



Evaluating Microplastic Detection Techniques in Human-Impacted Water Systems: A Mini-Review

Kalampyr Bexeitova,^{1,2} Ulan Zhantikeev,¹ Yelriza Yeszhan,¹ Inabat Sapargali,¹ Kenes Kudaibergenov,¹ Kainaubek Toshtay,² Sergey Mikhlovsky,³ Rachid Amrousse,⁴ Ronny Berndtsson⁵ and Seikhan Azat^{1,*}

Abstract

Microplastics (MP) have emerged as significant global pollutants, garnering considerable attention from both the scientific community and the public. The significance of microplastic research lies in its capacity to inform effective pollution control strategies and mitigate associated environmental and health risks. The review illuminated the complexities and challenges inherent in analyzing microplastics and nanoplastics within anthropogenically affected water systems. It underscored the necessity of standardizing methodologies to enhance the accuracy and comparability of research findings. The adoption of advanced analytical techniques represents a significant advancement in the field, paving the way for more effective pollution mitigation strategies. By adhering to this structured approach, the review aspires to contribute a comprehensive overview of current methodologies in microplastic research and to enrich the ongoing discourse surrounding environmental pollution and its far-reaching impacts.

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1. Introduction

Microplastics (MP) are currently emerging global pollutants that are receiving significant attention from both the research community and the public. MP are defined as plastic particles no larger than 5 mm,^[1,2] while plastic particles are in the smallest size class (<100 nm or <1000 nm, definition unclear) are instead called nanoplastics (NP).^[3] There are many studies on MP occurrence in the environment, in contrast to NP, which up until now has been very hard to accurately identify in natural matrices. Compared to freshwater habitats, a lot more work has been done to explore seas and oceans.^[4,5] However,

freshwater waters are thought to be possible sources of MP for humans because they are the main sources of drinking water for human use.^[6,7] Testing for MP has previously been conducted on a few raw water samples from drinking water treatment plants (DWTPs), and the results have indicated the presence of MP (>4000 units per liter).^[8] The presence of MPs has also been reported in lakes, rivers, and dams around the world, even in remote areas. Thus, the open-source program office (OSPO) will likely have to deal with the presence of a “new” pollutant, MP, at least in some areas.^[9]

Urgent action is needed to address this global issue. The significance of MP research lies in its potential to inform effective pollution control measures and mitigate environmental and health risks. There are various methods for cleaning water from microplastics, and new approaches that can be expected to be effective.^[10] Miller *et al.*^[11] emphasizes the need for standardized recovery and characterization methods to ensure accurate pollution estimates. This is further supported by Gong and Xie,^[12] who highlights the importance of analytical methods in identifying MPs and understanding their eco-environmental effects. The exponential growth in MP research^[13] underscores its increasing relevance, with a shift towards ecosystem effects and feedback^[14] indicating a broader understanding of its impact. These findings

¹ Laboratory of Engineering Profile, Satbayev University, 22 Satbayev Str., Almaty, 050013, Kazakhstan

² Faculty of Chemistry and Chemical Technology, Al-Farabi Kazakh National University, 71 Al-Farabi Ave., Almaty, 050040, Kazakhstan.

³ ANAMAD Ltd., Sussex Innovation Centre, Science Park Square, Falmer, Brighton, BN1 9SB, UK.

⁴ Faculty of Sciences, University of Chouaib Doukkali, El Jadida 24000, Morocco.

⁵ Division of Water Resources Engineering, Centre for Advanced Middle Eastern Studies, Lund University, P.O. Box 118, SE-22100 Lund, Sweden.

*Email: seytkhan.azat@gmail.com (S. Azat)

collectively underscore the critical role of MP research in addressing a pressing environmental issue.

This review of the research literature aims to give a general overview of the many research techniques used in the field of MPs research. It seeks to determine and assess these approaches' advantages and disadvantages as well as to highlight new approaches and developments in the field. To conduct a review on the topic of micro- and nanoplastic analysis methods in water systems, we followed a systematic approach that involved several key steps: - define the scope: The review focused on the analysis methods for MP and nanoplastics NP in water systems impacted by human activities. The aim was to assess the methodologies used in existing research, their advantages and disadvantages, and the need for standardization; - keyword selection The keywords included: microplastics, nanoplastics, freshwater, ecosystems, pollution, sources, research methods, pollution control measures, standardized recovery and characterization methods, eco-environmental effects, quantification and identification, sampling techniques, sample preparation. - literature Search: The search for relevant literature was conducted using various academic databases and search engines: Google scholar; PubMed; Web of Science; Scopus; ScienceDirect.

The review highlighted the complexities and challenges associated with analyzing microplastics and nanoplastics in anthropogenic-affected water systems. It underscored the importance of standardizing methodologies to improve the accuracy and comparability of research findings. The use of advanced analytical techniques was noted as a significant advancement in the field, paving the way for more effective pollution mitigation strategies.

By following this structured approach, the review aimed to provide a comprehensive overview of the current methodologies in microplastic research and to contribute to the ongoing discourse on environmental pollution and its impacts.

2 Analyses techniques

The emergence of MP research is a growing field, with studies focusing on their properties, distribution, and impacts. Despite efforts to reduce contamination, the presence of MPs continues to rise, necessitating further research.^[15] Standardized methodologies for quantification and identification, as well as a better understanding of their concentration, source, and hazards, are crucial for future research in this field.

Researchers now employ a variety of techniques to identify MPs, depending on their objectives. Based on their capacities, the equipment they have access to, and their study goals, various research organizations employ various techniques for sampling, sample preparation, and qualitative analysis of particles.^[16,17] In currently used methods for assessing the level of pollution by MP particles in natural waters, each stage of the study introduces uncertainties and possible errors into the results obtained (Table 1).

There are two primary water sampling techniques that are common, in compliance with worldwide monitoring protocols for MP contamination (AMAP, 2021; GESAMP, 2019; HELCOM BLUES, 2022). The first technique involves employing specialized nets, such as manta trawls and neuston nets, to gather samples from the sea surface layer (0–20 cm). The second method gathers samples from the subsurface (1–6 m depth) using pumps or ship-based flow systems, which are then integrated with a filtration system or cascade of filters. The study's objectives, the area, the kind of water body, and the resources available, such as the kind of vessel, its capacity to stop, and the availability of required equipment, all influence the selection of a particular sample technique and apparatus.^[18]

MP particle losses or significant external contamination of the sample are caused by varying order of steps in the laboratory processing routine and either an excessive or inadequate number of steps.^[19] Due to this, the results of the examination of MPs in natural waterways are provided with varying quality and resolution, making it difficult or impossible to compare the findings of different studies.^[20]

But in recent years, the field of MPs research has seen important milestones and key discoveries. The definition of MPs has been a topic of debate, with proposing a comprehensive definition that considers size, origin, and physical and chemical properties.^[21] Van Cauwenberghé^[22] made a groundbreaking discovery by finding MPs in deep-sea sediments, highlighting the widespread pollution of these particles. Hernández-Sánchez *et al.*^[23] emphasized the need for standardized methodologies and interdisciplinary research to understand the origin, distribution, and effects of MPs. These studies collectively underscore the urgency of addressing the global issue of MP pollution.

Identification, quantification, and in-depth analysis of MP particles discovered in environmental samples are all phases in the MP characterization process. Understanding the distribution and effects of small plastic pieces in various environments requires taking these crucial steps. A methodological way to identify the typology, size, shape, and origin of MPs is known as characterization methodology.

The first step in studying MPs is to separate them from the sample matrix by utilizing gradient centrifugation and filtering procedures, and then analyze the particles under a microscope. Primary information on the morphological features of particles is obtained by optical microscopy. Techniques including pyrolysis gas chromatography-mass spectrometry (GC-MS), Fourier transform spectroscopy (FTIR), scanning electron microscopy (SEM), and Raman spectroscopy are employed for further examination. SEM provides high-resolution images to study surface morphology, while FTIR and Raman spectroscopy enable the identification of polymer materials based on their vibrational spectra.^[24,25] When it comes to precisely characterizing the chemical structure of MPs, Raman spectroscopy employs scattered light to identify molecular vibrations, whereas FTIR studies infrared absorption to

Table 1. Stages involved in MP contamination estimation, their benefits, and drawbacks.^[19]

Analysis stage \ Type	Natural water					Factors that cause mistakes or uncertainty when calculating MP concentrations
	Surface (0–20 cm)		Subsurface /water column (1–6 m)			
Sampling	Neuston network	Manta sampler	Ship flow system	External pump (on deck or submersible)		Variation in minimum MP size and challenges when comparing outcomes
	(90–330 μm)		(26–200 μm)			
Particle extraction/sample preparation	Visual sorting	Density separation	Decomposition of natural organic matter	Filtration		There are no standard MP extraction protocol; there is insufficient data on the stability of MP to various oxidants, pH, temperature
Identification	Visual					False positives; no data on polymer composition
	Hot needle method					
	Near-infrared spectroscopy (NIR).	Fourier transform infrared spectroscopy, FTIR	Fluorescence analysis methods	Raman spectroscopy	Pyrolytic gas chromatography -mass spectrometry (Py -GC-MS)	Inability to recognize fibers; Raman method: only a portion of the discovered particles can be identified since the polymer and pigment spectra overlap. This is because the analysis process is time-consuming and expensive.
Analysis and quality assurance control of quality	When sampling and preparing samples, use blank samples					Real MP concentrations may be overestimated or underestimated as a result of sampling and sample preparation methods that commonly fail to assess the degree of MP extraction and regulate the degree of contamination.
	Checking the degree of particle recovery and correct identification (“ recovery tests ”)					
	Working in a clean laboratory environment					
Data presentation	Metadata; Characteristics of MP particles: size, morphology, color, polymer type; concentration:					Findings for several MP size groups, various units for expressing concentrations, infrequent presentation of mass concentrations, entry of various particles (fibers, semi-synthetic, copolymers) into the database, and accounting for anthropogenic non-plastic particles; several methods for reducing external pollution
	pcs/km ² , pcs/m ³ , mg/km ² , mg/m ³		pcs/L, pcs/m ³ , mg/m ³			

disclose the functional groups and composition of polymers. In GC-MS pyrolysis, a sample is thermally broken down to release volatile components, which are then detected. Each of these techniques has benefits of its own: GC-MS pyrolysis offers information on polymer composition and additives, while FTIR and Raman spectroscopy are non-destructive and enable quick identification. They do, however, have several drawbacks, such as the potential impact of the sample matrix and the operator skill requirements. The goal of the study, the sample's properties, and the equipment's accessibility all influence the technique chosen. A summary of the applications, advantages and limitations of each method is presented in Table 2.

The range of sample types, analytical techniques, and research aims across the examined publications makes it difficult to compare them in terms of sampling and analytical methodology. There are variations at every level of the study

process, including sampling, sample transportation, laboratory procedures, and analysis.

At the time, nearly every country in the world has drinking water MP (and/or NP) regulations in place. There is no established process for identifying MPs in drinking water. Several studies have used spectroscopic techniques like FTIR or Raman to examine if MPs are present in drinking water samples.^[66–68] To measure the mass of MPS, pyrolysis in conjunction with gas chromatography-mass spectrometry is recommended by several other investigations.^[69] Both expensive equipment and a lot of time are needed for these approaches. Therefore, dying techniques must be considered because they are simpler to use and demand less time. While Nile red staining is utilized to identify MP in drinking water, Rose Bengal staining has been beneficial for counting MPs in drinking water. Additionally, staining allows for the observation of surface alterations, MP deterioration, and

Table 2. Typical methods for the analysis of MPs in the environment, Advantages and disadvantages of different MP detection methods.

Method of detection	Advantages	Disadvantages	Reference
Visual recognition	Easy and quick	Small particles are hard to recognize, and a good probability to count twice.	[26]
Stereomicroscopy	Facile, rapid, and simple	Lack of knowledge on the kind of polymer, its chemical makeup, tiny, transparent MPs, and the likelihood of inaccuracy	[27]
Scanning electron microscope-energy-dispersive X-ray	Provide detailed information of external surface morphology with higher magnification A promising technique that can be used to simultaneously analyze the surface morphology and elemental composition of MPs	Pretreatment is a difficult procedure. The cost is high and the work efficiency is low. The quantity of MPs is not very well estimated. MPs cannot be reliably identified by color. This technique is mostly used to find certain MPs.	[28–31]
FE- SEM	photos of MP samples at high magnification taken without preparing the sample beforehand for observation The MP pieces are deposited directly on the carbon tape on an aluminum plug; neither metal nor carbon coating of the sample is required.	Need vacuumed medium, are costly, unable to distinguish the color of plastic particles, and are difficult to set up due to their increased size.	[32]
Polarized light microscopy	Simple and quick	Because of their amorphous form, NPs and MPs are not electron dense and need heavy metal staining, making TEM inefficient for viewing them in thick and opaque plastic samples. Typically, polymers are made up of elements having weak elastic interactions with electrons, meaning that they do not contrast well in TEM.	[33]
Electron Energy Loss Spectroscopy (EELS)	The electron source, or TEM, is connected to the EELS setup. Because of this, EELS is an effective method for researching the dielectric characteristics of films and the chemical structure of polymers with a high degree of spatial resolution.	EELS can achieve high spatial resolution, it may not be sufficient for detecting very small microplastics, especially those below a certain size threshold (>100 nm). The electron beam used in EELS can potentially damage sensitive microplastic samples, leading to alterations in their chemical structure or morphology during analysis.	[33,34]
Mass spectrometry	an essential technique for finding polymers in MPs. The structure, molecular weight, degree of polymerization, primary functional groups, and end group structure of polymers may all be determined from the mass spectrum of such polymers. This technique may be applied to environmental sample MP measurement and chemical characterization study.	This method's applicability domain is limited. Furthermore, this technique is still unable to measure the overall Amount of MPs in the environment.	[35–37]

FTIR	Ability to examine chemical compositions, non-destructive technique, auto-mapping, and reduced likelihood of erroneous data a method of vibrational spectroscopy that can provide details about functional groups and chemical bonds in materials. This technique is commonly used for MP component analysis and qualitative detection.	Approach that is costly, labor-intensive, and time-consuming Its use is limited to identifying MPs larger than 20 μ m. Furthermore, this approach is readily impacted by a number of variables.	[38–40]
FPA-FTIR	Provide the sample in high definition with a brief description.	Restricted diffraction span, difficult to examine samples below 10 to 20 μ m, and stretched fiber image	[41,42]
ATR-FTIR	As of right now, spectroscopy for further chemical identification and microscopic identification of plastic-like particles are two viable methods for identifying MPs in environmental samples. Micro-ATR-FTIR serves as a supplement to these methods. Unlike transmission mode, reflectance and ATR-FTIR modes do not require sample preparation procedures for thick and opaque MPs. Furthermore, steady spectra on irregular MP surfaces may be produced via ATR mode.	For MPs smaller than 50 μ m, it is typically challenging to acquire a clear spectrum that can be reliably characterized. Additionally, because ATR-FTIR spectroscopy measurement is a type of surface contact study, the pressure produced by the ATR sensor may harm delicate MPs. Furthermore, it takes a long time for the ATR mode to recognize each particle separately. To further lessen the possibility of false positives, it is advised that a spectrum of surfactants, such as sodium stearate and sodium dodecyl sulfate (SDS), which are sometimes mistaken for plastic, be recorded together in the FTIR library.	[43–46]
Raman spectroscopy	Able to test chemical compositions, non-destructive technology, reduces the possibility of erroneous data, and analyze samples smaller than 1 μ m	Fluorescent dyes and pigments interfered with, making it a costly, time-consuming, and labor-intensive process In Raman spectroscopy, the detection time is rather long. Furthermore, there is a need to enhance Raman spectroscopy for the purpose of analyzing MPs.	[47–50]
Thermoanalytical analysis	Able to simultaneously identify the chemical composition and polymer a technique for material analysis that involves examining how certain qualities change with temperature and time. This technique may be used to the mass concentration of MPs and chemical characterization study.	Damaging technique and restricted capacity for multiple plastic polymers detection. The preprocessing procedure for samples is laborious. Furthermore, because this approach destroys environmental samples, it cannot be used to analyze the physical characteristics of MPs.	[31,37,51–53]
Thermogravimetry	Enables quantitative thermal examination of a sample by calculating the sample's weight loss at a specific temperature.	Without specifying what the constituent parts are. It is easy to distinguish between polypropylene (PP) and polyethylene. It is possible that polyester (PES), polyamide (PA), and polyvinyl chloride (PVC) are not recognized. Phase change signals are hard to identify when they are	[51,54,55]

Pyrolysis gas chromatography mass spectrometry	For the simultaneous identification and measurement of the most prevalent MPs in complicated samples, it is good. Ions and breakdown products unique to each polymer are utilized to identify it.	transformed, such polyethylene terephthalate (PET) and polyurethane (PU). Lack of particle size information is one of the primary drawbacks of Py - GC - MS characterization for MP. As a result, some research integrated this technique with others like FTIR and microscopy.	[56–58]
New approaches			
"Nile-Red" (9-diethylamino-5-benzo[a] phenoxazinone; NR)	A dye that has the absorption, selective, and fluorescent qualities that allow it to attach preferentially to polymeric materials rather than organic ones, allowing for the quick detection and measurement of MP.	The fluorescence signal of Nile Red can be quenched by various environmental factors, such as the presence of organic matter or other substances in the sample. This can lead to underestimation of microplastic concentrations. While Nile Red can indicate the presence of microplastics, it does not provide detailed information about the chemical composition or polymer types without further analysis (e.g., FTIR or Raman spectroscopy).	[59,60]
Atomic force microscopy (AFM)-IR, AFM- Raman microscopy	Additionally, the target plastic's chemical structure can be ascertained by combining AFM with IR or Raman spectroscopy. The Fourier transform is used to examine the radiation pattern to estimate the vibration frequency and amplitude. Thermal expansion of the sample owing to IR absorption produces vibration of the AFM cantilever. Additionally, AFM-IR enables simultaneous imaging of the target's IR absorption spectra with a spatial resolution of 50–100 nm. AFM and IR spectra of PS beads measuring 100 nm were successfully acquired in earlier investigations.	Finding a single target of nanoscale plastic particles in an unknown material that can be targeted by AFM-IR is challenging and time-consuming. These issues can be resolved by automated FTIR / Raman mapping or particle tracking using Raman spectroscopy; however, these methods necessitate costly equipment, which not all MPs laboratory can afford.	[61,62]
Near-infrared spectroscopy	NIR spectroscopy is a non-destructive technique, allowing for the analysis of samples without altering or damaging them. This is particularly beneficial for environmental samples where preservation is important, also can be used to identify different types of polymers based on their characteristic absorption bands, allowing for the differentiation of various microplastic types. NIR studies the spectrum in the range of more than 4000–15,000 cm ⁻¹ , whereas FTIR analyzes the spectrum in the 600–4000 cm ⁻¹ range. Typically, vibrational combinations of XH molecules, such as CH, OH, and NH, are used to evaluate NIR spectra.	The NIR spectra of different polymers can sometimes overlap, making it challenging to distinguish between similar materials without additional analytical techniques. Accurate quantitative analysis requires careful calibration with known standards, which can be time-consuming and may introduce variability.	[43,63]

	NIR spectroscopy can be calibrated for quantitative analysis, allowing for the determination of microplastic concentrations in samples. Method does not require harmful solvents or reagents, making it a more environmentally friendly option compared to some other analytical techniques.	
Vis-NIR quantification	Vis-NIR spectroscopy calculates the reflectance at each wavelength by measuring the quantity of light reflected from a sample's surface in the 350–2500 nm wavelength range. Considering the chemical composition of micro-nanoplastics, it is possible to quantitatively determine them using method Vis-NIR spectroscopy. To identify MPs, an open library of near-infrared spectral data for a variety of plastics that are often found in the environment, including low-density polyethylene (LDPE), PET, and PVC, is available.	Organic particles can still be mistaken for plastic as a visual identification method; therefore, human judgment must be relied upon. [64,65]

fragmentation.^[60,70] A variety of techniques are used to examine how MPs degrade. One such way was the use of iDye pink, which allows to observe surface alterations in the MPs using conventional optical microscopy (Fig. 1).^[71] The study examined the surface changes and destruction of plastics. As a result of the studies under the influence of cold plasma on microplastics, a decrease and destruction of plastic from 3–5 mm (initial) to 2 (2.5 min) and 2 mm were determined.

Given that iDye pink is used in water rather than acetone or methanol like Nile Red is, iDye pink is a more viable and eco-friendly option for MP characterization.^[66] The application of staining methods in conjunction with microscopic and spectroscopic methods was suggested in this work. Specifically, iDye staining has been suggested as a Nile Red staining substitute for the purpose of defining MPs. For a more precise characterization, it is possible to combine iDye pink, a solution that is more stable than Nile Red, with spectroscopic methods including FTIR and Raman. This greatly reduces complexity and saves time while improving the MPs analysis procedure. Nevertheless, MPs are made up of a wide variety of components, and their fluorophore staining intensities range. It is also essential to thoroughly research these properties.^[72]

A polymer's chemical identity (and occasionally its quantity) can be ascertained by Py-GC-MS, μ FTIR, or μ -Raman scattering. Raman and ATR-FTIR spectroscopy have not been employed in many investigations, though. Recent research has discussed the advantages of using AFM-IR, or atomic force microscopy-infrared spectroscopy, to discover

functional groups in micro areas. Still, no conclusions can be made.^[73–75] The fact that the data are presented in several units of measurement adds another layer of difficulty to the comparison of research results. The concentration is reported in some studies as weight per liter, whereas it is reported in other studies as the weight of the sample as a whole or as the number of particles present in the sample. To make the results more comparable, there is a strong propensity to quantify them as MPS/L or MPS/m³.^[76,77]

Additionally, recent studies have shown the potential to analyze particles smaller than these, down to 100 nm, using confocal RM. Raman microscopy in conjunction with optical tweezers may be used to investigate liquids containing micro- and nanoparticles as small as 50 nm. This combination enables real time integration with fractionation field data to detect particles chemically in addition to dividing and characterizing them.^[78] The examination of NPs may also make use of Raman spectroscopy with strengthening surfaces (SERS). In the future, Raman spectroscopy with probe strengthening may be used to increase spatial permission (TERS). Nevertheless, similar techniques may be used to different kinds of polymers. But further evidence on actual samples is needed, particularly considering potential impact from organic remnants such humic acids that are challenging to eliminate.^[79]

3. Statistical processing data for analysis of MP and NP pollution

Spectroscopic methods yield comprehensive data that reflect the physical characteristics of particles, such as size, shape,

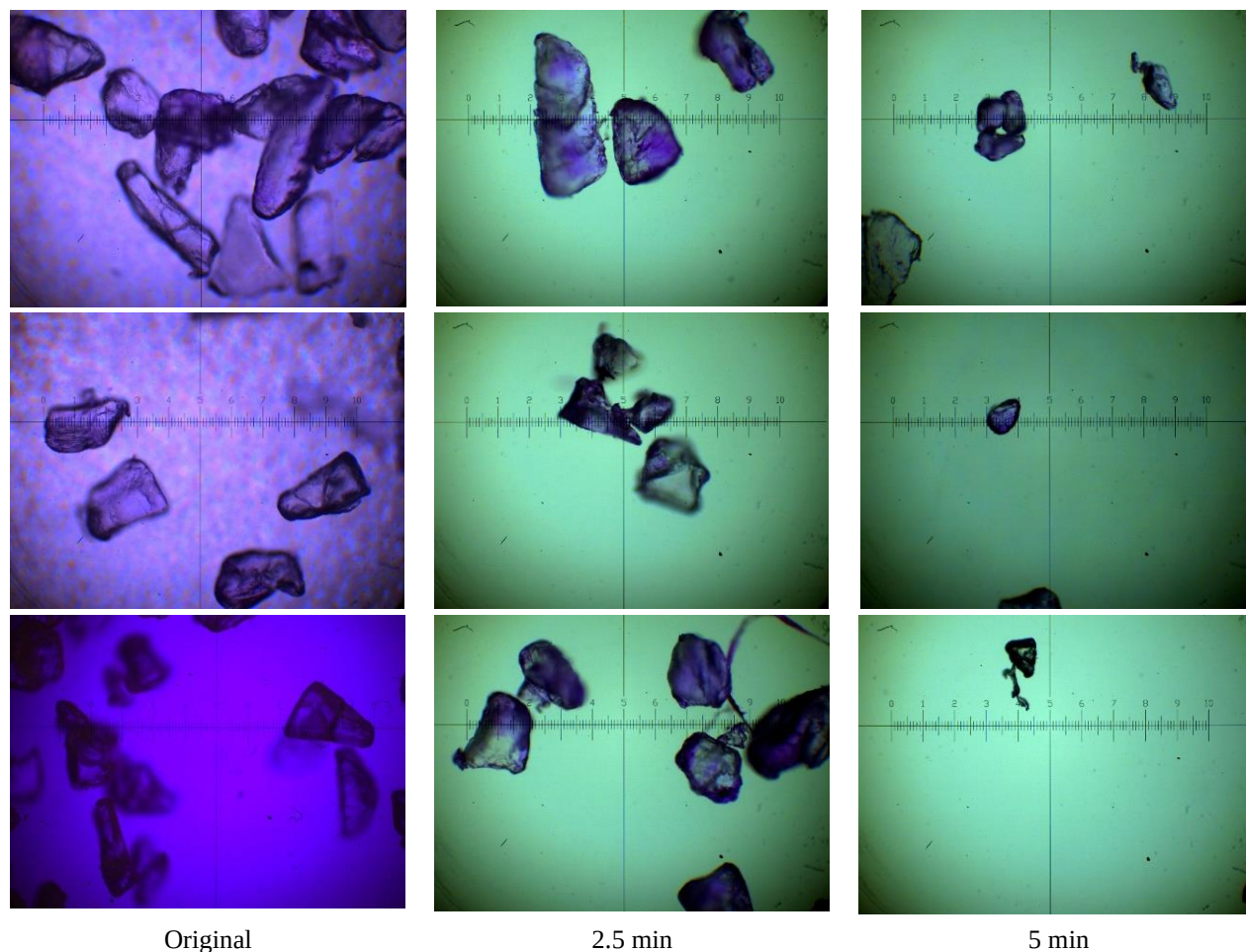


Fig. 1 Application of iDye pink to detect surface changes of MP exposed to cold plasma.

and color, in addition to their chemical makeup. To this end, data analysis necessitates a thorough evaluation of large spectrum arrays and related particle properties. Processing data efficiently requires the use of computational and automated methods, given the volume of data. Manufacturers of analytical equipment are starting to use particle analysis software, which offers sophisticated capabilities for interpreting spectra and automates the process of gathering them. Research groups are simultaneously creating their own methods for processing data utilizing commercial and open-source software, such as for integrated RM and μ -FTIR analysis and μ -FTIR and RM visualization.^[80,81] To guarantee precise identification and quick processing, many spectra are produced by any analytical method that is used. These spectra need to be carefully analyzed. Standardized processing of all spectra, efficiency when handling massive volumes of data, and user-friendly formats for data presentation and operator assessment thereafter are all features of the best software systems. Several approaches are available for spectral estimation, including model-based classification, database correlation, and descriptive techniques like independent component analysis (ICA) and multivariate curve-aligned least squares (MCR-ALS). Comparing spectral similarity using metrics like Pearson correlation, least squares, and absolute and Euclidean distance is the foundation of data

characterization. However, because of the processing power needs, this approach may be challenging for huge data sets. An alternative is to use chemometric classifiers, such as random decision forest (RDF) classifiers, which can simplify the process by preprocessing the data with spectral descriptors.^[82,83]

The most popular method now in use is still correlating spectra with observed data bases. Search criteria, data processing, and spectrum quality all play a major role in the correlation process and can have a big impact on the outcomes. While manual evaluation by a skilled spectroscopist is still the best way to confirm identification, automated techniques also provide quality standards like hit quality index (HQI). It is advised to set the bar for acceptable outcomes at an HQI of 70%.^[84] Furthermore, one may determine the correlation's selectivity by comparing the HQI differences of the first- and second-best fits. To differentiate between closely related polymers or polymer subclasses, these techniques would need more manual verification.

It is important to note that the range of methods used by developers might make HQI produced by various software programs incomparable. Furthermore, the HQI value is correlated with the sample's features and the quality of the spectral data, regardless of whether it is an environmental sample or a reference standard. As a result, consideration must

be given to the preprocessing techniques employed, the correlation algorithms employed, and the databases utilized in the study to correlate the spectra.^[85] The numerical value of the HQI cannot be used as a general quality measure because it varies on several factors. If a laboratory only uses HQI as a quality criterion, then it is important to establish and confirm HQI threshold values, considering the equipment's capabilities and the kinds of samples that are evaluated.^[86]

Although empirical evidence currently suggests statistical hypothesis testing cannot consistently identify the proper HQI value, it is advised that HQI thresholds be examined using appropriate technique instead of choosing a random value. It is suggested that the basic polymers polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polycarbonate (PC), polyvinyl chloride (PVC), polymethyl methacrylate (PMMA), polytetrafluoroethylene (PTFE), polyamide (PA, nylon), and polyurethanes (PU) be included in the standard spectral identification kit. The use of several kinds of PU is advised since the latter might change based on the monomers, producing a range of infrared (IR) and Raman spectra.^[87] It is also advised to broaden this scope to include other polymers like natural rubber, copolymers, acrylonitrile butadiene styrene (ABS), and non-synthetic and/or non-polymeric materials that are frequently present in samples, such as proteins, cellulose, amorphous carbon, and inorganic materials like quartz and other minerals. Additives, such as pigments and dyes, can be identified using Raman spectroscopy. These materials may have more noticeable peaks than polymers, therefore detecting them may need optimal measurement conditions. Including a collection of standard polymer colors might make it easier to identify possible polymer particles. Although there are commercial spectrum libraries available, a variety of software tools enable the production of customized libraries, which might be better since they can contain spectra of suspected contaminants unique to a laboratory and are acquired using the same equipment as the database.^[88] Similar to commercial software programs, Cowger *et al.* has created a new open library (Open Specy) for Raman micro spectroscopy (RM) and infrared spectroscopy (IR) identification of MPs. By uploading and sharing their spectra, users may help the library expand and get better.^[89]

Operators need to be aware of the variations in polyamide and protein spectra. Comparing qualitative data makes it easy to discern between the two types of spectra. However, identification must be based on the most noticeable peaks shared by infrared (FT) and Raman spectroscopy due to aberrations in the spectra of ambient materials. Long carbon chains in molecules can result in comparable IR and Raman spectra; this is demonstrated by polyethylene and substances like stearates, stearamides, and sodium dodecyl sulfate.^[90]

Analytical technique validation and quality control in analytical chemistry, operational characteristics (OC) and quality control (QC) criteria are used to verify the efficacy of a procedure. All these factors support the method's efficacy

and dependability. These comprise evaluations of background levels, overall technique validity, recovery, repeatability, reproducibility, and limits of detection and determination (LOD and LOQ). Studies known as interlaboratory comparisons (ILCs) are also required to validate the precision and correctness of techniques applied in various laboratories.^[91,92]

Validating analytical methods is essential, particularly when examining MPs (MPs), which provide the following difficulties: MPs are present in samples as particulate matter, causing an uneven distribution, in contrast to soluble contaminants. At present, MP identification does not have any appropriate certified reference resources.^[93] Mass-based methods are ineffective because of the low predicted concentrations and sizes of MPs in pure water. The European Union started the first worldwide ILC research on MP in water, but the findings have not been released yet. They could form the foundation for upcoming international proficiency examinations.^[94]

Most MP studies only include GC/QC data on the analysis of control samples for the purpose of monitoring contamination; these data are seldom connected to LOD/LOQ or efficacy, repeatability, and reproducibility.^[95] Depending on the selected analytical approach and its dependability in detecting and identifying MPs, inadequate method validation impacts quantitative analysis. The filtering step and the detection and identification potential of methods like IR spectroscopy/RM have important analytical limits. Nonetheless, subjectivity still exists in the evaluation of data. To increase consistency and comparability of results, analyses must be carried out under tight OH/QC supervision. A more precise knowledge of the distribution of MPs, particularly tiny ones, will be possible with the application of OC/QC during the sample, preparation, and detection phases.^[95]

Determining the method's parameters and performing a preliminary validation for the purpose of analyzing MP and NP in water is the primary step in the quality system. Important actions for this method that are advised are

1. Checking the accuracy of particle sizes obtained by measuring devices: detectors need to be calibrated using engraved plates or established size standards to verify the precision of particle sizes. Optical microscopy must be used to verify the dimensions of any non-standard materials. For imaging approaches, particle sizes must be within a tolerance of $\pm 10\%$ or ± 1 pixel.^[96]
2. Verification of the qualitative identification of polymers of the minimum size: Polymer identification at the lowest detectable level should be done for the most common kinds (PE, PET, PC, etc.). It is possible to employ MPs from synthetic particles, standards, or actual samples. Quality indicators must be recorded for comparison with the database if an automated method is utilized.
3. Limit of detection (LOD) determination: LOD is a measure of the laboratory's capacity to manage contamination and filtering effectiveness. It is known as the lowest concentration

of an analyte that can be found. LOD may be computed for particulate matter, such MP, by taking three standard deviations and adding the mean of the blank samples. Every range of particle sizes requires the determination of this value. LOD calculation formula: $LOD = 10 \text{ blanks' mean} + 3 \text{ blanks' standard deviation}$ ^[97]

The verification needs to account for the various polymers present in the samples and cover the whole analytical procedure. The total of all polymers can be used to represent LOD. All sample parameters, processing techniques, and analytical techniques must be included in the MP analysis report for the determination of total MPL.

Improvements in sampling, separation, and characterization techniques are only a few of the multidisciplinary approaches needed for MP quantification methodology. First, from the standpoint of sampling, it is imperative to incorporate more uniform techniques across various settings, including freshwater, marine ecosystems, and soil.^[98,99] This entails locating representative sampling sites and removing any possible confounding variables. Furthermore, real-time data might be obtained by implementing automated sampling equipment and continuous monitoring systems, which would record temporal variations in MP concentrations and give insight into dynamic transport processes.^[100]

IR, Raman spectroscopy, and sophisticated imaging technologies are just a few of the analytical techniques that may be used to create a thorough characterization of MPs. Characterization, identification, and quantification techniques require standardization and improvement^[35] Utilizing cutting-edge technology like remote sensing, hyperspectral imaging, and microspectroscopy can enable quick and automated MP examination. Particle classification and measurement may be done more precisely by creating reliable machine learning models and image analysis methods. Researchers and industry collaboration may result in the development of extensive MP databases that enable cross-study comparisons and the construction of global baselines.^[101,102]

Innovative and established methods for sampling, separating, and characterizing MPs are part of the MP quantification technique. These developments will make it possible to measure MP pollution more precisely in terms of its amount, sources, and possible effects. This will help with focused mitigation plans and well-informed decision-making. Utilizing cutting-edge technologies that transform sampling, separation, and characterization procedures is necessary for quantifying MPs.^[103,104] Our capacity to precisely measure MP pollution will increase with the use of remote sensing, nanotechnology, robotics, and artificial intelligence. This will result in more efficient mitigation plans and a better environment.

4. Conclusions

Advancements in sampling methodology is promising in the ongoing battle against MP pollution, enabling researchers to

gather more representative and extensive samples from various environmental regions worldwide. Modern remote sensing methods, such sophisticated imaging and spectroscopic equipment carried by satellites or unmanned aerial vehicles, can track the concentration of MPs in real time across wide geographic areas. With the introduction of extremely sensitive and selective instruments like mass spectrometers and Raman spectroscopy systems that can detect and measure minute amounts of MPs in the environment, analytical equipment is set to experience major advancements. More information on the distribution and destiny of MPs in the environment might be gained by identifying and classifying them using enhanced extraction techniques and the creation of new analytical instruments.

To improve the reliability of analytical findings, standardizing environmental reference materials might be essential for method validation, quality control, and interlaboratory comparisons. Simultaneously, automation is essential for streamlining the procedures involved in sample preparation and analysis, boosting productivity, and lowering human error. Recent advances in the study of MPs lead to the conclusion that sophisticated detection techniques like Raman spectroscopy and machine learning algorithms will probably be able to identify and quantify MPs in environmental samples with greater accuracy. MPs are widely found in atmospheric aerosols, which may provide insight into the hitherto underappreciated role that airborne MPs play in environmental contamination. When combined, these advancements may provide researchers with a better understanding of the origins, movement, and environmental effects of MPs, which will help them create focused mitigation plans.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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