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CHLORIDE CONTENT OF STREET CLEANING WASTE AND ITS POTENTIAL ENVIRONMENTAL IMPACT

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Abstract
According to the data of the Central Statistical Office for 2017, the average amount of municipal waste generated per capita is 486 kg. Poland ranks last but one in terms of the amount of municipal waste generated. About 56% of municipal waste is processed, but still about 40% is landfilled. They may contain chlorides, especially those from the winter period, resulting from the use of deicing agents. Chlorides cause salinity of surface and ground waters and soil salinity, which in turn leads to deterioration of water purity and a decrease in biodiversity of aquatic organisms, changes in the microbiological structure and increased toxicity of metals. Chlorides also damage road surfaces and bridges, corrosion of plumbing pipes. Once the chlorine-containing sweepers are deposited in a landfill, this waste may contribute to an increase in chemical aggressiveness, which is important in the design of anti-filtration barriers, and in the rehabilitation of contaminated land and soil. The level of water and soil salinity has a significant impact on the critical infrastructure, especially in terms of water supply – the risk of corrosion of pipes and their decline in species biodiversity. An important role in the critical infrastructure is played by the storage of dustmuds – the risk of failure of security measures in storage yards. Therefore, it is very important to determine the salinity level in this stored waste. The salinity level of street sweeping waste from different street locations is not commonly studied. Therefore, such a study was conducted for a midsized city. The study shows that the highest chloride concentrations in street and sidewalk sweeping waste are found around manholes and the lowest concentrations are found on sidewalks.
The aim of the research is to determine the amount of chlorides in sweepings in the annual cycle to determine the potential risk associated with their impact on selected aspects of the environment.

Keywords: **Chlorides in sweepings; Environmental pollution; Disruption of ecosystems; Waste treatment.**

1. INTRODUCTION

The main objective of comprehensive waste management is to take action to prevent the generation of waste or, when this is not technically possible, to reduce its quantity and its negative impact on the environment. Waste management should follow the hierarchy: prevention at source, preparation for reuse, recycling and use of useful materials, other recovery methods, including incineration, and final disposal of treatment residues. In large urban areas, there is a wide variety of waste streams, and the diversity results in the need for mass reduction and the need to dispose of all streams, regardless of nature. One of the municipal wastes is street sweepings generated in street cleaning and washing processes. What is interesting is both their quantity and composition, as well as the variability of their character on a yearly basis. According to the European Waste Catalogue [1] waste from street cleaning are classified under the code "20 03 03 – waste from street and yard cleaning", are treated as one of the municipal waste streams that should be collected and disposed of in a comprehensive system. This waste may constitute 10 to 15% of the mass of municipal waste. However, the studies carried out to date have not taken into account the amount of suspended solids washed off during street cleaning and washing processes, which also has a significant impact on the quantity and quality of waste. According to research [2], the amount of suspended solids represents 7–75% of the solid waste in relation to the amount of sweepings collected each day, only during sweeping. In general, the most studied phenomenon reported in the literature is the impact of street cleaning on air quality and secondary emissions. They do not present conclusive results. As a result of some studies conducted in this area, an increase in PM10 (Particulate matter) levels [3, 4] and an increase in the proportion of mineral components in particulate matter especially in the PM10 fraction have been registered [4, 5]. In contrast, it has been shown that street sweeping alone can have a periodic adverse effect on the removal of pollutants from the air; Vaze and Chiew [6] found that there were more fine particulate matter particles in the air after street sweeping compared to before sweeping. In addition to studying street cleaning by sweeping alone, street washing and its effects on ambient air quality have also been studied. The study by Watson et al. showed that the effectiveness of street washing (without sweeping) was more related to the effect of humidification than to the effective removal of particulate matter. On paved roads, the effect of street washing on air quality has been studied in Germany and Scandinavian countries [3, 4, 7]. The results showed that the effectiveness depends strongly on the local situation (location, meteorology, road quality). Results presenting the effectiveness of street sweeping and washing were also presented in publication [8], where the concentration of suspended particulate matter was controlled. Publications [9, 10] describe the evaluation of the effectiveness of mechanical street cleaning and washing with water to reduce PM10 concentrations in ambient air. A considerable number of publications describe the negative impact of the composition of sweepings deposited on the streets of cities and in urbanized areas on the environment of these areas. Publication [11] analyzed dust collected from streets and soil from cities with high, medium and low population density and in a non-urbanized area. The study found that high population density increased the salinity of the sweepings and soil, but had no effect on the concentration of metals in the soil. Publication [12] presents the results of the study and identification of contaminants found in street dust from London (UK), New York (USA) and Halifax (Canada), Christchurch (New Zealand) and Kingston (Jamaica). The identified pollutants were divided into two groups: those from soil and those from other sources, including tire wear, car exhaust emissions and salt use. The study noted that concentrations of most elements increase with decreasing dust particle size.

The salinity of the sweepings consequently causes an increase in the salinity of wastewater, either from street cleaning or runoff during precipitation, and the increased chloride content interferes with the defosfation and defoliation process [13] It is a waste deposited in the landfill due to the lack of management technology [14] that consequently causes the salinity of landfill leachate [15].

The objective of the research presented here will be to determine the amount of chlorides in the sweepings on an annual basis to determine the potential risk associated with their effects on selected aspects of the environment.

2. CHLORIDES AND THEIR EFFECTS ON THE ENVIRONMENT

De-icing agents and salt are commonly used winter materials for road de-icing. On average, over 500 thousand tons of sodium chloride is used on roads in Poland [16]. For comparison, a country such as Sweden, where snowfalls are significantly higher, does not exceed the level of 300 thousand tons of road salt consumption per year. On the other hand, the USA uses 20 million tons of road salt annually. According to the Polish Law [17], for road maintenance in winter period one can use: NaCl, $CaCl_2$, $MgCl_2$. In addition, sand is used for winter road maintenance in Poland to improve grip. When the snow and ice melt, salt is washed away and together with precipitation or water from street cleaning it ends up in the soil, groundwater and surface water polluting them. It affects entire ecosystems. A strong influx of chloride ions disrupts the ability of freshwater organisms to regulate fluid flow [18] Changes in the salinity of a pond or lake can also affect the way water mixes with the changing seasons, leading to salty pockets near the bottom and biological dead zones. Increased salinity in water bodies can lead to decreased biodiversity of aquatic organisms, changes in microbial structure, and increased metal toxicity [19]. Increased chloride concentrations also contribute to groundwater salinization [20]. According to the Polish law, for groundwater quality class I the concentration must not exceed 60 mg/dm^3, for class II 150 mg/dm^3, for class III 250 mg/dm^3 [21]. For surface waters, the chloride concentration for Class I must not exceed 5 mg/dm^3, while for Class II it must not exceed 8.2 mg/dm^3, there are no standards for the other classes [22]. Road salt can also affect the environment in other ways. When it runs off the road, it can damage the soil, destroy trees and vegetation or restrict their growth [23] up to 100 meters from where the salt is spread. In addition, chlorides cause corrosion of sewer infrastructure and erosion of road surfaces [24]. Roadside roads can also turn into artificial licks that are attractive to animals such as elk and moose. As a result, we run a higher risk of animals being killed in collisions with vehicles. Birds are also frequent victims of this type of incident. [25, 26, 30–32].

3. MATERIALS AND METHODS

In the proposed research approach, a research methodology is proposed to determine the amount of chlorides in street cleaning waste and to determine the potential environmental risks associated with their presence. In terms of the work undertaken, the following are proposed:

– selection of time and place of study
– selection of sampling sites
– laboratory analyses of samples
– development of research results and conclusions.

The study was conducted in a medium-sized city with a population of about 55,000. The area from which street cleaning waste is removed is about 140 km, while the area of sidewalks is about 450 thousand m^2. The amount of sweepings collected annually ranges from 300 tons to 1200 tons per year, depending on the quality of winter in a given year. The ratio between sand and salt NaCl is 50:50, at temperatures below 20°C $CaCl_2$ is also used in the ratio 50:50 with sand. Sidewalks are gritted only with sand without salt. After collection, this waste is deposited in a landfill for non-inert and hazardous waste. The fee for depositing this waste is 300 PLN net.

Samples for testing were collected during two periods of increased street and sidewalk cleaning i.e. end of summer – August/September and end of winter – March. Sampling for laboratory tests (solid waste and street cleaning wastewater samples) were taken directly from the waste container of the street and sidewalk cleaning truck according to the standards [27, 28]. Due to the possibility of salt accumulation in different areas of the operated roads, it was proposed to take samples not only from the streets, but also from the wastewater and manholes. The samples labeled Streets 1 and sidewalks are solid samples. Samples for the study were taken from this waste by dissolving about 200 g of waste in distilled water and then filtered and a representative sample was obtained for the study. On the other hand, samples from Streets 2 from around the manholes and samples from Streets 3 (street washing) were taken in semi-liquid form, filtered and a representative sample was obtained for testing. For each sampling location: Streets 1, Streets 2, Streets 3, sidewalks 30 representative samples were obtained and analyzed for chloride. The chloride content of wastewater and street sweepings was determined using the standard: PN-ISO 9297:1994 [29].

4. RESULTS AND DISCUSSION

The results from the chloride content of the 30 samples for each site are presented in Table 1 and Figure 1 below

Table 1.
Chloride content of individual street and sidewalk cleaning samples after summer and winter

Location	Chloride content in street cleaning wastewater [mg/dm^3] after summer			Chloride content in street cleaning wastewater [mg/dm^3] after winter		
	Average	Value min.	Value of max.	Average	Value min.	Value of max.
Streets 1	35.42	29.3	41.4	362.75	321.6	399.8
Streets 2 (sewage wells)	59.8255	45.6	71.9	1467.93	1201.4	1732.8
Streets 3 (washing the streets)	43.886	38.3	49.3	421.73	436.3	468.5
Pedestrian walkway	36.42	25.8	46.2	53.13	45.9	59.2

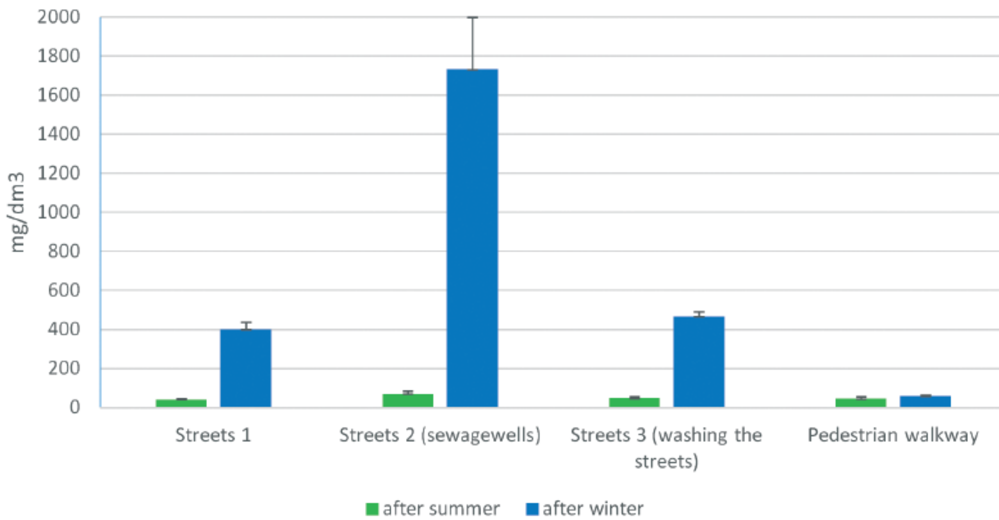

Figure 1.
Comparison of chloride content [mg/dm^3] on selected streets in cleaning sweepings collected after summer and winter, including standard deviation

The study showed significant differences in the amount of chloride in the "after winter" and "after summer" periods. This is understandable due to the specificity of the periods in which the study was conducted. In the samples collected for testing in the "after summer" period, the highest average chloride concentration of about 60 mg/dm^3 was obtained in the samples of Streets 2 collected from the vicinity of sewage wells. This was followed by an average concentration of about 44 mg/dm^3 obtained in the Streets 3 samples collected from street washing. Average concentrations of similar value were obtained in Streets 1 samples of approximately 35 mg/dm^3 and in samples collected from pedestrian walkway of approximately 36 mg/dm^3. During the post-winter season, average chloride concentrations peaked at approximately 1468 mg/dm^3 in samples from Streets 2 collected from around sewage wells. In samples from Streets 3 (street washing), the average chloride concentration was recorded at approximately 422 mg/dm^3. In samples from Streets 1, the average chloride concentration was approximately 362 mg/dm^3. The lowest chloride concentration from this period was recorded in samples from pedestrian walkway averaging about 53 mg/dm^3. From the results obtained in these two seasons, a correlation is observed between the concentrations at the given sampling sites. Both the highest chloride concentrations are found in samples collected near sewage wells and the lowest chloride concentrations are found in samples collected from pedestrian walkways.

Low chloride concentrations at pedestrian walkways are due to the ban on salt sprinkling on pedestrian walkways. The high concentration of chlorides at sewage wells is due to runoff into the sewer system and the accumulation of street runoff along with sweepings near the manholes. This high average concentration of chlorides present in street cleaning debris is due to the long, snowy, and cold winter during which roads were generously spread with sand and salt.

To compare the results with a medium-sized city, below in Table 2, there are the results of a study on one of the access streets in a large city conducted during the months of April/May.

Continuing the studies presented in the book "Analysis of changes in the urban environment as a result of street cleaning in selected zones of the Cracow agglomeration", additional studies were carried out on a one-way access street about 700 m in the center of Cracow. Chloride concentrations on the pedestrian walkway were 118 mg/dm^3 on the roadway and 500 mg/dm^3 on the street. Chloride concentrations on pedestrian walkways are significantly lower than on roadways. There is a definite decrease in chloride concentration until May 3, 2020, then it increases significantly. The highest value of chloride concentration was recorded during the first washing on 28.06.2020 (it was about 956 [mg/dm^3] and then it decreased slightly after washing the roadway twice to the level of about 894 [mg/dm^3]. In general, a very high environmental load can be observed as a result of the construction works from about the middle of May 2017 to the end of the research cycle (the last days of June) as a result of the construction works,

Table 2.
Comparison of selected parameters of environmental pollution tested on streets in Krakow during street cleaning processes with parameters determined on other streets as a result of similar activities

Location	Length of surveyed section [m].	Chloride content of street cleaning wastewater [mg/dm^3]		
		Average	Value min.	Value of max.
Access street	700 (One-way, 2-day left/right experiment),	500	965	34,1
	Pedestrian walkway, 700 (One-way, 2-day left/right experiment),	118	210	25
Alley Krasińskiego	1020 (two-way, three-day experiment full width)	394	762	25.6
Street Porucznika Halszki	770 (two-way, three-day experiment full width)	385	749	25
Street Bulwarowa	550 (two-way, three-day experiment full width)	34	52,9	15

storage of large amounts of loose materials (sand, gravel) and a significant load of transport of construction materials.

When comparing these data from the commuter street with the results from the book, they were at a higher level than the results from other streets in the large metropolitan area.

5. CONCLUSION

1. The results of the tests for chlorides in sweepings, conducted in a medium and large city, gave an idea of their amount and, consequently, of their penetration into the soil, underground and surface waters polluting them and affecting entire ecosystems
2. The differences are very significant and amount to almost 1050 mg/dm^3 in the post-winter period between the sampling point near a sewage wells and a roadway. There are also significant differences between accumulation of pollutants in large and medium size cities, especially visible in one of the access streets in large city, where chloride concentration on pedestrian walkways is higher by 64 mg/dm^3 on average, while on the street – by 70 mg/dm^3.
3. High chloride concentrations at sewage wells can adversely affect wastewater treatment processes, resulting in increased salinity in water bodies. In contrast, low chloride concentrations at pedestrian walkways provide an opportunity for ecosystems along sidewalks not to be disturbed.
4. The observed high concentration of chlorides in sweepings after the winter period in both large and medium-sized cities can cause damage to traffic routes, generating repair costs
5. Such a high concentration of chlorides in the sweepings, deposited in the landfill in large quantities can cause an increase in the salinity of landfill leachate, which in turn affects the prolonged decomposition of matter and the formation of biogas and the possibility of salinization of groundwater and impede biological processes in sewage treatment plants.

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