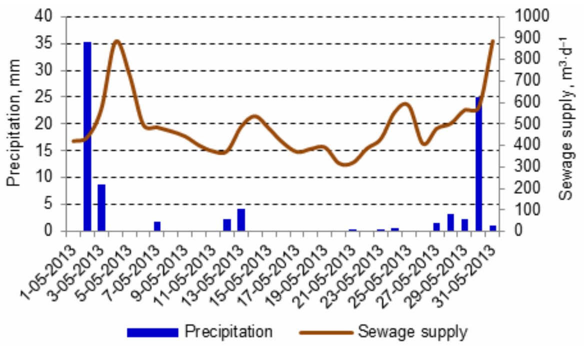

Fig. 4. Effect of precipitation on the increase of sewage amount entering the treatment plant in May 2013; source: own study

In March 2014, the amount of sewage supplied during dry weather increased to 380 $m^3 \cdot d^{-1}$ due to connecting new households to the commune sewerage system. Mean daily sewage supply this month fluctuated around 560 $m^3 \cdot d^{-1}$ and was by 180 $m^3 \cdot d^{-1}$ greater than during dry weather. Total precipitation in March 2014 was 31.2 mm. Mean daily share of precipitation water (UWO) in total amount of supplied sewage was 26.8%. During this period, average daily addition of accidental water (DWO) was 136.6%.There were two two-day periods (15–16 March and 23–24 March) when total precipitation was 18.1 mm and 6.6 mm, respectively, and sewage supply rose up to nearly 700 $m^3 \cdot d^{-1}$. Consequently, the share of precipitation water amounted to 42% of total supplied sewage. The size of precipitation, and amount of inflowing sewage in March 2014 are shown in Figure 5.

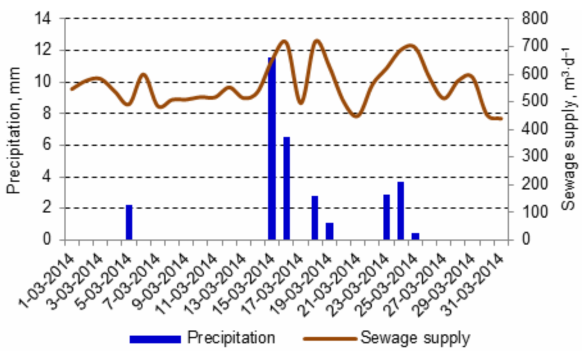

Fig. 5. Effect of precipitation on the increase of sewage amount entering the treatment plant in March 2014; source: own study

Mean sewage supply in dry weather in August 2015 was similar to previous research period and oscillated around 410 $m^3 \cdot d^{-1}$. Mean daily sewage supply this month was 641 $m^3 \cdot d^{-1}$, and total precipitation was 67.7 mm. Mean sewage supply on individual day was greater by 231 $m^3 \cdot d^{-1}$, and mean share of precipitation water (UWO) in total amount of sewage in the sewerage system was 36.1%. During this period, average daily addition of accidental water (DWO) was 156.4%. On 12 August a rainfall of 13.5 mm was recorded that caused an increase in sewage supply up to 857 $m^3 \cdot d^{-1}$, and elevated the share of precipitation water on this day to 52.2% of total sewage amount. Another characteristic period with rainfall of 38.7 mm occurred on 16 August and consequently the amount of sewage that reached the WWTP on the next day increased to 1170 $m^3 \cdot d^{-1}$. The share of precipitation water on 17 August was 65% of the total sewage that entered the WWTP on that day. On 17 August the amount of sewage supplied to the facility exceeded its capacity by 370 $m^3 \cdot d^{-1}$. The size of precipitation, and amount of inflowing sewage in August 2015 are shown in Figure 6.

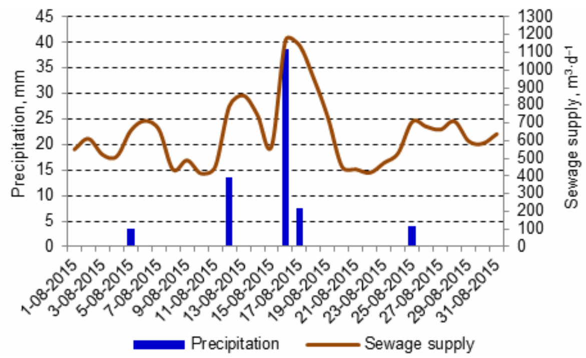

Fig. 6. Effect of precipitation on the increase of sewage amount entering the treatment plant in August 2015; source: own study

In Table 1 presents a summary of the share of accidental (precipitation) water UWO and percentage addition of extraneous water DWO in analyzed periods.

Increased supply of accidental water into the analyzed sewerage system during intense precipitation brings about many unfavorable consequences. The first one is hydraulic overloading of the sewer chan-

Table 1. The percentage of characteristics of the accidental water and additions of the extraneous water flowing into the sanitary sewer system

No.	Period	Precipitation water, %	Daily addition of accidental water, %
1.	September 2010	41.1	169.7
2.	July 2011	48.4	193.9
3.	October 2012	30.5	143.8
4.	May 2013	34.6	153.0
5.	March 2014	26.8	136.6
6.	August 2015	36.1	156.4
	Average	36.2	158.9

Source: own study.

nels. Volume and capacity of the sewer channels are too low to accommodate additional supply of precipitation water during intense rainfalls and some sections of the sewerage network begin to function as in a pressure system. When a gravity system operates as a pressure system, leaks may appear at pipe and manhole joints, and sewage overflow may occur at basement and ground floor levels of low-lying residential buildings. Another negative effect of supplying the sewerage system with large amounts of accidental water is hydraulic overload of the sewage treatment plant facilities. Excessive amounts of wastewater entering the WWTP during rainfalls may negatively affect technological processes that require constant flow velocity or fixed time of sewage retention in a sand trap, a primary settling tank or a biological reactor. Dimensions of the sand trap and the primary settling tank are designed so that to achieve laminar flow of wastewater allowing for sedimentation of sand particles and settleable solids. When these two objects are supplied with increased amount of sewage, the laminar flow is turned into a turbulent one and the sedimentation processes are disturbed or stopped altogether. Biologically non-degradable waste that is not retained during the mechanical treatment (sand trap and primary settling tank) and enter the biological reactor may impair the metabolism of activated sludge microorganisms. Excessive amount of precipitation water in the sewage entering the WWTP may negatively affect also biological processes occurring in the biological reactor. Sewage diluted with large amounts of rain water is poor in organic pollutants expressed as BOD_5 that is an essential factor for proper course of nitrification and denitrification processes.

Apart from technical and technological factors, the most important aspect affecting the operation of the analyzed sewerage system is the economic factor. Enhanced sewage supply resulting from intense rains increases the operating costs related to energy consumption for pumping and aeration of sewage and accidental water mixture. The estimated cost of treating 1 m^3 of sewage in the analyzed sewerage system is about 0.5 Euro. In the six-year study period, daily cost of wastewater treatment ranged between 140 and 186 Euro in dry weather. On the days when the treated sewage contained high share of precipitation water, the operating costs soared up to even 560 Euro. Obviously, the additional costs are borne by all residents served by the sewerage system. The operator of the sewerage system may solve the problem of high share of precipitation water in two ways. The first solution involves building storage reservoirs that would capture excessive wastewater during intense rainfalls. This approach is, however, very expensive and it will only improve technological processes of sewage purification (balancing daily flows) without reducing the treatment costs. Another solution involves broad-based and systematic measures aimed at the location and removal of illegally connected roof gutters within residential properties. This would generate additional costs related to the detection of illegal connections, but would later on allow for a reduction of the operating costs.

CONCLUSIONS

1. The share of precipitation water entering the sanitary sewage system in the six investigated research periods ranged from 26.8% to 48.4%.
2. On specific daily periods with intense precipitation, the share of precipitation water in total amount of sewage in the sewerage system may increase to 75%.
3. Although in general the investigated sewage treatment plant was hydraulically underloaded, on the days with intense rainfall when precipitation water infiltrated to the sewerage system, the facility was overloaded as compared with its design capacity.
4. The pipes of the analyzed sewerage system should be carefully checked and on-site inspections should be performed to detect and eliminate illegal connections of roof gutters from which rainwater leaks into the sewerage system and increases the amount of treated sewage.

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Piotr M. BUGAJSKI, Grzegorz KACZOR, Krzysztof CHMIELOWSKI

Zmienność dynamiki dopływu ścieków do oczyszczalni w aspekcie przedostawania się wód opadowych do systemu kanalizacyjnego

STRESZCZENIE

W artykule przedstawiono analizę dotyczącą wpływu wielkości opadów atmosferycznych, które trafiają do kanalizacji sanitarnej jako wody przypadkowe, na zmienność ilości ścieków poddawanych procesom oczyszczania. Analizą dotyczącą wpływu wód przypadkowych na ilość ścieków dopływających do oczyszczalni objęto wartości średnie dobowe z badanych okresów oraz średnie dobowe dopływy ścieków z przypadków incydentalnych. Badania prowadzono w okresie od 2010 do 2015 roku, w którym wyróżniono 6 charakterystycznych okresów badawczych po jednym w każdym roku kalendarzowym, w których stwierdzono zwiększoną ilość ścieków w kanalizacji sanitarnej w porównaniu z ilością ścieków w kanalizacji w okresie pogody bezdeszczowej. W wyniku przeprowadzonej analizy dotyczącej zmienności ilości ścieków w kanalizacji w 6 okresach badawczych stwierdzono, że udział wód przypadkowych stanowił od 26,8 do 48,4% ogólnej ilości ścieków dopływających do oczyszczalni, natomiast w przypadkach incydentalnych w warunkach intensywnych opadów atmosferycznych udział wód opadowych w ogólnej ilości ścieków w systemie kanalizacyjnym wzrastał do 75%. W okresie badań w incydentalnych przypadkach wody opadowe przedostające się do kanalizacji powodowały przeciążenia hydrauliczne obiektu ponad dopływ maksymalny, na jaki została zaprojektowana oczyszczalnia.

Słowa kluczowe: *opad atmosferyczny, system kanalizacyjny, ścieki, wody opadowe*