JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(11), 261–272
https://doi.org/10.12911/22998993/154034
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.08.15
Accepted: 2022.09.19
Published: 2022.10.01

Analysis of the Hydraulic Load of a Local WWTP in the South-Eastern Poland Including Hydraulic Capacity of the Sewage Receiver

Anna Młyńska[1*], Dariusz Młyński[2], Krzysztof Chmielowski[2]

[1] Department of Water Supply, Sewerage and Environmental Monitoring, Faculty of Environmental Engineering and Energy, Cracow University of Technology, ul. Warszawska 24, 31-155 Cracow, Poland

[2] Department of Sanitary Engineering and Water Management, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Cracow, ul. Mickiewicza 24/28, 30-059 Cracow, Poland

* Corresponding author's e-mail: anna.mlynska@pk.edu.pl

ABSTRACT

The paper constitutes the analysis of hydraulic load of a local wastewater treatment plant in the south-eastern Poland along with the analysis of sewage receiver hydraulic capacity and related receiving waters protection. Assuming that the daily outflow of treated sewage should not exceed 10% of the mean-low flow (SNQ) of the receiver, no case of daily sewage outflow greater than 10%·SNQ = 51 840 $m^3 \cdot d^{-1}$ was recorded. Moreover, average daily hydraulic load of the treatment plant was lower than the limit value by over 70% and the maximum recorded value – by over 40%. Furthermore, the conducted analysis shows that the particular months differed from each other in the values of the daily hydraulic load of the wastewater treatment plant at the outflow; May was the month with the highest average daily sewage outflow, while September was characterized by the lowest average daily outflow of treated sewage. There was also no clear dependence between the hydraulic load of the WWTP and the day of the week. Daily sewage outflows ranging from 10 000 $m^3 \cdot d^{-1}$ to 12 000 $m^3 \cdot d^{-1}$ constituted the largest part of all observations. The daily sewage outflows directed to the receiver prove that there is no threat to the preservation of the water environment quality.

Keywords: hydraulic load, sewage, sewage receiver, sewage outflow, mean-low flow, SNQ, wastewater treatment plant, WWTP.

INTRODUCTION

In the recent years, a significant development of technical infrastructure has been observed in Poland, enabling the implementation of tasks related to the water and sewage management. From the environmental protection point of view, wastewater treatment plants (WWTPs) are particularly important facilities, as they treat or even neutralize sewage before it is released to the natural environment. Although a significant increase in investments in sewage treatment was mainly achieved by the European Union funds that Poland received after joining its structures nearly twenty years ago [Godela et al. 2017, Lenart-Boroń et al. 2019], very intensive development of water and sewage management in rural agglomerations, both in terms of quantity and quality of the infrastructure, has been observed since the beginning of the nineties of the last century. The construction of several thousand new wastewater treatment plants and the modernization of the existing ones, have significantly reduced the discharge of untreated or partially treated sewage to surface waters [Piasecki 2019].

Due to the need to protect the natural environment where treated sewage is discharged, properly functioning WWTPs should ensure an appropriate level of pollutants reduction. Each treatment plant is designed for a specific hydraulic capacity. The sewage flow rate is an important parameter that allows not only to scale particular devices in technological line of wastewater treatment plant, but also allows to plan the most effective course of sewage treatment processes. Nevertheless, wastewater treatment plants may deal with not only hydraulic overload, e.g. as a result of uncontrolled inflow of incidental and infiltration waters to the sanitary sewage system during rainy weather [Bugajski et al. 2017, Kozłowski et al. 2022], but also with an unfavorable condition of hydraulic underload [Młyński and Chmielowski 2016, Młyński et al. 2016, 2017], resulting from the discharge of sewage from sewered areas in amounts smaller than specified at the design stage of the treatment plant. Hydraulic overload of WWTP has a negative effect on technological efficiency of devices, causing leaching of activated sludge from bioreactors. The lack of biodegradable organic matter limits biological treatment processes [Xu et al. 2014, Marek et al. 2021]. On the other hand, hydraulic underload of wastewater treatment plants may interfere with particular stages of pollutants reduction processes, as they require certain volumes of sewage to be effective [Spellman 2013]. An evident variability in the amount of sewage flowing into a treatment plant hinders the optimization of its operation. In a situation where the particular technological solutions used in the technological line of a treatment plant are not adapted to the periodically occurring underload or hydraulic overload, the quality of sewage discharged into the natural environment may not meet the legal requirements [Kaczor et al. 2015, Bugajski et al. 2021]. This relates to the observations by Mucha and Mikosz [2009], who point out that small and large wastewater treatment plants have their own specificity resulting from the amount and composition of sewage treated, as well as the technologies and design solutions used; therefore, small facilities cannot be treated as miniaturized versions of the big ones. Having regard to the above, an important element of the proper operation of a wastewater treatment plant should be ongoing monitoring and analysis of the amount of sewage flowing out of the areas covered by this WWTP. This type of analysis can be found, for example, in the paper of Młyńska et al. [2017] or Młyński et al. [2018] that suggest the use of certain statistical tools to forecast the amount of sewage discharged from a sewered area of analyzed agglomeration. Similar studies can be found in the literature, where the authors deal with the modeling of sewage inflow to WWTP, aimed at reducing the negative effects of its hydraulic overload during rainy weather [Kroll et al. 2016]; such a situation may occur as a result of the expansion of the existing sewerage infrastructure.

Treated sewage is directed from WWTPs to receivers, i.e. the soil or surface water (streams, rivers, lakes). In the case of large facilities that receive a sewage from the areas with central sewerage systems, the receiver is usually flowing water, while in areas with scattered buildings, unconventional solutions are used, e.g. plant and soil treatment systems [Pawęska and Kuczewski 2009]. As can be concluded from research carried out so far, the impact of treated sewage on the quality of the water environment is not entirely clear. For example, Chen et al. [2004] suggest a negative effect of sewage discharge on nitrogen concentration in water of the receiver. Similarly, the unsatisfactory quality of flowing waters of the receiver studied by Kanownik et al. [2017] is related to the discharge of treated sewage. On the other hand, studies by Ofman et al. [2017] showed that properly treated sewage does not affect the quality of receiving waters. The results of research by Kowalik et al. [2015] show that although the discharge of treated sewage to one of the rivers of the southern Poland caused a statistically significant increase in half of the tested physicochemical indicators of the receiving waters and the change in the water quality class from I to II, the concentrations of pollutants in the treated sewage did not exceed the limit values specified in the water law permit. Wąsik et al. [2017] showed, however, that although most of the tested physicochemical parameters allowed for the classification of the treated sewage-receiving river to I or II class of water quality, microbiological contamination expressed by the numbers of coliforms and Escherichia coli classified the quality of the river below the point of sewage discharge even to IV and V class. In addition to the permissible values of particular pollutant indicators in sewage discharged to receivers, which are legally regulated in Poland [Regulation 2019], amount of discharged sewage is a very important factor influencing the maintenance of the appropriate quality of the receiving water and its ecological balance. It is assumed that this amount should not exceed 10% of the so-called design flow of the receiver, which is the mean-low flow (SNQ) from the multi-year period [Kurek et al. 2019]. By maintaining an appropriate amount of sewage discharged into the receiving waters, an appropriate degree of dilution is guaranteed, thus protecting the quality of the water environment. However, it should also be taken into account that the discharge of too large volume of sewage in a short time may adversely affect the condition of receiving waters, causing bulking of bottom sediments, and thus, increased oxygen uptake and the resulting disturbance of ecological balance [Pluta and Mrowiec 2015].

Taking into account the importance for control the amount of sewage flowing through the WWTP line and the amount of sewage discharging to the receiver, in this study, the analysis of hydraulic load of a local WWTP along with the analysis of sewage receiver hydraulic capacity were performed. This was conducted in terms of the protection of receiving waters, i.e. it allowed identifying, whether the flowing waters of the receiver are exposed to excessive discharge of sewage that could cause its degradation. This study covers the analysis of sewage discharge from the WWTP in weekly and monthly cycles of the two-year research period.

CASE STUDY

The objective wastewater treatment plant is located in the south-eastern Poland. This WWTP serves the area of an agglomeration, which is partially sewered by a combined sewerage system; the treatment plant receives municipal and industrial sewage (including delivered sewage). An Equivalent Number of Inhabitants of this WWTP is 75 920. The WWTP operates in a two-stage treatment system (mechanical-biological treatment plant) (Fig. 1). The mechanical part of the wastewater treatment plant consists of three dense screens, from which the sewage flows through two technological lines to grit chambers and then to two primary settling tanks. The biological treatment is carried out in pre-denitrification, defosfatation, denitrification and nitrification chambers grouped in two chambers, followed by three radial secondary settling tanks. The treated sewage is directed to a natural receiver (river), the mean-low flow (SNQ) of which is 518 400 $m^3 \cdot d^{-1}$. The amount of treated sewage discharged to the receiver is measured in the chamber on the drainage channel with the use of a measuring orifice with an ultrasonic probe. The hydraulic load of the wastewater treatment plant is described by the following parameters: average daily flow (dry weather) – 15 000 $m^3 \cdot d^{-1}$, maximum daily flow (rainy weather) – 28 000 $m^3 \cdot d^{-1}$, average hourly flow (dry weather) – 625 $m^3 \cdot h^{-1}$, maximum hourly flow (dry weather) – 1000 $m^3 \cdot h^{-1}$, maximum hourly flow (rainy weather): screens and main pumping station – 2500 $m^3 \cdot h^{-1}$; grit chambers, primary settling tanks, biological reactors, secondary settling tanks – 1500 $m^3 \cdot h^{-1}$. Excess sewage downstream of the screens' hall, i.e. before the inflow to further devices of the technological line, is captured and collected in a retention reservoir with a capacity of 1000 $m^3 \cdot h^{-1}$.

MATERIALS AND METHODS

The analysis of the hydraulic load of the WWTP was carried out on the basis of the amount of sewage outflows obtained from the

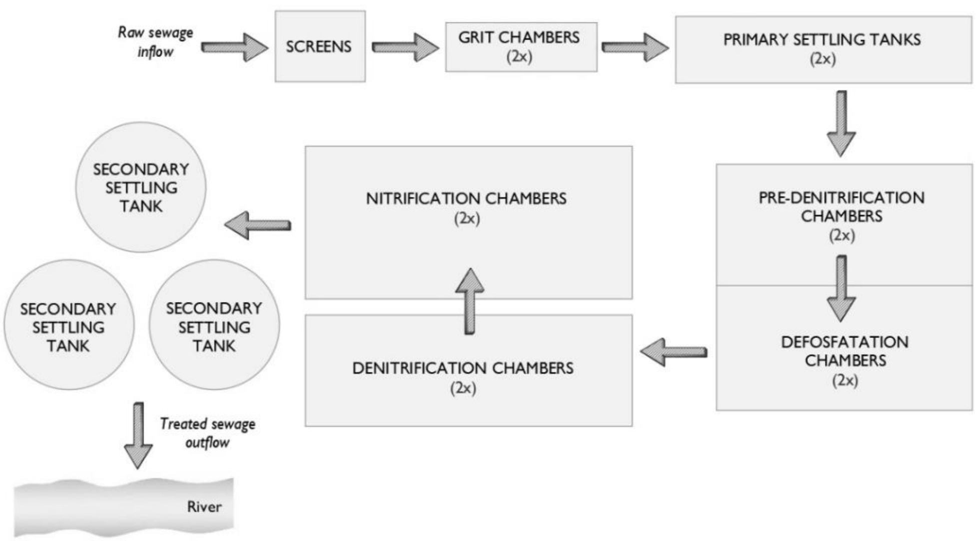

Figure 1. A simplified scheme of the objective WWTP

facility operator from the period 2018–2019. These measurements were conducted with the use of a measuring orifice with an ultrasonic probe located on the drainage channel directing the treated sewage to a natural receiver (river). Hourly measurements of the treated sewage outflows were the output data and they were the basis for the determination of the daily outflows of treated sewage. The analysis of hydraulic load of the WWTP in relation to the mean-low flow (SNQ) of the receiver was preceded by the calculation of descriptive statistics, such as maximum (Max), minimum (Min), average (Avg), standard deviation (S), coefficient of variation (CV), kurtosis (Kurt) and skewness (Sk). Additionally, the daily sewage outflows were analyzed in particular months (January–December) and on each day of the week (Monday–Sunday) of the analyzed period of 2018–2019; for this purpose, the values of basic descriptive statistics (maximum, minimum, average, coefficient of variation, kurtosis) were also determined. The daily sewage outflows from the wastewater treatment plant were analyzed in relation to the value constituted 10% of the mean-low flow (SNQ) of the receiver. In order to protect the quality of the receiving water, the sewage discharge rate from the treatment plant should be less than 10%·SNQ, thus in the analyzed case: $10\%\cdot SNQ = 10\%\cdot 518\,400\ m^3\cdot d^{-1} = 51\,840\ m^3\cdot d^{-1}$. A further part of the paper includes histograms of the frequency of the occurrence of daily sewage outflows with a specified size, both for the whole research period (2018–2019) and for particular months (January–December). For this purpose, seventeen class intervals with characteristic sewage outflow values were distinguished, starting from the flow of 9000 $m^3\cdot d^{-1}$, with the range of each interval equal to 1000 $m^3\cdot d^{-1}$ and with the last interval covering sewage outflows exceeding 25 000 $m^3\cdot d^{-1}$. The analysis of the daily hydraulic load of wastewater treatment plants with the use of histograms are also presented by Bugajski [2007, 2009], Masłoń [2014, 2017], Młyński and Chmielowski [2016], Młyński et al. [2016], as well as by Bugajski et al. [2021].

RESULTS AND DISCUSSION

Initial analysis of the daily sewage outflows to the receiver

The results of the daily sewage outflows presented in Figure 2 and in Table 1 indicate that the permissible amount of sewage discharge to the receiver, i.e. 51 840 $m^3\cdot d^{-1}$ (constituted a 10% of the receiver's SNQ flow), was not exceeded even once in the two-year research period. The average daily sewage outflow was at the level of less than 14 000 $m^3\cdot d^{-1}$, meaning that it corresponded to the hydraulic capacity of the facility for dry weather (determined at 15 000 $m^3\cdot d^{-1}$). On the other hand, the highest sewage outflow recorded in the research period was lower than the adopted limit value for the receiving waters (i.e. 10%·SNQ) by as much as over 40%. The

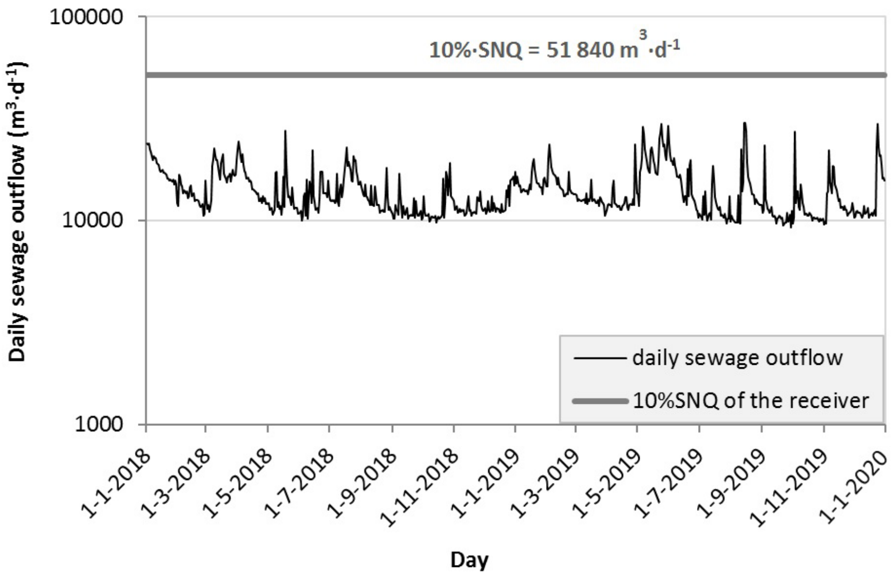

Figure 2. Daily sewage outflows from the objective WWTP in the period of 2018–2019

Table 1. Descriptive statistics for daily sewage outflows in the period of 2018–2019

Max	Min	Avg	S	CV	Kurt	Sk
($m^3 \cdot d^{-1}$)				(–)		
30 150	9 270	13 955	3 799	0.27	2.58	1.55

Note: Max – maximum, Min – minimum, Avg – average, S – standard deviation, CV – coefficient of variation, Kurt – kurtosis, Sk – skewness.

variation of the daily sewage outflows in the period of 2018–2019, expressed by the coefficient of variation CV = 0.27 can be considered as moderate or even low. Kurtosis (Kurt = 2.58) indicates a leptokurtic concentration of variables around the mean value and the skewness (Sk = 1.55), additionally proves the right-hand asymmetry of the daily sewage outflow distribution (prevalence the outflows with values less than the mean value). A moderate variability of the amount of sewage inflowing to a similar treatment plant was reported by Masłoń [2014], Młyński et al. [2016] and by Chmielowski [2019]. The other studies of Młyński et al. [2018] showed a strong variability of the hydraulic load of the wastewater treatment plant in the three-year research period. However, as in this study, the variables of the sewage inflow were subjected to right-hand asymmetry and were characterized by a leptokurtic distribution. Moderate and strong variability of the hydraulic load of the tested wastewater treatment plants, the right-hand asymmetry of the variables of sewage inflow and its leptokurtic distribution were observed by Młyński and Chmielowski [2016] and Młyński et al. [2017]. During the initial statistical data analysis it was observed that the hydraulic load of the receiver in the two-year period was much lower than the limit value ensuring the receiving water protection (i.e. sewage outflows not greater than 10% of the receiver's SNQ flow). Nevertheless, a detailed analysis of the wastewater treatment plant hydraulic load at the outflow was carried out, both on a monthly and weekly basis. The results are presented in the further part of this paper.

Daily sewage outflows on a monthly and weekly basis

The data presented in Figure 3 show the differences in daily sewage outflows in particular months of the analyzed period. May was the month with the highest average daily sewage outflow (17 223 $m^3 \cdot d^{-1}$), while the lowest values were observed in September (11 136 $m^3 \cdot d^{-1}$). In May, August and December, there were cases of the largest daily sewage outflows (about 30 000 $m^3 \cdot d^{-1}$), which were still more than 40% lower than the limit value specified for the receiving waters. Similarly, the highest variability of the daily sewage outflows was characteristic for May, August and December (Fig. 4a) (coefficients of variation CV about 0.30; moderate variability). On the other hand, the lowest variability of the daily sewage outflows from the WWTP was observed in January, February and September (coefficients of variation CV about 0.16; low variability). A minimum daily sewage outflows ranged from 9270 $m^3 \cdot d^{-1}$ (September) to 12 240 $m^3 \cdot d^{-1}$ (January) (Fig. 3). Strong concentration of the sewage outflow variables around the average value was particularly evident in the period from August to December (positive kurtosis) (Fig. 4b). It was different in the period from January to July (excluding February), when the kurtosis was close to zero. The largest daily sewage outflows from the tested WWTP recorded in May, August and December and the greatest variability of the daily sewage outflows should probably be related to the increased inflow of rainwater or meltwater to the sewerage system operated by the analyzed wastewater treatment plant, which is characteristic for these months. Similar conclusions were drawn by Miernik et al. [2016], Młyński and Chmielowski [2016], Młyński et al. [2016] and Chmielowski [2019], whose research shows the highest hydraulic load of the wastewater treatment plant in summer (intensive rainfall) and in early spring (snow melting). A significant impact of the amount of precipitation on the hydraulic load of wastewater treatment plant was also demonstrated using statistical analysis e.g. by Młyński et al. [2017]. Based on the Fourier spectral method, Wąsik et al. [2016] showed a 56% coefficient of determination for the relationship between the sewage flow rate and the precipitation occurrence. In turn Masłoń [2014], based on the two-year analysis of the hydraulic load of a municipal wastewater treatment plant, also points out that yearly variation of the daily sewage flows results from the inflow of rainwater during rainy weather. However, at the same time, no repeated

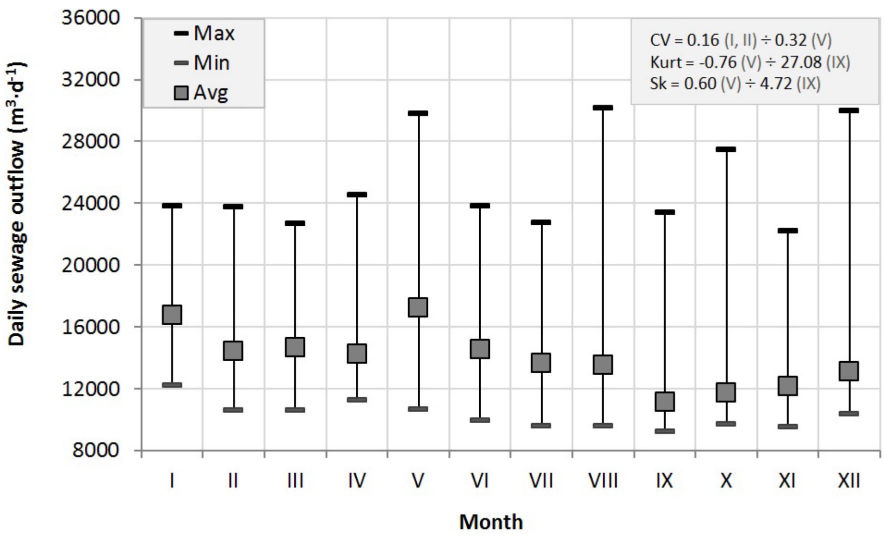

Figure 3. Daily sewage outflows from the objective WWTP in particular months in the period of 2018–2019

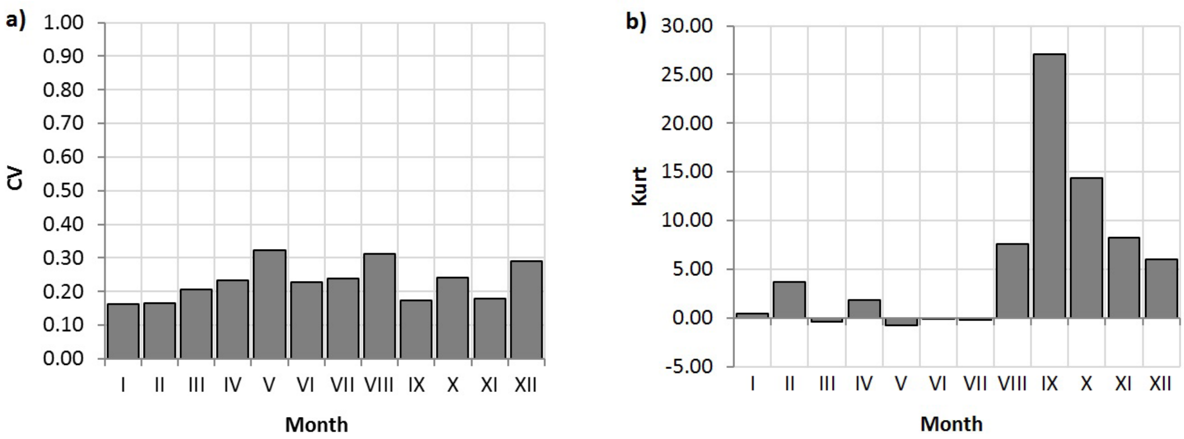

Figure 4. (a) Coefficients of variation and (b) kurtosis for daily sewage outflows from the objective WWTP in particular months in the period of 2018–2019

seasonality of sewage flows was observed in particular months of the analyzed period.

Contrary to the particular months of the analyzed period of 2018–2019, the average daily hydraulic load of the WWTP on particular days of the week varied in a much narrower range, i.e. from about 13 730 $m^3 \cdot d^{-1}$ (Sunday) to about 14 200 $m^3 \cdot d^{-1}$ (Wednesday) (Fig. 5). The smallest daily sewage outflows were recorded on different days of the week, hence there was no correlation between the minimum hydraulic load of the wastewater treatment plant and the day of the week. On the other hand, the maximum flows reaching 30 000 $m^3 \cdot d^{-1}$ were recorded from Monday to Friday, whereas on Saturdays and Sundays, the maximum hydraulic load of the treatment plant was much lower (about 24 000–25 000 $m^3 \cdot d^{-1}$). For the whole week, the variability of the daily hydraulic load of the WWTP was moderate (Fig. 6a) and the values of the coefficient of variation (CV) on particular days of the week did not differ much from each other. The concentration of the hydraulic load variables around the mean value was clear from Monday to Friday (Kurt = 2.33–3.54) (Fig. 6b). On Saturday and Sunday, kurtosis was closer to zero, which proves that the daily sewage outflows were more dispersed from the mean value than on weekdays. Summarizing the above, it can be stated that there is no clear dependence between the hydraulic load of the wastewater treatment plant and the day of the week. Only Saturdays and Sundays were characterized by a slightly different treated sewage outflows than the other days of the week. The studies conducted by Kaczor [2006], Bugajski [2007] or Młyński et al. [2016], also show that the hydraulic load of wastewater treatment plants does

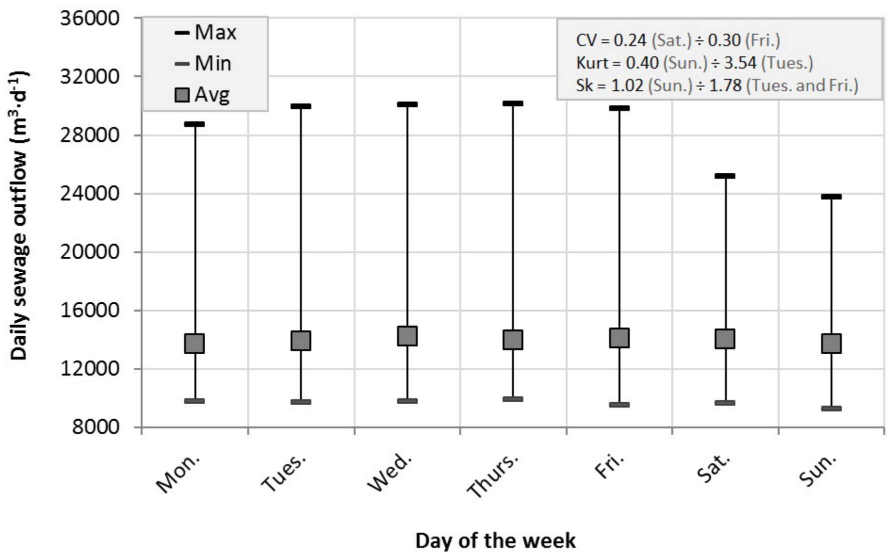

Figure 5. Daily sewage outflows from the objective WWTP in particular days of the week in the period of 2018–2019

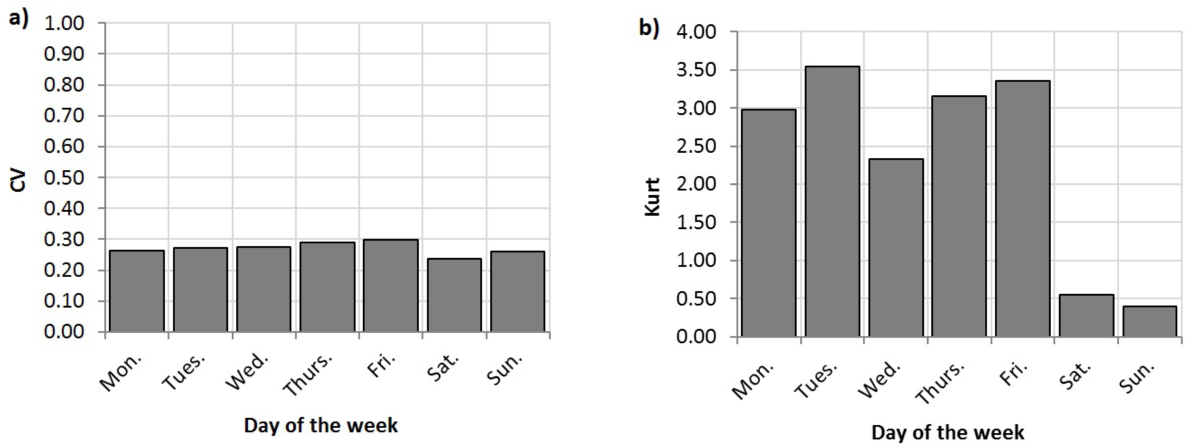

Figure 6. (a) Coefficients of variation and (b) kurtosis for daily sewage outflows from the objective WWTP in particular days of the week in the period of 2018–2019

not differ significantly on particular days of the week. Moreover, as was stated by Kaczor [2006], weekly distribution of the wastewater treatment plant hydraulic load is compatible with the most common structure of weekly water consumption. Both the results presented in this study and in the paper of Kaczor [2006] and Młyński et al. [2016] show similar trends in the occurrence of the smallest average daily sewage flows, usually on Sundays and Mondays and one of the largest – on Saturday.

Frequency of the daily sewage outflows on a monthly basis

Over the whole research period of 2018–2019 (Fig. 7a), the largest part of all observations included the daily sewage outflows in the range of 11 000–12 000 $m^3 \cdot d^{-1}$ (19%) and 10 000–11 000 $m^3 \cdot d^{-1}$ (nearly 18%). The frequency of daily treated sewage outflows above these values decreased gradually. Although the frequency histograms presented in Figures 7b-m show a slightly varied distribution of the daily hydraulic load of the WWTP for particular months, it was observed that in most cases, the largest share of the daily sewage outflows ranged from about 10 000 $m^3 \cdot d^{-1}$ to 14 000 $m^3 \cdot d^{-1}$. In September and October it was observed that the daily sewage outflows in the range of 10 000–11 000 $m^3 \cdot d^{-1}$ constituted as much as 55% of all observations. Similarly, also March, November and December can be indicated as months when a significant part of all observations (about 40%) were the values of the daily hydraulic load within one class interval (in the case of March it was the range from 12 000 to 13 000 m^3·d^{-1}; in November and December – the range between 11 000 and 12 000 m^3·d^{-1}). In the remaining months, the frequency of daily sewage outflows with a specified size was distributed more evenly in particular class intervals. In addition, from May to July and between winter and spring, larger share of sewage flows with the size of around 20 000 m^3·d^{-1} could be observed than in the other months. According to the observations of Miernik et al. [2016], Młyński and Chmielowski [2016], Młyński et al. [2016], as well as Chmielowski et al. [2019], such a situation is related to the impact of rainwater and meltwater to the sewerage systems, which is typical for these periods.

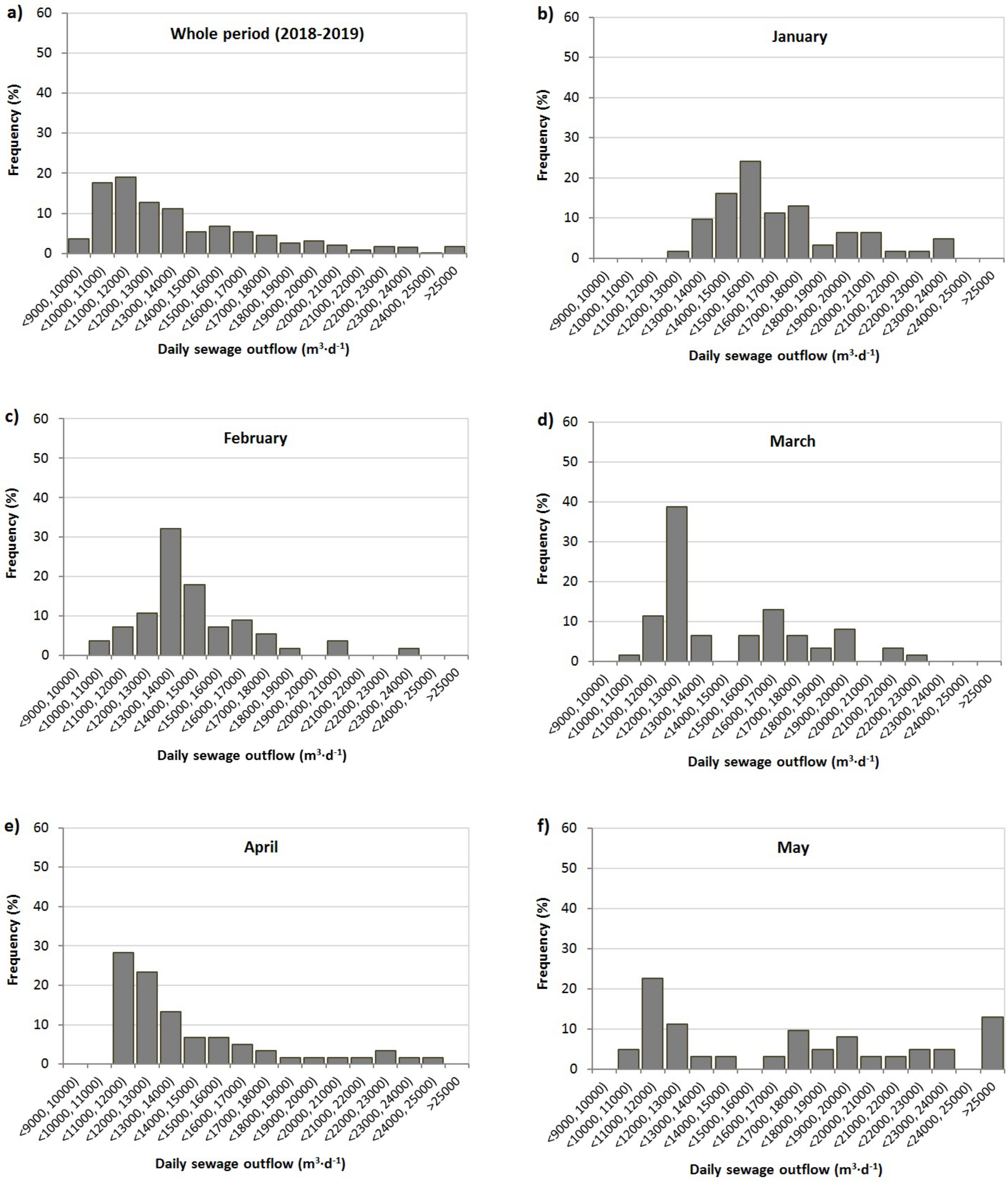

Figure 7. Frequency of the daily sewage outflows with a specified size from the objective WWTP: (a) in the whole period of 2018–2019 and (b-m) in particular months in the period of 2018–2019

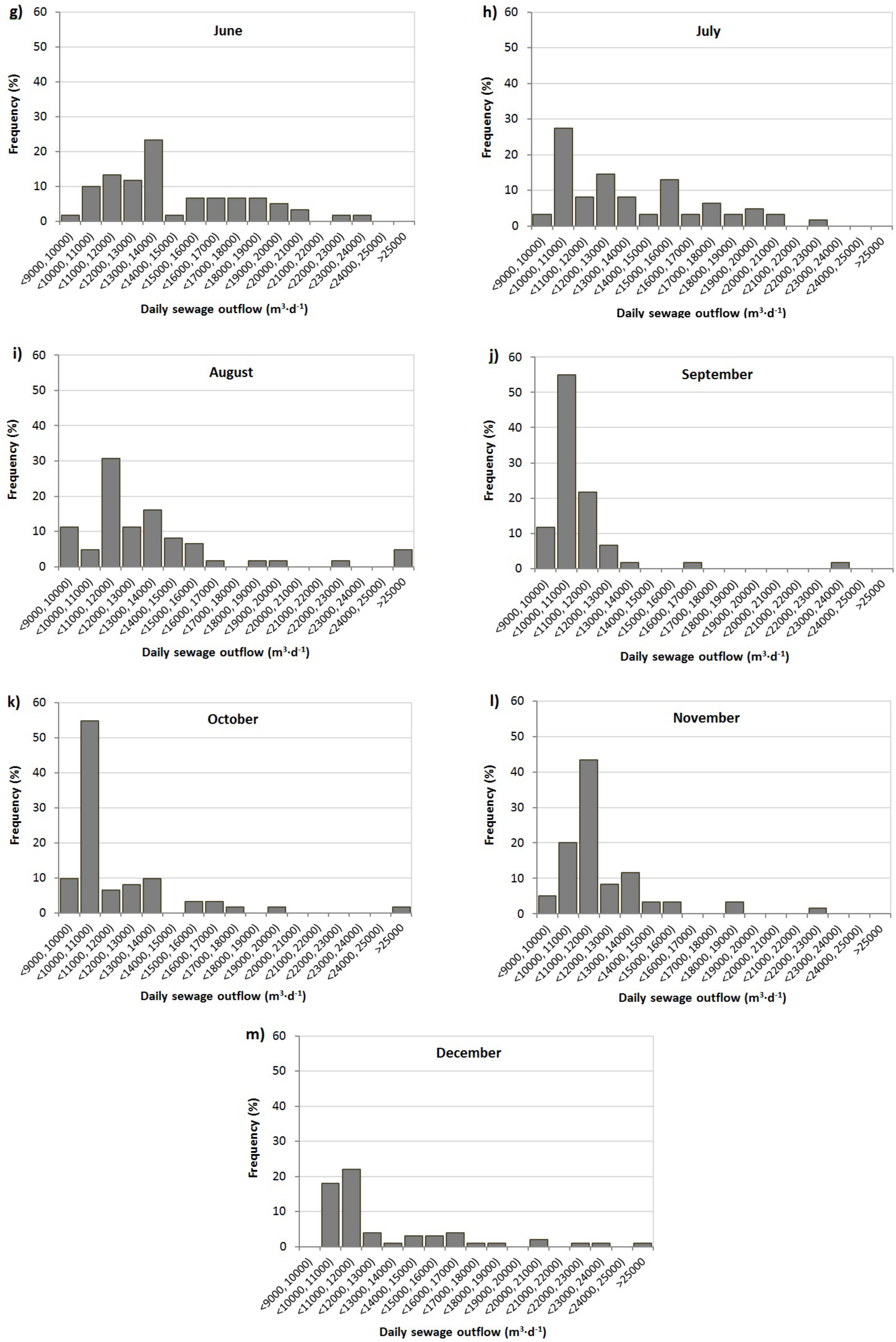

Figure 7. Cont. Frequency of the daily sewage outflows with a specified size from the objective WWTP: (a) in the whole period of 2018–2019 and (b-m) in particular months in the period of 2018–2019

CONCLUSIONS

Both the hydraulic overload and underload of particular devices in technological line of WWTP disturbs the treatment processes. Hence, investigation of hydraulic load should be an integral part of the proper operation of such facilities. However, control of the amount of the outflowing treated sewage is also important. Knowledge about the amount of sewage discharged from WWTP into the natural receiver, e.g. river, enables the assessment whether there is no threat to the receiving waters as a result of excessive sewage discharge. Taking the above into consideration, in this study also included the analysis of hydraulic load of the treated sewage outflow in terms of the sewage receiver capacity and related receiving waters protection.

The daily sewage outflows from the analyzed WWTP were referred to the value constituted 10% of the mean-low flow (SNQ) of the receiver. In the analyzed two-year research period of 2018–2019, there was no exceedance of the 10%·SNQ value, i.e. 51 840 $m^3 \cdot d^{-1}$. Moreover, the average daily hydraulic load of the wastewater treatment plant was lower than the limit value by over 70% and the maximum value of the daily treated sewage outflow was lower than the value of 10%·SNQ = 51 840 $m^3 \cdot d^{-1}$ by over 40%. These results clearly show that treated sewage did not pose any threat to the water environment of the receiver. Although the daily treated sewage outflows were within the desired limits and with a large reserve, the additional analysis also shows that particular months differ from each other the daily hydraulic load of the WWTP. May was the month with the highest average daily sewage outflow, while September was characterized by the lowest hydraulic load. The maximum values of the daily sewage outflows were recorded in May, August and December, which is probably due to a significant share of rainwater in the total amount of discharged sewage. On the other hand, the results of the analysis of the daily sewage outflows on a weekly basis indicate lack of a clear dependence between the hydraulic load of the WWTP and the day of the week; only Saturdays and Sundays differed from the other days, showing slightly different daily outflows of treated sewage. Moreover, it was observed that the most often, the daily sewage outflows ranged from 10 000 $m^3 \cdot d^{-1}$ to 12 000 $m^3 \cdot d^{-1}$, constituted about 20% of all observations from the two-year research period. Also particular months differed from each other in the distribution of the frequency of daily sewage outflows with a specified size. Obtained results of weekly and monthly WWTP's hydraulic load distribution correspond with the observations of other similar studies available in the current literature.

REFERENCES

1. Bugajski P. 2007. Dynamics flow to sewage treatment plant in Głogów Małopolski. Infrastructure and Ecology of Rural Areas, 2, 103–109. (in Polish)
2. Bugajski P. 2009. Variability of the amount of the sewage flowing into the treatment plant in Tęgoborza. Infrastructure and Ecology of Rural Areas, 9, 23–32. (in Polish)
3. Bugajski P., Kaczor G., Chmielowski K. 2017. Variable dynamics of sewage supply to wastewater treatment plant depending on the amount of precipitation water inflowing to sewerage network. Journal of Water and Land Development, 33, 57–63. https://doi.org/10.1515/jwld-2017-0019
4. Bugajski P., Nowobilska-Majewska E., Majewski M. 2021. The impact of atmospheric precipitation on wastewater volume flowing into the Wastewater Treatment Plant in Nowy Targ (Poland) in terms of treatment costs. Energies, 14(13), 1–12. https://doi.org/10.3390/en14133806
5. Chen J., He D., Zhang N., Cui S. 2004. Characteristics of and human influences on nitrogen contamination in Yellow River system, China. Environmental Monitoring Assessment, 93(1-3), 125–138. https://doi.org/10.1023/b:emas.0000016796.51583.80
6. Chmielowski K. 2019. Impact of atmospheric precipitation on the variability of wastewater discharge from a selected sewage system in Jaworzno. Acta Scientiarum Polonorum. Formatio Circumiectus, 18(2), 39–49. http://dx.doi.org/10.15576/ASP.FC/2019.18.2.39
7. Godela A., Lewańska M., Myga-Nowak M. 2017. Changes in surface water microflora caused by discharge of purified sewage into rivers. World Scientific News, 75, 26–32.
8. Kaczor G. 2006. Unit sewage outflows from rural sewer system in Koszyce municipality. Infrastructure and Ecology of Rural Areas, 2, 171–182. (in Polish)
9. Kaczor G., Bergel T., Bugajski P. 2015. Impact of extraneous waters on the proportion of sewage pollution indices regarding its biological treatment. Infrastructure and Ecology of Rural Areas, IV/3, 1251–1260. http://dx.medra.org/10.14597/infraeco.2015.4.3.090.
10. Kanownik W., Policht-Latawiec A., Gajda A. 2017. Influence of Sitkówka sewage treatment plant on

the Bobrza River water quality. Journal of Water and Land Development, 34, 153–162. https://doi.org/10.1515/ jwld-2017-0049.

11. Kowalik T., Bogdał A., Borek Ł., Kogut A. 2015. The effect of treated sewage outflow from a modernized sewage treatment plant on water quality of the Breń river. Journal of Ecological Engineering, 16(4), 96–102. https://doi.org/10.12911/22998993/59355
12. Kozłowski E., Kowalski D., Kowalska B., Mazurkiewicz D. 2022. Method for assessing the impact of rainfall depth on the stormwater volume in a sanitary sewage network. Archives of Civil and Mechanical Engineering, 22, 1–13. https://doi.org/10.1007/s43452-021-00329-w
13. Kroll S., Dirckx G., Donckels B.M.R., Van Dorpe M., Weemaes, M., Willems P. 2016. Modelling real-time control of WWTP influent flow under data scarcity. Water Science and Technology, 73(7), 1637–1643. https://doi.org/10.2166/wst.2015.641
14. Kurek K., Bugajski P., Młyński D., Nowobilska-Majewska E. 2019. The impact of treated sewage on water quality in Mordarka stream. Journal of Ecological Engineering, 20(1), 39–45. https://doi.org/10.12911/22998993/93874
15. Lenart-Boroń A., Bojarczuk A., Jelonkiewicz Ł., Żelazny M. 2019. The effect of a Sewage Treatment Plant modernization on changes in the microbiological and physicochemical quality of water in the receiver. Archives of Environmental Protection, 45(2), 37–49. https://doi.org/10.24425/aep.2019.127979
16. Marek K., Pawęska K., Bawiec A. 2021. Treatment of wastewater with high ammonium nitrogen concentration. Journal of Ecological Engineering, 22(4), 224–231. https://doi.org/10.12911/22998993/134079
17. Masłoń A. 2014. Evaluation of the effectiveness of wastewater treatment plant in Jasło under different hydraulic loading. Archives of Waste Management and Environmental Protection, 16(2), 57–66. (in Polish)
18. Masłoń A. 2017. Analysis of unevenness of the wastewater inflow into the Zamość WWTP. Polish Journal for Sustainable Development, 21(1), 41–48. (in Polish) https://doi.org/10.15584/pjsd.2017.21.1.5
19. Miernik W., Młyński D., Wałęga A., Chmielowski K., Karwacki K. 2016. Impact of treated sewage on sewage treatment plant in Myślenice on the quailty of their receiver. Infrastructure and Ecology of Rural Areas, I(1), 191–207. (in Polish) http://dx.medra.org/10.14597/infraeco.2016.1.1.014
20. Młyńska A., Chmielowski K., Młyński D. 2017. The analysis of the sewage quantity discharging from the sewerage agglomeration in Sanok. Ecological Engineering, 18(3), 202–209. (in Polish) https://doi.org/10.12912/23920629/69375
21. Młyński D., Chmielowski K. 2016. Analysis of hydraulic load of selected wastewater treatment plant in Jasło County. Ecological Engineering, 50, 171–178. (in Polish) https://doi.org/10.12912/23920629/65496
22. Młyński D., Chmielowski K., Młyńska A. 2016. Analysis of hydraulic load of wastewater treatment plant in Jasło. Journal of Water and Land Development, 28, 61–67. https://doi.org/10.1515/jwld-2016-0006
23. Młyński D., Chmielowski K., Młyńska A. 2017. The analysis of the quantity variability of the sewage inflowing to the selected wastewater treatment plants of Sanok district. Acta Scientiarum Polonorum. Formatio Circumiectus, 16(1), 77–90. https://doi.org/10.15576/ASP.FC/2017.16.1.77
24. Młyński D., Kurek K., Bugajski P. 2018. An analysis of seasonal waste draining for the urban agglomeration using statistical methods. Water, 10(8), 1–14. https://doi.org/10.3390/w10080976
25. Mucha Z., Mikosz J. 2009. Rational application of small wastewater treatment plants according to sustainability criteria. Technical Transactions. Environment Engineering, 106(2-Ś), 91–100. (in Polish)
26. Ofman P., Puchlik M., Simson G., Krasowska M., Struk-Sokołowska J. 2017. Impact assessment of treated wastewater on water quality of the receiver using the Wilcoxon test. E3S Web of Conferences, International Conference on Advances in Energy Systems and Environmental Engineering (ASEE17), 22, 1–8. https://doi.org/10.1051/e3sconf/20172200127
27. Pawęska K., Kuczewski K. 2009. The characteristic of treated sewage outflow from plant-soil treatment plant area. Polska Inżynieria Środowiska pięć lat po wstąpieniu do Unii Europejskiej. Monografie Komitetu Inżynierii Środowiska PAN, 2, 153–159.
28. Piasecki A. 2019. Water and sewage management issues in rural Poland. Water, 11(3), 1–16. https://doi.org/10.3390/w11030625
29. Pluta K., Mrowiec M. 2015. The analysis of sewage system influence on receivers. Ecological Engineering, 45, 183–194. (in Polish) https://doi.org/10.12912/23920629/60615
30. Regulation of the Minister of Maritime Economy and Inland Navigation of 12 July 2019 on Substances Particularly Harmful to the Aquatic Environment and Conditions to Be Met during Sewage Discharge into the Water or into the Ground and during Rainwater or Snowmelt Discharge into the Water or into the Water Devices. (in Polish)
31. Spellman F.R. 2013. Handbook of water and wastewater treatment plant operations. CRC Press, 3rd Edition, Boca Raton, US.
32. Wąsik E., Bugajski P., Chmielowski K., Cupak A. 2016. The influence of precipitation in Sądecki Basin on the variability of quantitative wastewater inflowing into the treatment plant Wielopole. Infrastructure and Ecology of Rural Areas, 2(2),

543–555. (in Polish) http://dx.medra.org/10.14597/infraeco.2016.2.2.038

33. Wąsik E., Chmielowski K., Młyński D., Bedla D. 2017. Selected aspects of functioning of the sewage treatment plant in Szczawnica in terms of receiver water quality. Ecological Engineering, 18(6), 41–51. (in Polish) https://doi.org/10.12912/23920629/79568
34. Xu J., Shi Y., Zhang G., Liu J., Zhu Y. 2014. Effect of hydraulic loading rate on the efficiency of effluent treatment in a recirculating puffer aquaculture system coupled with constructed wetlands. Journal of Ocean University of China, 13(1), 146–152. https://doi.org/10.1007/s11802-014-2000-3