Marine Pollution Bulletin 177 (2022) 113534

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Microplastic abundance in the Thames River during the New Year period

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ARTICLE INFO

Keywords:
Microplastics
River Thames
Microfibres
New Year fireworks

ABSTRACT

Microplastic pollution is widely studied; however, research into the effects of large-scale firework displays and the impact on surrounding waterways appears to be lacking. This study is potentially the first to look at microplastic abundance in rivers after a major firework event. To assess the impact of the 2020 New Year's firework display in London, a 3 litre water sample was collected over nine consecutive days at Westminster on the River Thames. A total of 2760 pieces of microplastics (99% fibres) were counted using light microscopy, and further analysis was performed on representative plastic samples (354) using Fourier Transform Infrared Spectroscopy (FTIR). Whilst anthropogenic microfibres made up 11%, most microplastic identified (13.3%) were polychloroprene. This study demonstrates the occurrence of a short-term influx of microplastics in the River Thames following the New Year fireworks, which will have an additional detrimental impact on the ecology and aquaculture of the river and neighbouring waterways.

1. Introduction

Plastic production and inefficient waste management schemes and policies have resulted in plastic particles being found in varying sizes (macroplastic (>5 mm), microplastic (<5 mm), nanoplastic (1-1000 nm)) in aquatic and terrestrial habitats (Da Costa et al., 2016; Huang et al., 2020; Hurley et al., 2020; Law, 2017; Peng et al., 2020). Microplastics (MP) with size <5 mm in particular are becoming ever increasingly abundant locally and globally, with their impact widely documented (Browne et al., 2011; Zhao et al., 2018). Microplastics can leach and sorb harmful toxins from the surrounding environment. As a result, MPs can transfer pollutants into organisms and result in bioaccumulation and biomagnification within food chains (Farrell and Nelson, 2013; Miller et al., 2020). Many previous studies have focused on the effect of MPs in the marine environment. However, the focus appears to be shifting to freshwater systems due to rivers being the major pathway of plastic pollution estimated at 1.15 to 2.41 million tonnes per annum worldwide, with 80% of plastic originating from the terrestrial environment (Horton et al., 2017; Lebreton et al., 2017; Meijer et al., 2021).

Freshwater and estuarine ecosystems are essential resources fully utilised as a food and water source, a network for economic development, industry, and agriculture (Carpenter et al., 2011). Due to their connectivity and population density being higher around water systems, rivers have become a significant contributor and pathway for introducing plastics to the sea and making it polluted (Claessens et al., 2011; Willis et al., 2017). A range of sources have been identified for plastic pollution in rivers via natural processes such as flooding and wind (Bruge et al., 2018; Tramoy et al., 2019), and anthropogenic sources such as wastewater treatment plants (WWTP's), human littering, building works and road run-off (Horton and Svendsen, 2017; Kay et al., 2018; Lechner and Ramler, 2015; Seo and Park, 2020). Another less examined potential source is large-scale nationwide firework events that contribute to atmospheric, terrestrial, freshwater and marine pollution due to their explosive nature and use worldwide (Tandon et al., 2008).

The amount of pollution released varies depending on the scale of the firework event. These events can range from small scale celebrations to larger nationwide events. The global Diwali festival, Independence Day in the USA (Seidel and Birnbaum, 2015), and Bonfire Night (gunpowder plot) in the UK are examples of large-scale firework events. One of the

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https://doi.org/10.1016/j.marpolbul.2022.113534
Received 22 November 2021; Received in revised form 28 February 2022; Accepted 1 March 2022
Available online 15 March 2022

biggest celebrations worldwide is New Year, celebrated each year with huge firework displays. Research studies such as Moreno et al. (2010) and Greven et al. (2019) have already shown that setting off fireworks results in clouds of smoke which increase the amount of CO_2 and the atmospheric pollution within the immediate area in the short term (Ravindra et al., 2003). These studies have documented that fireworks can on average cause a 42% increase in air pollutants, due to charcoal being the most commonly used fuel (Ravindra et al., 2003; Seidel and Birnbaum, 2015). The amount of plastic varies depending on the type of firework involved. According to Toader et al. (2017), a pyrotechnic mixture like fireworks contains roughly 10% of a natural or artificial polymeric binder. These binders are typically made from either a natural material such as starch or Arabic gum, synthetic material such as shellac, novolac, or synthetic polymers such as nitrocellulose, polybutadiene, polyisobutylene, polyurethane or polyvinyl chloride (PVC) (Naik and Patil, 2015; Poulton and Kosanke, 1995). Rocket type fireworks that explode in the air also have a mortar and a tube sealed at the bottom end to help the firework get enough momentum to lift off the ground (Naik and Patil, 2015). These mortars are made from wrapped paper, high-density polyethene (HDPE), or steel (Poulton and Kosanke, 1995). Rockets also have plastic cones at the top to aid flight (Naik and Patil, 2015).

Toxic substances, metals, plastics, cardboard, and many other materials and compounds have been found around firework display sites (Attri et al., 2001; Baranyai et al., 2014). The resulting particles of plastic, cardboard, smoke and airborne particulates or chemical pollutants tend to accumulate close to the fireworks display area (Azhagurajan and Selvakumar, 2014). Due to rain, surface run-off and subsurface drainage, these particles may reach rivers in these cities, and subsequently impact water resources. The majority of the New Year firework displays take place in cities or are located over water, for example, in the UK (London, Westminster), Australia (Sydney Harbour), Brazil (Rio de Janeiro, Copacabana), Hong Kong (Victoria Harbour), Singapore (Marina Bay).

The 2020 firework display held at Westminster caused a level 4 (moderate) air pollution level, with an air quality index value of 105 (PM 2.5) in the surrounding area of Westminster (The World Quality Index Project, 2021). To compare, the Diwali festival of lights in Delhi in 2019 reached the maximum index value of a hazardous 500 (PM 2.5) for air quality due to the concentrations of airborne pollutants caused by the number of fireworks released (Central Pollution Control Board, 2020). Whilst these pollutants are airborne, they still pose risks to the aquatic environment. Dutcher et al. (1999) and Perry (1999) found that the heavy metals used in pyrotechnic devices can travel 62 miles over two days. It is likely that plastic or MP could similarly cover the same distance once airborne, contributing to atmospheric pollution. These airborne particles eventually settle in and pollute waterways due to being washed down with rainfall. Hence it was expected that an increase in MP concentration in the atmosphere would lead to an increased concentration on nearby land or water after a firework event.

Our study aimed to investigate the impact of London's 2020 New Year firework celebrations on microplastics (MP). The objectives were 1) to quantify the abundance of MP in the River Thames at Westminster where the fireworks were taking place, and 2) to classify MP by shape, colour and polymer.

2. Methodology

2.1. Study area

Water sampling took place on the River Thames at Westminster, London, close to the Millennium/London Eye on the river's south bank

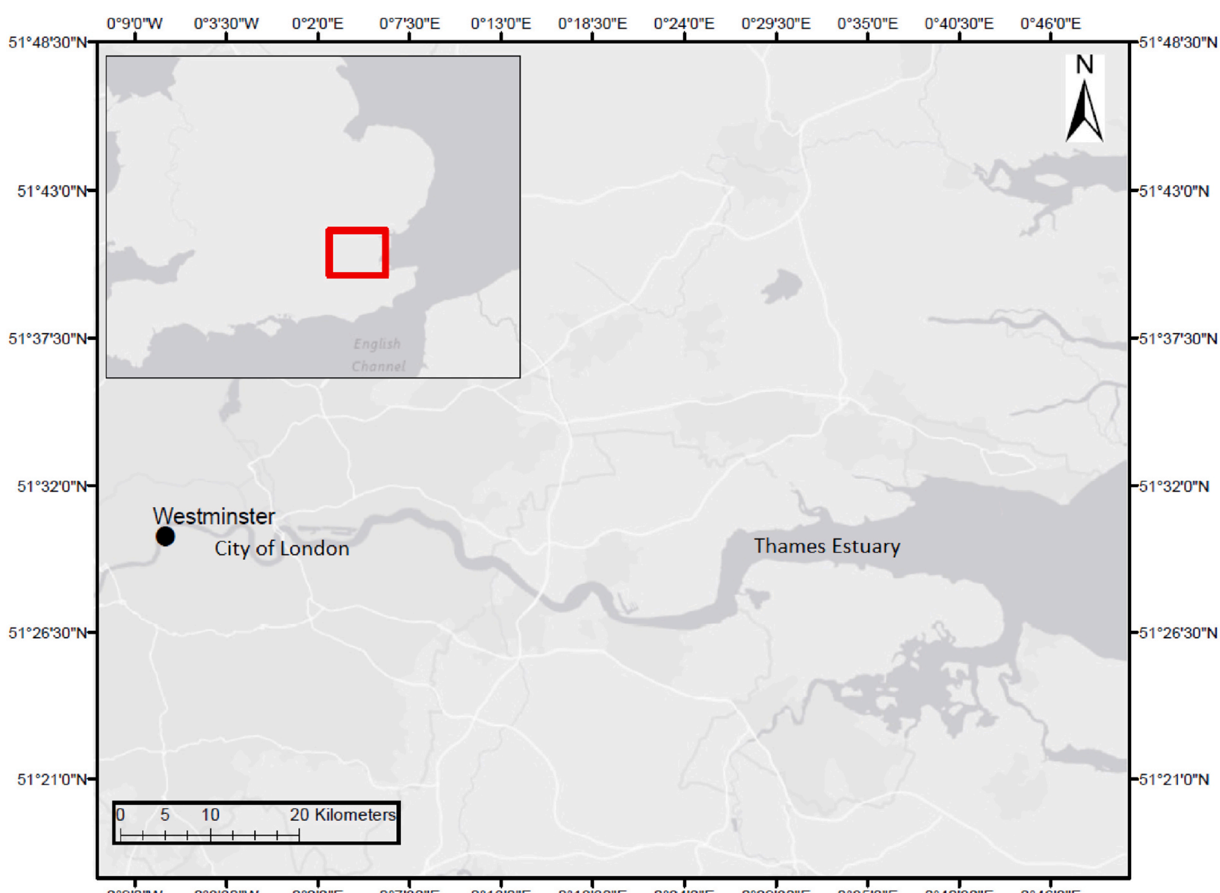

Fig. 1. Location of water sampling site on the River Thames, Westminster, London.

(Fig. 1). The sampling site was chosen due to its proximity to the firework detonation area, expected to have a relatively higher concentration of microplastic from the New Year celebrations. Westminster is a highly urbanised area of London located on the River Thames with a residential population of 254,375 in 2018 (Greater London Authority, 2021). As a result of the businesses and tourist attractions in the area, Westminster's daytime population increases to over a million people (Westminster City Council, 2019). The site is a low lying stretch of the Thames, with Westminster having 4.7 km of River Thames frontage (Westminster City Council, 2008).

The New Year London firework celebrations attracted thousands of people to the area. A total of 86,265 tickets were scanned on the night; however, this does not include residents and businesses within the area who do not need to buy tickets. A total of 12,000 fireworks were set off in roughly 15-minute intervals with a cost of approximately £2 million (Phillips, 2020).

2.2. Water sample collection

Nine samples were collected at high tide from a land-based infrastructure (Fig. 1): 8 samples were collected on consecutive days from 29/10/19 to 5/01/20, covering pre-and post-New Year Day fireworks. One more sample was taken on 23/01/20 to check if the abundance of microplastics had returned to levels observed in the area before the firework event. The New Year Day samples were taken almost 6 h after the firework displays. Surface water samples were collected from a single location on the bank of the river, near the fireworks detonation site that would be most indicative of microplastics input from the fireworks. The surface water at the site of entry to the river could only be reached during high tide. Hence, sampling at the first high tide of the day leading to daily variation in sample collection times (between midnight and 8 AM, Table 1) was rational and the closest timeframe to the New Year fireworks. On each sampling day, three 1 litre bottles of water were collected in Gosselin cornering high-density polypropylene (HDPE) natural rounded plastic bottles. The bottles were sealed on-site to be transported back to the University of East London's Docklands campus for filtering and analysis. Concurrently, rainfall data was gathered using rainfall gauges at a meteorological station close to the site, and downloaded from the weather monitoring system ORP (2020).

2.3. Filtering and contamination controls

The water samples were filtered using a Haldenwanger Porcelain Buchner funnel with Whatman 1001–125 qualitative filter paper circles (11 μm pore size, 10.5 s/100 ml flow rate, grade 1, 125 mm diameter). Strict health and safety protocols and precautions were used in the field during collection and in the laboratory to prevent contamination of samples. Field and laboratory safety protocols were adhered to, such as wearing cotton clothing, cotton lab coats and latex gloves. Cotton clothing was worn at all times except on one occasion when a purple polyester raincoat was used during sample collection. Due to potential contamination from the raincoat used, all purple particles and fibres were discounted if they were identified as polyester during FTIR protocols. Other protocols included covering the filter immediately after filtering to avoid airborne contamination, and reduce the time that samples were exposed to air. Used bottles were washed out with distilled water, and surfaces were cleaned before and after use. The use of plastic equipment was kept to a minimum, but this was not always practical. Hence, quality control tests were carried out for all experiments in this study to test for potential plastic contamination (Table 2): a) dampened filter paper placed on laboratory worktops to check for airborne contamination whilst samples were exposed, which were analysed daily, b) three high density polyethylene (HDPE) bottles rinsed with distilled water and filtered, and c) filtering blanks created using 3 × 3 L of distilled water passed through the filtration setup.

2.4. Classification of microplastics (MPs)

The filter papers were examined under a Keyence digital microscope VH-S3OB with a VH-Z250R/W/T lens attachment at 50× magnification, and observed MPs were classified and counted. Based on "The Guide for Microplastic Identification" (Marine and Environmental Research Institute, 2020), the type of MPs observed were classified into two main types: 1) shape: a) fibre, b) fragment including bead, foam, pellet, and other, and 2) colour (blue, black, red, white, orange, yellow, brown, pink, green, purple, transparent, etc.). The width was also measured to confirm all suspected plastic fell into the microplastic categorisation. For this study, any piece of plastic with a larger width than 5 mm was discounted as they were classified as macroplastic, and length was recorded from the remaining plastic fraction.

A selection of particles was scanned using a Fourier-Transform Infrared Spectrometer (FTIR) (Bruker model Alpha), fitted with a platinum ATR Model with Opus 8.2 software. FTIR scans particles down to 10 μm in size, is used to determine the chemical composition, and it is a popular technique to identify polymers (Alfonso et al., 2021; Uurasjärvi et al., 2021). Due to the limitations of FTIR, and to reduce the number of samples lost in transition from filter system to the FTIR, it was determined that individual particles were required to have a length greater

Table 2
Cross contamination controls - microfibre count and type of colours present a) on desk filters (n = 10) exposed to the atmosphere on a daily basis, b) in distilled water kept in HDPE bottles (3 × 3 L), and c) on filtering blanks where distilled water was run through the filtering set up. Routine observation showed only microfibre on the control sample filters.

Tested for cross-contamination	Microfibre colour				Fourier-transfer infrared (FTIR) tested
	Blue	Black	Red	Transparent	
Desk based filters (10)-atmospheric	3	3	2	0	2 black fibres: polyethylene terephthalate (PET)
Distilled water (3 × 3 L)	1	1	0	0	1 black fibre: polypropylene (PP)
Plastic bottles (3)	0	3	2	0	2 red fibres: high density-polypropylene (HDPE)

Table 1
A comparison of microplastics observed per litre of water sampled in the River Thames at Westminster between the period 29/12/19–5/01/20 and on 23/01/20.

Date	Time of sample collection	Average microplastic fibre (MPF) (±SD)	Average microplastic particles (MPP) (±SD)	Average length (μm) (±SE)
29/12/2019	03:31	21 (0.82)	0.67 (0.94)	986 (3.2)
30/12/2019	04:11	36.67 (10.62)	0	1608.9 (4.98)
31/12/2019	04:40	44.3 (6.44)	0	892.45 (2.03)
01/01/2020	05:43	508.3 (40.45)	2 (1.41)	663.40 (1.6)
02/01/2020	05:45	43.67 (9.04)	2 (2.82)	1437.42 (6.38)
03/01/2020	06:30	52.33 (8.38)	2 (0.82)	1014.4 (4.65)
04/01/2020	07:15	43.67 (2.62)	1.3 (1.25)	1608.81 (9.67)
05/01/2020	08:28	37 (2.16)	0.33 (0.47)	1309.84 (6.65)
23/01/2020	00:29	121.67 (5.58)	2.67 (2.36)	1170.80 (3.29)

than 200 μm. The FTIR analysis was carried out on 354 particles, and enabled identification of shell and biogenic waste that under simple observation can be mistaken as MPs. Spectra were analysed using OpenSpecy (Cowger et al., 2021). Spectra that had no defined peaks (i.e. <55%) were classified as "no hit"; particles were classified by polymer type (i.e. polystyrene, polyethylene), or as 1) natural (i.e. chitin or sand), or 2) anthropogenic microparticle or fibre (i.e. cotton, semi-synthetic cellulose-Rayon). The FTIR equipment and fine tweezers were cleaned with ethanol before and after handling each sample to reduce the risk of contamination and false readings.

2.5. Statistical analysis

Statistical analysis was carried out on the reults data using IBM SPSS Statistics 26 (Statistical Product and Service Solutions) (IBM, 2021). Where microplastic total (MPT), microplastic particles (MPP) and microplastic fibres (MPF) quantities are stated, it refers to the mean value (± SE) of the triplicate samples taken on a given date. Data was standardised to MP mL^{-1} based on 1 L of water collected per replicate. Analysis of Variance (ANOVA) was used to determine relationships between date and MP abundance, based on standardised microplastic (MP) concentrations. Due to a limited amount of rainfall (one event) during the sampling period, it was impossible to conduct statistical analysis to determine the impact of rainfall on MP abundance in the present study.

3. Results and discussion

Microplastics were observed in all samples collected during this study, and a total of 2760 MP pieces were identified. There was variation in abundance (Fig. 2), ranging from the lowest concentration (MPT 22 pieces L^{-1}) observed on 29/12/19 (the first sampling day) to the highest concentration (MPT 510 pieces L^{-1}) observed on 01/01/20, following the fireworks display on New Year Eve. Within 24 h of this peak, MP concentration returned to its pre-firework event range (MPT 34 pieces L^{-1}) observed in samples from 29th to 31st December 2019.

The average MPT abundance over the study period, excluding the 1st January 2020, was 51.2 pieces L^{-1}. The sample taken later in the month, on 23rd January, showed a spike (124.3 pieces L^{-1}) that is more than twice this average abundance value.

The presence of MPs in the River Thames before the New Year event suggests that there are sources and factors to increase the value other than fireworks, which is supported by previous studies on sources of MPs into the River Thames (Horton et al., 2018; McGoran et al., 2017; Rowley et al., 2020). This study is part of a larger ongoing study where samples from 8 sites along the River Thames were collected monthly from May 2019 to May 2021. The maximum microplastics abundance (61 pieces L^{-1}) measured during the study period covering a larger stretch of the river, through all seasons, and at high and low tide, clearly shows that it is highly exceeded by abundance measured (maximum 508 pieces L^{-1}) in samples taken following the fireworks event on the river. Potential sources of MPs within the River could be the result of sewage systems (Browne et al., 2011), personal care products (Rochmann et al., 2016), anthropogenic activities such as swimming, boating, fishing, or littering (Zhang et al., 2015) or tire wear particles (TWP) from road runoff (Goßmann et al., 2021). Sewage system input can take approximately one month for the litter to make its way through the system and exit from the estuary into the sea, potentially explaining why microplastics are already present in the river system (Munro et al., 2019). Rowley et al. (2020) found that microplastic abundance at Putney, a site located upstream of Westminster, increased when Hammersmith pumping station combined sewage overflow (CSO) released higher quantities of sewage into the River Thames. Given the site's central location and busy roads surrounding it, it is important to consider the possibility of TWP entering the river, thus adding to the MP pollution. Previous studies have accounted TWP for 28–45% of MPs in rivers or water sources near roads (IUCN, 2017; Royle et al., 2019).

The hydrodynamics of the river may also explain the daily variation in microplastic abundance during this study. Rowley et al. (2020) also found that roughly 35 thousand MPs per second travel downstream at Putney, and 94 thousand MPs per second at Greenwich. This section of the river at Westminster is also reasonably straight compared to the section at Greenwich, which may mean that the flow is faster, leading to more MPs being dispersed to other areas of the river (Baldwin et al., 2016). This leads to MPs being found throughout the river system and varying flow depths depending on the plastic type and size (Kooi et al., 2017).

One study (Dunn and Friends of the Earth, 2019) reported 84.1 pieces L^{-1} of MP in a water sample taken from a site (not identified)

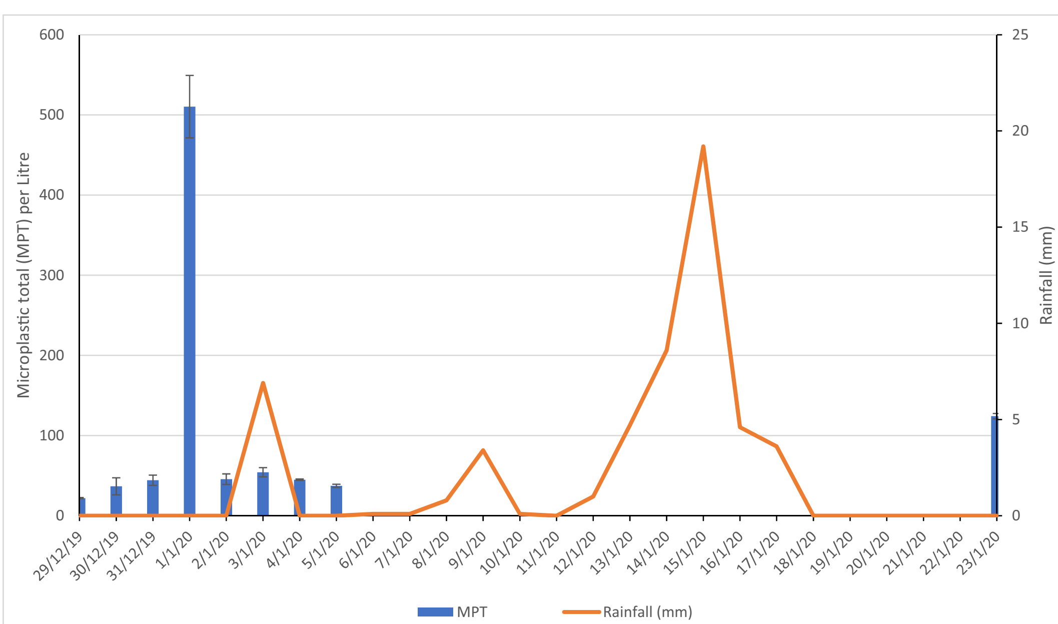

Fig. 2. Mean (±SE) microplastic total abundance (MPT) per litre in water samples collected in the River Thames, Westminster, London on consecutive days at high tide from the 29/12/19 to 5/1/20 and on the 23/1/20 and rainfall (mm) records during the sampling period.

along the River Thames. The study does not inform about the sampling date and the pre-sample conditions such as rainfall, seasonality or tide conditions, making it difficult to compare the data with the current study. Rowley et al. (2020) found an average of 24.8 m^{-3} and 14.2 pieces of plastic m^{-3} at Putney and Greenwich respectively. However, unlike the current study, the authors omitted microfibres in their MPs analysis, so their values may likely be underestimated. Differences could also be due to variations in sampling period, location on the river and other factors, including rainfall intensity and hydrology of the catchment area.

3.1. Impact of New Year firework event

Mean MPT abundance ranged from 21.7 to 44.3 pieces L^{-1} on the three sampling dates prior to the firework event. However, samples collected hours after the firework show a sharp increase in MPT to 510.3 pieces L^{-1} (Fig. 3) (One-way Anova, $f_{1,8} = 12.94$, $P < 0.001$) with an MPF of 508.3 pieces L^{-1} (Table 1). In comparison, MPT abundance measured 24 h prior to the event was 44.3 pieces L^{-1}. Microplastic abundance within 24 h had returned to baseline values whilst there was a slight variation 45.7 pieces L^{-1} (MPT) was deemed to be close enough to pre-firework levels recorded on 31st December 2019. This indicates that fireworks are a significant source of plastics and microplastic debris within the environment and may ultimately contribute to the pollution of rivers. Such pollution after firework events is a known occurrence globally, with microplastics and large amounts of cardboard debris collected in large quantities. In 2016, the National Park Service in San Francisco removed four 50 gallon waste containers full of charred firework fuses, plastic and cardboard pieces after Super Bowl festivals (San Francisco Baykeeper, 2016). Microplastics were not explicitly collected, possibly due to their small size (Choksi-Chugh, 2016). In the same area, after a second firework show, over 30 lb of firework debris washed up at the Aquatic Park beach and continued to wash up for weeks after the event (Choksi-Chugh, 2016). It is possible that peak MP abundance in the River Thames was missed as a water sample was only collected once after the New Year show during our study instead of multiple times over the following 24 h. Sijimol and Mohan (2014) reported that perchlorate concentrations spiked 14 h after a firework show, reaching concentrations between 24 and 1028 times higher than the baseline value.

3.2. Effect of rainfall on microplastics

There was only one rainfall event recorded between 29/12/19 and 05/01/20, but there were multiple rainfall events between the 6th and 23rd January (Fig. 2). In total over the sampling period, there were 11 days of rain events ranging from 0.1 to 19.2 mm rainfall, but a sampling day coincided with a rainfall event only on 3rd January when 6.9 mm rainfall was recorded (ORP, 2020). The highest amount of rainfall during the sampling period (19.2 mm) was recorded on 15th January. Relatively higher MP abundance (124.3 pieces L^{-1}) than found in all other samples except on 1st January was recorded in samples taken a week later, on 23rd January. This spike on 23rd January may be attributed to the rainfall events that occurred between the 12th and 17th January (Fig. 2). However, the absence of more samples taken closer to these dates makes it difficult to imply rainfall as a possible cause for the spike in MP abundance.

There was a 19% increase in MPT abundance from 2nd to 3rd January. However, on the 4th of January, MP abundance had returned to its pre-rainfall value. Previous studies (Hitchcock and Mitrovic, 2019; Hitchcock, 2020; Zhao et al., 2015) have found that rainfall is a significant factor for MPs abundance in rivers. Hitchcock (2020) found that MP abundance was 40 times higher after two days of heavy rainfall than

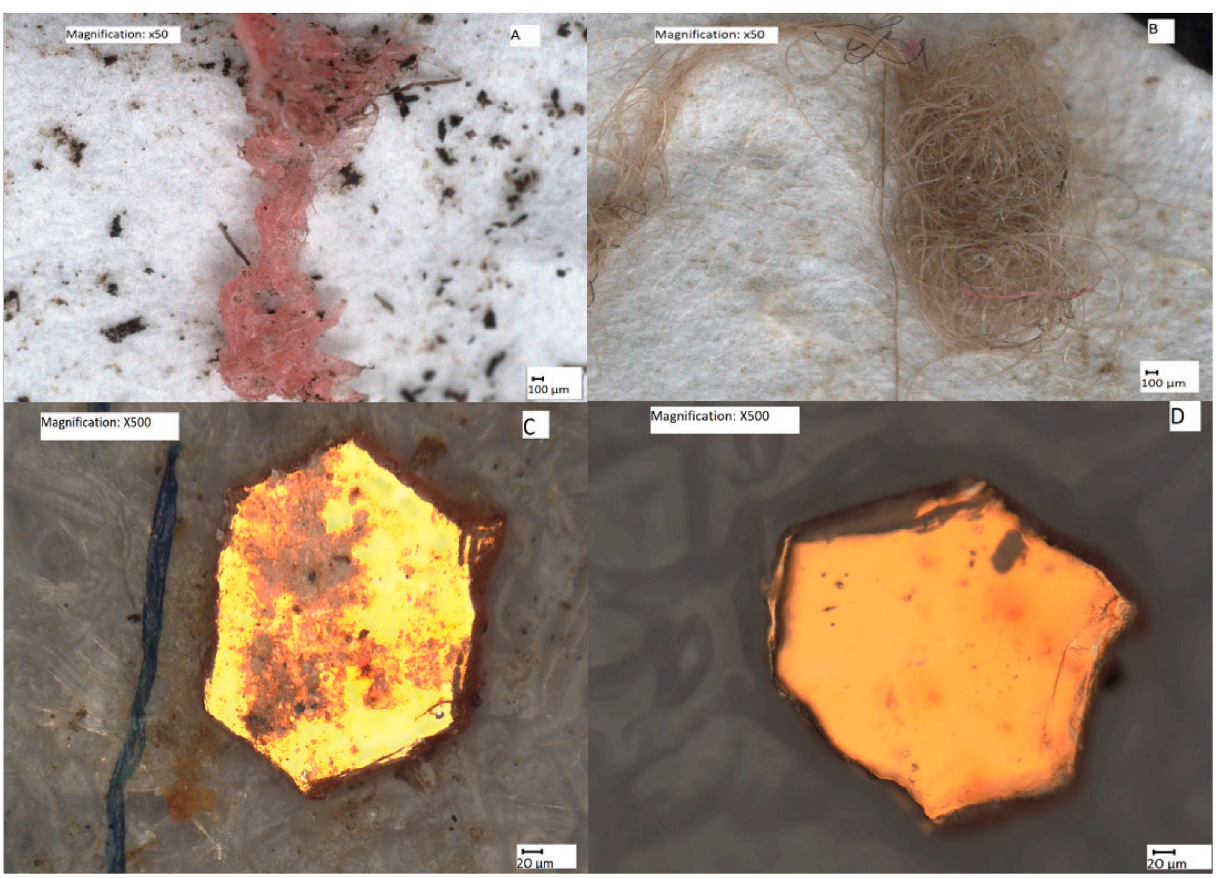

Fig. 3. Types of microplastics observed in water samples collected from the River Thames, Westminster from 29/12/19 to 5/1/20, and on 23/1/20: A) Fragment – has rough or uneven edges with irregular shape, B) fibre – frayed ends, same width throughout, C) fibre and “glitter” – holographic, and D) glitter.

before, increasing from 400 particles m^{-3} to a maximum abundance of 17,833 particles m^{-3} during the peak rainfall. Rainfall increases the turbulence of the water, thus increasing the energy within the river. As a result, MPs are resuspended and likely to be present in more significant numbers than at times of no rainfall when MP's are likely to sink and are stored in the benthos (Horton and Dixon, 2018). Due to a single rainfall event during the study period immediately following the firework event, the effect of flow velocities on MP could not be analysed, and a significant correlation between rainfall and microplastic abundance could not be observed.

3.3. Characteristics of microplastics

The shape, colour and length of MP observed during the present study were recorded. The objective was to classify MP's shape into six groups (fibres, fragments, bead, foam, pellet and other) (Figs. 3 and 4). Fibres (MPF) (98.95%) were the most abundant throughout the study, whilst fragments (1%) and other (glitter) (0.5%) made up the rest; no beads, foam or pellets were recorded (Fig. 4). Whilst fibres were found in every sample, fragments were not found samples taken on 30th and 31st December. Five pieces of glitter were recorded (4 pieces on 1st January and one piece on 3rd January 2020) and classified as "other". Predominant of fibres as found in this study has also been reported by other authors (Salvador Cesa et al., 2017), who reviewed synthetic fibres are in the aquatic enviroment. They can enter rivers through multiple sources, but the most likely is through the clothes shedding fibres during the washing process and entering rivers via wastewater treatment plants. Browne et al. (2011) found that a single garment can produce >1900 fibres per wash. Fibres may also be in high abundance due to sampling close to the River Thames' edge, as this is where the sewage outflows or effluents are likely to discharge (Luo et al., 2019).

In total, nine different plastic colours were recorded: blue, black, red, white and others. Black (93%, 2566 pieces) was the most abundant colour category, followed by red (3.4%, 94 pieces) and blue (2.3%, 64 pieces) throughout the study (Fig. 4). Similar studies on estuaries also show a high abundance of coloured microplastics due to the intense human activities in the area and along the river (Zhang et al., 2018; Zhao et al., 2015).

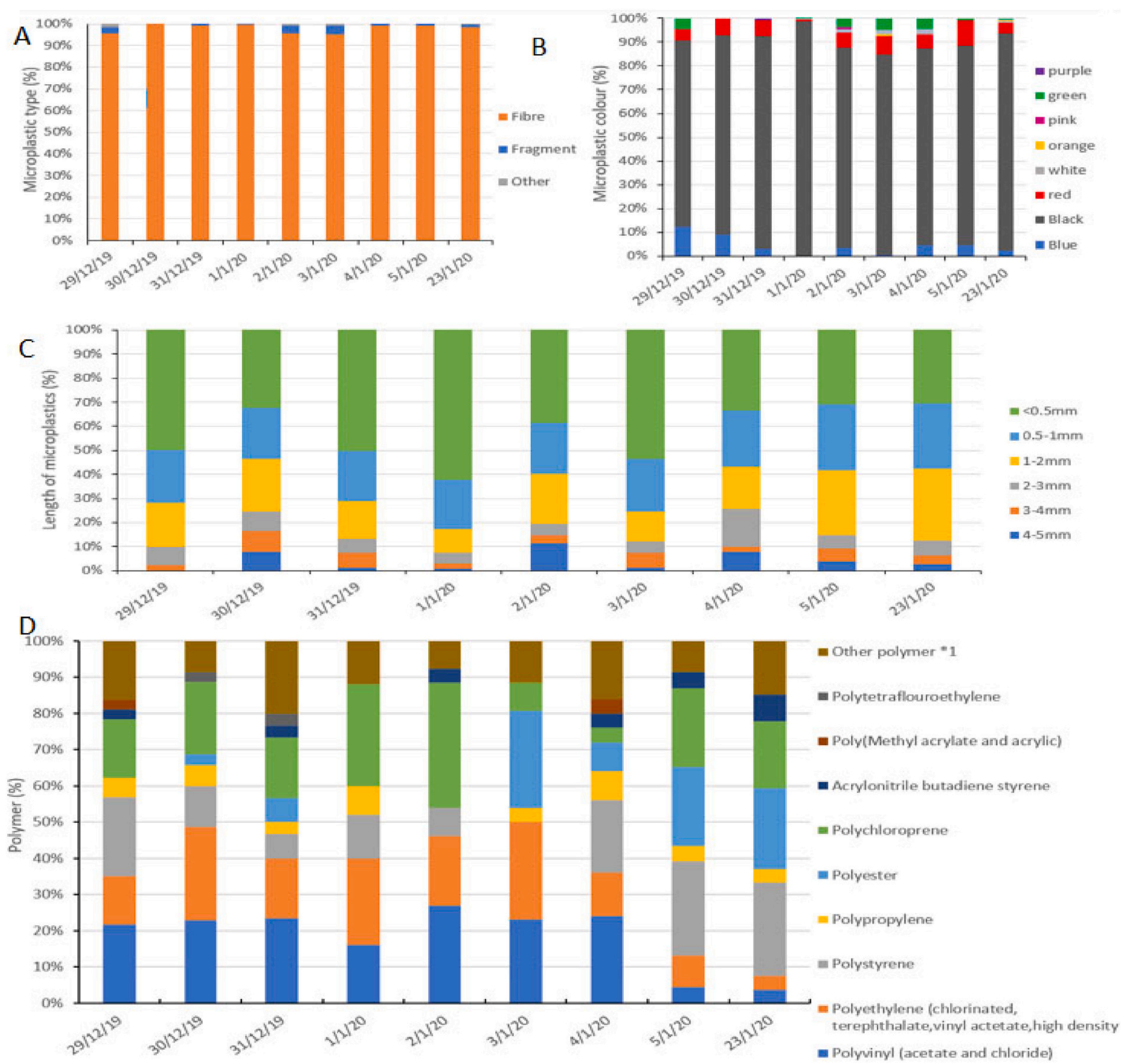

Fig. 4. Measurements of MPs in water samples collected from the River Thames, Westminster from 29/12/19 to 5/1/20 and on 23/1/20: A) abundance of MP types, B) range of colours, C) % composition of MP lengths, and D) % polymer identified via FTIR. *1 Other polymer comprises of the following polymers; cascamite resin glue, polyacetal, polyamide-epichlorohydrin resin, polybutadiene, polybutylene, polydimethylsiloxane, polyethlenimine, polyisoprene chlorinated, and polyphenylene sulfide.

The microplastics were put into five size categories: <0.5 mm, 0.5-1 mm, 1–2 mm, 2-3 mm, 3-4 mm and 4-5 mm. Smaller MP's (<0.5 mm) were in high abundance throughout the study, making up to 50% at times during this study and 62% on the 1st January (Fig. 4). The high presence of smaller MP's may result from fragmentation of larger pieces of plastic within an estuarine system from physical variables (salinity, light and temperature) and microbial degradation (Fernandino et al., 2016). The increase in smaller MP's present on January 1st may be due to fragmentation of firework casing. However, further studies would be needed to confirm this.

A total of 354 MP pieces were taken from the samples and identified using FTIR. As a result, 24 different polymers such as polystyrene, polyethylene and polychloroprene as well as natural material such as sand and chitin (22 pieces), anthropogenic microfibres (38 pieces) were identified; and 41 pieces were unidentified using FTIR (Fig. 4). The most dominant polymers were polychloroprene (e.g. rubber) (13.3%, 47 pieces), followed by polyvinyl chloride (PVC) (13%, 46 pieces) and polyethylene (PE) (12.15%, 43 pieces). These are the most common polymer types produced globally and used worldwide, mainly within the packaging industry (Andrady, 2015). They are commonly identified in aquatic environments, marine and freshwater, and associated with the sediment and organisms (Zhang et al., 2017). Previous studies (Horton et al., 2018; McGoran et al., 2017; Rowley et al., 2020) support results from this study where fibres dominate MP counts and polyethylene (PE) and polypropylene (PP) being recorded. Styrene butadiene (2%, 7 pieces) was also identified, suggesting the presence of TWP in the River Thames (Kreider et al., 2019). The presence of TWP is to be expected due to the location and proximity of main roads to the river, especially within the London region. Boucher and Friot (2017) estimate TWP's contribute to 28% of primary microplastics in the ocean. However, due to the methodological limitations within microplastic studies, TWP's are only mentioned in 1% of environmental studies (Kole et al., 2017).

The types of plastic identified in this study may also be due to the plastic density as only the surface water was sampled. Natural material (6%, 22 pieces) and anthropogenic microfibres (11%, 38 pieces) also made up a percentage of FTIR samples. In total, 11.6% (41 pieces) of samples could not be identified via FTIR.

On visual observation, the water sample on January 1st 2020 was much darker than the sample collected on any of the other sampling days (Fig. 5). After the firework event, three pieces of gold glitter were recorded and later tested with FTIR, and these were identified as PET.

3.4. Cross-contamination

Although plastic laboratory equipment was used, it was limited, and glassware and porcelain equipment were used as much as possible. Due to practicality and safety issues with transporting large amounts of water, high-density polypropylene (HDPE) bottles were used instead of glass bottles. Contamination issues are common and reported among studies due to the nature and size of MPs (Browne et al., 2011; Dris et al., 2016; Foekema et al., 2013; Lusher et al., 2017).

Potential cross-contamination sources were tested for MP from plastic (HDPE) bottles used to hold and transport the environmental samples, and from distilled water used to irrigate the filtering system (Table 2). Three plastic bottles were rinsed with distilled water and then filtered through filter papers to adhere to the same experimental procedure. Filter papers were also used to check for atmospheric contamination in the laboratory. Data from control experiments for contamination were taken into account by subtracting the MP counts (abundance) in controls from the counts (abundance) in the water samples. Although cross-contamination controls were taken due to the size and abundance of microplastics, particularly microfibres, some level of contamination cannot be ruled out.

Contamination control was also performed on distilled water that was used to rinse equipment. Tests conducted on 3 bottles of 3L distilled water showed a total of only 2 fibres; 1 blue and 1 black (Table 1). Desk-based filters (10) contained plastics (8 fibres: 3 blue, 3 black, 2 red) which were considered, as did the high-density polypropylene (HDPE) bottles (5 fibres: 3 black, 2 red). Some fibres from contamination controls were sampled using FTIR (Table 1). Five randomly selected fibres were selected out of the 15 that were found on filters for the cross-contamination controls. Two black fibres were identified as polyethylene terephthalate (PET), one black fibre as polypropylene (PP) and two red fibres as high-density polypropylene (HDPE).

Fig. 5. Observed colour differences of water samples taken from the River Thames, Westminster on the 31/12/19 (clear) and 1/1/20 (dark). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Conclusions

Microplastic pollution leads to a vast range of potential impacts on wildlife and humans, with the leading pollution source being human activities. Many studies have been conducted to examine the effects of human activity on MP abundance in the surrounding environments. A limited number of research studies look at fireworks as a source, and studies that mention fireworks as a source refer to plastic firework casing classified as a macroplastic (Filella et al., 2021; Ory et al., 2020). The results of this study show a clear indication that fireworks are a potential source of MP pollution influx within a short space of time in estuarine environments. A 1,051% increase in MP abundance was observed between December 31st 2019 and January 1st 2020, increasing from 44.3 pieces L^{-1} to 510 pieces L^{-1} within 24 h, with the only major event in the area being the New Year firework celebrations. Although there is no clear link between the impact of rainfall and MP abundance in this study due to a lack of rainfall events, it cannot be ruled out as having an impact on MP abundance within the River Thames. While this study focused on a single large event, it could imply that many local displays throughout the region would have the same effect. This study showed that fireworks can have short and long-term impacts on the environment, not just from an atmospheric pollution point of view, but also plastic pollution in the aquatic environment that needs further exploration. As such, low pollution options or alternatives, e.g., drones, should be considered to prevent or lower the impacts these displays cause. Unfortunately, due to the Covid-19 pandemic and secrecy of the 2021 New Year celebration plans, the 2020 and 2021 displays could not be conducted and compared to see how the impact on MP abundance varied. However, these displays appear to result in an influx of pollution in one area within a short period, which has unknown consequences on the area's ecology and biodiversity. Furthermore, it will be important to conduct detailed investigation on the vertical and horizontal transport of MPs, and macroplastics that potentially break down and degrade into MPs over time, as well as toxic chemicals that adsorb to the plastics, to evaluate the effects of fireworks on plastic pollution in the River Thames.

CRediT authorship contribution statement

Ria Devereux: Conceptualization, Methodology, Investigation, Writing – original draft. **Elizabeth Kebede Westhead:** Supervision, Writing – review & editing. **Ravindra Jayaratne:** Supervision, Writing – review & editing. **Darryl Newport:** Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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