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Research on the properties of waste from streets cleaning

Anna Wassilkowska, Agnieszka Generowicz*, Anna Młyńska

Cracow University of Technology, Faculty of Environmental Engineering and Energy,
Poland

*Corresponding author. E-mail: agnieszka.generowicz@pk.edu.pl

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Abstract: Nowadays, environmental pollution is a common problem influenced by, among other factors, the increased accumulation of waste of different types and with different impacts on the environment. Streets sweeping, especially in urban areas, collects dust of various origins, compositions, and properties. Dust accumulation on streets and sidewalks may cause a significant deterioration of the natural environment, influencing not only water, soil and air, but also human life and health. In the literature, there are many studies describing the impact of street waste on the natural environment, e.g., on greenery and roadside trees, secondary emissions causing high human exposure, rainwater pollution, and consequently, surface water pollution. Street cleaning is one of the elements of urban area management within the broader concept of “smart city” management. The aim of this study was to investigate waste from the city streets (sweeping residues) using SEM-EDS microscopic examination. Waste was collected from the streets and sidewalks of a large city. Based on the results, it is possible to evaluate the quality of the urban space.

Introduction

Street sweepings, i.e., road-deposited sediments, are municipal waste systematically removed by sweeper vehicles in order to prevent them from reaching the aquatic environment and to reduce the harmful effects of dust on human health (Lloyd et al. 2018, Yang et al. 2016, Operacz et al. 2023). The primary European Waste Catalogue (EWC) code for street sweepings is 20 03 03 (street-cleaning residues). Sweeper vehicles belonging to the Municipal Cleaning Company (MPO) in Cracow, Poland, operate with a closed-circuit water spray system and are certified according to the EU standard PM10. The study by Kryłów and Generowicz (2019) confirmed that the current technology of streets cleaning and washing contributes to the reduction of suspended dust in the air with a particle size below 10 µm. Dry matter, mineral and organic substances and heavy metals have been determined in street sweepings (Generowicz et al. 2023, Gronba-Chyła et al. 2025, Gronba-Chyła et al. 2021). In the literature (Bi et al. 2013, Adamiec et al. 2016, Fang et al. 2017), attention has been paid to the grain size classification of street dust. Particle size is an important parameter influencing the accumulation of heavy metals on roads (Hengren et al. 2006). Heavy metal concentrations in street dust increase significantly as particle size decreases (Li et al. 2010). The largest mass of pollutants was associated with particles in the size range of 100–250 µm (Lau and Stenstrom 2005). Samples are collected using a modified vacuum cleaner, and the dust passes through filters and sieves. In the study by Adamiec et al. (2016), it was found

that individual particles are, on average, no larger than 65 µm; however, they actually form agglomerates with diameters of 1000–2000 µm. In the study by Gunawardana et al. (2014), X-ray diffraction analysis revealed that road dust consisted mainly of silicates and aluminosilicates, including quartz (SiO₂), constituting more than 70% of the volume, albite (NaAlSi₃O₈), microcline (KAlSi₃O₈), chlorite (H₈Mg₆O₁₈Si₄), and muscovite (H₂KAl₃(SiO₄)₃). The authors stated that the differences in the physical and chemical properties of particles in the size ranges <75 µm and 75–150 µm result from different proportions of minerals and organic matter, whereas for larger particles (150–300 µm and 300–425 µm), the adsorption properties of pollutants are similar due to significantly high quartz content.

The determination of the level of contamination of street sweepings with heavy metals such as Zn, Cd, Cu, Pb, Ni and Cr is important (Li et al. 2010, Isa et al. 2008), as some of these metals are considered toxic, while others, e.g., Fe, Ca, Ba and Mn, are mainly associated with the Earth’s crust. Typically, metal concentrations are determined by atomic absorption spectrometry (Rashed 2008, Skorbilowicz and Skorbilowicz, 2019), although other methods, such as inductively coupled plasma-optical emission spectrometry, have also been used (Isa et al. 2008, Fang et al. 2017). Common pollutants in streets dust include Pb, Mn, and Fe (Rashed 2008). In the study by Lau and Stenstrom (2005), the metal content of street sweepings was determined. The particle-size fraction of 125–250 µm was the richest in metals. Furthermore,

the authors stated that street-sweeping technologies available in the 1970s were not able to remove particles containing the highest metal loads. Generowicz et al. (2020) found that 60% of the road dust consisted of minerals of a terrestrial origin, of which 40–50 % was quartz, 10–20 % was clay, and the organic fraction accounted for 2% of the volume. Recently, scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM-EDS) has been applied to the analysis of trace elements in atmospheric particles separated by size on glass fiber filters (Sevimoglu and Kuzu 2025, Kwaśnicki et al, 2024). Yang et al. (2016) also reported that, prior to microstructural analysis, street sweepings were divided into aerosolized and bulk dust fractions.

The aim of this study was to identify and describe the microscopic characteristics of street cleaning residues, with particular emphasis on developing an analytical approach that does not require prior separation of the entire sample into particle-size classes before SEM analysis. This objective is important because street cleaning residues are highly heterogeneous materials composed of particles of different origins, sizes, morphologies, and chemical compositions. Conventional size-fractionation procedures may be time-consuming and can potentially disturb the original structure of the collected material, thereby limiting the ability to assess the sample as it actually occurs in urban environments.

Therefore, this study focused on detecting and precisely documenting whether individual particle-size fractions exhibit significant differences in elemental composition, as well as identifying clear compositional trends based on the examination of a statistically large number of particles. Such an approach makes it possible to obtain a more representative and comprehensive characterization of street cleaning residues, including particles that may be of environmental or health significance because of their chemical composition or small size.

The justification for this research lies in the need to better understand the actual composition of material removed from urban streets by mechanical cleaning systems. By characterizing the microscopic and elemental properties of the collected residues, this study provides a basis for assessing the actual efficiency of street sweepers in capturing different types of particulate matter. The results may also support the optimization of street-cleaning strategies and contribute to a more accurate evaluation of their role in reducing urban dust pollution.

Research papers available in the literature present both potential technical solutions for street-cleaning systems and analyses of their environmental effects, ranging from technological descriptions of the equipment and its capabilities, through descriptions of complete cleaning and sweeping

systems, to analyses of the changes occurring in the human environment as a result of streets cleaning. Many scientific publications characterize and analyze the composition of waste collected from streets (Järlnskog et al. 2020, Lloyed et al. 2018, Kladnik et al. 2024, Gronba-Chyła, 2026, Kochanek et al. 2025).

Investigations conducted in Cracow have so far aimed to demonstrate the positive changes in environmental quality resulting from streets cleaning, including improvements in resident’s quality of life and the aesthetics of the urban area. The results clearly demonstrate environmental improvements, including waste reduction, enhanced quality of urban infrastructure (sidewalks and streets), reduced amounts of pollutants transported by stormwater, and improved air quality throughout the studied city areas. Studies of streets-cleaning residues (Gronba-Chyła et al. 2022, Generowicz et al. 2020) indicate the presence of heavy metals. Their removal from urban areas and the identification of appropriate disposal options constitute a difficult and challenging interdisciplinary task. This article also aims to confirm previous research findings regarding the quality of street-cleaning residues and the environmental changes occurring in urban areas as a result of street cleaning.

Materials and methods

The material for this study consisted of street waste collected in March and April 2025 in the city of Cracow by the Municipal Cleaning Company (MPO) using sweeper vehicles on three streets (a total of four samples) (Table 1). The streets were first swept, after which samples of solid waste were collected from the sweepers (designated as *street sweepings* and *sidewalk sweepings*). The streets were subsequently washed, and samples of wastewater were collected from the sweepers (designated as *sweeper wastewater*).

Krasińskiego Street is located in the center of Cracow, whereas Stella-Sawickiego Street is situated in the eastern part of the city. Both streets serve as main thoroughfares. They consist of two carriageways, each with three traffic lanes separated by a green median strip, and are characterized by high-traffic volumes. Kujawska Street is located to the west of Cracow city center. It is a local street with moderate traffic, primarily serving as access to nearby buildings, and consists of a single carriageway and two lanes. The samples day from Krasińskiego Street were collected on 24 March 2025. The weather was cloudy, with no precipitation, and the maximum air temperature reached 14°C. The samples from Stella-Sawickiego Street and Kujawska Street were collected on 25 April 2025. On that day, the weather was cloudy with light rainfall, and the maximum air temperature reached 14°C.

Table 1: Collected and tested samples of the street waste.

No.	Sample	Street	Date of collection	Sample type/form
1	Kr24z	Krasińskiego	24 March 2025	Sweepings from street
2	Kr24s			Sewage from sweeper
3	SS	Stella-Sawickiego	25 April 2025	Sweepings from sidewalk
4	Ku	Kujawska		Sweepings from street

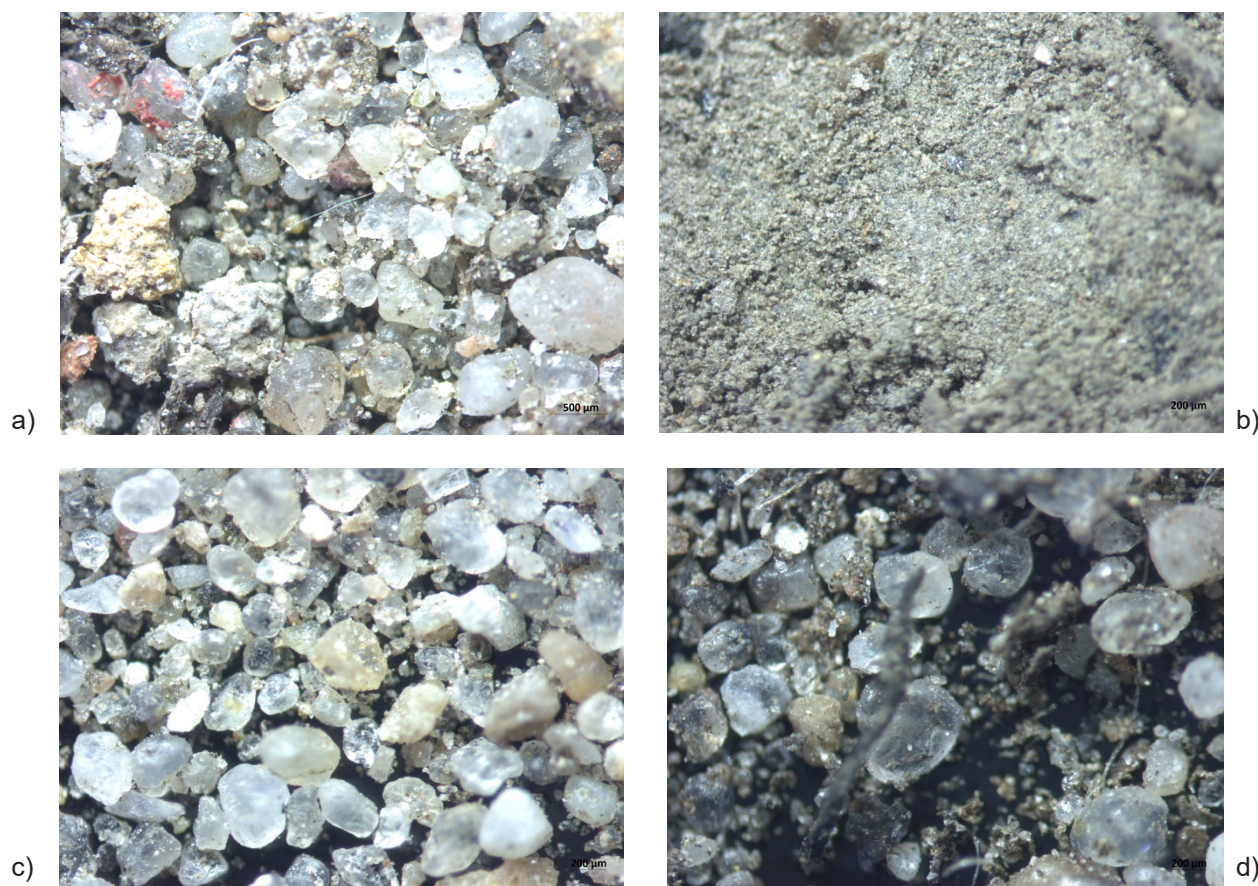


Fig 1. Optical microscope images of the granular microstructure of street sweepings residues in nominal magnification of x30: a) sample Kr24z – quartz, b) sample Kr24s – dust, c) sample SS – quartz and dust, d) sample Ku – quartz and soot.

Small wet samples of the collected waste were placed in plastic bags and subsequently dried under ambient laboratory conditions. The dried waste particles were placed on stubs and then photographed and analyzed for their size, shape, and composition. Optical microscopy was used for the preliminary assessment of larger particles (Figure 1) using a Zeiss Stemi 508 stereoscopic microscope. SEM-EDS examination was performed using a Hitachi S-3400N scanning electron microscope at magnifications of x50, x100, x500, x700, x1000, x2000, and x5000. Microscopic images of waste particles were acquired under a vacuum of 25–30 Pa at an electron-beam accelerating voltage of 15 kV using a backscattered electron detector (BSE). Spectrometric analysis was performed on eighteen randomly selected individual particles with grain sizes above 10 μm , as well as on ten micro-areas measuring 20×20 μm^2 containing fine dust, using an EDS system from Thermo Scientific.

Several limitations of this study should be acknowledged. First, the research was based on a relatively small number of samples. The material was collected from three streets in Cracow, with a total of four samples obtained during two sampling campaigns conducted in March and April 2025. Although the selected streets represent different traffic conditions and urban settings, the limited number of sampling locations and collection dates restricts the generalizability of the results to the entire city or to other seasons. Street cleaning residues may vary considerably depending on traffic intensity,

meteorological conditions, road surface characteristics, surrounding land use, and the time elapsed since the last street cleaning or rainfall event. Therefore, the results should be interpreted as an initial microscopic and elemental characterization of selected street cleaning residues rather than as a comprehensive and representative assessment of all urban street waste in Cracow.

Another limitation is related to the SEM-EDS analytical method. SEM-EDS is a valuable technique for identifying particle morphology and determining the elemental composition of individual particles or selected micro-areas. However, it provides primarily semi-quantitative elemental data and does not allow the direct identification of mineralogical phases or chemical compounds. The accuracy of EDS analysis may also be affected by particle geometry, surface roughness, sample heterogeneity, matrix effects, and the small analyzed area. Moreover, light elements may be detected with lower accuracy, whereas elements present at very low concentrations may remain below the detection limit of the method.

In this study, EDS measurements were performed on randomly selected particles larger than 10 μm and on selected micro-areas containing fine dust. As a result, the obtained data describe the composition of analyzed particles and micro-areas but may not fully represent the bulk chemical composition of the entire sample. The lack of prior separation of the whole material into particle-size classes allowed the residues to be analyzed in a form closer to their actual collected state;

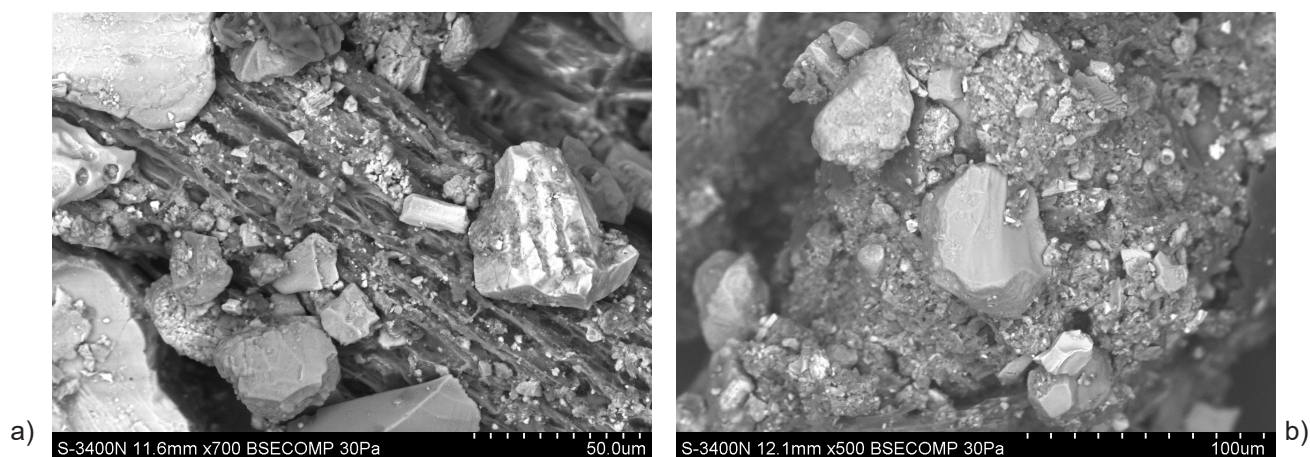


Fig 2. BSE waste microstructure images: a) sample SS at nominal magnification of x700, b) sample Ku at nominal magnification of x500 indicating fine-grained irregular-shape particles into dust background.

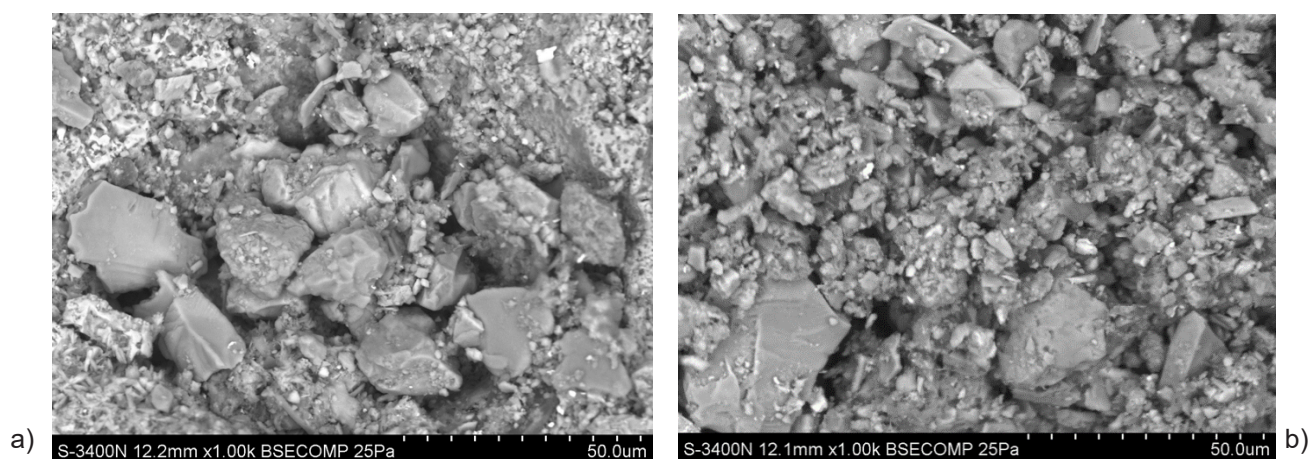


Fig 3. BSE waste microstructure images: a) sample Kr24z, b) sample Kr24s at nominal magnification of x1000 indicating clumped particles into loose dust.

however, it also limited the possibility of directly comparing the chemical composition of strictly defined particle-size fractions. Consequently, the findings should be regarded as indicative of compositional trends and particle-level variability rather than as a comprehensive quantitative geochemical characterization of street cleaning residues. The presented study is preliminary, and future research should include a larger number of samples collected different seasons and complement SEM-EDS with additional analytical techniques, such as XRD analysis, ICP-OES/ICP-MS, and sieve analysis.

Results and discussion

The research aimed to characterize the particle size and chemical composition of waste collected from urban streets and, subsequently, to indicate its potential negative impact on the environment and the associated consequences for human life and health. The results were presented accordingly.

Drying the waste samples under ambient laboratory conditions produced samples of good quality in terms of their final moisture content and granulation. Figures 1a and 1b clearly shows that the street-spraying technology enables the street sweeper to separate quartz particles and dust particles *in situ*, while the sweeper is collecting street sweepings.

Table 2: Grain-size estimation in sweepings samples using optical and electron microscopes.

No.	Sample	Coarse-grained fraction (mm)	Fine-grained fraction (mm)	Compact dust particles (μm)	Loose dust particles (μm)
1	Kr24z	0.8; 0.6; 0.3	< 0.2 (sand)	< 50	< 10
2	Kr24s	—	—	< 50	< 10
3	SS	1.0; 0.7; 0.4	< 0.2	< 50	< 10
4	Ku	< 0.8	< 0.2 (coal)	Inclusions in coal	< 10

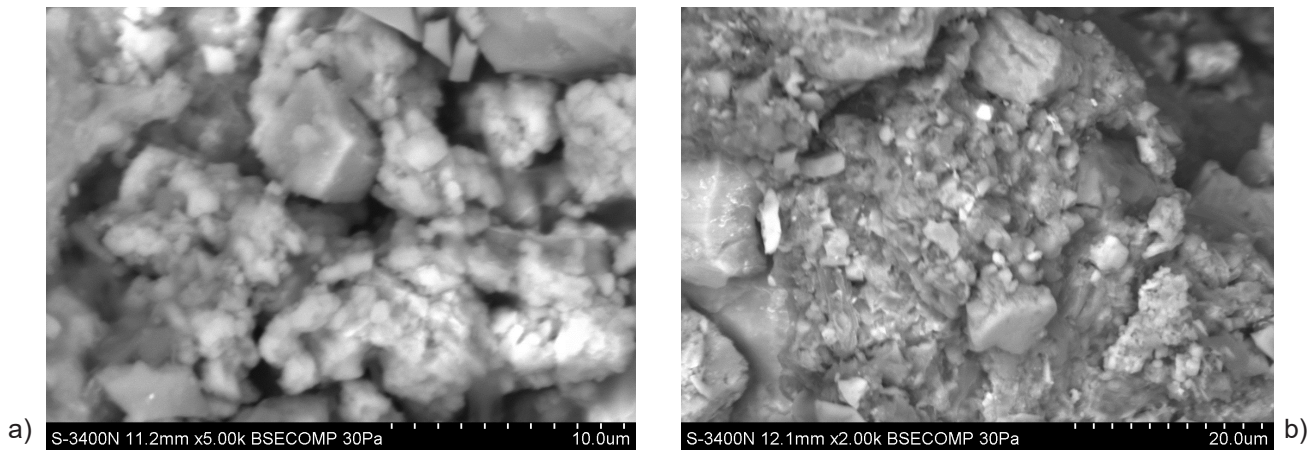


Fig 4. BSE waste microstructure images: a) sample SS at nominal magnification of x5000, b) sample Ku at nominal magnification of x2000 indicating particles of sizes below 5 µm.

The following characteristics of the collected samples were observed: the street sweepings sample Kr24z was composed mainly of quartz with different particle sizes (max. grain size of 0.8 mm), whereas sample Kr24s contained only the fine dust fraction (max. particle size of 50 µm). The particulate matter was classified into four particle-size fractions (Table 2) by measuring particles in BSE images acquired at seven different magnifications ranging from x50 to x5000.

Based on the examination of the microstructure of the street waste, BSE images of the sweepings were obtained at magnifications that allowed their visual classification into particle-size classes (Figures 2–4). The corresponding energy-dispersive X-ray (EDS) spectra (Figure 5) were then used to determine the elemental composition of selected micro-areas within the samples (Table 3–6).

According to Table 2, the coarse-grained fraction included all particles in the range of 0.2–1.0 mm. Particles with sizes ranging from 50 to 200 µm were classified as the fine-grained fraction (Figure 2). Compact dust consists of particles in the size range of 10–50 µm (Figure 3), whereas particles smaller than 10 µm were classified as loose dust (Figure 4). Morphologically, the dust particles are non-spherical. The ultrafine particles have

dimensions of approximately 0.5 µm. Based on this visual classification of particle-size fractions, elemental composition analysis was then performed on randomly selected individual particles (Tables 3–5) or on micro-areas composed of dust (Table 6). Tables 3–6 present representative examples of EDS measurements (selected analyses for individual samples), whereas representative EDS spectra are shown in Figure 5. Based on simulations, it was assumed that the X-ray interaction depth for EDS is approximately 5 µm (Wassilkowska et al. 2014). Therefore particles smaller than 5 µm are too small for reliable point analysis and should instead be analyzed as part of aggregated dust micro-areas.

Regardless of the form of the analyzed samples, where sample Kr24z constituted of street sweepings and sample Kr24s consisted of wastewater from the sweeper, the dust fraction appeared similar in all cases. It contained fine agglomerates measuring 10–50 µm and particles smaller than 10 µm and was characterized by high porosity (Figure 3). In the study by Gunawardana et al. (2014), it was found that the fine particles smaller than 75 µm constitute an amorphous fraction composed of a small proportion of clay minerals, such as illite, kaolinite, and chlorite, although these minerals also

Table 3: EDS analysis of the elemental composition of the coarse grains (above 200 µm).

Test number in sample	Chemical element (weight %)												
	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
Kr24z(3)	17.8	58.4	–	–	0.2	23.3	–	–	–	0.4	–	–	–
Kr24z(15)	9.5	62.2	–	–	0.6	26.6	–	–	–	1.2	–	–	–
SS(4)	–	65.3	–	–	–	34.7	–	–	–	–	–	–	–
Ku(6)	27.3	57.1	–	–	0.3	15.3	–	–	–	–	–	–	–

Table 4: EDS analysis of the elemental composition of selected particles with dark BSE contrast of sample Ku.

Test number in sample	Chemical element (weight %)												
	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
Ku(7)	77.6	19.5	–	0.1	0.4	0.8	–	0.2	–	1.5	–	–	–
Ku(9)	86.8	12.7	–	0.0	0.1	0.3	–	0.0	–	0.2	–	–	–

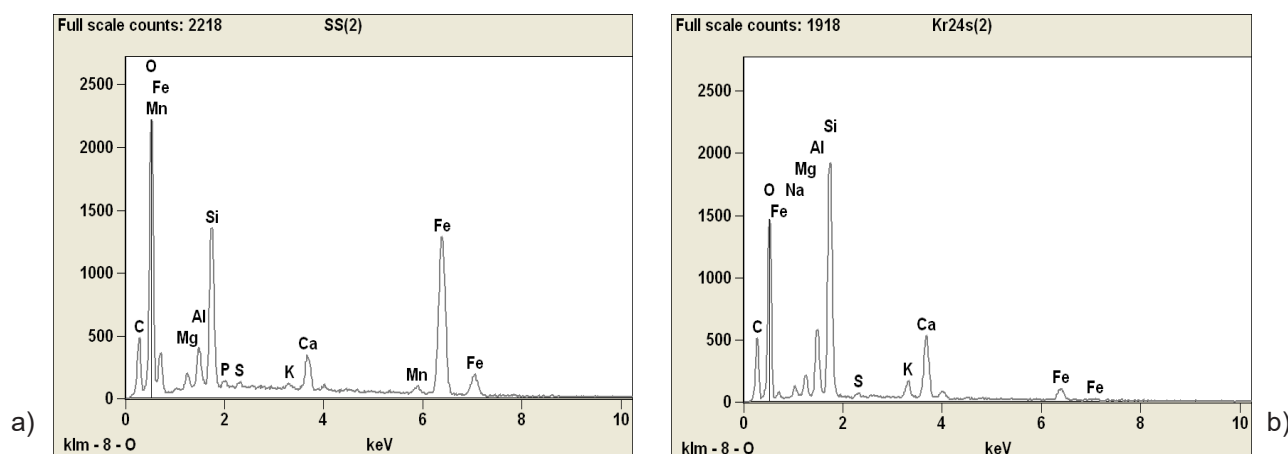


Fig 5. Examples of EDS spectra: a) from a random fine particle with bright BSE contrast, b) from the dust area of $20 \times 20 \mu\text{m}^2$.

occur in crystalline form. An important parameter governing the adsorption of pollutants by dust particles is their specific surface area, which, for particles smaller than $75 \mu\text{m}$, is four times greater than that for particles larger than $300 \mu\text{m}$.

The results of EDS measurements summarized in Tables 3–6 confirm distinct differences in the composition of the identified particle-size fractions. Based on the presence of the elements such as Si, Al, Ca, and O, it can be concluded that large particles with diameters of $0.2\text{--}1.0 \text{ mm}$ represent a mineral fraction composed of quartz (Table 3). According to Gunawardana et al. (2014), quartz is the dominant component of street sweepings with particle sizes greater than $150 \mu\text{m}$ because of its low abrasiveness. Crystalline silica is a mineral that is present in sand, rocks and construction materials. Inhalation of airborne particles containing crystalline silica, particularly those with aerodynamic diameters in the PM10 and PM2.5 size ranges, may pose a significant risk to human health.

In sample Ku, consisting of street sweepings collected from Kujawska Street, soot particles with dust inclusions

and diameters of 0.2 mm were identified. The sample was composed predominantly of carbon (Table 4). Carbon in street dust originates from both organic carbon and elemental carbon (soot), with its main sources including vehicle exhaust, tire wear particles, biomass burning, and industrial emissions. Soot is a significant component of street dust and is associated with various health hazards, such as respiratory irritation.

Fine particles with sizes ranging from 50 to $200 \mu\text{m}$ were analyzed in samples Kr24z and SS, in which this particle-size fraction was more abundant than in samples Kr24s and Ku. In addition to oxygen and carbon, these samples contained elements including Al, Ca, Fe, K, Mg, Mn, and Si, whereas sample SS also contained Ti (Table 5). As shown in Table 5, these elements occur mainly in the form of calcium, iron, and silicon oxides, with occasional occurrences of Mn, S and P.

Calcium is a naturally occurring element commonly found in building materials, such as cement. Calcium-containing compounds, such as CaCO_3 , CaSO_4 , and CaO , are common constituents of dust (Yang et al. 2016). Calcium phosphate in the form of hydroxyapatite ($\text{Ca}_5(\text{PO}_4)_3(\text{OH})$) has been

Table 5: EDS analysis of the elemental composition of grains with size fraction $50\text{--}200 \mu\text{m}$.

Test number in sample	Chemical element (weight %)												
	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
Kr24z(1)	37.1	39.5	—	0.9	1.1	6.8	—	—	0.3	5.6	—	1.1	7.6
Kr24z(2)	33.3	49.5	—	0.3	0.6	2.2	—	—	—	13.2	—	—	0.8
Kr24z(4)	23.5	42.3	—	1.5	0.3	8.6	0.4	—	—	10.7	—	4.5	8.1
Kr24z(5)	32.1	35.8	—	0.4	2.2	8.4	—	0.2	0.5	12.2	—	0.7	7.5
Kr24z(6)	37.6	49.4	—	0.1	0.4	5.7	—	—	—	6.7	—	—	0.0
Kr24z(9)	35.8	47.9	—	0.3	1.1	2.6	—	0.1	0.2	11.4	—	—	0.7
Kr24z(14)	19.9	37.6	—	0.8	2.3	9.0	0.6	—	0.2	17.6	—	1.3	10.8
Kr24z(16)	36.3	48.4	—	2.7	0.7	2.2	—	—	0.1	8.9	—	—	0.7
SS(2)	32.1	31.0	—	0.4	1.0	3.9	0.2	0.1	0.2	1.7	—	1.0	28.5
SS(7)	35.9	38.9	—	1.2	0.9	2.8	—	0.1	0.2	3.6	4.0	—	12.4
SS(9)	23.9	44.5	—	0.0	0.9	1.9	—	—	0.1	0.3	7.5	—	21.1
SS(11)	25.0	35.7	—	0.3	0.8	3.3	—	—	—	0.7	—	—	34.3

Table 6: EDS analysis of the elemental composition of the dust fraction.

Test number in sample	Chemical element (weight %)												
	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
Kr24z(10)	44.3	39.6	0.2	0.5	2.3	7.6	–	0.1	0.5	2.7	–	–	2.4
Kr24z(13)	35.6	43.5	0.1	0.5	2.5	10.3	–	0.2	1.0	3.6	–	–	2.8
Kr24s(1)	64.3	28.6	0.2	0.3	0.9	2.6	–	0.2	0.2	1.4	–	–	1.3
Kr24s(2)	43.6	37.7	0.5	0.7	2.1	7.2	–	0.2	0.9	4.3	–	–	2.9
Kr25s(4)	40.0	41.7	0.5	0.8	2.1	7.6	–	0.3	0.8	3.6	–	–	2.7
Kr25s(6)	41.0	40.7	0.5	1.0	2.7	7.3	–	0.3	0.8	3.5	–	–	2.4
SS(3)	50.4	37.1	0.2	0.2	0.8	6.3	0.1	0.1	0.4	3.0	–	–	1.4
SS(6)	64.7	31.1	0.1	0.2	0.4	2.3	0.1	0.1	0.2	0.6	–	–	0.5
Ku(2)	66.0	29.3	0.1	0.2	0.5	2.2	–	0.1	0.2	1.0	–	–	0.5
Ku(10)	46.8	35.3	0.9	0.4	2.8	8.4	–	0.3	0.3	3.0	–	–	1.9

identified in aerosolized dust samples with particle sizes of 30–90 nm and a spherical morphology (Yang et al. 2016). Iron is a common element present in the environment as a result of corrosion processes. Aluminum is one of the most abundant inorganic elements in the Earth's crust, along with calcium, magnesium, potassium, and sodium. However, in the study by Skorbiłowicz and Skorbiłowicz (2019), aluminum was not identified as a component of street sweepings.

Manganese is a component of fine dust particles (50–200 μm), which consist of a mixture of dirt, tire wear debris, and road surface material. Sulphur originates from vehicle exhaust emissions and the wear and tear of vehicle parts such as tires and brakes. Phosphorus is derived primarily from leaf litter and other organic pollutants. Potassium is a naturally occurring crustal element but may also originate from anthropogenic sources, such as construction activities or the decomposition of organic materials. Titanium dioxide is added to concrete and asphalt road surfaces as a photocatalyst to reduce air pollution (e.g., volatile organic compounds), when exposed to sunlight.

Based on the SEM examination, it was concluded that the dust fraction consists of irregular particles with dimensions smaller than 50 μm . Since the dust occurred in both agglomerated and loose forms, morphologically homogeneous areas measuring $20 \times 20 \mu\text{m}^2$ were selected for EDS analysis. These micro-areas contained clusters of particles smaller than 10 μm , including ultrafine particles with dimensions of approximately 0.5 μm . The EDS results are summarized in Table 6. Similar elemental compositions (expressed as averaged weight percentages) were found in all analyzed samples. The average contents were approximately: Si – 6.2%, Ca – 2.7%, Fe – 1.9%, Al – 1.7%, Mg – 0.5%, K – 0.5%, Na – 0.3%, S – 0.2%, C – 49.7%, O – 36.5%, and P – 0.1% (detected only in sample SS). The conducted study indicates that Na was detected only in the dust fraction. Sodium-containing compounds are natural components of asphalt and engine oil. As these materials undergo mechanical wear, they break down into smaller particles that become mixed with street dust. By removing sodium-containing particles together with other pollutants, street sweepers prevent their transport

into stormwater drainage systems and surface waters, thereby reducing environmental pollution.

Heavy metals associated with road traffic, such as those originating from tire wear, including Cu, Zn, Ni, and Pb, have often been detected in EDS studies (Gunawardana et al. 2014, Generowicz et al. 2020). In the present EDS analysis (Figure 5), however, these elements were missing in either the fine-grained fraction or the dust fraction (Table 5–6), which may be related to the detection limit of 0.1 weight % for multicomponent, porous materials.

Street sweepings pose a threat to the natural environment, including water, soil, and human health, when their mineral fraction is contaminated with harmful substances. Based on the present analysis of street sweepings collected from three streets in Cracow, it was found that the key components, including Fe, Mn and Ca, occurred predominantly in particles larger than 50 μm , whereas the dust fraction also exhibited relatively higher contents of S and Na.

Conclusions

Street sweepings collected from the city streets were classified into particle-size fractions using the magnification scale on the BSE images obtained by scanning electron microscope. Dust particles with sizes of approximately 50 μm exhibited irregular shapes and were embedded in a background matter composed of particles smaller than 10 μm . The dust fraction containing particles smaller than 10 μm consisted of Si, Al, Fe, Ca, Na, Mg, S, and K. EDS measurements of selected micro-areas showed that particles in the size range of 50–200 μm were characterized by higher contents of Si, Ca, and Fe and occasionally contained Mn, most likely in the form of oxides. The heavy metals identified in the analyzed samples included Fe and Mn, whereas the light metals included Al and Ti. The presented SEM-EDS analysis demonstrated that modern sweepers are capable of effectively removing dust fractions smaller than 10 μm from streets. These particles may act as carriers of heavy metals and organic pollutants.

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Badania właściwości odpadów pochodzących z czyszczenia ulic

Streszczenie. Celem niniejszego badania było zbadanie odpadów z ulic miasta (pozostałości po zmiataniu) z wykorzystaniem mikroskopii SEM-EDS. Odpady zebrano z ulic i chodników dużego miasta. Na podstawie uzyskanych wyników możliwa jest ocena jakości przestrzeni miejskiej. Materiał badawczy stanowiły odpady uliczne zebrane w marcu i kwietniu 2025 roku na terenie miasta Krakowa przez Miejskie Przedsiębiorstwo Oczyszczania Miasta z wykorzystaniem zmiatarek na trzech ulicach. Do wstępnej oceny większych cząstek wykorzystano mikroskopię optyczną z wykorzystaniem stereoskopowego mikroskopu optycznego Stemi 508 firmy Zeiss. Badania SEM-EDS wykonano przy użyciu skaningowego mikroskopu elektronowego Hitachi S-3400N przy powiększeniach x50, x100, x500, x700, x1000, x2000 i x5000. Rozkład wielkości cząstek poszczególnych grup frakcyjnych zawartych w zmiotkach ma kluczowe znaczenie dla opracowania koncepcji oczyszczania dla różnych klas wielkości cząstek. Na podstawie aktualnej analizy zmiotek z trzech ulic w Krakowie stwierdzono, że kluczowe składniki, takie jak Fe, Mn i Ca, występują najczęściej w cząstkach o wielkości powyżej 50 μm , a pył charakteryzuje się również wyraźnymi pikami zawartości S i Na. Przedstawiona analiza SEM-EDS dowiodła, że nowoczesne zmiatarki samochodowe są w stanie skutecznie usuwać z ulic pyły o wielkości poniżej 10 μm .