Abundance and type of microplastics along an urban density gradient in the Allander Water and River Kelvin, Greater Glasgow, Scotland

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Abstract

Microplastics have now been found in air, water, and soil, polluting a wide range of environments globally and presenting potential health threats to humans and other organisms. This study aimed to investigate the type and abundance of microplastics in two urban rivers in Glasgow, Scotland. Here we sampled sediments from the more suburban Allander Water and an urban reach of the River Kelvin, northwest and west of Glasgow's city centre, respectively. Samples were sieved to separate size fractions, and microplastics were identified by both optical microscopy and Raman spectroscopy. We found that microplastics were present in sites along both rivers, with the type of microplastics varying from site to site. The outcome of this study provides useful information for local councils to design effective plastic waste management policy, as well as adds to the growing body of literature evidencing the widespread distribution of microplastic pollution.

Keywords: microplastics; pollution; urban rivers

Introduction

Plastic is a widely used material in our daily lives, and this polymer finds applications in various fields such as the automotive, aerospace, medical, and construction industries (Andrady and Neal, 2009). However, with the increase in population and improvement in living standards, the production and consumption of plastic products globally have been continuously rising, leading to a corresponding increase in plastic waste generation. The packaging and construction industries stand as the two most extensively utilized markets for microplastics. If plastic waste is not properly treated for harmless disposal, larger plastic items, upon entering the environment, may undergo natural weathering and other physicochemical processes, giving rise to microplastics and nanoplastics that are even more challenging to detect and manage.

Microplastics have diverse sources, including the floating and sinking of plastic waste, the use of plastic products, and the release of fibres during laundry and washing processes (Wang et al., 2019). Hernandez et al. (2017) found that textiles release a large number of microfibers, which have become a leading source of household microplastics. Most of the fibres released during the laundry process are between 100 and 800 μm in length. Based on their origins, microplastics can be classified into primary and secondary sources. Primary sources mainly stem from deliberate additions of plastic particles during human production and usage, such as plastic microbeads in personal care products like shower gels and toothpaste to enhance friction and exfoliation (Jemec Kokalj et al., 2018). Fendall et al. (2009) identified irregular microplastic fragments with diameters less than 0.5 mm in facial cleansers. Secondary sources refer to the smaller plastic particles generated from the physical, chemical, or biological breakdown of plastic items with relatively larger diameters (Browne et al., 2007). Over time, these particles undergo multiple fragmentation and decomposition processes, eventually transforming into microplastics.

Microplastics will be transported and migrated in the hydrosphere, atmosphere, pedosphere and biosphere under human influence and biological action (Zhang et al., 2023). Due to the low cost of sanitary landfilling of waste, this waste disposal method is widely used, resulting in a large amount of plastic and microplastics accumulating in the soil. Some microplastics are discharged into natural water bodies with wastewater or enter water bodies under surface runoff (Raju et al., 2018). When floods, typhoons, rainstorms and other natural phenomena occur, microplastics will also migrate; The impact of diverse human and other biological behaviours on microplastic transportation is even more challenging to predict (Lu et al., 2023). Due to many reasons, it is a complex and difficult task to predict the migration path of microplastics accurately. The physical migration of microplastics mainly includes the sedimentation, floating and accumulation of microplastics in an aquatic environment (Wang et al., 2016). Microplastics not only move in the horizontal direction with the water flow but also change their position in the vertical direction. Maes and Blanke (2015) pointed out that ocean currents are an essential factor in the migration of plastic waste. Their experiments showed that floating microplastic debris could complete migration between New Caledonia, Solomon Islands and Papua New Guinea within three months. Iwasaki et al. (2017) simulated the migration process of microplastics and mesoplastics particles in the Sea of Japan. The simulation results were consistent with the actual situation, emphasizing the impact of surface ocean currents and wind waves on the migration of these microplastic particles.

Microplastics can persist in the natural environment for a long time without easy degradation (Kaur et al., 2022). Moreover, their low density makes them prone to be transported and dispersed by water flow, leading to their widespread distribution in various aquatic environments, posing a severe threat to marine ecosystems. After entering the ocean, microplastics are highly likely to be ingested by marine organisms because of their unique tiny size, thus entering the food chain and web (Goswami et al., 2023). For instance, microplastics in aquatic environments can be ingested by plankton and fish. Rodrigues et al. (2021) found both fibre-type and fragment-type microplastics within plankton organisms. Guven et al. (2017) found that 58% of fish sampled from the Turkish waters of the Mediterranean Sea contained microplastics in their stomachs or intestines. On average, each fish ingested 2.36 microplastic particles, with fibre-type microplastics being the predominant type. These microplastics may gradually accumulate from lower trophic levels to higher trophic levels, ultimately affecting the overall stability of the marine ecosystem. Moreover, humans may ingest microplastics by consuming seafood, leading to potential health issues such as weakened immune responses, gastrointestinal discomfort, and in severe cases, even an increased risk of cancer occurrence (Mamun et al., 2023). Studies have shown that microplastics have the ability to adsorb organic pollutants (Yu et al., 2021). When microplastics are ingested, these toxic substances can be released, increasing the jeopardy of their accumulation in the food chain, and further polluting the marine environment.

In addition to the marine environment, microplastics are widely distributed in freshwater environments such as rivers, lakes, and reservoirs. The inland freshwater system provides water resources for human survival and habitats for freshwater organisms and is more closely related to human activities (Chu et al., 2015). Microplastics generally pollute rivers flowing through developed areas and densely populated areas. McCormick et al. (2014) measured the concentration of microplastics in an urban river in Chicago, USA, and found that it far exceeds the concentration of microplastics in other river ecosystems. They also found that microplastics can serve as habitats for microorganisms. Vaughan et al. (2017) conducted the first assessment of microplastic distribution and concentrations in small urban lakes within the UK, with the maximum concentration reaching 30 microplastic particles per 100 grams of dry sediment. Blair et al. (2019) conducted sampling, processing, and analysis of sediment from the River Kelvin in Glasgow and found the presence of microplastics in the freshwater system of the urban city. Further identification was carried out using scanning electron microscopy with energy dispersive spectroscopy, revealing that the total microplastic content in the River Kelvin ranged from 161 to 432 particles per kilogram of dry sediment. Here we expanded the study of Blair et al. (2019) to investigate microplastics distribution along an urban density gradient, from the River Kelvin to the upstream Allander Water, a smaller river that traverses a rural to suburban region of the Greater Glasgow area.

Methods

In this study, four sites were selected for sampling, and the information on the sampling sites is shown in Table 1, which was completed on June 13, 2023. The sediment on the surface of the river bank was collected with a spade, and the sediment collected at each sampling site was about 350 grams. After sampling, they were collected in glass jars, wrapped and sealed with aluminium foil, and transported to a dark and dry place in the laboratory for storage.

Table 1. Sampling site information

Site	River	Longitude	Latitude
Site 1	Allander Water	4°19'51.0"W	55°57'23.0"N
Site 2	Allander Water	4°18'55.8"W	55°56'17.2"N
Site 3	River Kelvin	4°18'24.3"W	55°53'57.5"N
Site 4	River Kelvin	4°17'03.2"W	55°52'42.2"N

The sample processing method in this study followed the protocol of Blair et al. (2019). First, we transferred the sediments from glass collection jars to aluminium foil trays and measured their wet weights. They were then dried in an oven at 100ºC for 24 hours and reweighed. Each dried sample was divided into two equal parts, one for microplastic identification research and one for recovery tests. The latter was supplemented with three different kinds of plastics for recovery tests: toothbrush fibres, wire fragments and Hama beads. We added ten beads or fifteen fibres and fragments to about 20 grams of dry sample. Samples were size fractionated using sieves of 2.8 mm, 2.0 mm, 1.4 mm, 1.0 mm, 0.71 mm, 0.5 mm, 0.355 mm, 0.25 mm, 0.18 mm, 0.125 mm, 0.09 mm and 0.063 mm, in an automatic shaker for 10 minutes. We obtained 13 sub-samples of different size fractions. A sodium chloride solution with a density of 1.2 grams per cubic centimetre was prepared with deionized water and 50 millilitres of solution was added to samples of each size fraction. After 24 hours of settling, the supernatant was filtered using Whatman 11-μm cellulose filters and washed three times with deionized water to remove excess impurities and salt. The filter paper was then transferred to a glass Petri dish to dry and stored for future use.

Microplastics were first identified using a stereo microscope (Olympus SZX7), picking out particles shaped differently from the sediment, such as fibres or coloured fragments. Percentage recovery efficiency was determined using spiked microplastic amendments (number of microplastics recovered / number added). These suspected microplastic objects were then photographed with an Axiocam 105 colour camera connected to a ZEISS Axiolab 5 microscope with magnification between ×10 and ×40. Some microplastic-like fragments, particles, or non-plastic fibres that were indistinguishable from the naked eye may have been misclassified as microplastics and required further analysis by Raman microscope (inVia confocal Raman microscope, RENISHAW, with CCD detector). We used a near-infrared laser with a wavelength of 785nm and grating of 1200 l/mm, or a green laser with a wavelength of 514nmand 2400 l/mm grating. An appropriate exposure time was selected for each sample, ranging from 4 to 20 seconds. Baseline subtraction was performed to increase the interpretability of Raman spectral data.

Results

To evaluate the reliability and stability of the density separation method used in this study to separate microplastics, a recovery test was conducted. Recovery rates for Hama beads and toothbrush fibres were 100% and 56.3%, respectively. Whereas the recovery rate for wire fragments was the lowest, only 32.22%.

The number of suspected microplastics observed under reflected light optical microscope, and the abundance of microplastics from each sampling site, are shown in Table 2. Among them, these observed suspected microplastics were divided into fibres, fragments and irregular objects. Fibres accounted for the majority, followed by fragments, and no suspected microplastic pellets were observed. The highest number of suspected microplastics was found at site 1, and the abundance of microplastics calculated on the basis of the number of suspected microplastics was also the highest of the four sites, at 64 items per 1kg dry sediment. The number of suspected microplastics observed at site 3 was the least, and the abundance of microplastics at this site was also the smallest, only 17 items per 1kg of dry sediment. It is worth noting that suspected microplastics in the shape of fibres were found at all four sites. At the same time, no irregular objects were observed in the sediment samples from site 1, and no fragments were found at site 4. However, observations of three different shapes of suspected microplastics were recorded at both sites 2 and site 3.

Table 2. Counts and abundance of suspected microplastics at different sampling sites

Sampling site	Sediment dry weight (g)	Fibres count (n)	Fragments count (n)	Irregular objects count (n)	Total count (n)	Abundance (Items per kg dry sediment)
Site 1	124.1	5	3	0	8	64
Site 2	114.2	2	1	2	5	44
Site 3	181.4	1	1	1	3	17
Site 4	133.6	4	0	1	5	37

Figure 1 shows the reflected light optical microscope image of some representative fibres. Most of these suspected microplastic fibres appear coloured rather than transparent, primarily in purplish red, blue and black. They varied in length but were mostly longer than 0.5 mm.

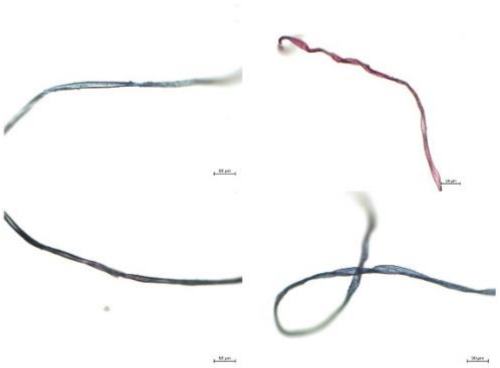

Fig. 1. Optical microscopy images of fibres. Scale bars are all 50 microns.

Figure 2 is the reflected light optical microscope image of some representative fragments. They come in various colours, such as violet and black, as well as transparent forms. While they are more regular in shape, appearing as squares or circles, compared to fibres they are smaller and more challenging to be detected by the naked eye. Typically, their diameter was less than 0.3 millimetres.

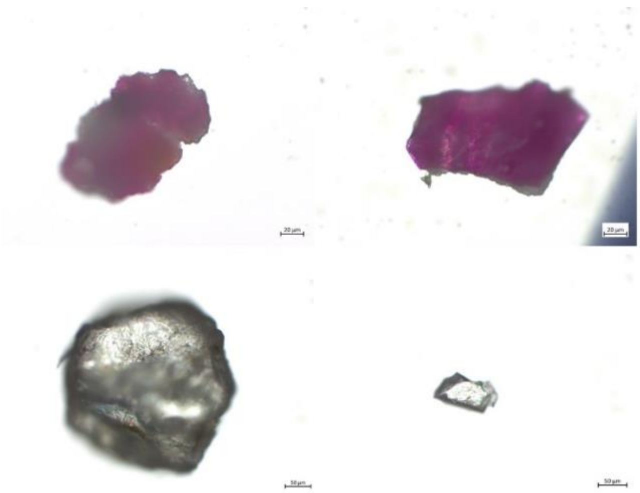

Fig. 2. Optical microscopy images of fragments. Scale bars are all 50 microns.

The reflected light optical microscope images of some representative irregular objects are shown in Figure 3. Unlike fibres and fragments, they came in a variety of shapes and were unevenly distributed in colour. They are highly likely to be microplastic films or other plastic products. In addition, they varied in size, and due to their irregular shapes, were challenging to measure in terms of accurate dimensions.

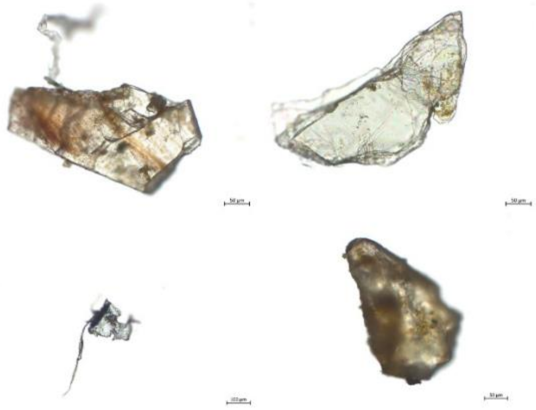

Fig. 3. Optical microscopy images of irregular objects. Scale bars are all 50 microns.

Among the three types of suspected microplastics mentioned above, coloured particles made up the majority. Although they varied in size, they were all imperceptible to the naked eye and needed to be identified under an optical microscope.

With the information from reflected light optical microscope images obtained in the previous step, ten suspected microplastic samples that are most likely to be microplastics were chosen for Raman analysis. Among these, the Raman results for three objects indicated their classification as microplastics, while the Raman results for three objects showed that they were identified to be minerals. Table 3 shows the number of particles characterised as microplastic after Raman analysis and the abundance of microplastics at their sites. It is noteworthy that the objects characterised as microplastics were all microplastic fibres, and no suspected microplastic fragments or irregular objects were identified as microplastics. The identified microplastic fibres were found at sites 1, 2, and 4. A single microplastic fibre was identified at each of these three sites, while no microplastics were separated from the sediment sample at site 3. Based on this, the microplastic abundance was calculated to be similar at sites 1, 2, and 4, with approximately eight items per kilogram of dried sediment, while the microplastic abundance at site 3 was determined to be zero.

Table 3. Counts and abundance of microplastics at different sampling sites

Sampling site	Sediment dry weight (g)	Fibres count (n)	Fragments count (n)	Irregular objects count (n)	Total count (n)	Abundance (Items per kg dry sediment)
Site 1	124.1	1	0	0	1	8
Site 2	114.2	1	0	0	1	9
Site 3	181.4	0	0	0	0	0
Site 4	133.6	1	0	0	1	7

As shown in Figure 4, under 40x magnification of the Raman microscope, the suspected particle is a fibre. According to its characteristic peaks appearing in the spectrogram, it was classified as microplastic, and its plastic type is polypropylene (PP).

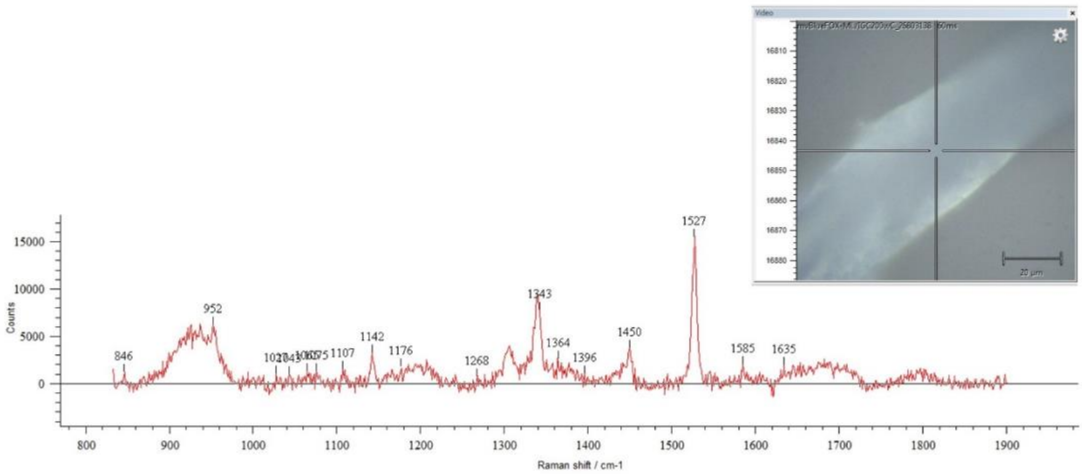

Fig. 4. Image of suspected microplastic (number 1) at site 1 under Raman microscopy and its spectrum

As shown in Figure 5a, it can be observed that the suspected microplastic appears violet in colour, and it is a fragment, not a fibre. By contrasting the characteristic peaks of the two spectra in Figure 5b, it can be ascertained that the particle is identified as the mineral iowaite rather than a microplastic.

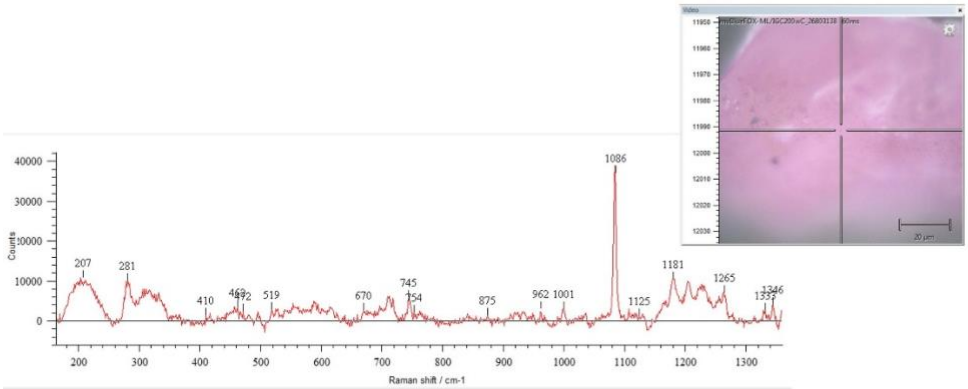

Fig. 5a. Image of suspected microplastic (number 2) at site 1 under Raman microscopy and its spectrum

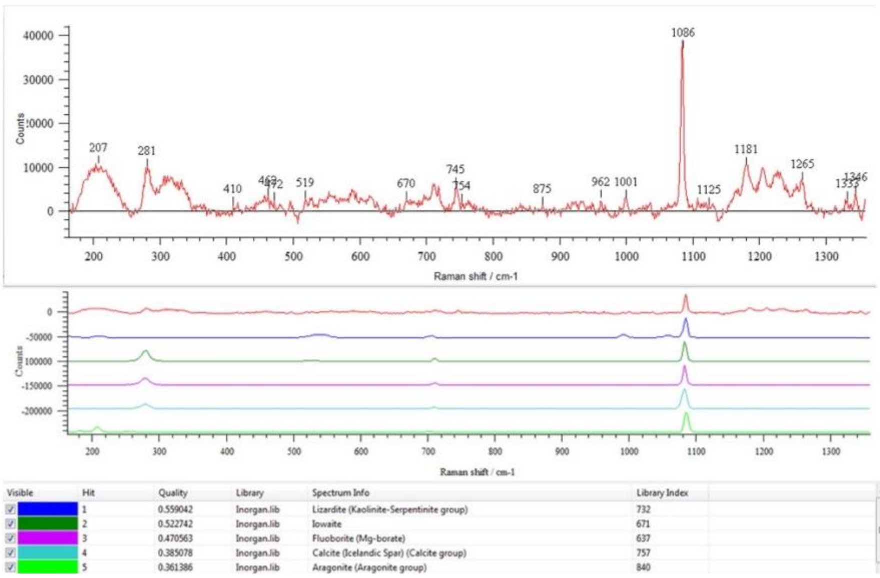

Fig. 5b. Comparison of the Raman spectrum of the suspected microplastic (number 2) at site 1 and the spectral library of minerals

As shown in Figure 6, under 40x magnification of the Raman microscope, the suspected particle is a fibre as well. According to its characteristic peaks appearing in the spectrum, it was classified as microplastic, and its plastic type is polycarbonate (PC).

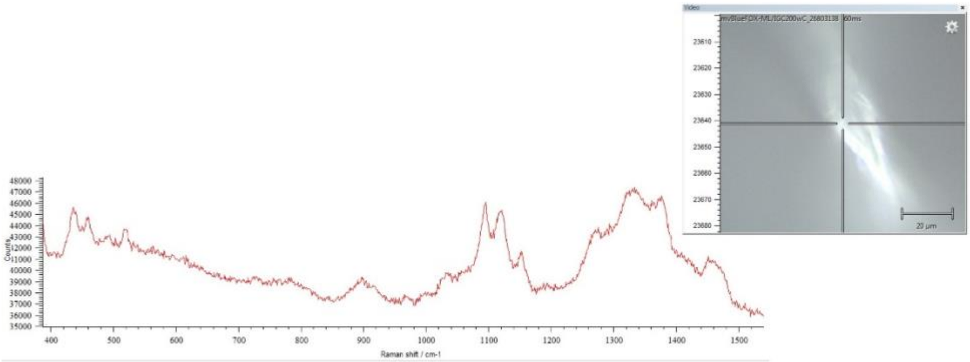

Fig. 6. Image of suspected microplastic (number 1) at site 2 under Raman microscopy and its spectrum

It can be seen from Figure 7a that the suspected microplastic appears transparent, and it is a fragment, not a fibre. By contrasting the characteristic peaks of the two spectra in Figure 7b, it can be ascertained that the particle is identified as the mineral muscovite rather than a microplastic.

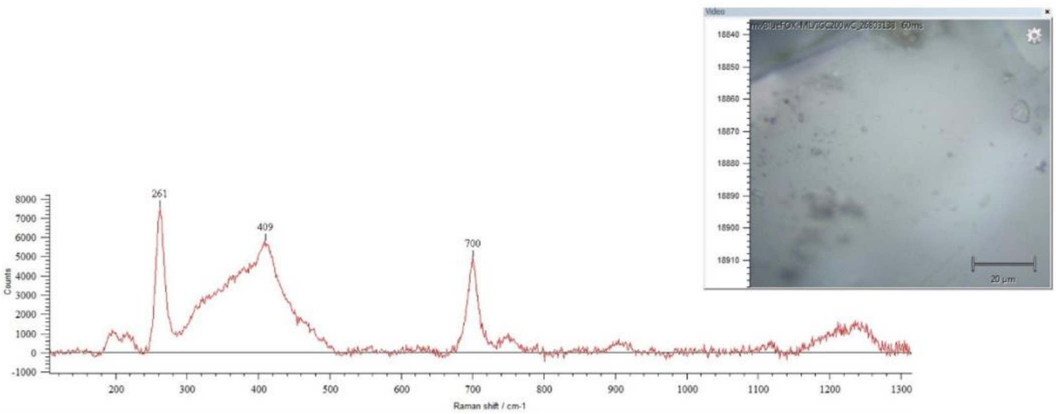

Fig. 7a. Image of suspected microplastic (number 2) at site 2 under Raman microscopy and its spectrum

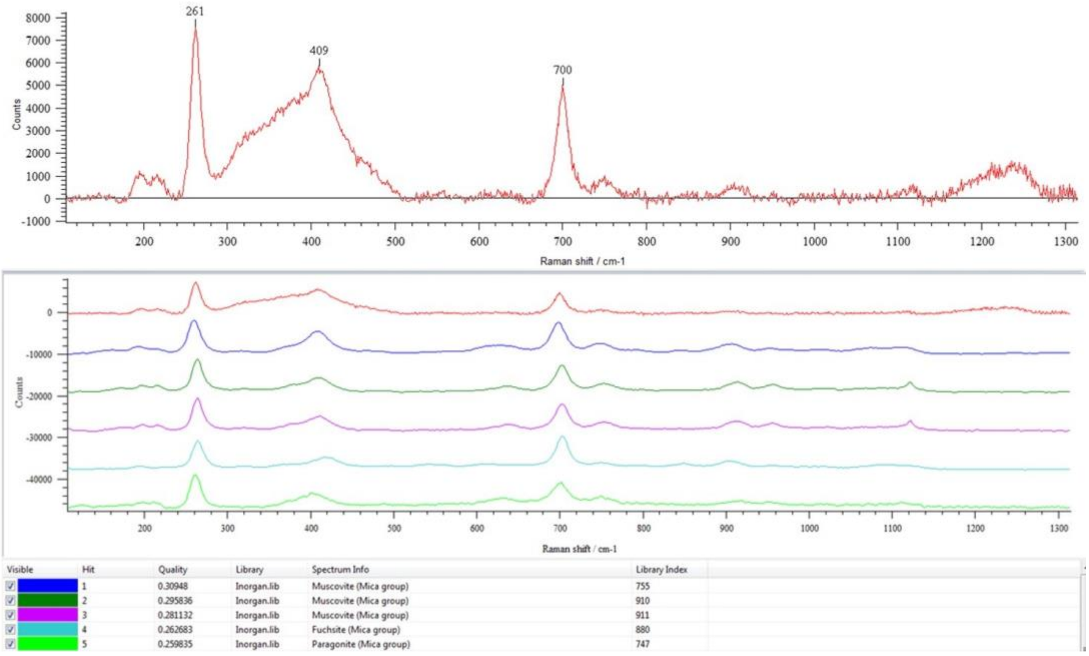

Fig. 7b. Comparison of the Raman spectrum of the suspected microplastic (number 2) at site 2 and the spectral library of minerals

It can be seen from Figure 8a that the suspected microplastic appear transparent as well, and it is a fragment-like particle. By contrasting the characteristic peaks of the two spectra in Figure 8b, it can be ascertained that the particle is identified as the mineral iowaite rather than a microplastic, which is highly likely the same as the one found in site 1.

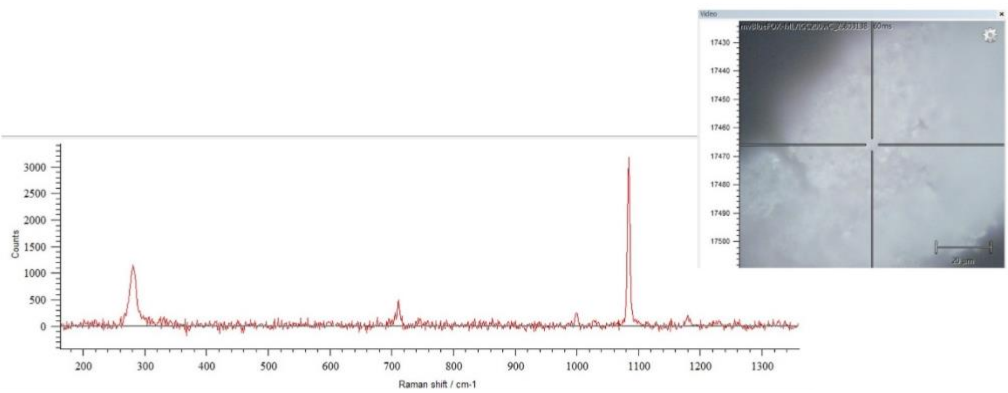

Fig. 8a. Image of suspected microplastic at site 3 under Raman microscopy and its spectrum

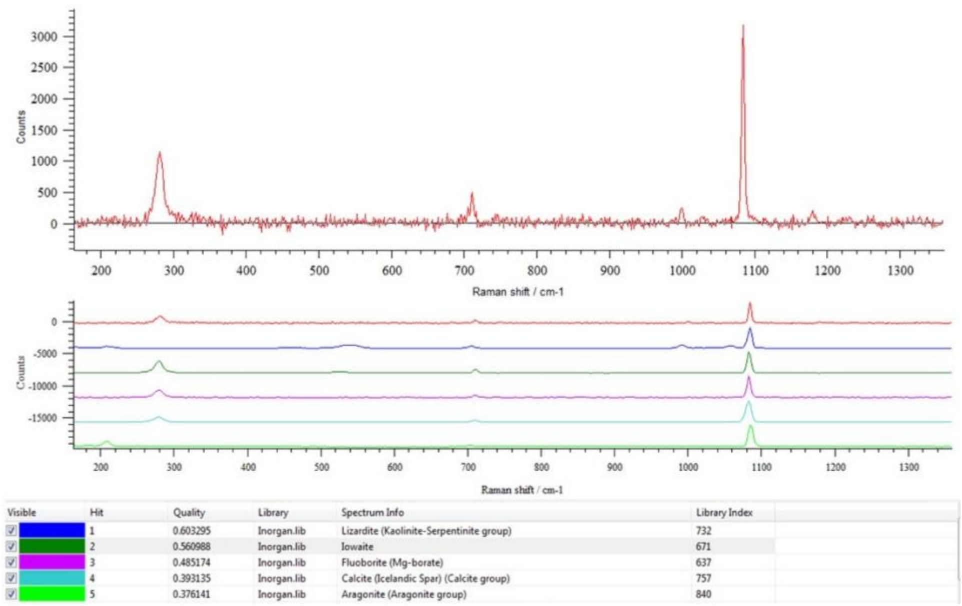

Fig. 8b. Comparison of the Raman spectrum of the suspected microplastic at site 3 and the spectral library of minerals

As shown in Figure 9, under 40x magnification of the Raman microscope, the suspected particle is a fibre-like particle. According to its characteristic peaks appearing in the spectrum, it was classified as microplastic, and its plastic type is polystyrene (PS).

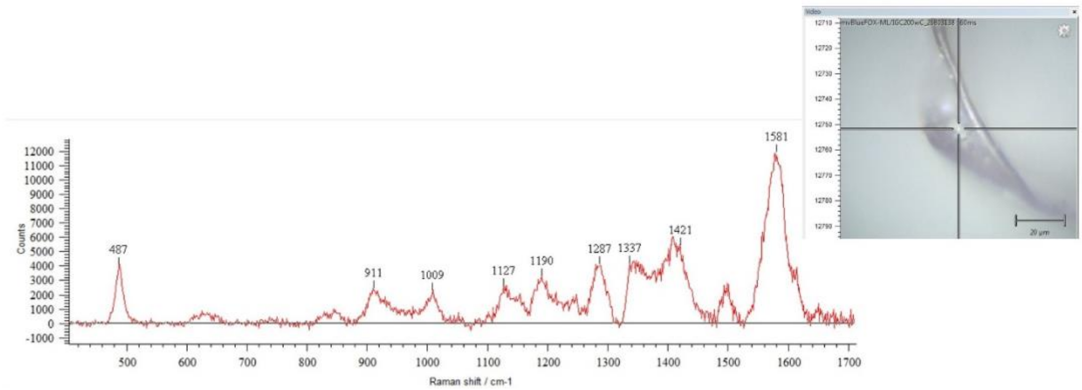

Fig. 9. Image of suspected microplastic at site 4 under Raman microscopy and its spectrum

Discussion

Due to the difference in physical properties, such as the size and density of the three kinds of spiked plastics, their recovery rates were also different after undergoing density separation. In the recovery test, it was observed that some wire fragments sank to the bottom of the sodium chloride solution, preventing their separation from other sediments and resulting in an inability to achieve a 100% recovery rate. This means that some high-density microplastics cannot be separated by this method. If environmental samples contain high-density microplastics, they are likely to be discarded due to gravity sinking. Another spiked plastic was Hama beads, which are polyethene (PE) plastic. According to Batra (2014), the density of PE ranges from 0.88 to 0.96 g/cm^3, and the sizes of the Hama beads used in the experiment mostly fall between 0.7mm and 2.0mm in size. As a result, they are less prone to loss during the density separation process and can be successfully wholly separated. Since the toothbrush fibres were predominantly smaller than 0.5 mm in size and difficult to detect by the naked eye, they are more likely to be lost and undetected during sieving and density separation processes. Consequently, the final recovery rate obtained was only 56.3%.

The results of the recovery test indicated that achieving complete recovery of microplastics from sediment samples in practical operations is challenging, and the possibility that some microplastics will be lost in the course of the experiment. This result can be interpreted as due to several reasons, such as errors in performing the separation step manually and the fact that samples with tiny dimensions are not easily detected and identified. The samples originating from different sources and with distinct compositions can also influence the recovery rate, all of which are factors to be taken into consideration when interpreting the results of the recovery rate. The incomplete recovery of spiked plastics highlights the limitations of the employed separation method, indicating the need for future research into more efficient and accurate microplastic separation techniques. Consideration could be given to using density separation solutions with varying densities or refining methods to filter supernatant more effectively, aiming to minimise potential sample loss. For example, configuring a higher-density separation solution can separate microplastics in a broader range of densities to avoid ignorance of microplastics in water and sediment environment samples.

The number of microplastics detected visually by microscopy was much more significant than those detected by Raman analysis, indicating that the visual inspection method for identifying microplastics may yield inaccurate results. Relying solely on visual identification for microplastic detection has numerous limitations, because of the subjective nature of visual inspection depending on the subjective judgment of the experimenters. Different practitioners might provide disparate assessments for the same sample, potentially leading to inconsistent outcomes. Even the same practitioner evaluating the same sample multiple times can yield varied results. In addition, there are many substances similar to plastics present in environmental samples, such as natural fibres or mineral particles, which may be misidentified as microplastics due to their similar appearance. In addition to the possibility of misclassifying non-microplastics as microplastics, there is also the possibility of inaccuracies in visual results due to oversight. For instance, transparent or semi-transparent microplastic particles are not visually noticeable and thus may be ignored. Due to the distinct colours and appearances exhibited by various types of microplastics, a lack of systematic knowledge regarding the visual characteristics of microplastics can also lead to misjudgments. Therefore, visual inspection is merely employed as a method for a rough estimation of the number and abundance of microplastics. It is necessary to integrate with more advanced analytical techniques, such as Raman spectroscopy analysis or Fourier transform infrared spectroscopy analysis, to acquire molecular structures, chemical bonding, and other related information. The same situation occurred in the study by Blair et al. (2019), where some particles judged to be microplastics in the visual inspection step were identified as non-microplastics in the subsequent chemical inspection step of SEM-EDS.

The abundance of microplastics at sites 1, 2 and 4 was similar, and even though site 3 had a microplastic abundance of 0, it can be assumed that microplastic particles are widely distributed in the Allander Water and the Kelvin River. Previous research has indicated that microplastic pollution is more severe in densely populated areas near cities (Duong et al., 2023).

As mentioned above, Raman analysis was performed on ten samples, yielding spectral data from six. In comparison, four samples had no visible characteristic peaks for analysis and were deemed invalid. Among the six samples with unique characteristic peak data, three were identified as microplastics, with their plastic types being PP, PC, and PS, respectively. The fibre particle at site 1 was classified as polypropylene plastic, with chemical bonds such as bending CH, bending CH_2, rocking CH_2, stretching C-C and symmetric bending CH_3, according to its characteristic peaks (Luo et al., 2023). Polypropylene is a polymer with relatively low density, and its excellent chemical corrosion resistance, heat resistance, and insulating properties have led to its widespread use in various industries, including packaging, medical, and textile sectors (Darweesh et al., 2023). Sampling site 1 is situated at a considerable distance from the city centre of Glasgow and is located near a country park and golf course, characterized by a rocky terrain in its surrounding environment. The discovery of microplastics at this site was somewhat surprising and suggests a new avenue for future microplastic research along urban density gradients in the rivers of Glasgow city.

Particles detected at site 2 were interpreted as polycarbonate plastic, according to Raman spectral libraries. These present representative chemical bonds such as in-plane bending CH, stretching C-O-C, and asymmetric stretching C-O-C (Luo et al., 2023). Over the past decade, polycarbonate materials have frequently been employed as substitutes for glass materials in container applications due to their superior durability compared to glass, as well as their lightweight and portable nature, making them suitable for use as materials for containers such as water bottles (Onghena et al., 2016). Sampling site 2, similarly located in the vicinity of the area traversed by Allander Water, is near parks and supermarkets that attract visitors. Recreational activities of residents in the area are highly likely to involve polycarbonate products, such as water bottles carried when picnics. Given that sampling site 2 is downstream of sampling site 1, and microplastic fibre particles have already been identified at site 1, it is not surprising that microplastic fibres were also found here.

The suspected microplastic at site 3 was identified as non-plastic through Raman analysis. However, this finding does not mean that there is no distribution of microplastics at site 3. According to the recovery test, the recovery rate of some microplastic particles is low, suggesting the possibility of undetected microplastic distribution in actual environmental samples. Sites 1 and 2 are located in the area where the Allander Water flows, while site 3 is located in the area where the Kelvin River flows. Given that the Allander Water eventually flows into the River Kelvin and considering the previous detection of microplastics in the former two locations, there is a likelihood that microplastics are present at site 3 but have not been detected.

In this study, the primary potential reasons for unsuccessful identification of microplastics included the difficulty in detecting small-sized microplastics and limitations in separation and identification. Since suspected microplastics were manually sieved and selected from sediment samples, it is possible to overlook extremely small microplastic particles in dry sediment samples. Additionally, the 1.2 g/cm^3 density separation solution ruled out the possibility of detecting high-density microplastics, making it incapable of identifying specific types of microplastics.

The suspected microplastic at site 4 was classified as polystyrene, which contains representative chemical bonds such as ring breathing, stretching C-C, scissoring CH_2, and stretching ring-skeletal (Luo et al., 2023). Polystyrene has good heat resistance and thermal insulation properties, making it extensively utilized in the packaging industry for applications such as disposable food containers and cups (Yang et al., 2015). Sampling site 4 is approximately 2 miles away from the city centre of Glasgow, where there are various commercial and recreational activities. These activities can generate numerous secondary microplastics from single-use items, packaging, and other sources, which enter the terrestrial environment through practices such as littering and improper waste disposal. Microplastics from the terrestrial environment can then enter nearby rivers, such as the River Kelvin, through surface runoff and rainfall. In the study conducted by Blair et al. (2019), they collected sediments from the Kelvin River near Kelvingrove Park as samples to analyze the quantity and abundance of microplastics in Kelvin River, and the sampling site was located a small distance downstream of site 4. In their study, they found that the microplastic abundances in this area were 161 and 432 items per kilogram of dry sediment in December 2015 and February 2016, respectively. Although the calculated microplastic abundance for sampling site 4 in this study is only seven items per kilogram of dry sediment, significantly lower than the values reported by Blair et al., it is in line with the overall conclusion of microplastic presence in the River Kelvin.

The factors influencing the distribution of microplastics in the River Kelvin within the city centre of Glasgow are not yet fully understood. Existing literature has shown a correlation between the distribution patterns of microplastics in urban rivers and the level of urbanization (Xu et al., 2021). Seasonal variations in the microplastic distribution and types in urban rivers may be influenced by factors such as population density and the distance of wastewater treatment facilities to the riverbanks. A more comprehensive study of microplastic pollution in the River Kelvin is needed in the future to understand the specific impact of urban activity and urbanization levels on it. Future research on microplastic pollution should be conducted with multiple sampling events, and appropriate statistical methods can be used for data analysis.

This study investigated the abundance and types of microplastics in Glasgow's urban rivers. The types of microplastics found were identified and qualified by visual inspection and Raman spectroscopy. The microplastics detected at these three sites included polypropylene (PP), polycarbonate (PC), and polystyrene (PS). As Scotland's largest city, investigation into the abundance and types of microplastics in Glasgow's urban rivers can provide representative data and references for microplastic pollution in modern urban environments.

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