PAN
POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.151804
2024, No. 63 (X-XII): 184–190

The influence of winter road maintenance on the presence of chlorides in wastewater entering small treatment plants

Grzegorz B. Kaczor*[1)], Agnieszka Cupak[1)], Agnieszka Karczmarczyk[2)]

[1)] University of Agriculture in Krakow, Faculty of Environmental Engineering and Land Surveying, Department of Sanitary Engineering and Water Management, Al. Mickiewicza St. 24/28, 30-059 Kraków, Poland

[2)] Warsaw University of Life Sciences, Department of Environmental Management, Institute of Environmental Engineering, Nowoursynowska 159, 02-776 Warsaw, Poland

* Corresponding author

RECEIVED 12.08.2024 ACCEPTED 20.11.2024 AVAILABLE ONLINE 23.12.2024

Abstract: During the appearance of the first snowfall, there is a revival of discussion on effective methods of protecting road surfaces and sidewalks against icing. In Poland and many other countries, so-called road salt, mainly sodium chloride (NaCl) with additives, is often used to lower the melting point of snow and ice. Using chemicals to protect road surfaces brings many negative side effects reported in the literature. Less frequently published research results indicate, and also alarm, that increased chloride concentrations can appear in wastewater flowing into sanitary (separate) sewers. In the case of small wastewater treatment plants, increased chloride concentrations can have a negative impact primarily on the biological processes of wastewater treatment and, after discharge from the wastewater treatment plant, on the biological life in the waters and the nearest recipient environment of the treated wastewater. The study aimed to determine the concentrations and loads of chlorides in wastewater flowing through the distribution sewer system to 4 small wastewater treatment plants located in Poland, in the Lesser Poland Province, during snowmelt and heavy rainfall in 2019–2023. The study showed a significant increase in concentrations and loads of chlorides in wastewater in February. Unit chloride load in raw sewage during snowmelt varied from 7 to 12 $kg \cdot d^{-1}$ per 1 km length of separate sewer network. There was also a repeated, but much lower, increase in chloride concentrations during summer and autumn precipitation. This is when the leaching of residual salt accumulated around the road surface occurred.

Keywords: chlorides, extraneous water, sewerage, treatment plant, wastewater

INTRODUCTION

Every year, the first snowfall revives the discussion on effective ways of protecting the road surface and sidewalks against icing. Of course, the necessity of winter road maintenance is indisputable. Research conducted a few years ago in the United States showed that using chemical anti-icing and de-icing agents reduced the number of car accidents by 88% (Mazur, 2015). What gives rise to controversy are the chemicals used for maintaining roads in winter. In Poland and many other countries, the most frequent agent used to depress the melting temperature of ice and snow is road salt, which consists mainly of sodium chloride (NaCl) with admixtures. Salt began to be applied as a de-icer on a large scale in 1940 when 170,000 Mg of NaCl were used for this purpose in the United States. In 2009, more than 15 mln Mg of road salt were used in the USA (Kelly *et al.*, 2008), and currently over 20 mln Mg (Foley and Steinman, 2023). Sodium chloride melts ice and snow by lowering the freezing point of the aqueous solution, preventing the formation of black ice. NaCl is effective in temperatures down to –9°C. Other frequently used chemicals to protect road surfaces in the winter period include magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), and mixtures of NaCl, $CaCl_2$, and $MgCl_2$ in various proportions (Czarna, 2013). Magnesium chloride works effectively to −15°C, and calcium chloride to −32°C. The road salt used in Poland is most often a mixture of 97% NaCl, 2.5% $CaCl_2$, and 0.5% of the anti-caking agent potassium hexacyanoferrate ($K_4[Fe(CN)_6]$). An alternative to chemicals are natural agents, such as sand (with a diameter of 0.1 to 1.0 mm) and natural or artificial aggregates with grain sizes up to 4 mm. Using both chemical and non-chemical agents can produce many negative side effects. However, numerous research results indicate that chemicals are by far more deleterious. A significant increase in the concentration of sodium and chloride ions in surface runoff (Wałęga and Cupak, 2012; Wałęga *et al.*, 2014; Dugan and Arnott, 2022) and inland waters located near roads (Corsi *et al.*, 2015; Foley and Steinman, 2023) has been observed since the 1970s. In Poland and other countries, the concentration of NaCl in roadside ditches can be as high as 5,000 $mg \cdot dm^{-3}$ during spring thaws (Mazur, 2015; Lancaster *et al.*, 2016). Road salt is an environmental hazard because of its destructive effect on both fauna and flora (Bach and Pawłowska, 2007; Dugan and Arnott, 2022). It also changes the soil structure (Gliniak, Sobczyk and Wielewska, 2016), thus blocking or limiting the plants' absorption of mineral compounds necessary for their growth and development (Dąbrowska *et al.,* 2014). Road salt also harms many components of road infrastructure and other technical and civil engineering objects located along roads (Jun *et al*., 2021).

The influence of chlorides on components of sewage systems is discussed much less frequently in research reports. Meltwater, which contains substantial amounts of chlorides, reaches, with the surface runoff, drain inlets of a storm drainage system or a combined sewage system to be carried to a sewage treatment plant. The standard wastewater treatment process eliminates only negligible amounts of chlorides, which means high chloride loads flow along with purified wastewater into a receiver (usually a stream or a river). Here, it is only the absorptive capacity of the receiver that decides whether or not they will harm the physiology of the fish, water plants, and other aquatic biota (Dugan and Arnott, 2022).

Less frequently published research results show that alarmingly increased concentrations of chlorides may also be found in sewage flowing into sanitary (distribution) sewage systems. In the case of small wastewater treatment plants, elevated concentrations of chlorides may negatively affect biological wastewater treatment processes (Hong, Chan and Shim, 2007), biological life in the waters, and the immediate surroundings of a receiver of treated wastewater. Literature reports indicate that chlorides, possibly through the degradation of activated-sludge microorganisms, reduce the efficiency of removal of organic compounds and the effectiveness of nitrification, denitrification, and dephosphatation processes in biological reactors of sewage treatment plants (Zdybek, 2005; Dou *et al*., 2022). That may lead to increased loads of biogenic compounds in waters receiving treated wastewater, which in the case of small wastewater treatment plants are usually small streams, brooks, or drainage ditches.

In Poland in July 2022, high atmospheric temperatures, low water stages in the river, and enormous water salinity from wastewater discharges, mainly from mines, led to the most severe environmental disaster in Europe (Komunikat, 2022). Nearly 250 Mg of fish died. It was found that the high salinity of the river water caused excessive growth of so-called golden algae (*Prymnesium parvum*) and the discharge of their toxins in the Oder River. Of course, the main source of river salinity is saline sewage from mines, but other factors contribute to global salinity, among them point sources such as sewage outflows from sewage systems.

The Polish regulations [Rozporządzenie, 2019] state that the concentration of chlorides in industrial wastewater must not exceed 1,000 $mg \cdot dm^{-3}$, and the concentration of chlorides combined with sulphates should be lower than 1,500 $mg \cdot dm^{-3}$. Additionally, the total content of chlorides and sulphates in a receiver of treated wastewater should not exceed 1 $mg \cdot dm^{-3}$ when treated wastewater is completely mixed with the water in the receiving water body.

Chlorides usually infiltrate a distribution sewage system with extraneous flow (inflow) of stormwater or snowmelt, which usually gets into sewage collectors through openings or gaps in manholes or sewage well covers (Kaczor, 2009; Kaczor, 2011; Kaczor and Bugajski, 2012; Assel van, Kroll and Delgado, 2023).

The study aimed to determine the concentrations and loads of chlorides in wastewater flowing via distribution pipes into small wastewater treatment plants during snow melts and intensive precipitation events, as well as their impact on the wastewater treatment process.

MATERIALS AND METHODS

STUDY SITES

Chloride concentrations in wastewater were measured in the years 2019–2023 in four sewerage systems near the Kraków agglomeration (Małopolskie Voivodship). The geographical locations of the study sites are given in Figure 1.

In the study, we assessed the impact of extraneous flow water into the sewerage systems on selected aspects of the operation of the small wastewater treatment plants. The general characteristics of the investigated facilities are in Table 1.

The analysed sewage systems A, B, and C collect sewage from single-family housing estates located in typically urban areas. The drainage basin of facility D, in addition to areas with single-family houses, also encompasses arable fields and green areas. In all four sewage networks, sewage collectors run under paved roads or pedestrian paths. All analysed sewer systems are the separation type.

Site inspections of the investigated drainage basins provided evidence that meltwater containing chemical de-icing agents infiltrated the sewage collectors mainly through vent openings or pick holes in manhole covers of sewage wells.

STUDY METHOD

Raw sewage samples for qualitative tests were collected at the inflow of raw sewage from the sewage network into the individual sewage treatment plants upstream of the grates. Treated wastewater was sampled in the canal that discharged to the receivers. Throughout the study period, four to eight wastewater samples were tested in each month of the year. Physico-chemical analyses

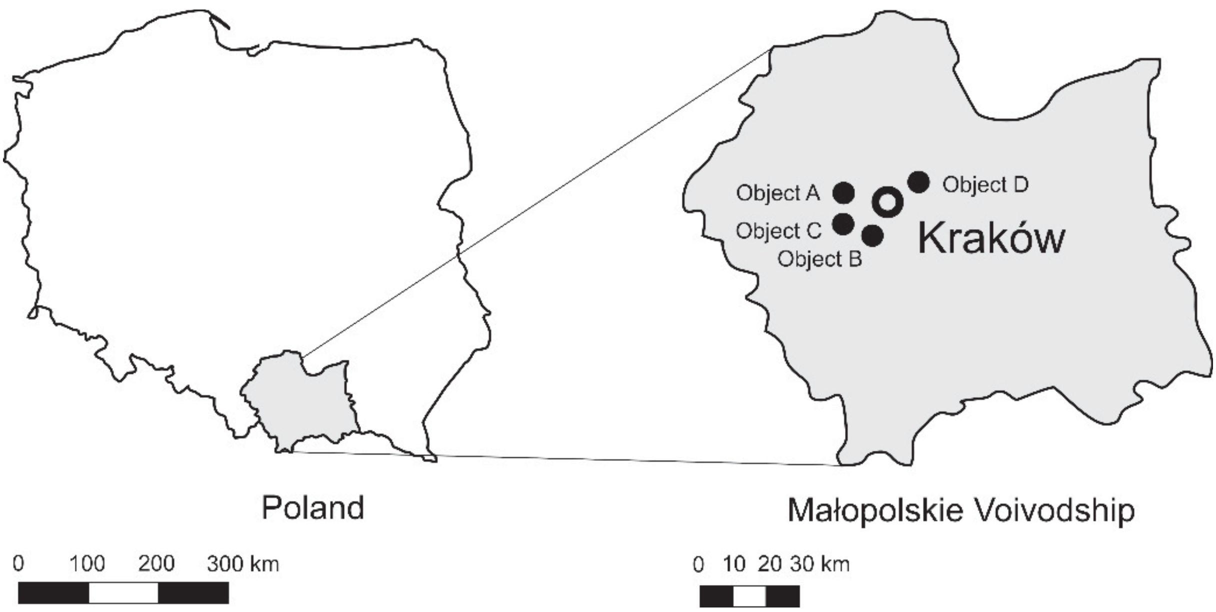

Fig. 1. Location of the study area in the Poland and Małopolskie Voivodship; source: own elaboration

Table 1. General characteristics of the analysed sewage networks

Parameter	Sewage network			
	A	B	C	D
Network length (km)	5.2	11.0	22.5	15.2
Piping material (–)	stoneware		PCV	
Age of sewage network (years)	20	17	16	17
Number of connections (pcs)	330	470	780	455
Number of users (–)	1485	2120	3650	2050
Mean daily sewage outflow during rainless weather ($m^3 \cdot d^{-1}$)	185.6	263.8	736.6	365.2
Extraneous water flow per year (%)	16.4	37.0	34.8	27.6

Source: own study.

covered such wastewater quality parameters as biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids, all forms of nitrogen, total phosphorus, chlorides, and sulphates. All wastewater quality tests were performed in an accredited laboratory in Kraków using reference methods. The concentrations of chlorides in sewage, which is the focus of the present study, were determined in compliance with standard PN-ISO 9297: 1994 using the Mohr method by titration of chloride ions with silver nitrate in the presence of potassium chromate.

The chloride concentrations obtained in the individual months were analysed statistically to determine the mean, minimum, maximum, and standard deviation values.

It was assumed that the chlorides infiltrated the sewage systems with extraneous flow, such as stormwater or meltwater, which gets into sewage collectors mainly through sewer manholes and sewage well covers. The daily volume of extraneous flow into a given sewage system was given by Equation (1):

$$Q_{dp} = Q_{dm} - Q_{ds} \tag{1}$$

where: Q_{dp} = daily inflow of extraneous waters into a sewage system ($m^3 \cdot d^{-1}$); Q_{dm} = daily inflow of a mixture of wastewater and extraneous flow into a sewage system during rainy weather ($m^3 \cdot d^{-1}$); Q_{ds} = mean daily inflow of sewage without extraneous waters into a sewage system during rainless weather ($m^3 \cdot d^{-1}$).

Table 1 shows the average daily wastewater outflow from the individual sewage systems during rainless weather and the percentage share of extraneous waters in total annual sewage outflow from each network.

Chloride loads in wastewater were calculated according to Equation (2):

$$L_{\mathrm{Cl}} = Q_d \cdot C_{\mathrm{Cl}} \tag{2}$$

where: L_{Cl} = chloride load in wastewater ($g \cdot d^{-1}$ or $kg \cdot d^{-1}$); Q_d = daily sewage outflow from sewage system ($m^3 \cdot d^{-1}$); C_{Cl} = concentration of chlorides in sewage ($mg \cdot dm^{-3}$ or $g \cdot m^{-3}$).

The Kruskal–Wallis test, a non-parametric equivalent of analysis of variance, was used to confirm statistically that chloride concentrations significantly increased during the winter months. Failure of the condition, that the data follow a normal distribution and the condition about homogeneity of variance excluded the use of ANOVA.

The Kruskal–Wallis test first examined whether the chloride concentrations in each month were from the same population. If the test showed that at least one month's median was statistically different from the other months, the winter months were excluded from the analysis and repeated. If, after excluding chloride concentrations in the winter months (January to March including) from the analysis, the Kruskal–Wallis test already showed that the medians were statistically consistent at the $p = 0.05$ level, then the null hypothesis that chloride concentrations in the winter months were different from chloride concentrations in the other months of the year, was adopted.

A statistical cluster analysis was used to compare the results from all four facilities. Ward's method was applied to estimate the distance between clusters and to group the objects. The Euclidean distance was used as a measure of distance between clusters.

RESULTS AND DISCUSSION

The mean monthly chloride concentrations in effluents from the four investigated sewage systems across the year are shown in Figure 2.

For a comprehensive illustration of the variability of these concentrations, the average concentration values are presented against the standard deviation range. The results indicate that the highest concentrations of chlorides in household sewage flowing out of sewage systems A, B, C, and D were recorded in February. In the case of all investigated facilities, chloride concentrations during the thawing period showed high variability, measured by standard deviation. Minimum chloride concentrations were observed in June, August, and September, depending on the site. The mean chloride concentrations in raw wastewater during the thawing period were higher than the means for the remaining months of the year by 33.2% – in sewage system A, 45.3% – in sewage system B, 68.2% – in sewage system C, and 33.2% – in sewage system D.

It is important to emphasize that in some sewage samples, the maximum concentration of chlorides exceeded 500 mg·dm^{-3}.

Statistical confirmation indicating that chloride concentrations during snowmelt significantly increased in winter months, compared to other months, was obtained using the non-parametric Kruskal–Wallis test. The value of the H-statistic for object A was 29.304, B – 8.994, C – 11.534, and D – 24.292, while the p-values ranged from 0.002 to 0.034. Since the calculated p-values were lower than the accepted significance level of $p = 0.05$, the hypothesis of H0, stating that there are no differences in the median chloride concentrations in the different months of the year, was rejected. With January and February excluded from the analysis, the p-values were 0.125 for object A, 0.904 for object B, 0.728 for object C, and 0.511 for object D. These results indicate no significant differences in median chloride concentrations from March to December.

An analysis of the data given in Figures 2 points to another negative effect of using chemical road de-icers. After the melt period, salt that remains in the top layers of soil or depressions in the pavement is washed out in the period of intensive precipitation in August (sewerage systems A, B, and C) and in October (sewerage D) to infiltrate again into the sanitary sewage system with surface runoff. A similar observed relationship is confirmed by Dou *et al.* (2022). Chloride concentrations in this period, for some of the investigated facilities, were only slightly lower than during the spring thaws. In summer and autumn rainfall, an increase in the standard deviation of chloride concentrations is also visible, which means that after the precipitation stopped, the concentrations of chlorides in sewage have been decreasing.

To make general conclusions based on the four analysed study objects, indicating in which months of the year significant changes in chloride concentrations in wastewater are observed, statistical cluster analysis was used, with estimation of distances between clusters using Ward's method. The results of this analysis are shown in Figure 3. The analysis results show that in February chlorides (as already known from previous studies to be elevated) are significantly distinguished from the entire population. A separate group is formed for months March, August, November, January and December. During these months, chloride concentrations are also higher. The last group includes months September, July, October, May, April and June, in which chloride concentrations in wastewater are the lowest.

Increased concentrations of chlorides during thawing and intense summer precipitation result in increased loads of these

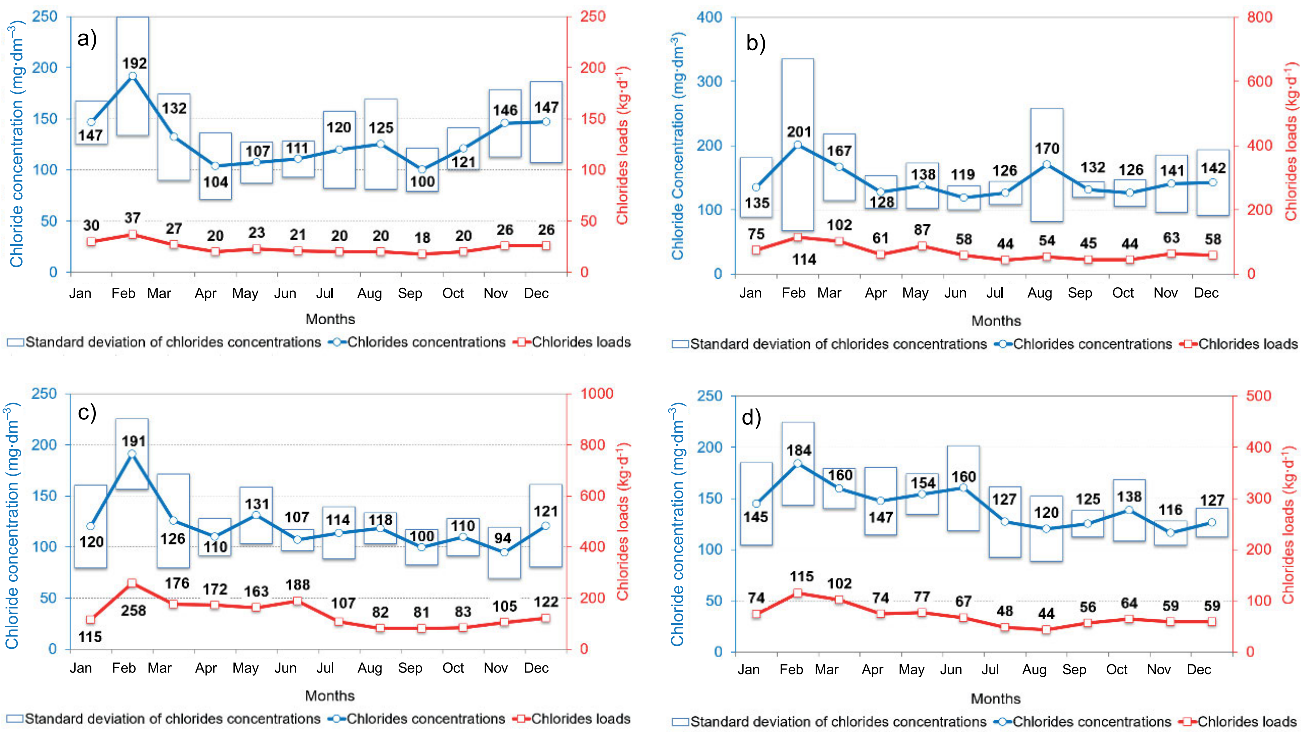

Fig. 2. Mean concentration and load of chlorides in wastewater effluent from: a) sewage system A, b) sewage system B, c) sewage system C, d) sewage system D; source: own study

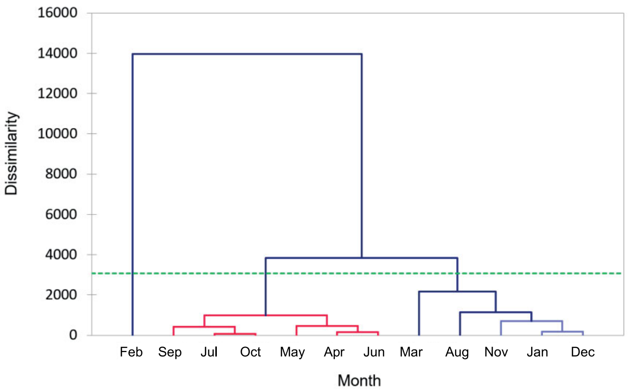

Fig. 3. Results of cluster analysis of chloride concentrations by month of the year; source: own study

pollutants in the inflow to receivers. The red line in Figure 2 marks the mean daily chloride loads in treated wastewater. In the thawing period (February), a mean of 37 kg·d^{-1} of chlorides discharged into the receiver from sewage system A, 114 kg·d^{-1} – from sewage system B, 258 kg·d^{-1} – from sewage system C, and 115 kg·d^{-1} from sewage system D. These numbers do not seem too alarming, but they look different when one considers the total monthly loads of chlorides discharged into the receivers during the months when thaws occurred. For example, in February, a total of 1035 kg of chlorides were discharged into a receiver from sewage system A, 3200 kg from sewage network B, 3035 kg from facility C, and 3230 kg from sewage system D. The figures given in Mg are much more daunting when viewed from the perspective of protection of surface waters.

Since there is a lack of research on the concentrations and loads of chlorides in wastewater flowing into small wastewater treatment plants, we calculated its average load to 1 km of sewer system. The study showed that it ranges from 7 to 12 kg·d^{-1}·km^{-1} depending on the object. The average value was 8.9 kg·d^{-1}·km^{-1}. These are very relevant results because they allow the estimation of the inflow of salts to the receiver waters from each small sewage system.

To complement our study, we attempted to assess the impact of the elevated chloride concentrations during the thawing period on the overall operational efficiency of the individual wastewater treatment plants. Table 2 compares the mean values of five pollution parameters in sewage treated in in each month of the year. During the thawing period, there was a visible increase in BOD_5, COD, total suspended solids, and total phosphorus values in wastewater discharged to the receivers. That occurred even though the pollutants in sewage were diluted with meltwater. It is impossible to conclude unequivocally that the increase in chloride concentration deteriorated the efficiency of the treatment plant since other factors, such as lowering the temperature of the wastewater by meltwater or increasing the pollutant load in the raw sewage could have led to the same effect. The activated sludge was sensitive to the temperature decline (Gnida *et al.*, 2016). Be that as it may, the reduced quality of purified sewage in February is visible.

However, many authors point out that increased chloride concentrations inhibit the growth of microorganisms in biological reactors and changes in bacterial metabolism and population of protozoa, resulting in a reduction in sludge settling and an increase in effluent turbidity (Pernetti and Palma Di, 2005; Zdybek, 2005; Hong, Chan and Shim, 2007; Dugan and Arnott, 2022). Results (Jovanović *et al.*, 2020) show that salt concentration and salt load have the biggest impacts on nitrification. At the same time, they point out, which is noticeable in the analysed sewage systems, that chloride removal by biological methods does not produce visible results (Pernetti and Di Palma, 2005; Hong, Chan and Shim, 2007; Tauber *et al.* 2021).

When interpreting the results, one should note that some chlorides naturally reach the sewage system together with the pollutants drained into the system by users (Dugan and Arnott, 2022). Tap water itself may contain primary concentrations of chlorides,

Table 2. Mean values of selected pollution parameters of sewage discharged from the treatment plants under study to the receiver

Month	Mean values of pollution parameters in treated sewage discharged from treatment plants A, B, C and D																			
	BOD_5 (mg O_2·dm^{-3})				COD (mg O_2·dm^{-3})				total suspended solids (mg·dm^{-3})				total nitrogen (mg·dm^{-3})				total phosphorus (mg·dm^{-3})			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Jan	13.4	16.0	13.5	13.2	58.9	59.9	61.1	56.8	14.2	19.7	22.9	17.4	47.1	32.6	35.2	51.5	3.9	2.7	3.6	6.4
Feb	15.4	22.0	15.2	13.5	72.1	88.5	66.0	73.0	19.2	31.1	24.5	17.4	45.6	30.9	40.3	43.3	5.8	3.4	4.6	7.2
Mar	13.9	11.3	13.3	17.8	65.7	63.5	54.1	75.1	17.4	24.1	20.0	23.8	43.1	26.3	32.8	48.8	5.3	2.4	4.7	7.0
Apr	12.3	12.6	14.8	11.2	60.5	57.7	62.2	61.8	18.1	19.2	27.5	14.2	39.6	32.8	35.8	47.5	5.4	3.5	5.0	5.6
May	13.1	10.9	11.5	16.1	51.1	52.8	53.4	61.3	14.8	18.9	15.1	20.0	44.2	43.0	34.7	56.2	4.6	2.9	2.6	7.7
Jun	12.0	13.4	12.3	19.2	50.8	51.1	45.9	63.1	13.7	16.4	11.0	24.6	37.3	35.6	37.3	47.1	4.6	2.5	2.8	6.3
Jul	9.7	14.8	12.7	10.4	44.0	64.0	63.0	56.7	12.9	20.2	20.6	17.5	37.1	44.4	38.5	45.1	2.0	2.6	5.3	5.8
Aug	12.7	13.3	15.1	11.7	53.6	53.7	52.6	57.4	19.6	20.7	19.4	14.6	53.1	48.7	41.1	58.8	5.0	3.3	4.9	5.5
Sept	11.0	14.4	10.0	13.2	50.8	66.3	56.6	61.5	16.7	16.6	19.3	18.7	39.2	41.7	43.0	49.9	5.9	7.1	5.1	7.0
Oct	12.0	13.6	12.4	13.5	52.5	62.1	52.6	58.9	16.2	16.7	19.9	19.7	34.5	39.9	43.1	45.8	4.7	3.6	3.8	5.5
Nov	13.9	14.2	13.7	13.5	58.4	53.1	55.7	70.6	18.4	17.7	23.4	18.1	45.2	36.9	44.1	40.5	5.9	4.1	4.2	7.4
Dec	11.4	17.1	15.1	16.5	59.9	62.5	50.3	74.7	18.0	23.5	22.0	20.3	40.4	40.1	37.2	58.4	3.7	3.9	3.4	6.8

Explanations: BOD_5 = biological oxygen demand, COD = chemical oxygen demand.
Source: own study.

which is also confirmed by Zdybek (2005). The mean chloride concentration in tap water in the Kraków agglomeration was 29.6 mg·dm^{-3} for 2022. Still, the increase in Cl concentrations and loads in wastewater during the spring thaws and intensive rainfalls in summer and autumn is indisputable. This relationship is confirmed by Corsi *et al.* (2015) Dugan *et al.* (2020), Dugan and Arnott (2022).

Are salt concentrations in treated wastewater discharging into small streams low or high? Dugan *et al.* (2020), studying chloride concentrations in 2773 US lakes, showed values ranging from 169 to 200 mg·dm^{-3}. Discharges from sewers into small watercourses will produce similar concentrations in those waters, given the dilution of wastewater with receiving waters. However, it is relevant to note that saline water from road and sidewalk surfaces will flow into these waters (Dugan and Arnott, 2022).

Hong, Chan and Shim (2007) point out that fish extinction in freshwater can already start at chloride concentrations above 500 mg·dm^{-3}. Kelly *et al.* (2008) found that this process could be affected by chloride concentrations of water runoff from the street, which can be as high as 3,000 mg·dm^{-3}.

Sanitary sewers mix snowmelt water with domestic wastewater, so salt concentrations are usually lower than 500 mg·dm^{-3}. However, the increased chloride load in water, shown in the paper, is not negligible. In addition to affecting living aquatic organisms, the salt in wastewater also affects aquatic vegetation. The paper (Kelly *et al.*, 2008) indicated that chloride concentrations above 300 mg·dm^{-3} already negatively affect aquatic vegetation, and such concentrations appear in treated wastewater discharged into small watercourses.

The results obtained in the present study indicate a need for further research assessing the impact of chloride loads on aquatic biota in small watercourses, which receive purified wastewater from sewage systems.

CONCLUSIONS

Our study showed that the concentrations and loads of chlorides in wastewater discharged through distribution sewerage increased during snow melts and summer and autumn precipitation events. It was found that the chlorides infiltrated sewage collectors along with meltwater or stormwater, mainly through manholes covering sewage wells.

The highest chloride concentrations were recorded in raw and treated wastewater in all studied wastewater systems in February. The maximum concentration of chlorides exceeded 500 mg·dm^{-3}. Unit chloride load in raw sewage during snowmelt varied from 7 to 12 kg·d^{-1} per 1 km length of separate sewer network.

It is difficult to unequivocally and indisputably assess the influence of the increased chloride concentrations on the biological process of wastewater treatment because spring thaws substantially decrease the wastewater temperature, and the extraneous flow strongly dilutes the contaminants. These two factors strongly reduce the efficiency of processes occurring in biological reactors. The increase in chloride concentrations in raw sewage can be treated as an inhibiting factor.

The results of this study provide additional arguments in the discussion on the choice of deicing methods for winter road maintenance. From the perspective of environmental protection, the results strongly support the use of natural, non-chemical agents, a common practice in Scandinavian countries. That entails the cumbersome activity of cleaning up and reclaiming gravel or sand after the winter period. However, measures have already been developed, although costly (a 70% increase in the cost of winter road maintenance), to implement this process efficiently. Another problem is that using gravel, which naturally bounces off from under the wheels of moving vehicles, can potentially increase incidents of damage to car bodies and windshields. When making their final decision on which road maintenance method to use, maintenance authorities must decide what is more important: environmental protection or financial and technical considerations.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

Assel van, J., Kroll, S. and Delgado, R. (2023) "Calculation of dry weather flows in pumping stations to identify inflow and infiltration in urban drainage systems," *Water*, 15(5), 864, pp. 1–23. Available at: https://doi.org/10.3390/w15050864.

Bach, A. and Pawłowska, B. (2007) "Wpływ zanieczyszczenia środowiska na stan roślinności drzewiastej w Krakowie [The impact of environmental pollution on the condition of tree plants in Kraków]," *Czasopismo Techniczne*, *Architektura*, 10, pp. 114–116. Available at: https://repozytorium.biblos.pk.edu.pl/redo/resources/34826/file/suwFiles/BachA_WplywZanieczyszczenia.pdf (Accessed: June 12, 2024).

Corsi, S.R. *et al.* (2015) "River chloride trends in snow-affected urban watersheds: increasing concentrations outpace urban growth rate and are common among all seasons," *Science of The Total Environment*, 508, pp. 488–497. Available at: https://doi.org/10.1016/j.scitotenv.2014.12.012.

Czarna, M. (2013) "Przegląd środków chemicznych stosowanych w zimowym utrzymaniu dróg w Polsce [Overview of chemicals used in winter road maintenance in Poland]," *Zeszyty Naukowe Uniwersytetu Zielonogórskiego*, 31, pp. 18–26. Available at: http://zbc.uz.zgora.pl/Content/45586/PDF/2_czarna_przeglad.pdf (Accessed: June 12, 2024).

Dąbrowska, J. *et al.* (2014) "Methods of protecting roadside greenery from the harmful effects of road salt," *Architektura Krajobrazu*, 3, pp. 44–55. Available at: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-480029f2-7775-450f-89fb-ff0a20ef4c26/c/dabrowska_methods_3_2014.pdf (Accessed June 12, 2024).

Dou, W. *et al.* (2022) "A review on the removal of Cl(-I) with high concentration from industrial wastewater: Approaches and mechanisms," *Science of The Total Environment*, 824, 153909, Available at: https://doi.org/10.1016/j.scitotenv.2022.153909.

Dugan, H.A. *et al.* (2020) "Lakes at risk of chloride contamination," *Environmental Science & Technology*, 54, pp. 6639–6650. Available at: https://doi.org/10.1021/acs.est.9b07718.

Dugan, H.A. and Arnott, S.E. (2022) "The ecosystem implications of road salt as a pollutant of freshwaters," *Wiley Interdisciplinary Reviews: Water*, 10(2), e1629, pp. 1–12. Available at: https://doi.org/10.1002/wat2.1629.

Foley, E. and Steinman, A.D. (2023) "Urban lake water quality responses to elevated road salt concentrations," *Science of The*

Total Environment, 905, pp. 1–11. Available at: https://doi.org/10.1016/j.scitotenv.2023.167139.

Gliniak, M., Sobczyk, W. and Wielewska, I. (2016) "Przestrzenna zmienność parametrów fizykochemicznych gruntów z terenów silnie zasolonych [Spatial variability of physicochemical parameters of soils from highly saline areas]," *Annual Set The Environment Protection*, 18, pp. 372–386. Available at: https://www.ros.edu.pl/images/roczniki/2016/023_ROS_V18_R2016.pdf (Accessed: June 12, 2024).

Gnida, A. *et al.* (2016) "The effect of temperature on the efficiency of industrial wastewater nitrification and its (geno)toxicity," *Archives of Environmental Protection*, 42(1), pp. 27–34. Available at: http://dx.doi.org/10.1515/aep-2016-0003.

Hong, Ch.Ch., Chan, S–K and Shim, H. (2007) "Effect of chloride on biological nutrient removal from wastewater," *Journal of Applied Sciences in Environmental Sanitation*, 2(3), pp. 85–92. Available at: https://www.researchgate.net/publication/43993021_Effect_of_chloride_on_biological_nutrient_removal_from_wastewater (Accessed: June 12, 2024).

Jovanović, N. *et al.* (2020) "Modelling the effect of salt from road runoff on nitrification of a wastewater treatment plant," *Water Practice & Technology*, 18(4), pp. 922–929. Available at: https://doi.org/10.2166/wpt.2023.059.

Jun, L. *et al.* (2021) "Influence of deicing salt on the surface properties of concrete specimens after 20 years," *Construction and Building Materials*, 295, 123643. Available at: https://doi.org/10.1016/j.conbuildmat.2021.123643.

Kaczor, G. (2009) "Otwory we włazach kanalizacyjnych jako jedna z przyczyn przedostawania się wód przypadkowych do sieci rozdzielczej [Holes in the sewage canals' hatches as one of the cause for the accidental water infiltration to the separate sewer system]," *Infrastruktura i Ekologia Terenów Wiejskich*, 9, pp. 155–163. Available at: http://www.infraeco.pl/pl/art/a_15683.htm?plik=678 (Accessed: June 12, 2024).

Kaczor, G. (2011) "Wpływ wiosennych roztopów śniegu na dopływ wód przypadkowych do oczyszczalni ścieków bytowych [Impact of spring snowmelt on inflows to the household sewage treatment plant]," *Acta Scientiarum Polonorum Formatio Circumiectus*, 10(2), pp. 27–34. Available at: http://actascipol.upwr.edu.pl/pl/action/getfull.php?id=3114 (Accessed: June 12, 2024).

Kaczor, G. and Bugajski, P. (2012) "Impact of snowmelt inflow on temperature of sewage discharged to treatment plants," *Polish Journal of Environmental Studies*, 21(2), pp. 381–386. Available at: https://www.pjoes.com/pdf-88764-22623?filename=Impact%20of%20Snowmelt%20Inflow.pdf (Accessed: June 12, 2024).

Kelly, V.R. *et al.* (2008) "Long-term sodium chloride retention in a rural watershed: Legacy effects of road salt on streamwater concentration," *Environmental Science and Technology*, 42(2), pp. 410–415. Available at: https://doi.org/10.1021/es071391l.

Komunikat (2022) "Komunikat 07/2022 interdyscyplinarnego zespołu doradczego ds. kryzysu klimatycznego działającego przy Prezesie PAN na temat katastrofy ekologicznej na Odrze i antropogenicznej zmiany klimatu [Statement no. 07/2022 by the Interdisciplinary Advisory Team for the Climate Crisis to the President of the Polish Academy of Sciences about the disaster on the Odra river and anthropogenic climate changes]," *Nauka*, 4, pp. 183–187. Available at: https://doi.org/10.24425/nauka.2022.142930.

Lancaster, N.A. *et al.* (2016) "Impact of chloride on denitrification potential in roadside wetlands," *Environmental Pollution*, 212, pp. 216–223. Available at: https://doi.org/10.1016/j.envpol.2016.01.068.

Mazur, N. (2015) "Wpływ soli do odladzania dróg na środowisko przyrodnicze [Impact of road deicing salt on the natural environment]," *Inżynieria i Ochrona Środowiska*, 18(4), pp. 449–458. Available at: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-81e06819-425d-42d1-bc56-a19c712c2c95/c/Mazur_Wplyw_4_2015.pdf (Accessed: June 12, 2024).

Pernetti, M. and Palma Di, L. (2005) "Experimental evaluation of inhibition effects of saline wastewater on activated sludge," *Environmental Technology*, 26(6), pp. 695–704, Available at: http://dx.doi.org/10.1080/09593330.2001.9619509.

Rozporządzenie (2019) "Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 12 lipca 2019 r. w sprawie substancji szczególnie szkodliwych dla środowiska wodnego oraz warunków, jakie należy spełnić przy wprowadzaniu do wód lub do ziemi ścieków, a także przy odprowadzaniu wód opadowych lub roztopowych do wód lub do urządzeń wodnych [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]," *Dz.U.* 2019, poz. 1311. Available at: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190001311 (Accessed: June 12, 2024).

Tauber, J. *et al.* (2021) "Influence of road salt thawing peaks on the inflow composition and activated sludge properties in municipal wastewater treatment," *Water Science & Technology*, 84.2, pp. 314–322. Available at: https://doi.org/10.2166/wst.2021.045.

Wałęga, A. and Cupak, A. (2012) "Kinetyka przemian zanieczyszczeń w ściekach opadowych w seminaturalnej oczyszczalni w trakcie procesu infiltracji [Kinetics of pollutant transformations in rainwater in a semi-natural sewage treatment plant during the infiltration process]," *Gaz, Woda i Technika Sanitarna*, 8, pp. 345–347. Available at: https://sigma-not.pl/publikacja-69933-kinetyka-przemian-zanieczyszcze%C5%84-w-%C5%9Bciekach-opadowych-w-seminaturalnej-oczyszczalni-w-trakcie-procesu-infiltracj-gaz-woda-i-technika-sanitarna-2012-8.html (Accessed: June 12, 2024).

Wałęga, A. *et al.* (2014) "Transformation of pollutants in the stormwater treatment process," *Polish Journal of Environmental Studies*, 23, 3, pp. 909–916. Available at: https://www.pjoes.com/pdf-89262-23120?filename=Transformation%20of.pdf (Accessed: June 12, 2024).

Zdybek, I. (2005) "Wpływ jonów chlorkowych na efektywność biologicznej defosfatacji ścieków [Effect of chloride ions on the efficiency of enhanced biological phosphorus removal from wastewater]," *Ochrona Środowiska*, 2, pp. 13–17. Available at: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPOB-0005-0009/c/Zdybek.pdf (Accessed: June 12, 2024).