



Application of ultraviolet absorption spectroscopy for the determination of nitrogen compounds in anthropogenically impacted surface waters: A case study of the Kłodnica River

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Abstract

Ultraviolet (UV) absorption spectroscopy is a rapid and reagent-free method for the determination of nitrogen compounds in surface waters; however, its application in anthropogenically impacted systems is limited by matrix interferences. This study evaluates the use of UVC spectroscopy for quantifying nitrogen compounds in the Kłodnica River, a watercourse strongly influenced by industrial and mining activities. Absorbance was measured at 220 nm, 235 nm, 254 nm, and 275 nm for ultrapure water, potassium nitrate reference solutions, and five river samples, both before and after filtration through a 0.45 µm membrane. Filtration enabled separation of light scattering caused by suspended particles, while multi-wavelength analysis was applied to compensate for natural organic matter interference. The results show that reliable quantification is achieved using wavelength pairs based on 220 nm, where absorbance of nitrogen compounds dominates over background effects. In contrast, measurements at 235 nm were strongly affected by matrix components, resulting in unstable correction and poor agreement with reference concentrations. Absorbance differences confirmed the influence of turbidity. A clear relationship between wavelengths enabled effective correction. The findings highlight the importance of wavelength selection and site-specific correction strategies for UV-based monitoring in complex, anthropogenically impacted waters.

1. Introduction

Monitoring of nitrogen compounds in surface waters is recognised as an important component of environmental protection and sustainable water management. Nitrogen species, particularly nitrates and nitrites, play a key role in aquatic ecosystems; however, their excessive concentrations may lead to adverse environmental effects, including eutrophication, oxygen depletion, and biodiversity loss [1–3].

In Poland, surface waters are increasingly influenced by industrial and mining activities, resulting in complex mixtures of contaminants, including nitrogen compounds and dissolved salts. Rivers located in highly industrialised regions, such as the Upper Silesian Industrial Area, receive

significant volumes of wastewater characterised by high variability in chemical composition and suspended solids content. The Kłodnica River represents a typical example of such a system, as its water quality is strongly affected by mining discharges, industrial effluents, and urban runoff. Under these conditions, the determination of nitrogen compounds becomes challenging, particularly when conventional analytical techniques are applied [4–6].

Widely used methods, such as colorimetric analysis and ion chromatography, are well established and provide high accuracy [6–8]. Standardised analytical procedures for these techniques are described in widely accepted protocols [9]. However, these approaches require laboratory conditions, involve chemical reagents, and are relatively time-consuming, which limits their applicability for *in situ*

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or high-frequency monitoring [7–10]. Consequently, there is increasing interest in alternative approaches that enable rapid, reagent-free, and potentially continuous measurements.

Ultraviolet (UV) absorption spectroscopy, particularly in the UVC range (200–280 nm), has emerged as a promising tool for the detection of nitrogen compounds in water. This technique is based on the strong absorption of nitrate ions at short wavelengths, which enables direct optical detection without the need for chemical conversion [11]. Moreover, the development of optical sensors has enabled high-frequency and *in situ* monitoring of water quality parameters, including nitrogen species [12–13].

Despite these advantages, the practical application of UV spectroscopy in natural waters is significantly hindered by matrix effects. Two main sources of interference are typically observed: light scattering caused by suspended particulate matter and absorbance associated with natural organic matter (NOM) [12, 14–16]. The latter is commonly characterised using surrogate parameters such as absorbance at 254 nm and specific UV absorbance, which are widely used indicators of dissolved organic carbon in water [17]. Both turbidity and organic matter contribute to the total measured absorbance and may lead to significant errors in nitrogen quantification if not properly corrected.

The total absorbance can therefore be expressed as the sum of contributions from nitrogen compounds, turbidity-related scattering, and organic substances:

$$A_{\lambda} = A_N + A_{\text{TURB}} + A_{\text{NOM}}, \quad (1)$$

where A_{λ} is the total absorbance at wavelength λ , A_N represents the absorbance due to nitrogen compounds (primarily nitrate and nitrite), A_{TURB} corresponds to attenuation caused by light scattering by suspended particulate matter, and A_{NOM} denotes the absorbance associated with dissolved organic matter. Each component follows the Beer–Lambert law; however, only A_N is directly related to the target analyte concentration, while the remaining terms act as interfering contributions.

The influence of these interferences becomes particularly critical in anthropogenically impacted waters, where both suspended solids and organic matter are highly variable and often elevated. In such environments, the selection of appropriate wavelengths and the application of effective correction strategies are essential to ensure reliable quantitative analysis. Previous studies have demonstrated that multi-wavelength approaches together with turbidity compensation methods can significantly improve measurement accuracy [14–16, 18–19]. However, their effectiveness strongly depends on site-specific optical properties of the water matrix, particularly the composition and transformation of dissolved organic matter (DOM) [11, 16, 20].

In this context, the present study aims to evaluate the applicability of UVC absorption spectroscopy for the determination of nitrogen compounds in the Kłodnica River. Particular attention is given to the effects of sample filtration, wavelength selection, and matrix-related interferences. The study focuses on comparative analysis of selected wavelength pairs and the development of correction approaches adapted to highly anthropogenic surface waters.

2. Study area

The study was conducted in the Kłodnica River, located in the Upper Silesian Industrial Region in southern Poland. This river is strongly influenced by long-term industrial mining and urban activities. As a result, it receives significant volumes of wastewater, including saline mine water, industrial effluents, and municipal discharges, leading to a complex and variable chemical composition.

The physicochemical characteristics of the Kłodnica River are marked by elevated concentrations of dissolved solids, the presence of suspended particulate matter, and varying levels of organic compounds. These factors significantly affect the optical properties of water and can interfere with spectroscopic measurements of nitrogen compounds.

Water samples were collected from selected locations along the river and the Gliwice Canal, which is hydraulically connected to the Kłodnica system. Five sampling points (probes 1–5) were selected to represent different hydrological and pollution conditions, including areas influenced by various types of discharge.

The spatial distribution of the sampling points is presented in Fig. 1. The selected locations (Table 1) allow for assessment of how variability in water composition affects the accuracy and reliability of ultraviolet spectroscopic measurements in complex, anthropogenically impacted environments.



Fig. 1. Spatial distribution of sampling points along the Kłodnica River, illustrating the locations selected for water sample collection.

Table 1.

Location, naming, and basic characteristics of the sampling sites along the Kłodnica River and the Gliwice Canal.

Probe	Sampling point name	Coordinate
1	Kłodnica – before the confluence with the Bytomka River	50°17'11.1"N 18°43'22.9"E
2	Kłodnica – weir near Portowa Street	50°19'52.7"N 18°37'29.1"E
3	Kłodnica – Gliwice Canal, section V, bridge on Piastów Street	50°22'19.6"N 18°34'43.5"E
4	Kłodnica – Pławniowice, bridge near Nad Kanałem Street	50°23'10.1"N 18°28'34.0"E
5	Kłodnica – Kłodnicka Street, Łany	50°23'11.5"N 18°26'05.0"E

3. Experimental setup and measurement methodology

3.1. Optical measurement system

Spectroscopic measurements were carried out using a laboratory optical system designed for UV absorption analysis of water samples [21, 22]. The configuration ensured stable irradiation, precise wavelength selection, and reliable detection of transmitted light intensity across the UV spectral range. The experimental optical setup used in this study is presented in Fig. 2.

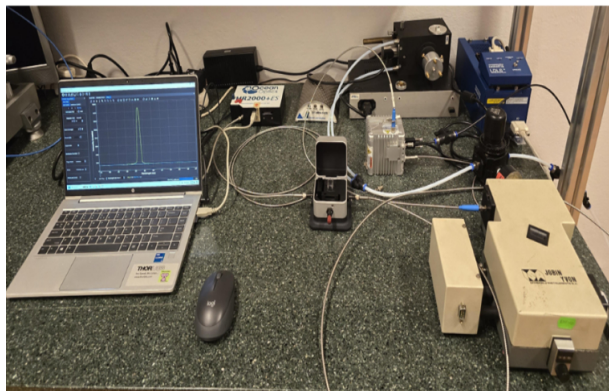


Fig. 2. Experimental optical setup used for ultraviolet absorption measurements, including the LDLS light source, Czerny–Turner monochromator, cuvette, and spectrometer.

The optical system used in this study included a high-brightness laser-driven light source (Energetiq EQ-99X LDLS) providing a broad and continuous emission spectrum from the UV to the visible and near-infrared regions (170–2500 nm). This source is characterised by high brightness and excellent temporal stability, which are essential for reproducible spectroscopic measurements.

Wavelength selection was performed using a Czerny–Turner monochromator equipped with a dual diffraction grating configuration, enabling precise isolation of narrow spectral bands. This arrangement allowed accurate adjustment of measurement wavelengths within the UV region of interest, ensuring repeatable and selective spectral acquisition.

The optical signal was transmitted through cuvettes with a fixed optical path length. The use of a constant path length ensured consistency and comparability of absorbance values across all samples.

Spectral measurements were recorded using an Ocean Optics HR2000+ES spectrometer operating within the 190–1100 nm wavelength range. The spectrometer was equipped with a detector suitable for UV measurements, enabling accurate acquisition of transmitted light intensity. The recorded transmission data were subsequently used for absorbance calculations during the data processing stage.

All measurements were performed under controlled laboratory conditions to ensure stability of the optical signal and to minimise the influence of external experimental conditions. Particular attention was given to alignment of optical components and minimisation of external interferences, allowing reliable comparison of spectral responses between reference solutions and environmental samples.

3.2. Sample preparation

Three types of samples were used in this study: ultrapure water, reference nitrate solution, and environmental water samples collected from the Kłodnica River.

Ultrapure water was used to establish the reference transmission level, while a potassium nitrate (KNO_3) solution (10 mg L^{-1}) served as a model system for nitrate absorbance under controlled conditions. Environmental samples were collected at selected sites (probes 1–5) and stored in sealed glass containers under refrigerated conditions prior to analysis.

All measurements were performed for both raw and filtered samples. Filtration was carried out using membrane filters with a pore size of $0.45 \mu\text{m}$ to remove suspended particles and reduce light scattering effects. This enabled separation of turbidity-related contributions from those associated with dissolved components, including nitrogen compounds and organic matter.

In addition, the samples were characterised physico-chemically, including determination of nitrate and selected inorganic constituents. The results, summarised in Table 2, indicate variability in nitrate concentration (approximately $2\text{--}8 \text{ mg L}^{-1}$), high levels of dissolved salts, and the presence of organic matter, as reflected by chlorophyll-a. These features highlight the complexity of the investigated water matrix and justify the application of multi-wavelength correction methods.

Table 2.
Physicochemical characteristics of selected water samples from the Kłodnica River.

Parameter	Probe 1	Probe 2	Probe 3	Probe 4	Probe 5
Nitrate	8.0	8.1	2.1	3.3	3.4
Nitrite	0.0	0.0	0.0	0.0	0.0
Chlorides	5200	2300	2700	1200	1300
Sulphates	750	620	600	390	390
Sodium	2900	1400	1800	670	760
Calcium	270	220	170	120	120
Magnesium	230	160	130	78	72
Potassium	78	57	49	30	28
Iron	0.647	0.670	0.277	0.338	0.553
Manganese	0.337	0.176	0.312	0.189	0.424
Phosphates	0.253	0.430	0.000	0.000	0.170
Chlorophyll-a*	4.4	1.2	117.5	97.2	60.5

*concentrations expressed in mg L^{-1} , except chlorophyll-a in $\mu\text{g L}^{-1}$.

3.3. Measurement procedure

Spectroscopic measurements were performed at four selected wavelengths in the UV region: 220 nm, 235 nm, 254 nm, and 275 nm. These wavelengths were chosen to represent spectral regions associated with strong absorbance of nitrate ions (220 nm and 235 nm) and absorption bands characteristic of dissolved organic matter (254 nm and 275 nm), commonly used for correction purposes.

For each sample, the measurement consisted of recording the transmitted light intensity at the selected wavelengths and calculating the corresponding absorbance values. Ultrapure water was used as a reference measurement to establish baseline transmission.

All measurements were carried out for both unfiltered and filtered samples, enabling direct comparison of the influence of suspended particulate matter on the optical response.

The selection of discrete wavelengths allowed evaluation of wavelength-dependent absorbance behaviour and assessment of the suitability of different wavelength combinations for quantitative analysis of nitrogen compounds in complex water matrices.

3.4. Data processing and correction methodology

Absorbance values were calculated from the measured transmission data using the Beer–Lambert law according to the relation:

$$A_{\lambda} = -\log_{10} \left(\frac{I_{\lambda}}{I_{0,\lambda}} \right), \quad (2)$$

where I_{λ} is the transmitted light intensity through the sample and $I_{0,\lambda}$ is the reference intensity measured for ultrapure water.

The uncertainty of each absorbance value was estimated by applying the law of propagation of uncertainty to (2). The calculation included the instrumental contributions associated with wavelength selection by the monochromator and optical-intensity measurement by the spectrometer. The resulting combined uncertainties are presented as error bars in Figs. 5 and 6. As replicate measurements were not performed, the error bars represent propagated instrumental uncertainty rather than the standard deviation of repeated measurements.

The total absorbance at a given wavelength was interpreted as a combined contribution of nitrogen compounds, suspended particulate matter, and dissolved organic substances, as discussed in section 1.

To evaluate the influence of turbidity, comparative analysis was performed for raw (unfiltered) and filtered samples. The difference between absorbance values obtained for these two sample types was used as an indicator of light scattering effects associated with suspended particles, and expressed as:

$$\Delta A_{\lambda} = A_{\lambda, \text{raw}} - A_{\lambda, \text{filtered}}, \quad (3)$$

where ΔA_{λ} represents the absorbance contribution associated with turbidity. This approach enabled qualitative assessment of the contribution of turbidity to the measured optical signal.

To reduce the influence of DOM, a multi-wavelength correction approach was applied. Absorbance measured at wavelengths sensitive to nitrate ions (220 nm and 235 nm) was analysed in combination with reference wavelengths (254 nm and 275 nm) characteristic of organic matter. Therefore, several wavelength pairs were considered, including 220/254, 220/275, 235/254, and 235/275 nm.

For each wavelength pair, a linear correction model was used in which the absorbance at the nitrate-sensitive wavelength was adjusted by subtracting a scaled contribution from the reference wavelength according to the relation:

$$A_{\text{corr}} = A_{\lambda 1} - k \cdot A_{\lambda 2}, \quad (4)$$

where $A_{\lambda 1}$ corresponds to the absorbance at the analytical wavelength, $A_{\lambda 2}$ represents the absorbance associated with organic matter, and k is the empirical coefficient describing the relative contribution of NOM to the measured signal. The coefficient reflects the optical properties of the investigated water matrix and was used to compensate for overlapping spectral contributions.

The value of the empirical coefficient k was determined using an iterative optimisation procedure. Several candidate values were evaluated, and for each value the corrected absorbance was correlated with the independently determined nitrate concentration using linear regression. The optimal coefficient was selected as the value yielding the highest coefficient of determination (R^2), indicating the best linear agreement between the corrected absorbance and the reference nitrate concentration. For the investigated water samples, the optimal value was found to be $k = 0.55$ and was therefore used throughout the subsequent analysis.

It should be noted that the selected value of k is specific to the investigated water matrix and should therefore be re-evaluated when the method is applied to other surface waters with different optical characteristics.

The relationship between absorbance and nitrate concentration was analysed using concentration values obtained independently from physicochemical characterisation of the investigated samples. This dependence was approximated using a linear model:

$$A = a \cdot C, \quad (5)$$

where A is the measured absorbance, C is the nitrate concentration, and a is the empirical coefficient. In contrast to standard calibration based on prepared reference solutions, this approach reflects real environmental conditions and inherently accounts for the influence of matrix components such as dissolved organic matter and suspended particles.

The applied data processing methodology was based on comparison of absorbance values for raw and filtered samples, estimation of turbidity influence using ΔA , correction of organic matter interference using multi-wavelength relationships, and evaluation of different wavelength pair combinations. This approach enabled assessment of matrix effects and provided a basis for identifying wavelength combinations that improve the selectivity and reliability of nitrogen determination in complex water matrices.

4. Results and discussion

4.1. Spectral characteristics of samples

The spectral characteristics of the analysed water samples were evaluated in the UV range from 200 nm to 300 nm for both raw and filtered samples. The results are presented in Figs. 3–6, which show the measured intensity distributions and corresponding absorbance values for all investigated cases, including ultrapure water, the KNO_3 reference solution, and environmental samples.

The obtained spectra exhibit a series of distinct intensity peaks corresponding to the selected measurement wavelengths (220 nm, 235 nm, 254 nm, and 275 nm), as shown

in Figs. 3 and 4. The reference signals recorded for ultrapure water and the KNO_3 solution show well-defined and high-intensity peaks, indicating stable measurement conditions and a strong optical response in the selected spectral range.

For environmental samples, a noticeable reduction in transmitted intensity is observed in comparison with the reference solution, particularly at shorter wavelengths. This effect is most pronounced around 220 nm, where significant differences between individual samples can be seen. The variability between samples decreases with increasing wavelength, and the intensity values for the different samples become more similar at longer wavelengths.

Comparison of raw and filtered samples (Figs. 3 and 4) reveals clear differences in the recorded signals. Raw samples generally exhibit lower transmitted intensity (corresponding to higher absorbance), particularly in the lower wavelength range. In contrast, filtered samples show higher transmitted intensity and a more uniform spectral response across different samples. This effect is especially visible in the region around 220 nm, where the differences between raw and filtered samples are most significant.

The absorbance values calculated for the considered wavelengths, presented in Figs. 5 and 6, confirm these observations. Because absorbance was determined only at four discrete wavelengths, the results in Figs. 5 and 6 are presented as individual data points connected by dashed guide lines. These lines are included solely to facilitate identification of data points corresponding to the same sample and do not represent measured or interpolated absorbance values between the selected wavelengths. The error bars indicate the combined instrumental uncertainty of the calculated absorbance values, estimated using the uncertainty propagation procedure described in section 3.4.

The highest absorbance is observed at 220 nm, followed by a systematic decrease with increasing wavelength. Differences between samples are more pronounced at shorter wavelengths and become less significant at higher wavelengths, where the absorbance values tend to converge.

Overall, the results indicate strong wavelength-dependent variability of the optical response and highlight differences between individual samples, as well as between raw and filtered conditions. These observations provide the basis for further analysis of matrix effects and the evaluation of correction methods presented in the following section.

4.2. Influence of matrix effects

The differences observed between raw and filtered samples, together with the wavelength-dependent absorbance behaviour presented in Figs. 3–6 indicate a significant influence of matrix effects on the measured optical signal.

Filtration resulted in a clear reduction of absorbance, most notably at 220 nm, which confirms the contribution of suspended particles to the optical signal through light scattering. The decrease in absorbance after filtration demonstrates that turbidity constitutes a major source of interference, particularly in the short-wavelength region.

At the same time, non-zero absorbance values observed at 254 nm and 275 nm for both raw and filtered samples indicate the presence of DOM. As these components remain in solution after filtration, their contribution cannot be eliminated by removing suspended particles and must be considered as a separate interference mechanism.

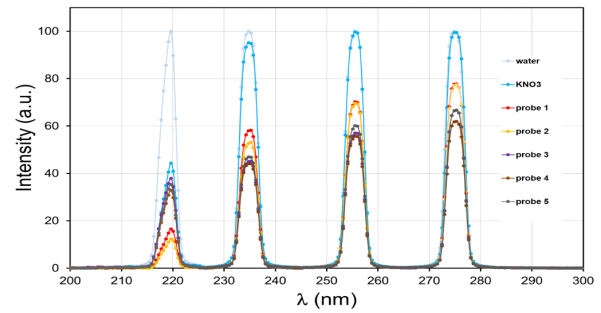


Fig. 3. Spectral distribution of transmitted light intensity for raw (unfiltered) samples.

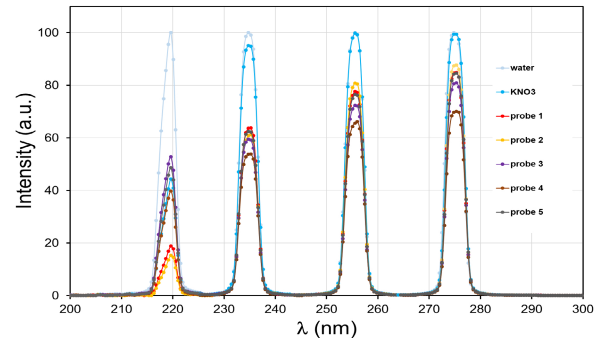


Fig. 4. Spectral distribution of transmitted light intensity for filtered samples.

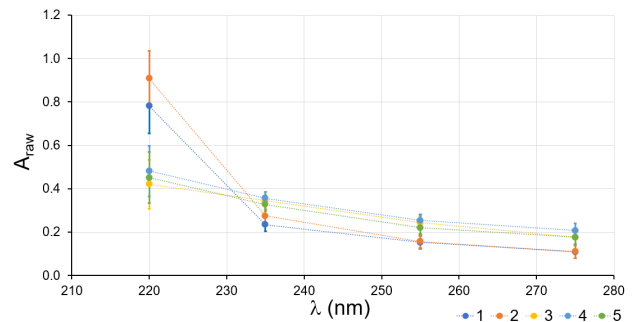


Fig. 5. Absorbance values calculated for raw (unfiltered) samples at selected wavelengths. Dashed lines are included solely as visual guides to connect data points corresponding to the same sample and do not represent measured or interpolated absorbance values between the selected wavelengths.

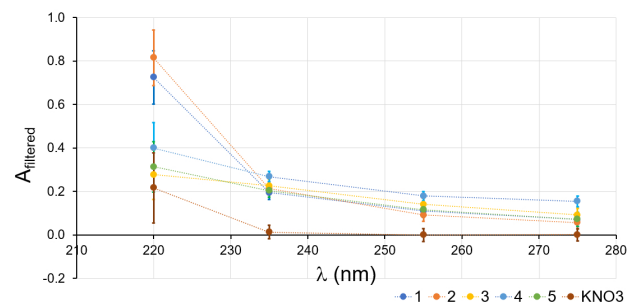


Fig. 6. Absorbance values calculated for filtered samples at selected wavelengths. Dashed lines are included solely as visual guides to connect data points corresponding to the same sample and do not represent measured or interpolated absorbance values between the selected wavelengths.

The combined analysis of filtration effects and wavelength-dependent absorbance shows that the measured signal results from the superposition of scattering and absorption processes. While filtration reduces the contribution of suspended matter, absorbance related to organic compounds persists and becomes relatively more significant at longer wavelengths.

4.3. Multi-wavelength correction and quantitative analysis of nitrate

To evaluate the effectiveness of the proposed correction approach, different wavelength pairs were analysed in terms of their ability to minimise matrix effects and improve the relationship between absorbance and nitrate concentration. The results are presented in Figs. 7–12.

The application of a multi-wavelength correction significantly influenced the quality of the obtained relationships between absorbance and nitrate concentration. For the wavelength pair of 220/275 nm, using a correction coefficient $k=0.55$, a strong linear relationship was observed (Fig. 7), with a coefficient of determination close to unity $R^2=0.9949$. A similarly high correlation was obtained for the 220/254 nm pair (Fig. 8), also characterised by $R^2=0.9942$. These results indicate that the use of shorter analytical wavelengths combined with reference wavelengths associated with organic matter allows for effective compensation of matrix effects.

In contrast, wavelength pairs based on 235 nm did not show a consistent relationship between absorbance and nitrate concentration. For both 235/275 nm (Fig. 9) and 235/254 nm (Fig. 10), the data points exhibit significant scatter, and no clear trend can be identified. The absence of

a well-defined relationship indicates that the absorbance at 235 nm is strongly affected by matrix components and cannot be reliably used for quantitative analysis under the investigated conditions.

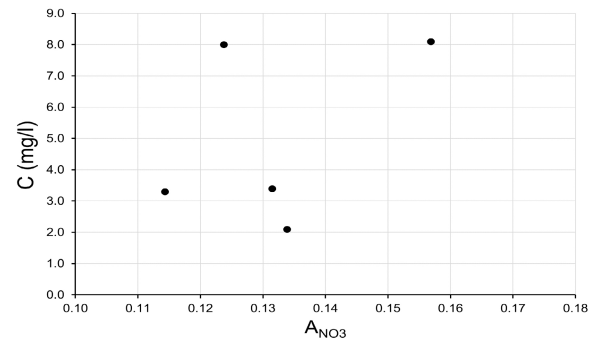


Fig. 9. Relationship between corrected absorbance and nitrate concentration for the wavelength pair of 235/275 nm.

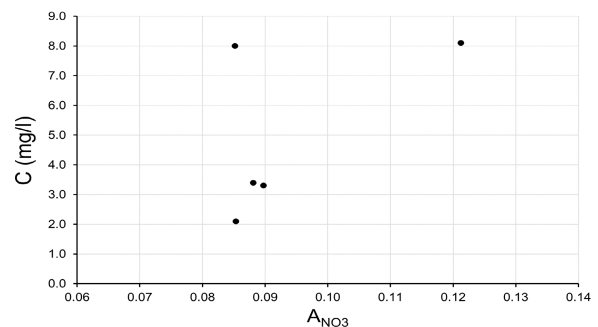


Fig. 10. Relationship between corrected absorbance and nitrate concentration for the wavelength pair of 235/254 nm.

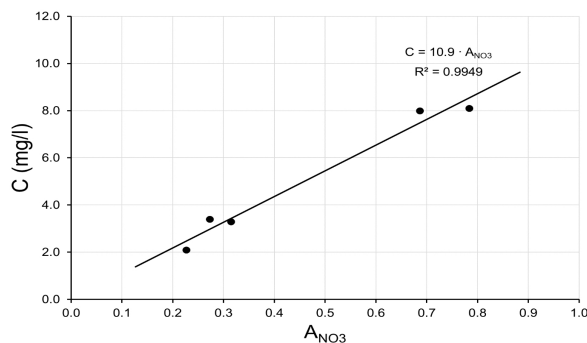


Fig. 7. Relationship between corrected absorbance and nitrate concentration for the wavelength pair of 220/275 nm ($k=0.55$).

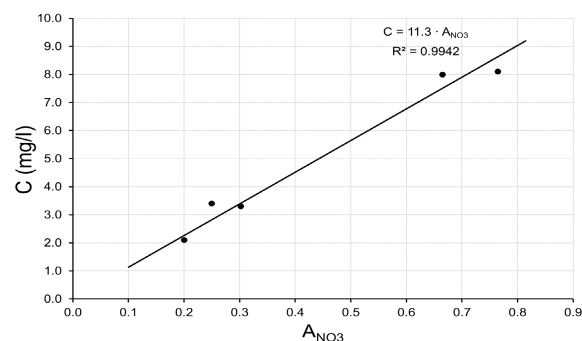


Fig. 8. Relationship between corrected absorbance and nitrate concentration for the wavelength pair of 220/254 nm ($k=0.55$).

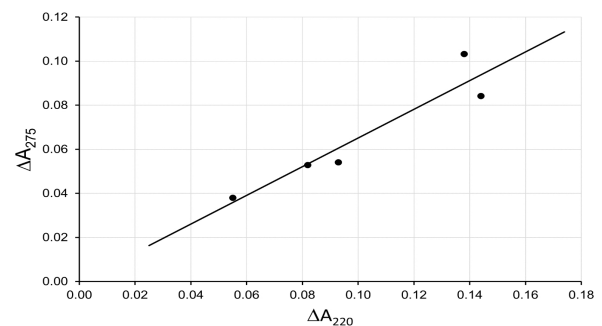


Fig. 11. Dependence of absorbance differences ΔA_{275} on ΔA_{220} , illustrating the effect of matrix-related attenuation across different wavelengths.

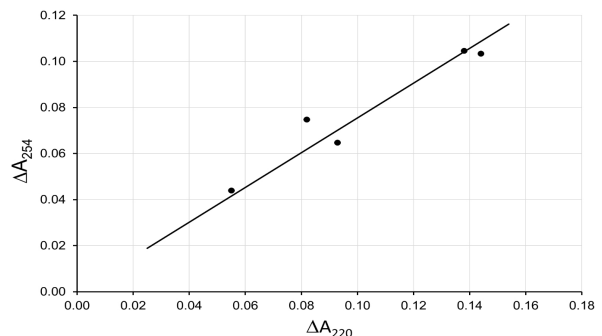


Fig. 12. Dependence of absorbance differences ΔA_{254} on ΔA_{220} , showing correlated behaviour of absorbance changes and supporting the multi-wavelength correction approach.

These results demonstrate that, although both 220 nm and 235 nm are commonly considered nitrate-sensitive wavelengths, their practical performance differs significantly in real water systems. The superior behaviour of 220 nm suggests that it is less affected by interfering components or that such interference can be more effectively compensated using multi-wavelength correction.

Further insight into matrix effects is provided by the analysis of turbidity-related differences (Figs. 11 and 12).

A nearly linear relationship between absorbance differences at 220 nm and 275 nm (or 254 nm) was observed, indicating that the contribution of suspended particles and organic matter affects multiple wavelengths in a correlated manner. This behaviour supports the validity of the applied correction model and justifies the use of a proportionality coefficient k for compensating interference effects.

Overall, the results demonstrate that multi-wavelength correction can significantly improve the accuracy of spectroscopic nitrate determination, provided that appropriate wavelength pairs are selected. Among the tested combinations, the use of 220 nm together with reference wavelengths (254 or 275 nm) was found to be the most effective approach for reducing matrix effects and achieving reliable quantitative results.

The error bars presented in Figs. 5 and 6 represent the propagated instrumental uncertainty of the calculated absorbance values. The uncertainty associated with the empirical selection of the correction coefficient k was not quantified separately and should be evaluated during further validation using a larger and independent set of environmental samples.

The present findings are in good agreement with previous studies on UV-based nitrate determination in natural waters. Pellerin *et al.* [11] emphasised that the measurements at approximately 220 nm provide the highest sensitivity for nitrate detection, although their performance strongly depends on effective compensation of matrix interferences. Similarly, Silva *et al.* [14] demonstrated that correction using additional wavelengths significantly improves nitrate determination in the presence of dissolved organic matter, while Dong *et al.* [15] reported that turbidity compensation substantially enhances measurement accuracy in waters containing suspended particles. Our results extend these observations by demonstrating that, under the challenging conditions of a highly anthropogenically impacted river system, wavelength pairs based on 220 nm (220/254 and 220/275 nm) provide considerably more reliable quantitative relationships than those based on 235 nm. This finding indicates that wavelength selection remains one of the key factors governing the applicability of UV absorption spectroscopy in complex environmental waters.

Unlike many previous studies performed using laboratory-prepared solutions or relatively simple water matrices, the present investigation demonstrates the effectiveness of the proposed correction approach under real environmental conditions characterised by highly variable salinity, suspended solids, and dissolved organic matter. Nevertheless, the proposed correction strategy should be regarded as site-specific, since the optical properties of natural organic matter and suspended particles may differ between water bodies.

5. Conclusions

This study confirms that UV spectroscopy in the UVC range can be applied for the analysis of nitrogen compounds in surface waters with complex chemical composition; however, its reliability is strongly dependent on proper treatment of matrix effects. The results demonstrate that measurements performed at 220 nm provide a significantly more robust relationship with nitrate concentration than those at 235 nm, particularly under conditions of high matrix variability. This indicates that shorter wavelengths, when combined with appropriate correction methods, are more suitable for quantitative analysis in highly anthropogenically impacted water systems.

The obtained results show that longer wavelengths are increasingly affected by overlapping absorption from DOM, while shorter wavelengths are more sensitive to both nitrogen compounds and matrix-related interferences. Consequently, the effectiveness of spectroscopic determination is governed not only by the choice of wavelength, but also by the ability to compensate for the combined influence of turbidity and dissolved organic substances.

The observed limitations of selected spectral ranges confirm that universal analytical approaches cannot be directly transferred to waters with diverse origins and contamination sources. Instead, measurement strategies must be adapted to local optical properties of the water matrix, including the variability of suspended solids and dissolved organic matter. In this context, filtration-based separation and multi-wavelength correction represent key elements of a reliable analytical procedure.

A limitation of the present study is the relatively small number of environmental samples collected from a single river system. Moreover, because the empirical correction coefficient was determined using the investigated sample set, the reported performance should be confirmed using an independent set of environmental samples. Consequently, the selected value of k should be regarded as matrix-specific rather than universal. Application of the proposed approach to other surface waters should therefore be preceded by local calibration, since the optical properties of dissolved organic matter and suspended particles may differ considerably among aquatic environments. Future work should include a larger number of sampling sites, seasonal measurement campaigns, and validation across water systems with different hydro chemical and optical characteristics.

From a broader perspective, the findings support the development of optical monitoring methods tailored to complex environmental conditions, such as post-industrial river systems. Following validation across broader spatial, temporal, and hydro chemical conditions, the proposed approach may be further developed towards automated or *in situ* water-quality monitoring systems.

Authors' statement

Research concept and design, A.O., E.M., I.Z., E.L.-M. K.B.; collection and/or assembly of data, A.O., K.B., Ł.D.; data analysis and interpretation, A.O., E.L.-M.; writing the article, A.O., K.B., S.D.; critical revision of the article, E.M., I.Z.; final approval of the article, E.M., E.L.-M.

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