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Seasonal variability of physicochemical parameters in stormwater sediments as indicators of urban environment

Edyta Wojtaś[1*], Justyna Kujawska[1], Grzegorz Łagód[1]

[1] Faculty of Environmental Engineering and Energy, Lublin University of Technology, Nadbystrzycka 40B, 20-618 Lublin, Poland

* Corresponding author's e-mail: e.wojtas@pollub.pl

ABSTRACT

Despite the growing awareness of the impact of storm runoff on the environment, the data concerning the composition of storm sewer sediments in seasonal and spatial terms remains limited. The objective of the present study was to assess the seasonal variability of selected physicochemical parameters of sediments and to determine their potential as indicators of the urban environment. Sediment samples were collected during four seasons at five locations (W14, W43, W51, D79, D82). The following parameters were examined in the sediments: pH, electrolytic conductivity (EC), total suspended solids (TSS), turbidity (NTU), chemical oxygen demand (COD), total carbon (TC), inorganic carbon (IC), dissolved organic carbon (DOC) as well as forms of nitrogen and phosphorus. The data were then subjected to statistical processing and principal component analysis (PCA). The results demonstrated a distinct differentiation of the sediment composition, contingent on spatial location and the prevailing season. The highest levels of contamination were found in the sediment from point D82 (e.g. COD: 679.5 mgO_2/kg, TSS: 600 mg/kg, NTU: 356), particularly during the spring and autumn months. The sediment collected from point D79 exhibited the lowest and most stable values. PCA analysis demonstrated that TSS, NTU, COD, P-PO_4^{3-}, EC and DOC are the variables that contribute the most to the PCs and therefore the samples can be differentiated on the 2-dimensional PCA mapping. The stormwater system sediments can serve as an effective tool for monitoring the quality of the urban environment and as a source of information on anthropogenic pressure.

Keywords: stormwater sediments, urban pollution monitoring, seasonal variability, principal component analysis.

INTRODUCTION

The phenomenon of rainwater contamination poses a substantial challenge in the context of safeguarding the urban environment. As urbanized areas develop, an increase in the amount of pollutants is observed, which are fed into storm sewer systems and then discharged directly into water receivers, often without prior treatment. Sediments represent a pivotal component present within these systems, with the capacity to amass a diverse array of chemical, organic, and suspended substances. This phenomenon can serves as an indicator of the quality of rainwater and the magnitude of anthropogenic pressure within a specific spatial area (Piasecki and Pilarska, 2023).

The sediments from storm sewers contain a multitude of pollutants, including heavy metals, nitrogen and phosphorus compounds, organic matter, and petroleum derivatives. These pollutants primarily originate from roadways, parking lots, and roofs. The chemical composition of these deposits is found to be strongly dependent on the characteristics of the catchment area, the type of land cover, the traffic intensity, and the weather conditions, in particular the frequency and intensity of rainfall (Szatyłowicz et al., 2017; Nawrot et al., 2019). Research has demonstrated that the first-flush of stormwater typically contains elevated concentrations of pollutants, resulting in their rapid discharge into the aquatic environment at the onset of precipitation. Absent the implementation of technical devices that direct the initial flush to a municipal or stormwater treatment plant, this phenomenon poses a significant environmental concern (Review on uncertainty of the first-flush).

Urban runoff may contain the substances that pose a risk to ecosystems and human health, including organic compounds and nutrients that contribute to eutrophication and the decline in the quality of surface waters (Gajewska et al., 2024). A particular concern is the presence of sewage sediments, which has the potential to act as a vector for secondary environmental pollution, particularly in the cases where it is transferred to watercourses (Shi et al., 2018). The systematic monitoring of physicochemical parameters of sediments can provide valuable information on the sources and dynamics of urban pollution, as well as a basis for planning effective remedial actions and designing stormwater treatment facilities (Codling et al., 2020).

Dissolved organic carbon (DOC) and total organic carbon (TOC) are frequently utilized as indicators of the presence of organic matter. The content of these elements in sediments can offer an indirect assessment of the organic carbon loading of the sewage system (Niu et al., 2024). Consequently, parameters such as chemical oxygen demand (COD) and the content of ammonium, nitrate and phosphate ions provide information on the potential eutrophic pressure exerted by sediments on rivers (Moloantoa et al., 2022). It is evident that seasonal changes in rainfall intensity and frequency have a significant impact on both runoff volume and sediment chemistry, which can result in substantial variations in environmental risk between seasons. Consequently, parameters such as COD and the content of ammonium, nitrate and phosphate ions serve as indicators of the potential eutrophic pressure exerted by sediments on rivers (Müller et al., 2020). This variability underscores the necessity for regular multi-parameter monitoring, which is instrumental in supporting effective stormwater management as well as the development of locally adapted retention and purification solutions for sustainable stormwater management in urbanized catchments (Szelag et al., 2021). Consequently, effective stormwater management in urbanized areas, coupled with the judicious planning of technical solutions that align with innovative blue-green infrastructure accounting LID systems, can be supported with suitably calibrated (in terms of hydraulic parameters and stormwater quality indicators) mechanistic or probabilistic models (Fatone et al., 2021; Szeląg et al., 2024; 2022). This is of particular significance from an environmental and public health perspective, given that the accumulation of pollutants in sediments, including heavy metals, biogenic compounds, and toxic organic substances, can result in their secondary penetration into surface waters, as well as soil and air (Majewski et al., 2021). This, in turn, can increase the risk of water and costal ecosystems as well as, in consequence human exposure to harmful compounds.

Despite the growing awareness of the impact of stormwater runoff on the environment, the data on the composition of sediments in different spatial locations and overtime are still limited. The objective of the present study was to evaluate the seasonal variability of selected physicochemical parameters of stormwater sediments, and to ascertain their potential as indicators of hazards in urbanized environments.

MATERIALS AND METHODS

The study involved the sediments collected from gravity storm sewers. The sediments were collected on the campus of the Lublin University of Technology (Figure 1). The stormwater network on the university grounds has been measured at a total length of 2501.70 m. Stormater is fed to the Bystrzyca River through channels with a diameter ranging from 0.160 m to 0.5 m. On the basis of the inventory, the network consists of 144 manholes with a depth ranging from 0.54 m to 6.00 m and 73 inlets. Sediments were collected from the bottom of the channels using a flat blade on a handle, from both manholes and storm inlets. A total of six sets of sediment samples were analyzed for qualitative purposes: three sets were obtained from manholes, and three from storm inlets. The samples were collected in 2024, on a quarterly basis. Each analysis was performed five times to ensure the repeatability and reliability of the results.

Sample preparation and water extraction

In order to determine selected physicochemical and chemical parameters in the sediments, a simplified leaching method was employed, as described in the work of Duda-Saternus et al. (2023), in accordance with the PN-EN 12457-2:2006 standard (Duda-Saternus et al., 2023). The selection of this method was made on the basis of its simplicity and the expediency of its execution. In the context of evaluating sediments from combined and storm sewers, which are in

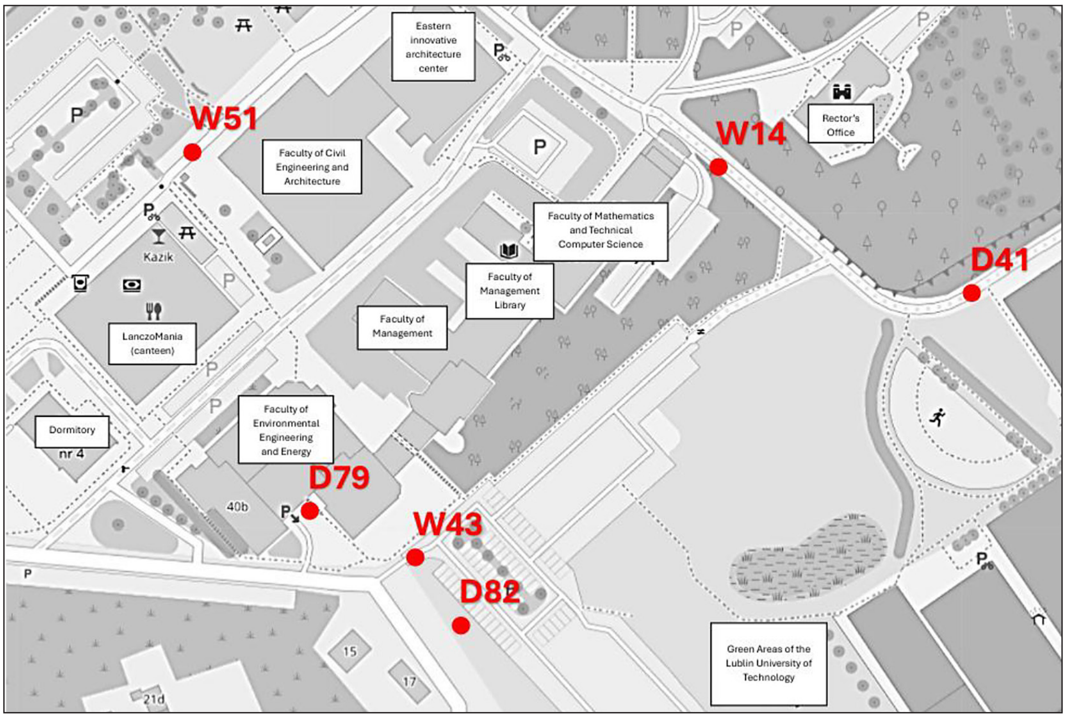

Figure 1. Sediment collection points from stormwater system (Streetmap.pl. https://www.streetmap.pl/topo/) The characteristics of the points collected for analysis are as follows: Inlets: W14 – access road to the sports hall of Lublin University of Technology; W43 – entrance to the parking lot of Lublin University of Technology; W51 – parking lot in front of the Faculty of Civil Engineering and Architecture; Wells – D79 – entrance to the parking lot of the Faculty of Environmental Engineering and Energy; D82 – parking lot behind the Faculty of Management of Lublin University of Technology; D41 – access road to the sports hall of Lublin University of Technology

most cases strongly heterogenous matrices, there is currently a paucity of clearly recommended analytical methods.

A quantity of 100 g of the sediment sample was weighed into conical flasks, followed by the addition of 900 ml of ultrapure water (Mili-Q, Millipore, USA). This resulted in a ratio of L/S equal to 10. The mixture was subjected to a 24-hour shaking process at a frequency of 100 rpm using an orbital shaker (SI 500, Stuart, Great Britain). Following the conclusion of the extraction process, the liquid phase was separated from the sediment. Depending on the type of planned analyses, the water extracts were then subjected to further processing in accordance with the requirements of the PN-EN 12457-2:2006 standard. Centrifugation was employed to purify a subset of the samples (MPW-223 centrifuge, MPW, Poland; 4000 rpm, 20 minutes), after which filtration was conducted through membrane filters with a pore diameter of 0.45 μm. In the case of other analyses, the samples were collected after a brief settling of heavy fractions, with no additional centrifugation.

The scope of physicochemical analyses

Physicochemical analyses were conducted in accordance with the applicable research procedures. The summary of these procedures is presented in Table 1. In order to ensure the reliability and repeatability of the results, all determinations were performed in five repetitions.

Data analysis methods

In order to reduce the number of variables and identify the main sources of variability in the environmental data set, principal component analysis (PCA) was used. PCA is a method of exploration statistical analysis that allows the transformation of the original set of correlated variables into a new coordinate system created by uncorrelated principal components (PC), while preserving as much of the information contained in the original data as possible.

Prior to the initiation of the analysis, the data underwent standardization, a process that entailed the transformation of the values for each variable into a form with a unit standard deviation and

Table 1. Methods for assessing the physicochemical quality of storm sewer sediments

Parameter to be denoted	Method	Device	Identification of the test method
pH	Potentiometric	CPC-501, ELMETRON, Polska	PN-EN ISO 10523:2012 *Water Quality - pH Determination*
Conductivity	Conductometric	Orion VerseStar Thermo Scientific	PN-EN 27888:1999 *Water Quality - Determination of Electrical Conductivity*.
Turbidity	Nephelometric	Waterproof TN-100 Turbidimeter, EUTECH INSTRUMENTS, Singapur	PN-EN ISO 7027-1:2016-09 *Water quality - Turbidity determination - Part 1: Quantitative methods*
Suspension	Spectrophotometric	DR 6000, HACH Lange, USA	Methodology applied in the device.
$N\text{-}NO_3$,	Application HACH-LANGE		Method No. LCK 339(0,23-13,5mg/l)
$N\text{-}NO_2$			Method No. LCK 341(0,015-0,6mg/l)
$N\text{-}NH_4$			Method LCK 304 (0,15-2,50mg/l)
N total			Metoda LCK 304 (0,15-2,50mg/l)
$P\text{-}PO_4$			Method No. LCK 349(0,05-1,50mg/l)
ChZT	Dichromate (cuvette tests)		PN-ISO 6060:2006 *Water Quality - Determination of Chemical Oxygen Demand* Method LCK 314
DOC, IC, TC	Catalytic combustion	TOC-$L_{CSH/CSN}$ Shimadzu	Device application note

zero meaning. The objective of standardization was to eliminate the influence of different units of measurement and the diverse range of values of individual parameters.

The analysis was performed on a data matrix consisting of 20 samples and 13 variables describing the physicochemical properties of examined samples. The analyzed data comprised parameters such as pH, EC, $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $P\text{-}PO_4^{3-}$, NTU, and DOC, TC, IC, across diverse seasonal periods (VI, IX, XI, III). The analysis was conducted utilizing Statistica 13.3 (TIBCO Software Inc.). The initial two principal components were utilized to visualize the data in the form of a biplot, which concurrently demonstrates the distribution of samples in the reduced dimension space as well as the directions and strength of the influence of individual variables.

RESULTS AND DISCUSSION

Physicochemical indicators represent a fundamental set of parameters utilized in the evaluation of the quality of rainwater and sediments from storm sewers, as well as surface waters. The analysis provides information not only about the current state of the environment but also demonstrates the strength and variability of the impact of human activity in urban areas. The presence of significant seasonal and spatial variations in the parameters examined in sediments necessitates continuous monitoring to accurately assess environmental contamination (Carrillo et al., 2021).

As demonstrated in Figure 2, pH and electrolytic conductivity (EC) values are pivotal in characterizing the chemical conditions of sediments and their potential influence on contaminant mobilization processes.

Across all the examined points, the pH values of the sediments were found to be within the slightly acidic to neutral range (6.5–7.5), which is indicative of sediments found in urban environments. It has been demonstrated that such conditions are conducive to maintaining the balance between the ionic forms of many pollutants, including heavy metals and biogenic compounds (Gasperi et al., 2014). The highest pH levels were recorded in sediments collected from points W51 and D82, with values reaching up to 7.55. This is likely attributable to the presence of alkaline mineral particles, such as cement dust or calcium compounds (Krimsky et al., 2021).

Greater disparities in values were observed in electrolytic conductivity values, which is an indicator of salinity and the presence of dissolved inorganic ions. The EC values of the sediments from the storm sewer ranged from 123.8 $\mu S \cdot cm^{-1}$ (D82, VI) to 1004 $\mu S \cdot cm^{-1}$ (W51, VI). The elevated EC values detected in the sediment samples from point W51 could be indicative of the presence of road salt residues utilized during the winter season, along with other chemical compounds that have been removed from paved surfaces, such as cleaning agents or fertilizers. It was observed

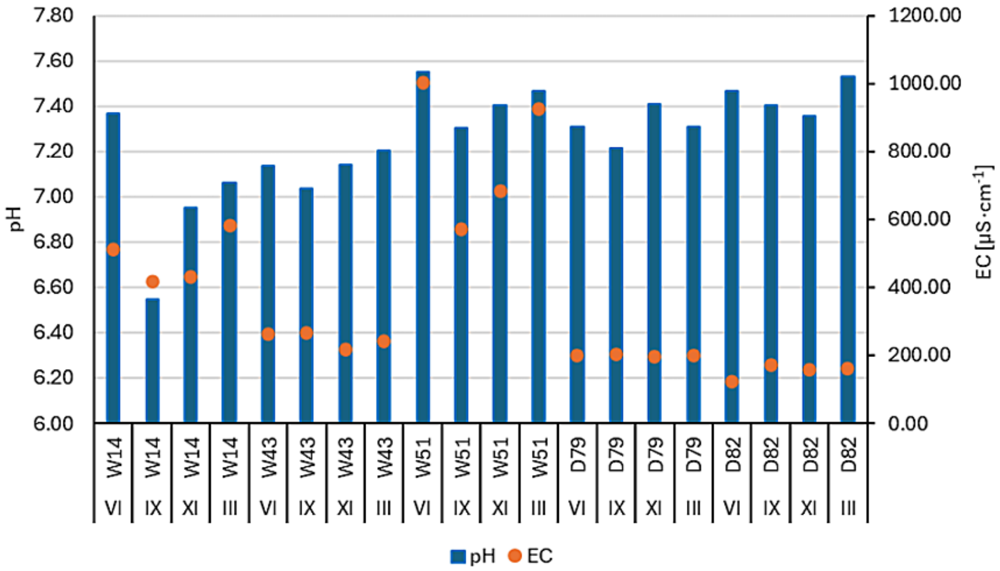

Figure 2. The pH and EC values of stormwater sediments

that the sediments collected at point W14 exhibited high conductivity levels, with measurements reaching up to 581.13 $\mu S \cdot cm^{-1}$ in March. This finding suggests the potential accumulation of ionic compounds during the winter-spring season, a phenomenon that has also been documented in the study conducted by Smith et al. (2020). The study noted an increase in conductivity following the application of winter salt, which supports the hypothesis that seasonal variations in conductivity may be attributable to changes in ionic composition (Smith et al., 2020).

The sediments collected from sites D79 and D82, which exhibited the lowest EC values (mean ~160–200 $\mu S \cdot cm^{-1}$), may be attributable to reduced exposure to road pollution or the efficacy of sediment retention within the sewage system. Smith et al. (2020) posited that settling sites located in less intensively used urban areas exhibit lower EC and more stable chemical conditions (Smith et al., 2020).

The highest EC values in storm sewer sediments were most often recorded in the spring period (III), which suggests the washing out and subsequent accumulation of road salts and soluble compounds following the winter season. This finding lends further credence to the notion that transition periods – characterized by the shift from winter to spring – represent pivotal moments with regard to the chemical loading of storm sewers (Gao et al., 2023).

The results of the total suspended solids (TSS) and turbidity (NTU) tests on storm sewer sediments revealed significant differences both between measurement points and in the individual seasons (Figure 3). TSS and NTU are indicators of the presence of solid particles in the sediments and their potential impact on the quality of receiving waters, especially in terms of pollution related to road traffic and surface runoff. The TSS values were found to be highly variable, ranging from 9 to 600 $mg \cdot kg^{-1}$ DM (averaging 144.8 $mg \cdot kg^{-1}$ DM) across individual samples. The observed substantial variations in the concentration of suspended solids may signify episodic runoff of rainwater with a high load of suspended material. This phenomenon is most likely associated with the "first flush effect", which refers to the intensive flushing of pollutants accumulated on hardened surfaces during the initial phase of precipitation (Mamun et al., 2020).

The turbidity, indicative of the presence of particulate matter and suspensions, exhibited a range from 5.36 to 356 NTU, with an average of 94.8 NTU. It is hypothesized that elevated turbidity levels in storm sewer sediments may signify a considerable risk of introducing both mechanical pollutants and those associated with the colloidal fraction, including heavy metals or organic micropollutants, into water receivers (Zgheib et al., 2012).

The sediments collected from point D82 exhibited elevated concentrations of both TSS and NTU, with levels reaching 600 $mg \cdot L^{-1}$ of suspended solids and 356 NTU of turbidity in September. The presence of such elevated concentrations is indicative of the fact that the turbidity of the sediments is predominantly determined by the

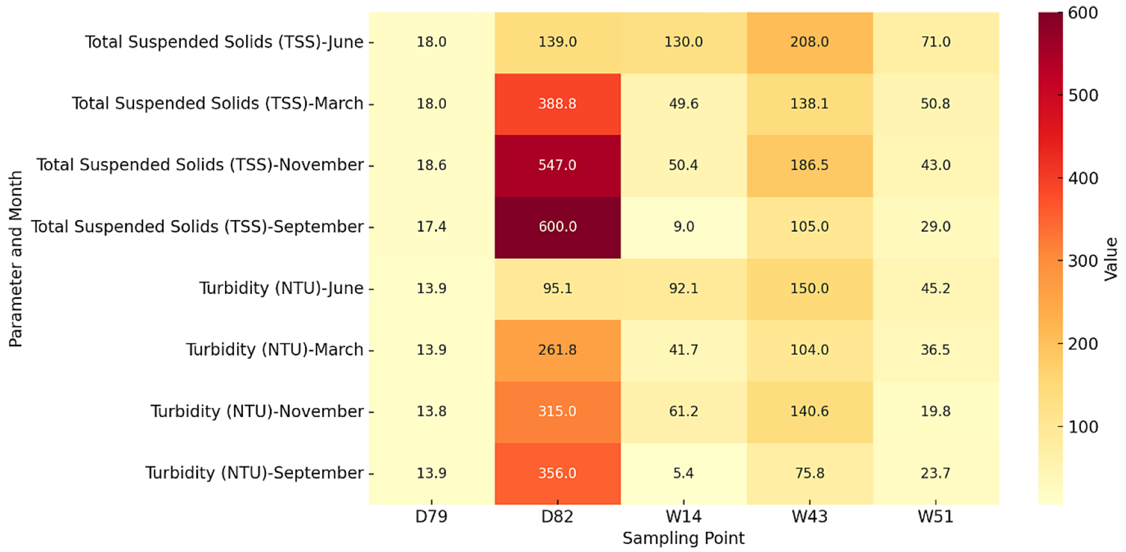

Figure 3. Heatmap of TSS and NTU in stormwater sediment samples

content of solid particles. This finding is consistent with the results of previous research on the mechanisms of pollutant transport in rainwater (Niu et al., 2024).

The sediments from point D79 exhibited the lowest and most stable values of the tested parameters, irrespective of the month in which the tests were conducted. TSS remained at a level of approximately 18 $mg \cdot L^{-1}$, and turbidity did not exceed 14 NTU. The constancy in the quality of the sediment may be attributable to enhanced isolation of the site from anthropogenic sources or the more efficacious deposition of suspensions in the sewage system prior to the sampling point (Regueiro-Picallo et al., 2020). Consequently, this point can be utilized as a reference, thereby representing sediments with a low level of contamination.

The seasonality of TSS and NTU values of sediments is noticeable at all points: the highest occurred in summer and autumn (VI, IX), while the lowest in winter or early spring (III). According to the research of Smith et al. (2020), this type of seasonal increase in suspended pollutants is associated with higher precipitation intensity, intensive use of urban spaces in the warmer months, as well as increased surface erosion due to changes in temperature and humidity (Smith et al., 2020).

Sediments from storm sewers can be regarded as significant indicators of the quality of the urban environment and potential sources of secondary pollution. A comprehensive assessment of the origin, composition and potential environmental impact of organic and inorganic matter accumulated in urban drainage systems can be enabled by analysis of selected physicochemical parameters. Such parameters may include COD, TC, IC and DOC. Determining the concentration of COD, TOC, IC in storm sewer sediments is a method of determining the level of organic and inorganic contamination. This, in turn, reflects the potential oxygen depletion that may be caused by these materials if they are transferred to surface waters (Lv et al., 2024). Elevated COD values are frequently associated with the presence of anthropogenic pollutants, including hydrocarbons, detergents and other pollutants from industrial activities or road traffic (Müller et al., 2020). TC values are indicative of the total carbon content, whereas IC values predominantly reflect carbonates and bicarbonates, typically of geological or construction material provenance (Jude et al., 2024). DOC concentration values are a pivotal indicator of the presence of dissolved organic matter in the sediments of urban drainage systems and have a direct impact on greenhouse gas emissions as well as the quality of receiving waters (Niu et al., 2024).

The values of COD, TC, IC, and DOC in storm sewer sediments demonstrated variations both in relation to the location and the time of conducting the tests (Figure 4).

The highest values of the parameters under study were recorded in the sediment collected from point D82. In September, the sediment was characterized by a maximum concentration of COD (679.54 $mgO_2 \cdot kg^{-1}$), indicating a significant load of sediments with organic substances highly susceptible to chemical oxidation. As demonstrated by Niu et al. (2024), the concentration of DOC in the sediments of street inlets exhibits significant variations, contingent on the specific function of the area in question. The highest concentrations of DOC were recorded in sediments situated near primary roadways (Niu et al., 2024).

The sediment collected from point D79 exhibited the lowest and most stable value of all the analyzed indicators. The absence of substantial seasonal variations, coupled with the relatively low concentrations of COD, TC, IC and DOC (with a mean COD of approximately 38 $mgO_2\ kg^{-1}$), implies that this region is less susceptible to surface pollution and that the drainage system is effective in fulfilling its retention and sedimentation functions. The sediment from site D79 exhibits the characteristic features of sediments from low-traffic areas, as evidenced by the findings of studies conducted in China on campus sites (Niu et al., 2024).

Conversely, the sediments collected from point W14 exhibited the most significant seasonal fluctuations, particularly about COD (180–386 $mgO_2 \cdot kg^{-1}$), suggesting a variable load on the sewage system attributable to the intensity of rainfall and land use during differing seasons.

Regarding seasonality, the highest concentrations of COD and IC were observed in the studied sewage sediments during summer and autumn (VI and IX, respectively). This phenomenon can be attributed to the heightened accumulation of pollutants on urban streets during periods of dry weather, followed by their mobilization during the initial intensive rainfall that occurs after a period of drought.

The analysis of nitrogen and phosphorus concentrations in storm sewer sediments enables the estimation of the potential risk of eutrophication of receiving waters and identification of the areas with increased nutrient load. The contents of phosphorus and nitrogen forms collected over a period of four seasons from five measurement points (W14, W43, W51, D79, D82) demonstrate clear variations both in time and space, as illustrated in Figure 5.

Research findings have indicated that the sediments from point D82 exhibited the highest concentrations of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ ions. This observation lends further credence to the hypothesis that these sediments contain elevated levels of nutrients. High concentrations of the ions were observed in the spring and autumn seasons (up to 9.7 $mg \cdot kg^{-1}$ for ammonium ions and 8.8 $mg \cdot kg^{-1}$ for nitrate ions). These findings are consistent with the results of Smith et al.

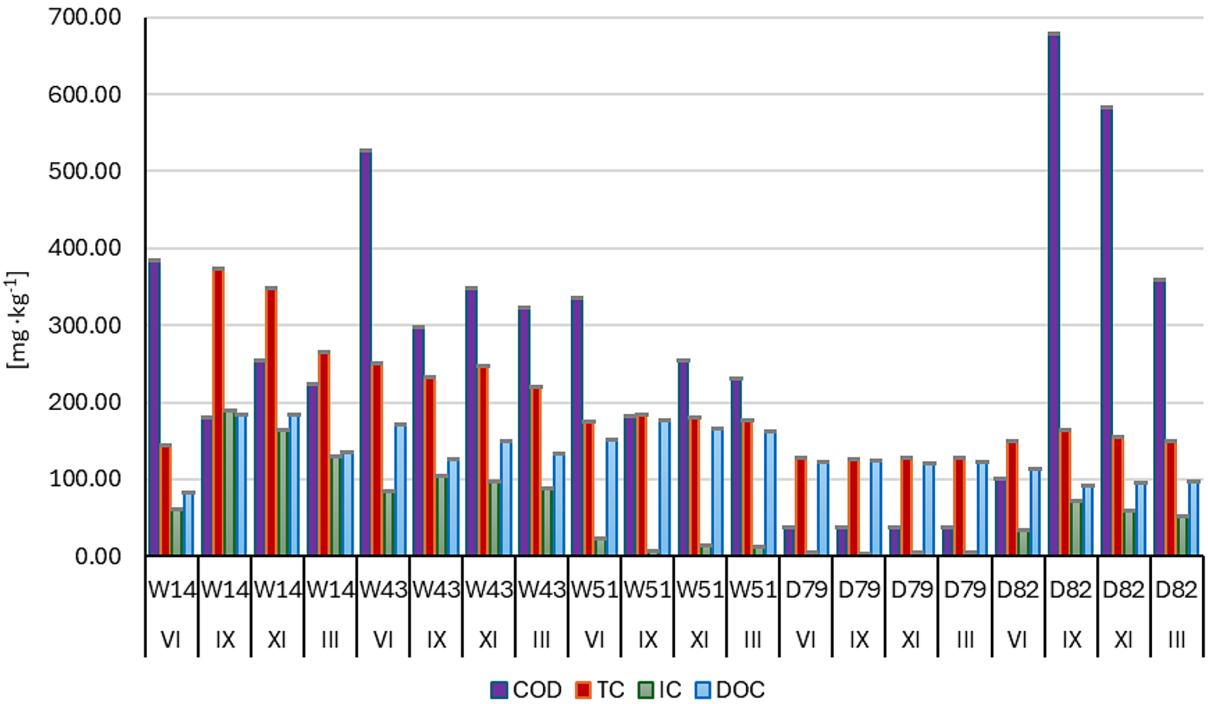

Figure 4. Values of COD, TC, IC, DOC in stormwater sediment samples

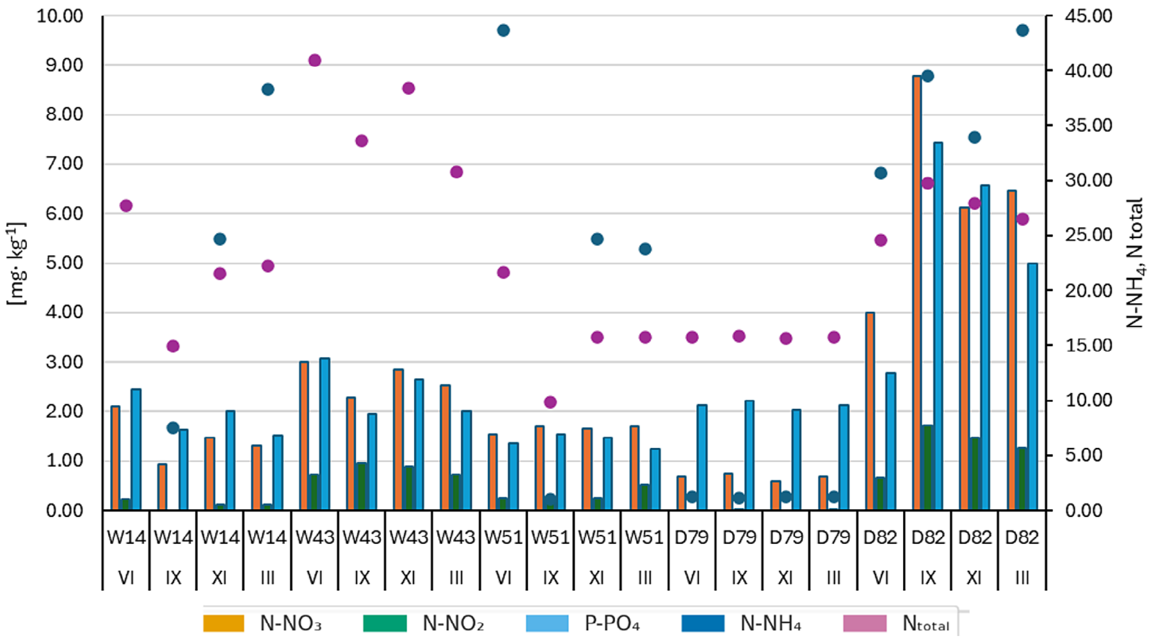

Figure 5. Values of concentrations of nitrogen and phosphorus forms in stormwater sediment samples

(2020), who found that in spring, the concentrations of total nitrogen and organic nitrogen were higher than in summer and autumn. This phenomenon can be attributed to two main factors: the intensive use of fertilizers during the spring period, and the occurrence of "hot moments", defined as short-term, intensive nutrient runoff following periods of drought (Smith et al., 2020). Moreover, the research conducted by Niu et al. (2024) has demonstrated that ammonium forms predominate in the sediments collected from storm sewer systems. This phenomenon can be attributed to the rapid decomposition of organic matter in environments characterized by limited oxygenation (Niu et al., 2024).

Regarding nitrate concentration, the highest values were also found in the sediment from point D82, where the concentration in September was 8.78 mg kg^{-1}, which may suggest intensive nitrification occurring in the periods between rainfalls. The nitrification process was also observed in analogous locations – in the transition zones between settling tanks and stormwater outlets (Liu et al., 2021). The sediment collected from site D79 exhibited remarkably low and consistent $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ concentrations throughout the year, suggesting a minimal influx of stormwater containing nutrients.

Nitrate (III) ions, representing a transitional form of nitrogen in the nitrification process, exhibited significant variation. The highest concentrations were recorded in the sediment from point D82 (1.71 mg kg^{-1} in September), which may indicate incomplete conversion of ammonia to nitrates or short-term anaerobic conditions.

Furthermore, significant variations in orthophosphate concentrations were observed among the study sites. The $P\text{-}PO_4^{3-}$ values of sediment from site D82 reached 7.44 mg·kg^{-1} in September, suggesting significant enrichment of sediments with phosphorus. This phenomenon may be attributed to the leaching of mineral fertilizers from green areas, the biodegradation of organic matter (e.g. leaves, mown grass), as well as detergent residues or chemicals flowing down from paved surfaces (Nutrient Pollution, EPA).

As demonstrated by Smith et al. (2020), total phosphorus and orthophosphate concentrations exhibit a marked increase during the spring and autumn months, particularly in the regions characterized by substantial deciduous vegetation. The primary sources of seasonal phosphorus in sediments include falling leaves, the decomposition of organic matter, and road sediments, such as those resulting from winter salt application (Smith et al., 2020).

The highest total nitrogen values were recorded in the sediments from points W43 and D82, with a maximum concentration of 40.91 mg kg^{-1} (W43, VI). A high total nitrogen content in sediments has been demonstrated to be a significant source of secondary pollution in receiving waters during periods of heavy rainfall.

Regarding seasonality, a marked increase in the concentration of nitrogen and phosphorus compounds is evident in storm sewer sediments during the summer and spring months. Smith et al. (2020) demonstrate that the highest nutrient loads in storm runoff occur in spring, even if the total amount of precipitation in the year does not differ significantly between seasons. Their research confirms that spring runoff is responsible for delivering most of the nutrients to receiving water at a key time of algal bloom development (Smith et al., 2020).

The results of the principal component analysis (Figure 6) conducted on the data from five measurement points of the storm sewer system (W14, W43, W51, D79, D82) allow for the indication of the parameters of the sediments with the most pollutants studied.

The first two principal components, designated PC1 and PC2, accounted for a cumulative 77.1% of the total data variability, with PC1 contributing 51.5% and PC2 contributing 25.6%.

In the spatial analysis of samples on the PC1–PC2 plane, a clear separation of samples was observed depending on their location and sampling date. The samples from point D82 collected in months IX and XI were in the upper right sector of the group, indicating their high content of both organic substances and nutrients. Conversely, the samples from point D79 and a proportion of those from point W51 exhibited lower values for these parameters, as evidenced by their positioning closer to the center or left part of the graph. The analysis of the clusters created by the individual measurement series taken at the analyzed points indicates the greatest variability within points D82 and W14, the average for W43 and the smallest for D79 and W51 in the subsequent seasons. one can also notice a fairly large similarity between points W14 and D82 in June.

A thorough examination of the factor loadings shown on the PCA biplot in Figure 6. Revealed connections between individual parameters in the data under consideration. The positive correlation occurred between TC and DOC, which is consistent with the fact that all these indicators refer to the level of organic matter in the samples. The parameters associated with the presence of nitrogen and phosphorus compounds exhibited a positive correlation, while their relationship with TC, IC and DOC was comparatively weaker. The results of the PCA analysis indicate that the main factors differentiating the quality of the studied sediments were the content of organic matter and the concentration of biogenic components, with clear spatial and seasonal differences.

CONCLUSIONS

The results obtained confirm that the sediments from storm sewers should be monitored

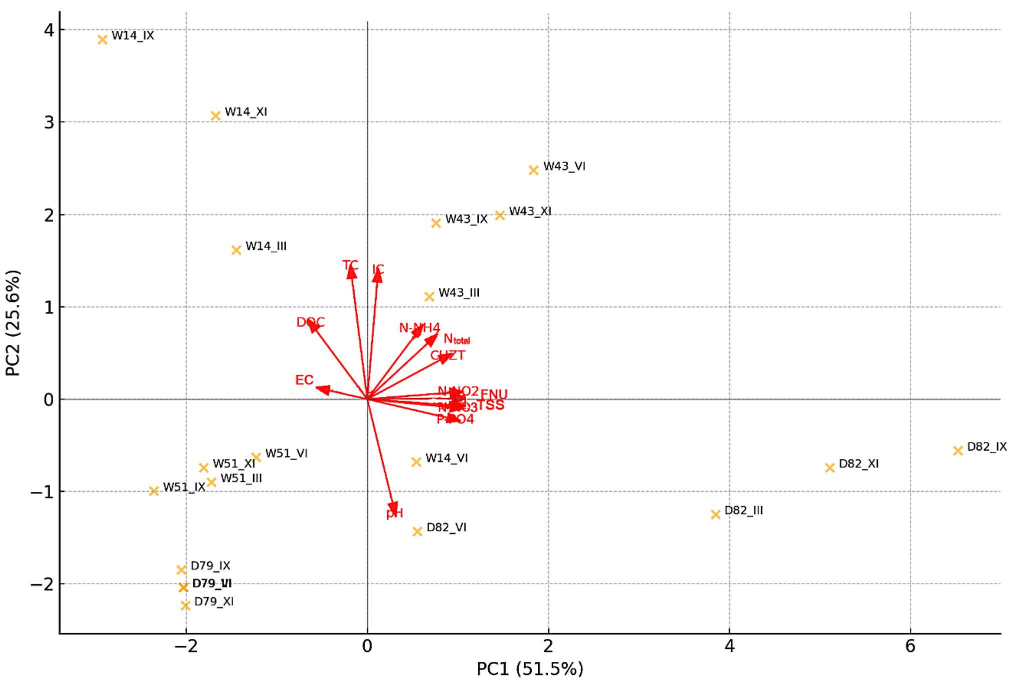

Figure 6. PCA biplot showing the arrangement of the studied sediments and the physicochemical parameters of stormwater sediments from five measurement points in different seasons

as an indicator of urban environmental pollution, and their composition provides information on potential sources and intensity of anthropogenic pressure. Particular attention was paid to parameters such as pH, electrolytic conductivity, chemical oxygen demand, total suspended solids, turbidity, forms of Carbon as well as concentrations of nitrogen and phosphorus forms, which showed high variability depending on the location and season. The highest values of the studied indicators were observed in the sediments from point D82. In turn, the sediments collected from point D79 were characterized by stable and the lowest concentrations of the analyzed pollution indicators, which suggests its potentially reference nature and the effectiveness of local technical solutions. The seasonality of sediment quality was clearly visible, especially in spring and autumn, when the highest concentrations of suspended solids, nutrients and organic matter were recorded, which is associated with intensive surface runoff after the winter period and with increased activity of urban space use.

This diversity shows the potential of using a multi-parameter approach to assess sediment quality and supports the idea of spatially differentiated management, considering local environmental conditions. Monitoring the variability of parameters of sediments from storm sewers on an annual basis not only supports the management of stormwater in cities but also provides a basis for designing more effective retention and purification solutions as well can serve as data source useful in calibrating models supporting the design and future operation. The implementation of modern solutions in the field of blue-green infrastructure and low impact development (LID) is in line with the goals of sustainable urban planning and is also an element of care for the stability of urban ecosystems.

The preliminary analyses and visualization results presented here demonstrate the potential for the utilization of the collected data in the creation of machine learning models. This, in turn, suggests the development of soft sensor solutions that predict results based on a reduced amount of input data.

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