Plastic microfibers found in high numbers around Kantamanto, the world's largest secondhand textile market in Accra, Ghana

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Abstract:

Located in Accra (Ghana), Kantamanto is the world's largest secondhand textile market where tons of garments are exported every week by Global North countries, including the USA, Canada, the UK, the EU27, China and South Korea. We looked at the abundance of microfibers from textiles in this very dynamic environment. Continuous monitoring of air quality using PurpleAir sensors showed large numbers of airborne particles around the market, which were shown to drop with rain events. Rainwater was collected and shown to contain dozens to hundreds of microfibers and microplastics, depending on the intensity of the rain and on whether dry weather preceded the rain. The first hour of rain seemed to bring down the larger numbers of airborne microfibers, especially if it had not rained for 3-4 days. Microfiber and microplastics counts from airborne samples showed numbers about >20x to >100x greater than those reported from other mega-cities, respectively. Comparison of these counts from water of the adjacent Korle Lagoon was similarly striking, with about >100x more microfibers and >200x more microplastics than reported for coastal waters around the world. The impacts of garments were also demonstrated beyond the microscale, with a strong similarity of global brand assemblages in the textile waste found in the market and on the nearby beaches.

Keywords: Microplastics; Airborne Dispersion; Rain flush; Waterborne Contamination; Fast Fashion Waste

Introduction

Air quality has been a global concern for many years considering the growing occurrence of smog in large cities and heavily industrialized areas, also referred to as black carbon ((Bird et al. 2015)(Alli et al. 2021)(Coppola et al. 2022)). Decreasing air quality has been intimately associated with increasing effects of climate change, since in many cases smog originates from burning fossil fuel (from large manufactories to single car engines and waste incineration) but also related to fire, from traditional burning stoves to wildfires ((Garland et al. 2017)(Coppola et al. 2022)). Poor air quality has public health implications, being associated with increased prevalence of lung diseases, asthma, and allergies, to only name a few obvious ones ((Carreras-Sospedra et al. 2024)). In this context, the US has instated the Clean Air Act in 1970, with few updates since then, to accommodate the increased knowledge gain in the field, but also the sensing instrumentation to monitor air quality ((Harrington et al. 2012)(Ko et al. 2020)(Cropper et al. 2023)).

One of such instrumentation is the PurpleAir network, which is a small instrument that detects particles "flying by" in the air at a given timepoint. The instrument can count particles of different sizes and a series of physical parameters of the air carrying them (temperature, and relative humidity, among others). The monitoring is continuous and the data usually publicly available in real-time, as these instruments are wireless and connected to the network. The web interface provides a summary of the data and output that qualifies the air quality in a few categories (www.PurpleAir.com), which are in line with the EPA Clean Air Act quality standards ((Barkjohn et al. 2021)(Jaffe et al. 2023)).

In most cases, PurpleAir data associated with average or poor air quality relate to big city activity in relation to motorized vehicle traffic (tire particle debris and black carbon) and local industries, although dust and pollen can also contribute to the signal, in addition to other particles

of various sources (like microplastics). Although the PurpleAir sensor measures the number of particles within their range size (and provides their mass concentration assuming material density), it does not provide what these particles actually are, in terms of their chemical makeup. In particular, it does not identify whether these particles have a natural basis (dust, pollen vs black carbon) or are purely synthetic, like microplastics (either tire fragments or microfibers from textile fabrics, for example).

A growing number of publications has shown that a significant source of microplastic is clothing, that specifically shed microfibers ((Carr 2017)(Carney Almroth et al. 2018)(Liu et al. 2019)(Nowack et al. 2021)(Liu et al. 2023)). Microfibers are thus a type of microplastics with a "fiber shape" (thus with a length greater than the diameter), which is nuanced, however, by the fact that some microfibers can also be natural, when shedding from clothing made of natural fibers like cotton, wool or plant-based material ((Finnegan et al. 2022)(Genchi et al. 2023)). Even though washing and drying textile are a major source of such microfibers, another important source is related to wearing them and hanging them outside where they are exposed to the elements (especially wind and UV), which facilitates their shedding ((Carney Almroth et al. 2018)(Belzagui et al. 2019)(De Falco et al. 2020)(Lim et al. 2022)(Zhang et al. 2022)).

Accra (Ghana) is home to the largest secondhand textile market in the world, named Kantamanto. The market expands within 500 meters of the Korle lagoon, and thus the interior of the market is not extensively subject to direct road traffic. There are over 5,000 stalls making the market, all exposed to some degree of open circulation of air although most are protected under a partial roof. About 15,000,000 garments are exported from Global North countries and enter the market every week, primarily on Thursday, in the form of 55kg bales that the market retailers purchase from importers. While some bales will make their way to markets in other parts of Ghana

or within the West African region, a majority of these bales will be opened in Kantamanto, the individual items then being retouched and displayed across the market during the week to be sold. As for the undesired or damaged items that go unsold, they are eventually cast aside, accumulating as waste around the market, with small piles of them being burned during the night to avoid excessive build-up, as space is needed.

Indeed, over the years, the market has grown to become a critical economic center for the region, where an estimated 30,000 people converge every day to work as market traders, upcyclers or to provide auxiliary support. Considering customers, the number of people buzzing through the market goes up to around 60,000 total, which comes with the recurring issues of gathering spaces that are continuously crowded in terms of waste management and sanitation. In addition, because the market is somewhat of a continuously on-going operation, entire communities established themselves on its outskirts to live in pop-up settlements (the largest one being named Old Fadama), adding to the growing impact from human activities.

Here, we were interested in assessing air quality within the market and on its outskirts, while also collecting the particles and analyzing them for content in microplastics, and specifically microfibers. We hypothesize that the air contains significantly more microplastics and microfibers than points of reference in other global cities due to the various extensive and lasting market activities with textiles, which would also be reflected in rainwater and in the surrounding lagoon. Overall, this is the first study to establish numbers of microfibers around Kantamanto, both from the airborne and waterborne settings. It highlights the close relationship between fast fashion waste and its subsequent release of microfibers in the environment, which to this day remains little considered.

Theoretical Framework

While Kantamanto Market is known to recirculate millions of garments a week as a hub of global fashion re-use, previous research by The Or Foundation has found that due to the relatively high costs of recirculating material and the low value of garments, a significant portion of those items is regarded as waste every week ((Skinner 2019)(Or Foundation 2022)). This is the result of a simple economic decision. Secondhand retailers with Kantamanto Market cut their losses when they have assessed that there is little chance of making any money back from the garments without investing more money into each piece. Many retailers fall into cycles of debt as a result of the situation. None of these costs, most notably the ecological costs of the pollution caused by such items of clothing when they are discarded as waste, is currently factored into the business models of the clothing brands whose clothes flow through Kantamanto Market. We begin to explore these costs by linking environmental pollutants back to garments discarded as waste and the brands that originally produced those garments.

Establishing the full cost of externalities related to garment production and disposal serves a vital purpose as global industries, including the multi-trillion dollar fashion industry seek to develop new circular business models. Whether or not the costs incurred within Kantamanto Market and the surrounding environments of Accra are factored into the business models of the brands producing those garments may determine whether or not the fashion industry can truly find new ground within ecological boundaries and socially just landscapes. Therefore, linking a company to pollutants from the products that the company created is a necessary step in registering such externalities within the profit and loss statement of a company so as to steer business models away from waste production. Significant research has previously been undertaken to establish

ecological and social impacts of a given brand's manufacturing supply chain, but until this point little information exists on the impacts of a company's garments after the original point of sale and disposal.

What is evidenced by the volume of microfibers in Accra's air and central waterway of the Korle Lagoon is that the business model of rapidly producing immeasurable volumes of mostly synthetic clothing is having a significant impact on people and planet. While the retailers and upcyclers of Kantamanto have done what they can to keep as many garments in circulation for as long as possible, often operating in subsistence debt, a sustainable future for fashion and the people working along the value chain across a garment's lifecycle relies upon the industry's biggest producers taking responsibility for the impact of their products.

Materials and Methods

The study area was the Kantamanto secondhand textile market in Accra, Ghana (Fig. 1), which we investigated in May 2023 for microplastics and specifically microfiber content, using airborne samples as well as waterborne samples (then from the nearby Korle Lagoon). Considering the dependence of our analyses on environmental conditions, we used an ATMOS41 ZL6 weather station (https://metergroup.com/products/atmos-41/) placed at the headquarters of The Or Foundation, which is located on the outskirts of the market. The weather station recorded a series of parameters every 15min, the most important ones used in this study being the time of the day when episodes of rain occurred, and the amount of rainfall for each.

The sample collection for microplastics and microfibers was always made keeping in mind the possibility of contamination ((Chen et al. 2020)(Prata et al. 2020)(Song et al. 2021) (Ma et al.

2024)). In the field, collectors wore bright yellow safety jackets and bright blue/yellow gloves (both easy to detect under an imaging microscope), and samples were collected standing downstream from the actual collection process. Samples were brought back in closed and cleaned containers to The Or Foundation. There, they were processed in the Environmental Research Laboratory, which is an enclosed room with no windows and no direct exposure to outside air, thus relatively sealed off from the surrounding activities of the local area. The samples were processed using similar guidelines against contamination. Negative controls of all the processing steps were performed on a regular basis using air as well as filtered water as medium since both can be sources of contamination.

PurpleAir collection. PurpleAir sensors (Flex Air Quality and Classic Air Quality Monitors) were used to monitor numbers of PM2.5 and PM10.0 particles as mass concentration ($\mu g/m^3$) in the air (www.purpleair.com). One PurpleAir sensor was permanently located in the area nearby the market, corresponding to the upper deck (4th floor, about 12m above street level) of The Or Foundation headquarters (Fig. 1). Another sensor was moved around for measurements in different locations, including in the heart of the market, positioned on a metal pole at either 5m or 10m height. Measurements were also taken 5km away from the market, in Osu, a residential area of Accra, to consider an area less crowded. Data from the PurpleAir were processed according to the protocol recommended by the vendor.

Airborne sample collection. A Coriolis (Bertin Technology) was used to collect particles from the same locations as the PurpleAir sensors. The Coriolis was run for 2 hrs each time at each location, with a vacuum rate of 50L/min as indicated by the manufacturer specifications. The particles that were collected in the cone receiver (which has a capacity of about 10mL) of the instrument were

retrieved following the following process: Filtered bottled water was added to the cone, shaken using a Vortex, and poured into a Falcon 50mL. The process was repeated five times to make sure all the particles were transferred.

Waterborne sample collection. Water was collected from 7 sites along the Korle lagoon, in order to be somewhat upstream, running next to, as well as downstream from the dumpsite that is known to receive significant quantities of textile waste leaving Kantamanto Market (Fig. 1). It must be noted that the Korle lagoon has a cement beam structure (hereafter referred to as surface barrier) crossing the width of the lagoon between OKS20 and OKS26 (the surface barrier is a remnant of an abandoned remediation project). This surface barrier is about 40m long and about 1.5m tall, with the watermark reaching about half-way the height of the barrier. As such, the surface barrier stops floating items from going further down the lagoon, which makes items build up in massive amounts upstream, to the point where the water surface can barely be seen in OKS20. In contrast, OKS26 (located just downstream the surface barrier) has much less of these items floating since it receives the water that flows under the surface barrier, from about 0.75m below the water surface. The surface barrier thus does not prevent heavier items (sub-surface, midwater or tumbling on the seafloor) to flow under the structure, downstream the lagoon and into the ocean.

Considering the poor quality of the water lagoon due to raw sewage input ((Nixon et al. 2007)(Koppelaar et al. 2018)(Owusu et al. 2023)), surface water collection was performed using an extended pole equipped with a dedicated bucket (made of a clean bright blue plastic easy to identify under microscope imaging for possible source of contamination, and for which control with clean water was also taken; if found in our samples, such bright blue particles were not accounted for). The water collection was performed 2 times (N=4) independently at the same site,

and each time two 50mL Falcon tube were filled with water from the bucket, sealed and maintained in a closed cooler for transportation.

Samples processing for microfiber counts. In the laboratory, the content of the Falcon tube was vortexed, and the water-containing-particles was transferred to a 50mL syringe (the exact volume was identified then) for filtration on a Advantec GF/F FiberGlass filter of 2.5 cm in diameter and 0.6µm pore size. Although in most cases the entire 50mL of the sample could be filtered with gentle pressure on the syringe, in some cases the filter would rapidly start clogging after just past a few mL. The filtration process was then stopped to avoid cracking of the filter and forcing water and material through. The filtered volume was marked down, and the number of items counted on the filter afterwards was expressed back to 50mL, for standard comparison across samples. Each filter was then placed on a small piece of aluminum foil that was folded back onto the filter without touching it, shielding the filter from direct deposition of airborne contamination, and to avoid losing material by direct contact with the foil. The filters were let sit in a drawer, overnight at least until dry (the filter is then stiff and can easily be moved around using metal forceps). This process was done for 3 of the 4 replicates as the 4th replicate was kept in the fridge to be sent later to the Deheyn lab (Scripps Oceanography, CA). There, the same process was conducted, which served as an independent quality control. Data showed similar results between the two laboratories.

Imaging was performed from each of the dried filters. The imaging used a 0.75x objective to allow for the entire filter to be seen in the field of view and be quickly imaged, which reduced exposure to possible contamination. The imaging was performed in brightfield first and followed immediately by epifluorescence imaging (ex. 360-380nm, em. >415 nm Long Pass filter) without the filter being moved. As such, each filter was not exposed to the elements for more than a couple

of minutes, to limit possible contamination as much as possible. In Ghana, we used a Motic SMZ-171 stereomicroscope equipped with color digital CCD camera Exelis MPX-20C. In California, we used a Nikon SMZ1800 stereomicroscope equipped with color digital CCD Nikon camera.

All counts were made from each digital image, by at least 4 individuals (3 in Ghana and 1 in CA). We used the brightfield digital images to count colored items (whether microfibers or microparticles, natural or synthetic, and possible contamination), used here as a proxy for their young and unweathered stage, thus indicating they were recently released in the environment. We used the fluorescent digital images to count synthetic microfibers and microplastics, which most fluoresce in blue. All microfibers (elongated blue, fluorescent items) were counted. As for microplastics, they were all counted as well, unless found in overwhelming numbers spread homogeneously across the filters. In such case, the counts were made from a fourth of the filter, and the numbers multiplied accordingly for full filter count. All items found with red fluorescence were by default considered natural microfibers or microparticles (the red fluorescence originating from chlorophyll), unless it was obvious from the corresponding brightfield images that these items showed colored dyes. In this case, these items were categorized as synthetic material. Our counts were thus presented in four categories: Recently released items (bright field counts), natural microfibers (red fluorescence counts), synthetic microfibers (blue fluorescence fibers) and microplastics (blue fluorescence particles) (Online Resource 1). The synthetic microfibers counts, which represented our main interest, are included in this paper, while the other counts are available as Online Resource, since showing the same trends as the synthetic microfibers, but in different (lower) ranges.

Textile waste by brand tag. To assess the relationship between the textile waste (this time as full garments) from Kantamanto market and the textile waste pollution found in the lagoon and at the beaches flanking the opening of the lagoon, which we establish through a gradient map to be a point source of water pollution, we compared the brand tags from 100+ garments found at the market versus the beach. By working with secondhand clothing retailers within Kantamanto Market, we know that full garments are indeed discarded at the market, ending in the lagoon waters, where they sink (and can tumble slowly midwater or on the seafloor without being stopped by the surface barrier in OKS20; see above) or in adjacent storm drainage systems flowing out to the coast. Our hypothesis therefore is that the sunken textile waste progressively makes its way out of the lagoon and into the ocean, from where the waste is distributed along the beaches. The textile waste on the beach would therefore originate mainly from the Kantamanto market, which should be reflected in similarities between the profile of tags found from the garments, considering the caveat of course, that the time for waste garments to travel from the market to the beach via the lagoon or other urban drainage systems remains unknown, and probably highly variable from item to item (e.g., due to different sizes, different shapes, different materials).

Textile waste by brand tags from the market was determined by a process that started each week, by speaking with ±10 market retailers (different each week). This was to inform the retailer about the study, and the willingness for them to keep for a week the items that could not be sold and that they were going to discard (as textile waste). We would then return to the retailers to acquire data from the textile waste, which we recorded on site directly through notes and photographs. Sorting through the textile waste, we recorded the garment type (e.g., Men's Shirts, Women's Joggers), the fiber type of each garment (cotton vs. polyester vs. nylon or other types, identified using a portable Fabritell NIR scanner or from the garments' tag), as well as the brand tag of each garment.

Textile waste by brand tags from the beach was determined by weekly beach cleanups organized by The Or Foundation. These involved digging into the sand to extract the numerous and heavy textile tentacles, defined here as entangled pieces of garments forming together long threads rooted deep into the sand. After the sand is rinsed off of the textile tentacles in the ocean, team members would sift through the garments and remove brand tags. These were brought back to the lab, let dry, photographed and their abundance recorded as above. Using Excel, a Pearson correlation coefficient was then tested for significance between the numbers of brand tags collected from the waste pile of the market, and those found buried in the beach.

Results

The results showed that the clothing from global sources sold into Kantamanto Market and discarded from the market as waste is a source of particles, but that the release and distribution of these particles can show large discrepancies, based mostly on market activities and weather (rain), which are variables both in time and space. The synthetic microfiber counts we report here always showed high values compared to the negative controls that showed only a few synthetic microfibers (typically 0 to 3), considered as background contamination, and not accounted for in our data. In general (especially with regards to microplastics shown in Online Resource 2-5), our negative controls were <2% of counts.

Of the microparticles that were collected (Coriolis® analysis) and counted by imaging, we show here the data for the synthetic microfibers and miroplastics identified in epifluorescence, while the other imaging data is shown as Online Resource. Overall, all the imaging data followed the same trend, but in different ranges of counts. In general, bright field counts were always the lowest and

below the hundred, followed by red fluorescence counts and the blue fluorescence microfiber counts (both about 10x greater than the bright field counts) and blue fluorescence particle counts (about 10x greater than the blue fluorescence microfiber counts). Broadly, this indicates our samples contained a sustained level of recently released microparticles, a large amount of natural microparticles and synthetic microfibers, and a much greater amount of microplastics (Online Resource 2-5).

PurpleAir counts were up to 5x greater at the market. The PurpleAir sensors all showed similar data in terms of the relative abundance of PM10 and PM2.5 particles (as expected since PM10 counts encompass PM2.5 counts), with PM10 counts up to125% greater than those of PM2.5. Overall, for May 29, 2023, which was a day with no rain (last rain event was about 40hrs prior) PM2.5 numbers flying by at a given timepoint ranged from 3 to 356µg/m^3, while those of PM10 ranged from 4 to 372µg/m^3. The number of particles was systematically greater for the sensors placed in the market, especially for the one at 10m height (up to 372µg/m^3), which was slightly greater than the one at 5m height (up to 332µg/m^3). The number of particles decreased when moving away from the market, whether at its outskirt at The Or Foundation headquarters at 12m (up to 103µg/m^3) or in the residential area control at 2m (with up to 94µg/m^3) (Fig. 2). Even though this trend in the data counts was observed throughout our study (thus showing higher numbers in the market relative to the outskirt and residential areas, and, within the market, higher numbers at 10m relative to 5m), the range in the numbers that were recorded was highly variable from day to day, and within a day also. This was depending on the activities at the market (most active from 0500 till 1800 every day, but starting as early as 0200 for the vendors) with burning of waste in locations immediately surrounding the market occurring overnight, on vehicle traffic on its

periphery and foot traffic across its web of stalls, but also, and most importantly perhaps, on the weather, especially in relation to wind and rain. Indeed, particle counts readings during days when rain occurred were decreased sharply as soon as rain started, before increasing back gradually after the rain stopped (Fig. 3). We therefore looked at the actual content of both airborne and rainwater samples, which were collected with the Coriolis sampler next to the PurpleAir sensor.

Airborne particles were dominated by synthetic textile microfibers and microplastics. Data from the Coriolis air sampler showed large numbers of microfibers that were relatively high across all sites of investigation within the market, ranging from about 30 to 180 microfibers (Fig. 4). We systematically found that, even within a ventilated warehouse, the microfiber counts were greater for the samples analyzed at 10m height compared to the 5m analysis; this was particularly evident for the sample taken in the open-air area of the market (Fig. 4). Measurements in the market were about 2x to 5x greater than the ones made 1km away, at the outskirt of the market, at the roof top of The Or Foundation headquarter (Fig. 4). Items smaller and non-fiber shaped were also counted in large numbers (by the several hundreds) and categorized as microplastics (Table 1; Online Resource 2).

Rainwater samples contained large amounts of synthetic textile microfibers, and microplastics as well. Rainwater samples contained synthetic microfibers (Table 1; Online Resource 3-4), within a range that varied with the duration of the rain event, with more synthetic microfibers in rainfall from shorter rain events (Fig. 5). In addition, the number of synthetic microfibers found in rainwater changed based of when the last rain event occurred, and as such, the greater the extent

of dry weather between two rain events, the greater the number of synthetic microfibers found in the rainwater (Fig. 6).

Water samples from the Korle Lagoon contained large amounts of microfibers as well (Table 1; Online Resource 5), which were greater when closer to the dumpsite and market compared to the locations that were further away (Fig. 7). In addition, and as expected, the numbers of synthetic microfibers peaked at OKS20, where surface items are stopped from flowing downstream by the surface barrier crossing the lagoon (Fig, 7).

Brands assemblage from the textile waste collected at the beach correlates to that of the textile waste in the market. Collected tags showed that the 10 most common brands found in the textile waste were Mark & Spencer, Associated British Foods (Primark), Asda (George), Sainsbury's (Tu), Next, Boohoo Group, Tesco (F&F), H&M Group, New Look Group, GAP, representing up to 63% or 77% of the items found, whether at the beach or in the market, respectively (Fig. 8). There was a significant correlation (59%) of occurrence between the tags from the two sites of waste collection.

Discussion

Our research around the Kantamanto secondhand textile market showed the abundant presence of textile synthetic microfibers, both in air and water. The data indicate that microfibers are somewhat related to the number of people present in the market and the market activities, especially during the busy time associated with the bales of clothes being delivered from the international shipping port early on Thursdays to be opened, and the clothes sorted out, shaken up to unwrinkle, and stretched for display, early in the morning on Saturdays and Wednesdays with collection and

burning of waste occurring overnight. We also showed that the microfibers that are released, at least during daytime when we conducted airborne analyses, can levitate around, and be carried to higher elevation with warm upward convection current from the heat released by the number of people, but also by the hot surfaces heated up by the sun. We showed that the microfibers could be carried at least 10m high into the air, from where they can spread around and fall back onto the ground later at nighttime, when heat-driven convection currents stop, or entrained down onto the ground by rain events. Indeed, rainwater was enriched with microfibers (and microplastics), which was especially true for rain events occurring after 3-4 days periods of no rain. In such a case, we showed that the first front of the rain (within the first hour or so, which would vary based on the rain intensity) can bring down many microfibers. Practically, from a public health perspective, this indicates that people who collect rainwater for drinking usage should skip the first front of the rain event, especially if it has not rained in several days, or should deploy filtration technology if any is available. Once on the ground, the microfibers then reach the nearby Korle Lagoon via runoff and surface water drain outflow, although it is more than likely that microfibers reach the lagoon waters also directly from aerial deposition and from mechanical erosion and weathering of the overflooded landfill material sitting along the banks of the lagoon. Ultimately, the Kantamanto Market appears as microcosm ecosystem associated with global secondhand textile that releases large amounts of microfibers, thus impacting locally the air quality and ecosystem services of the lagoon.

Global textiles in *Kantamanto as a source of airborne microparticles*. Using the PurpleAir sensor, we demonstrated that the mass concentrations of PM2.5 and PM10 particles were high and varied

largely around the market, decreasing when going further away from it. This indicated that the market was a source for airborne microparticles.

Accra has been the site of "true" atmospheric studies showing that the level of pollution in the air relates mainly to road traffic and burning stoves but also the natural particles from the sub-Sahara winds ((Arku et al. 2008)(Dionisio et al. 2010)). In these studies, the amount of PM2.5 and PM10 rarely surpasses the 100µm/m^3, but was consistently greater than the healthy air quality guidelines recommended by the World Health Organization, which is set at 10µm/m^3 ((Alli et al. 2021)). These studies occurred in locations similar to Osu in our study, located East of the market and namely being Nima, East Legon, Asylum Down and Ussher town ((Dionisio et al. 2010)(Zhou et al. 2011)). The PM2.5 and PM10 data for the market in our study therefore stand out by being greater in values, sometimes 5x to 10x greater, even when close to industrial areas ((Ofosu et al. 2012)).

Air quality studies in Accra also show a daily variation of microparticles being associated with people's activities, whether cooking or driving to/from work, thus increasing in the early morning (starting at 3-4am); however, these microparticle counts then decrease during the day and increase again at nighttime ((Alli et al. 2021)). One must note that in most of these studies the microparticle counts were made at human-level up to 7m, and it is possible therefore that the counts-decrease during the hot hours of the day reflect the advection effect of microparticle pushed up in the air, as described in our study here. These microparticles then resettled down to human level when the heat effect weakens at nighttime.

Aside from the secondhand textile market being clearly a site of intense generation of particles affecting negatively air quality, another peculiarity of the market resides in the fact that the PM10 were about up to 1.0-1.2x greater than PM2.5, while in other studies in Accra, the PM10 values are about 2-2.5x greater than the PM2.5 values ((Arku et al. 2008)(Dionisio et al. 2010)). This likely reflects an increase in PM2.5 from the market textile-related activities as opposed to reflect a relative decrease in PM10. Indeed, PM10 encompasses the counts of PM2.5 that are then topped with particles counts between 2.5-10µm for PM10, which accounts mostly to road dust, tire microplastics, Sub-Sahara dust, and/or pollen (PM10 is therefore strongly affected by environmental factors such as winds and flowering seasons). PM2.5 is mostly associated with the byproducts of engine combustion and black carbon ((Arku et al. 2008)(Dionisio et al. 2010)), PM2.5 being therefore related more directly to local human activities from fuel-based motors using in industries or homes, to fuel-powered engines in transportation. Since the interior of Kantamanto secondhand textile market is largely closed to traffic, the high levels of PM2.5 we measured likely reflect another source of airborne contamination. Aside from the individual use of stoves ((Zhou et al. 2011)), another major contributor is likely the particles originating from burning the excess textile waste, which generates heavy black smoke that contains a diversity of microparticles, as observed from wildfires ((Carreras-Sospedra et al. 2024)). Accordingly, these particles seem to correspond to the small fluorescent particles observed under epifluorescence in our study, and referred here to as microplastics.

In our study, brightfield and epifluorescence imaging of the airborne particles showed a dominance of microfibers with a size around 10 microns in diameter and a variable length up to 100 microns. This indicates that around the market, PM10 data could largely represent amounts of microfibers.

We also showed brightly fluorescent microparticles, which would represent PM2.5. The fact these particles are fluorescent makes them synthetic (plastic) since black carbon and PM2.5/PM10 particles in general have not been previously reported to show native epifluorescence properties. In fact, added staining methods are needed to image black carbon microparticles in fluorescence ((Chen et al. 2019)).

We also showed that airborne PM2.5 and PM10 decreased sharply in events of rain. This was directly related to the particles being pulled out of the air into waterborne phase, since rainwater contained large amounts of microparticles, including microfibers. This indicates that rain can be a major process by which airborne microfibers enter the waterways, in addition to wind driven processes that could deposit them onto water surfaces. Such effect of rain was recently described in the literature by looking at rain samples ((Do et al. 2023)).

Global textile waste as a source of microparticles for the nearby lagoon. We demonstrated that the Korle lagoon is a receptacle of textile microfibers from runoff, and textile waste from overflowing landfill. Water samples collected from the lagoon showed high numbers of microfibers (and other microplastics as well), with a distribution in abundance suggesting that microfibers originate directly from the dumpsite, via runoff following rain events and/or via weathering fragmentation of the overflowing pile of discarded textile. This is in addition to the microfibers probably reaching the water surface from airborne deposition. A majority of the clothing in the market contains polyester and as such, the microfibers released from these garments are prone to float in seawater. This was observed in the lagoon, since the surface barrier was the site of accumulation of microfibers, together with other microplastics as well as macroplastics.

Numbers of microfibers and microplastics, whether airborne or waterborne, were significantly greater than reported in other parts of the world. The numbers of microfibers found in our study, whether in the air or in the water, were usually by far the highest ever reported in an environment. This does not come to a surprise considering that methodologies used can lead to underestimation of microplastics, both from airborne and waterborne sources ((Xu et al. 2020)). In addition, a direct comparison across studies is challenging because the methodology for sample collection or for microparticle counting usually varied from study to study, based on local environmental limitations, local expertise, the distinction or not between microplastics and microfibers, but also on the scientific question driving a particular study. A relevant range of comparison considered levels of airborne microplastics in megacities, with numbers of microplastic possibly ranging broadly from <1 to >1,000 per m^3 ((Zhao et al. 2023)), depending on environmental factors (e.g., winds, wildfires, smog conditions) and methods of collection (e.g., dry or wet passive atmospheric fallout vs. active suspended particle measurement). However, under normal circumstances and using suspended particle measurement as a reference, one can measure relatively low numbers, around 4 microplastics per m^3 in Shanghai, 1.5/m^3 in Paris, and 0.6 in the French alps ((Sridharan et al. 2021)(Xu et al. 2024)), with often no quantified distinction between microfibers and microplastics particles, except for Xu and colleagues who identified that 10% to 25% of the microplastics were microfibers. In our study, the Coriolis data showed about 500 microplastics per m^3, thus about 100x what was found in Shanghai, and about 15 microfibers per m^3, which is about 20x greater than in Shanghai and about 125x the numbers from the French Alps.

A similar analysis can be done with waterborne microfibers and microplastics. Numbers of microfibers are reported around 2-30 counts per L in coastal waters ((Suaria et al. 2020)(Tang

et al. 2023)), which does not include lagoons as these have been much less investigated around the world for their content in microfibers, maybe due to challenges to access them. The same can be said for microplastics, which are reported up to 30 counts per L in harbors, otherwise being found with 0.5-2 counts per L in coastal and more open ocean waters ((Suaria et al. 2020)(Tsang et al. 2020)). The discrepancy in numbers relative to what we found in the Korle lagoon waters (up to 500 counts per L for microfibers and up to 6,000 counts per L for microplastics) is staggering and likely due to the source being the abundance in textile in the market as well as in the dumpsite (as waste) along the lagoon, yet one cannot discard the possibility that some of that difference could originate from the difference in techniques of sample collection. Indeed, a common way to collect microplastics involves a Manta net, which is not easily used in a shallow lagoon ((Royer and Deheyn 2019)) while this method has also been recognized to underestimate the numbers of microfibers that can pass through the mesh thanks to their elongate shape ((Barrows et al. 2018)(Du et al. 2022)(Concato et al. 2023)). Hence, the technique to collect set volumes of water for subsequent filtration and counts of microfilters (and microplastics) retained on filters, is likely more representative of the actual waterborne microfiber loads.

Garments discarded as waste from the Kantamanto market are flushed out of the lagoon and end up contaminating the oceanic coastal ecosystem and beaches. Beaches in Accra have masses of entangled garments that surface on and under the sand. These masses develop into long tentacles (sometimes bundles of 30cm in diameters and meters long) that go deep into the sand, and their extraction, through beach cleanups organized weekly by The Or Foundation represents a monumental effort. It is unclear how long it takes for garments to form tentacles like these with the back and forth of the waves and tides, and for them to be buried deep into the beach. It is clear

however that the local coastal community, including The Or Foundation's Beach Monitoring team which counts the tentacles every week, has observed them for several years. Taking the tags from the garments and comparing them to the tags from the textile waste in the market demonstrated that the garments found at the beach originate as part of the global secondhand clothing trade passing through Kantamanto Market.

The tags showed that the 10 most abundant brands found at the beach and market waste correlate well with one another. This is despite the clear difference in time between the two sites, the one at the beach possibly being months or years older than the waste at the market (which is current). This indicates that the brands identified are recurrent in the secondhand textile market, and that they have entered the market in relative abundance. The fact that they are abundant as waste can also reflect that the quality and the fashion of these brands are not at the standard of the local buyers who can choose from millions of garments on a weekly basis. While it is also possible that some of the garments are trashed directly at the beach after purchase and use for a little while, it is unlikely, however, under these "isolated" circumstances, that the garments would form the long tentacles that were observed, bundling sometimes several dozens pieces together.

The brands found as waste on the beach and found as waste within Kantamanto Market are headquartered and distributed principally within the USA, the EU and the UK. The companies, such as Marks & Spencer, Associated British Foods (Primark), Next, Boohoo Group, H&M Group, New Look Group, ASDA (George), and Gap, whose garments are directly correlated to environmental pollutants are all regarded as part of the fast fashion economy, whereby consumers are sold rapidly changing wardrobes at relatively affordable prices ((Economist 2015)). This business model is possible in part because the price of garments externalizes the environmental and social impacts caused by the clothing, such as the waste and pollution clearly identified in

Ghana. Current efforts (notably by The Or Foundation along with other local groups in France, Germany and California for example) aim to pass new policies requiring such brands to support the proper disposal of their products when their products reach the end of their lifecycle. If made Globally Accountable to communities like Kantamanto Market, as The Or Foundation and allied groups have called for, such policies, under the name of Extended Producers Responsibility (or EPR), would make brands more accountable to the communities impacted by post-consumer textile waste and would facilitate the distribution of having funds to properly deal with the garments when considered waste ((Circle Economy 2023)) whether that waste be in the USA, Europe, the UK or Ghana. These policy initiatives aim not only to bring awareness related to the issues of textile waste to consumers of both firsthand and secondhand garments, but also to clean up identified pollutants from textile waste and to reduce the overall volume of clothing through circular design principles of reuse ((Or Foundation 2023)). These efforts are then to be integrated into a sustainable and circular management of plastic-related production, reuse, recycle, and cleanup, with focus on the textile industry in particular since an underestimated reservoir of microplastics ((Gourmelon 2015) (Muthu 2017)(Koelmans and Kalčíková 2019)(Nielsen et al. 2020)).

A simple collection and processing technique to enable citizen science. In this study, we worked together with the local community to access sites for collections, to engage community leaders to implement new policies, and to empower citizens to help with sample collection. As such, we used a simple and straightforward technique that could be easily performed by any citizen (from high school student to elderly), with only short training needed. The technique was also shown to be effective to collect content in microfibers, but also microplastics. The technique relies on small

amounts of water (50mL) that can easily be collected by scientists and citizen scientists alike using standardized tubes, making this attractive for large sampling collection involving the community. The use of water volumes greater than 50mL was tested as well (including 1,000mL, 500mL, 200mL; data not shown) but shown to be more challenging. This was due simply to the larger volume to handle (with increasing risks of clogging), but also more challenging with counting the microfibers, due to excess debris on the filter, or due to difficulty on counting because of the excessive number of microfibers overlapping on each other in the field of view. It must be noted that in some instances here, the volume of 50mL had to be brought down to sometimes 10mL, to facilitate accurate counting. The proposed technique thus provides flexibility, by either adding more than 3 replicates of 50mL water samples, or only taking a sub-set of the 50mL volume for waters heavily charged with debris, and clogging the filtration process early on. The proposed technique thus complements the current one used for microplastics in particular, using Manta Net towing/trawling, which is bulky, requires a boat, and is thus difficult to access to citizens.

Conclusion

This study provides a comprehensive assessment of microfiber counts in the air, rainwater and lagoon around the Kantamanto Market and known dumpsites of global secondhand textile waste. The global textile waste passing through the market clearly appears as a significant source of microfibers (and microplastics), with counts in and around the market sometimes >100x greater than in other metropolises around the world. We demonstrated the dynamic distribution of microparticles once generated in the market, being carried upward by warm convection air into air from where they travel around and precipitate back into the area with winds and rain events. The effects of global textile waste passing through the market and entering the surrounding

environment goes beyond the microscopic particles. We indeed showed a strong correlation between garments considered waste at the market and the ones found on the surrounding beaches, by comparing brand composition of the garments. Overall, we highlight the fact that fast fashion waste needs new policy regulations and programs to bring awareness to consumers about the release of microfibers and microplastics by garments to levels that could possibly affect ecosystem services and public health and to ensure that cleanup programs and proper waste management efforts are sufficiently funded for existing and future waste streams.

Figures caption

Figure 1. Map (ESRI showing the areas of investigation around the Kantamanto market, indicating the locations for the PurpleAir sensor and the Coriolis air sampler (green/blue stars), and the water samples in the Korle lagoon (orange circles). Location of the surface barrier is also visible (green arrow) with the large floating patch of debris it stops from flowing down the lagoon. Main directions of surface water runoff and surface wastewater are also indicated (yellow arrows). HQ: Headquarters of The Or Foundation; WH: WareHouse, large, enclosed space immediately adjacent to the market and where textile waste is treated for reuse; OSU: Residential neighborhood in central Accra, about 5km from the market.

Figure 2. PM2.5 and PM10 particles mass concentration (box plots, in $\mu g/m^3$) across the various sites of investigation showing that the counts were systematically greater in the market, and within the market, greater at 10m compared to 5m. KM: Kantamanto Market, open area with passage of people between stalls. HQ: Headquarters of The Or Foundation just 1km off the center of the market; OSU: Residential neighborhood in central Accra, about 5km from the market.

Figure 3. PM2.5 (grey line) and PM10 (black line) particles mass concentration ($\mu g/m^3$) from the PurpleAir data recorded every 2min during a 24hrs period starting at midnight, for 3 different days with distinct intensity of rain events (date, duration of rain and volume of rainwater collected are indicated). Period of rain (gray shade) and volume of rainfall was provided by ATMOS41 weather station. Period of market activity is indicated on each panel. It must be noted that Thursdays are

when new bales of garments are delivered to the market to be opened and the garments inside sorted on Wednesdays and Saturdays.

Figure 4. Airborne synthetic microfibers counts (box plots) across the various sites of investigation showing that the counts were greater in the market and within the market, greater at 10m compared to 5m. Data were collected with the Coriolis air sampler for 2 hrs each time, thus representing counts for 6,000 L of air. N=9, from 3 sample replicates each counted by 3 different individuals. HQ: Headquarters of The Or Foundation; WH: WareHouse, large, enclosed space immediately adjacent to the market and where textile waste is treated for reuse; KM: Kantamanto Market, open area with passage of people between stalls.

Figure 5. Rainwater synthetic microfibers counts (box plots) collected with the Stratus Rain Gauge (with rain event volumes validated by an ATMOS41 weather station) set on the roof of The Or Foundation Headquarter. Samples correspond to different rain events, each with their own volumes (X axis). Data counts are expressed per set volume of 50 mL. N=9, from 3 sample replicates each counted by 3 different individuals. The number of synthetic microfibers was high for short rain events (within 2hr long) and decreased steadily as rainfall gets heavier and/or lasting longer. *This rainwater was collected the same day as the 185 mL rain event, but just a few hours later. This shows that the content of synthetic microfibers in volume of rainwater depends on precedent episodes of rain.

Figure 6. Rainwater synthetic microfibers counts (box plots) for rain events in relation to the time (number of days) since the last rain event. Data show that the number of synthetic microfibers

increase largely in the rainwater, after 4 days with no rain. N=9, from 3 sample replicates each counted by 3 different individuals. Data counts are expressed per set volume of 50 mL.

Figure 7. Synthetic microfiber counts (box plots) from Korle Lagoon water showing that site flanking directly the market in terms of runoff (OKS13) has the greatest counts, which increased even further at the site upstream from the surface barrier (OKS20) where floating debris and microparticles accumulated. N=9, from 3 sample replicates each counted by 3 different individuals. Data counts are expressed per set volume of 50mL.

Figure 8. Pie chart representation of the percent occurrence of tags for each brand found in the waste pile at the Kantamanto market (top) and found entangled and buried in the at the nearby beach (bottom). More than 60% of the tags originated from just 10 brands (Mark & Spencer, Associated British Foods, Asda, Sainsbury's, Next, Boohoo Group, Tesco, H&M Group, New Look Group, GAP).

Table 1. Minimum (Min), Maximum (Max), Mean and Median values for the counts of synthetic microfibers and microplastics (both found with native blue fluorescence) from samples of air, rainwater, and Korle lagoon water. For all counts, N=9, except for the airborne sampling counts (N=3). HQ: HeadQuarter of The Or Foundation (roof) at two different times (a,b); WH: WareHouse space adjacent to the market at two different heights (5, 10m); KM Kantamanto Market (center) at two different heights (5, 10m). All lagoon sample counts originate from 50mL of surface water. Data on counts for fresh microparticles (bright field imaging) and natural microparticles (red fluorescence) can be found in Online Resource 6.

		Synthetic Microfibers					Microplastics			
		Min	**Max**	**Mean**	**Median**		**Min**	**Max**	**Mean**	**Median**
Airborne particles	**HQa**	8	22	14	11		311	485	414	446
	HQb	7	15	11	10		252	290	275	282
	WH – 5m	12	35	21	16		1034	1700	1454	1629
	WH – 10m	27	48	37	35		1348	1855	1636	1704
	KM – 5m	52	74	60	54		1170	1400	1290	1300
	KM – 10m	99	144	124	128		1195	2930	1790	1244
Rainwater (HQ)	**16 mL**	92	96	94	94		946	1020	971	947
	20 mL	92	101	95	92		1358	1900	1600	1541
	160 mL	23	32	28	30		385	663	486	411
	190 mL	14	18	16	15		421	661	515	462
	180 mL	25	43	35	36		3149	3601	3331	3243
	200 mL	14	16	15	14		1365	1484	1427	1433
	185 mL	100	112	107	108		972	1264	1082	1009
	70 mL	62	71	67	69		738	1092	949	1017
	40 mL	94	126	108	105		1181	1479	1370	1449
	20 mL	9	18	12	10		273	285	279	279
Korle lagoon sampling sites	**OKS18**	3	11	7	6		125	253	187	174
	OKS14	4	10	7	7		251	489	328	269
	OKS13	5	46	24	22		293	600	443	435
	OKS12.5	9	18	13	12		208	532	350	395
	OKS20	53	81	68	68		246	485	357	364
	OKS26	7	15	11	12		74	284	194	182
	OKS8	6	19	13	13		42	267	170	165

Author's contribution. DDD and BS conceptualized the project. JA performed the field and laboratory work in Ghana, under DDD guidance. DDD performed analysis in California. DDD wrote the first draft of the paper, which was then reviewed and implemented by BS and JA.

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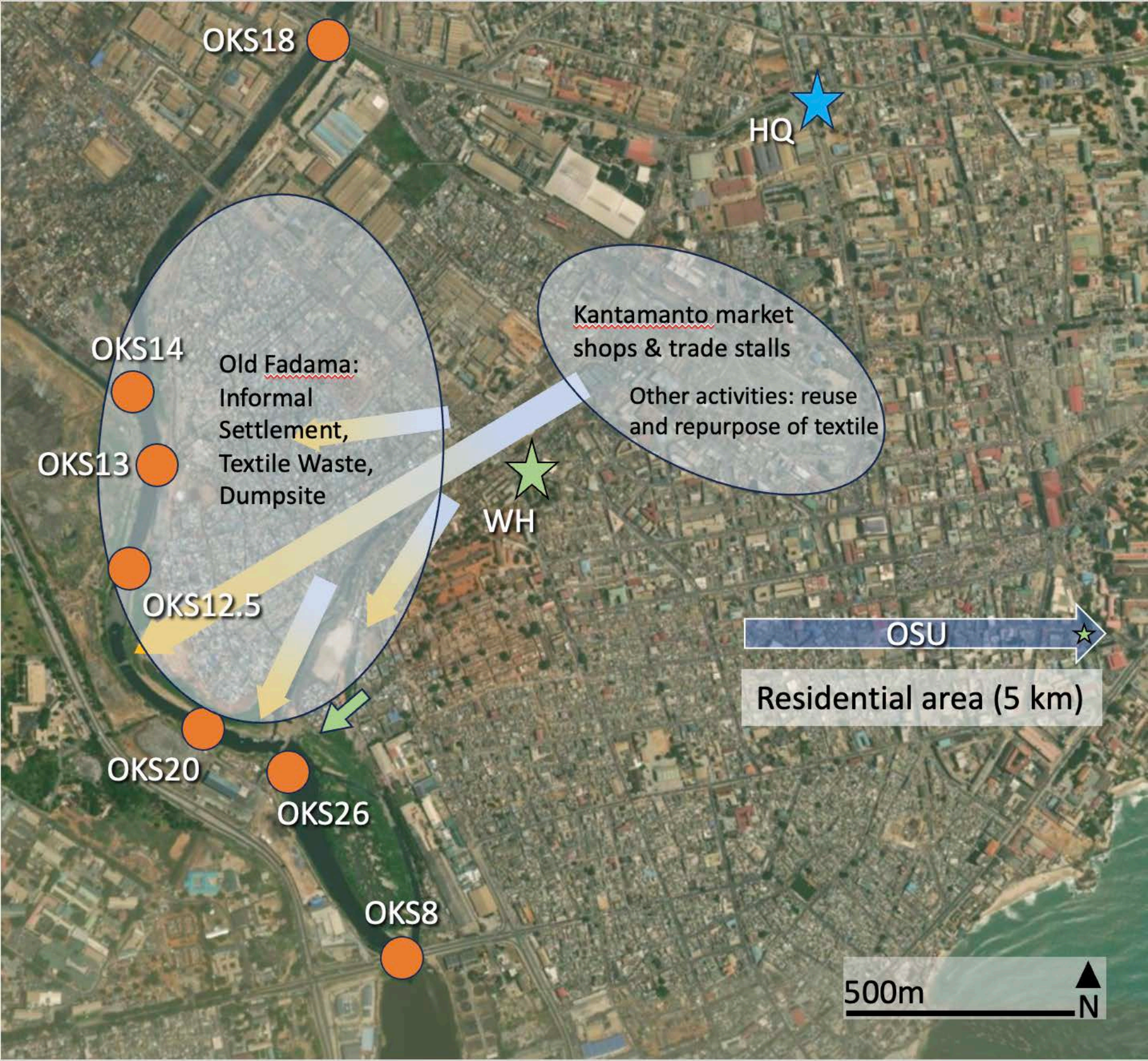
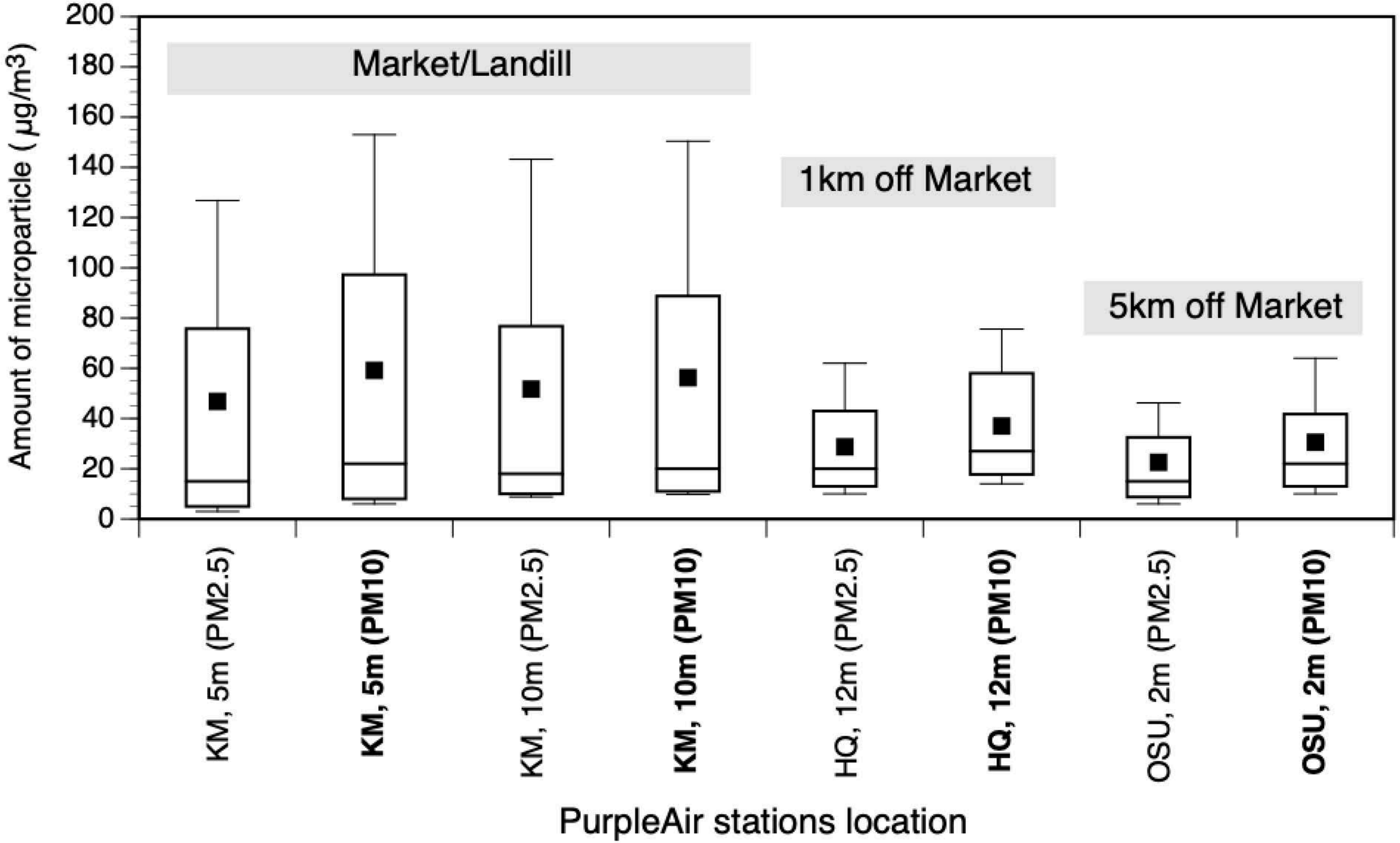
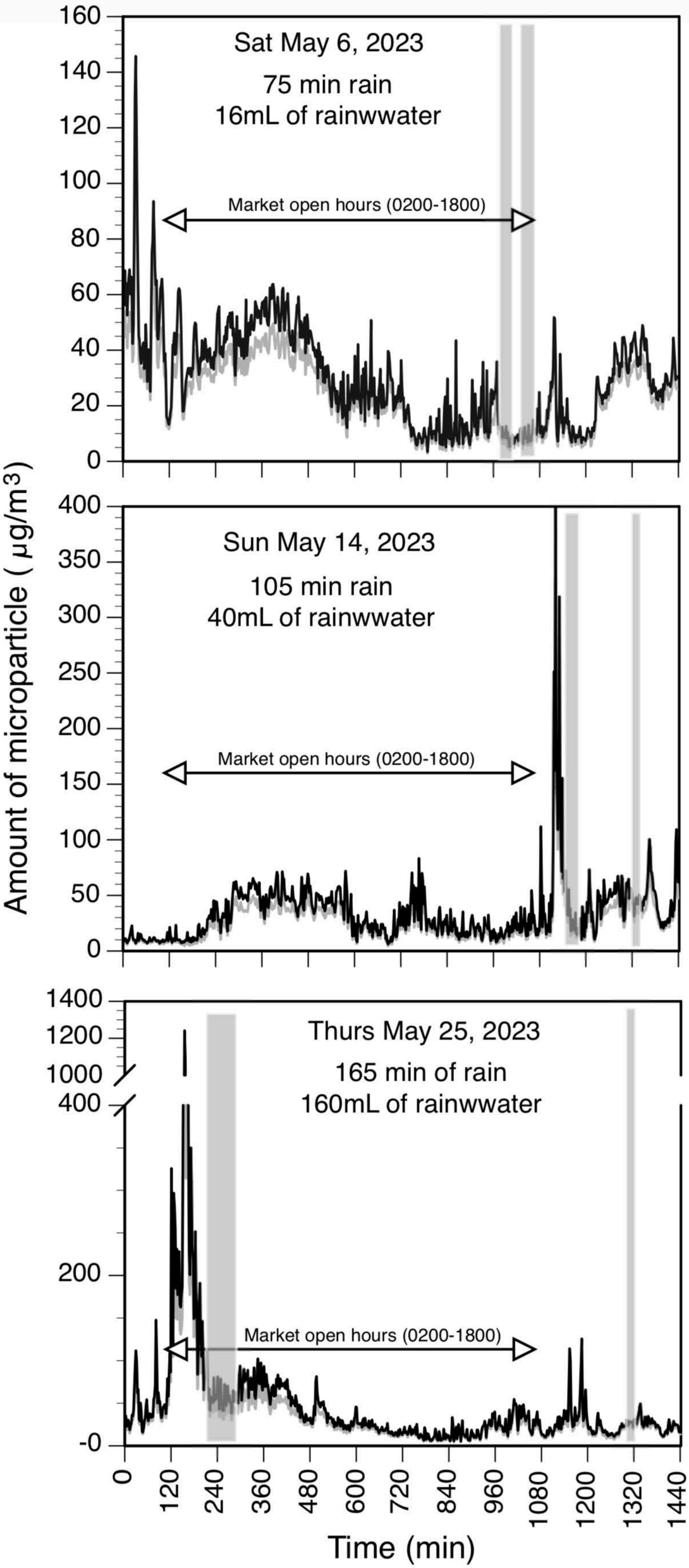
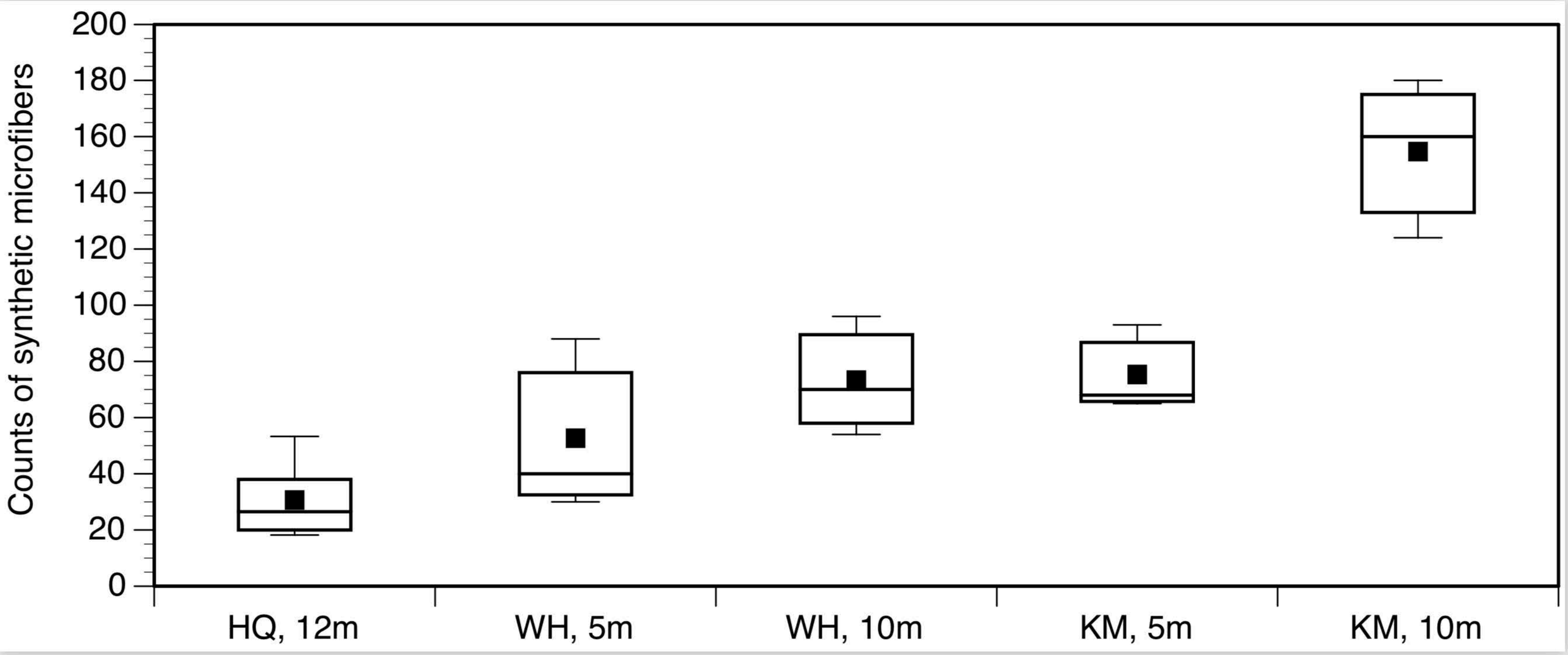
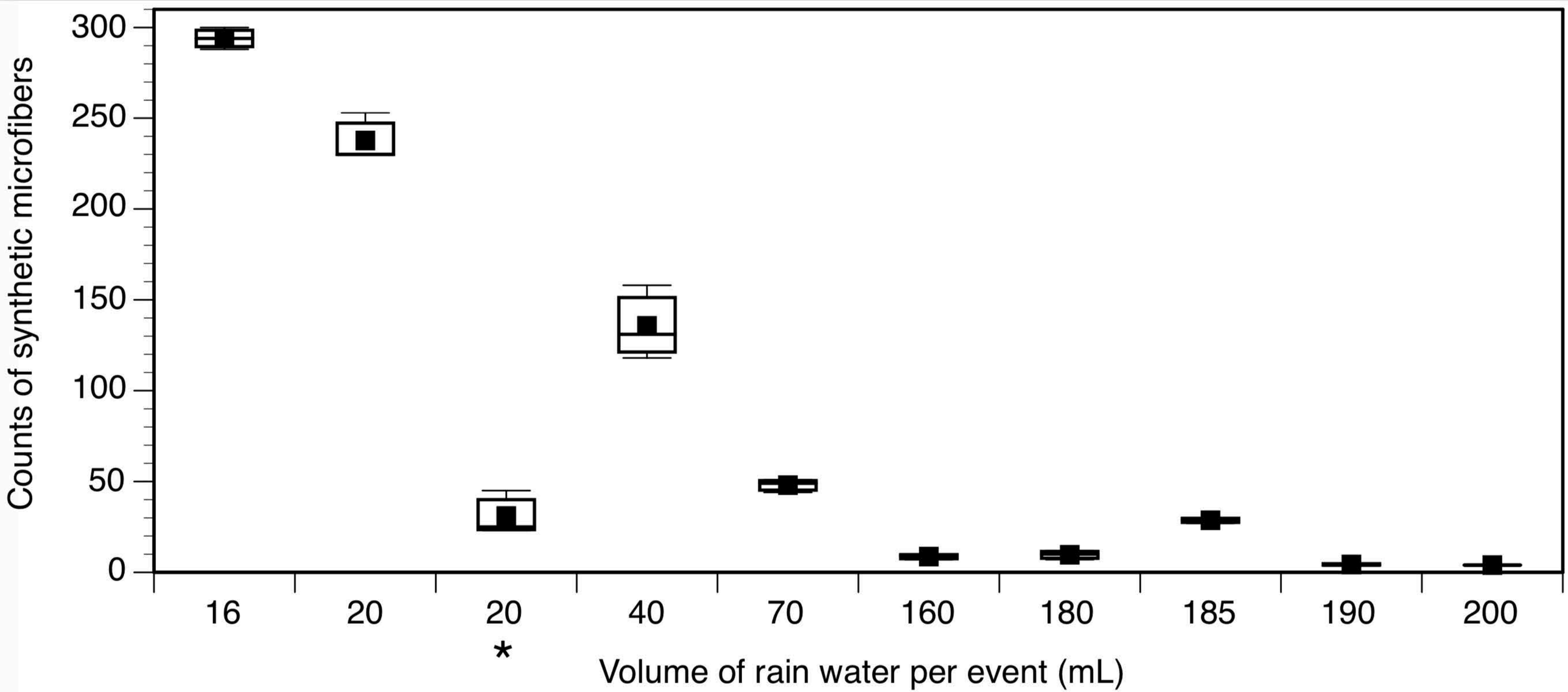
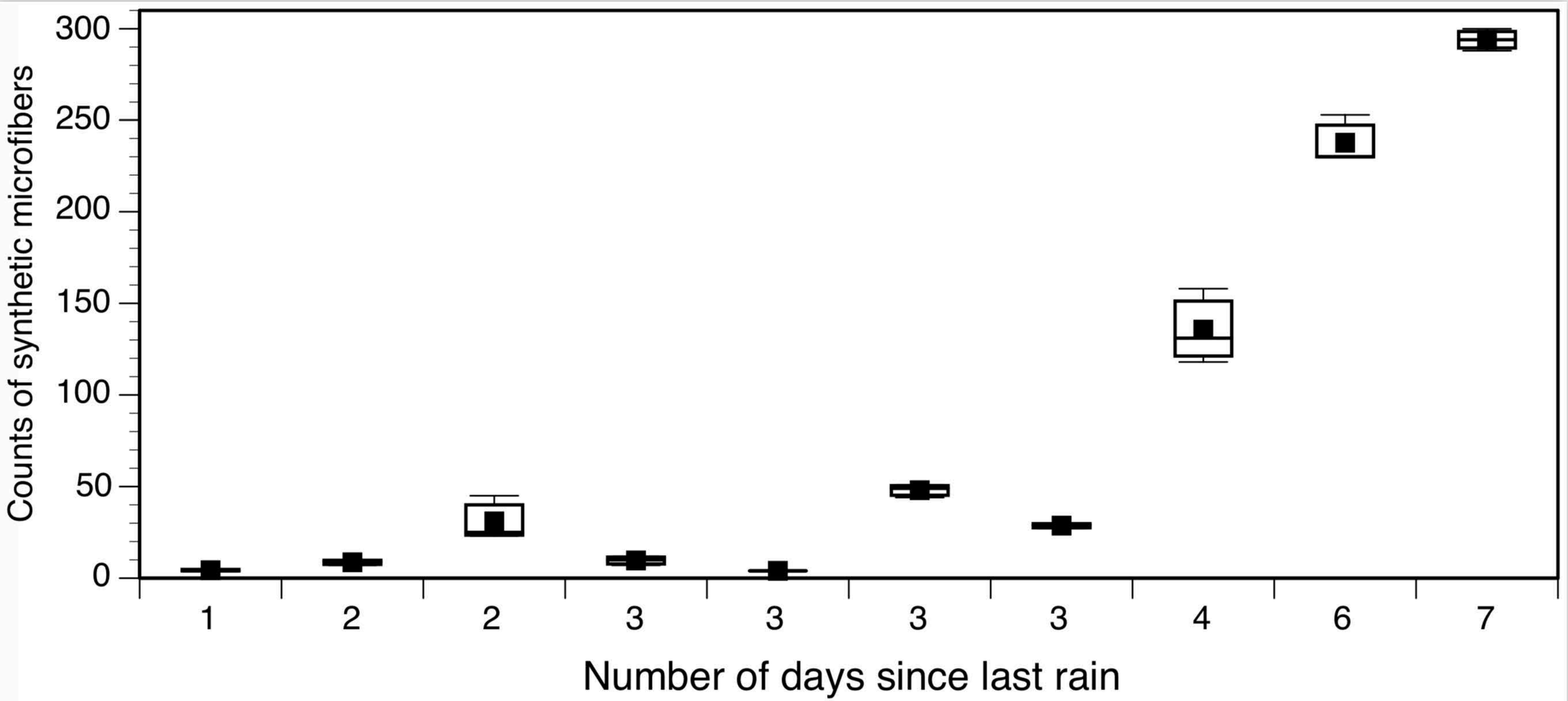

OKS18
HQ
Kantamanto market shops & trade stalls
Other activities: reuse and repurpose of textile
OKS14
Old Fadama: Informal Settlement, Textile Waste, Dumpsite
OKS13
WH
OKS12.5
OSU
Residential area (5 km)
OKS20
OKS26
OKS8
500m
N

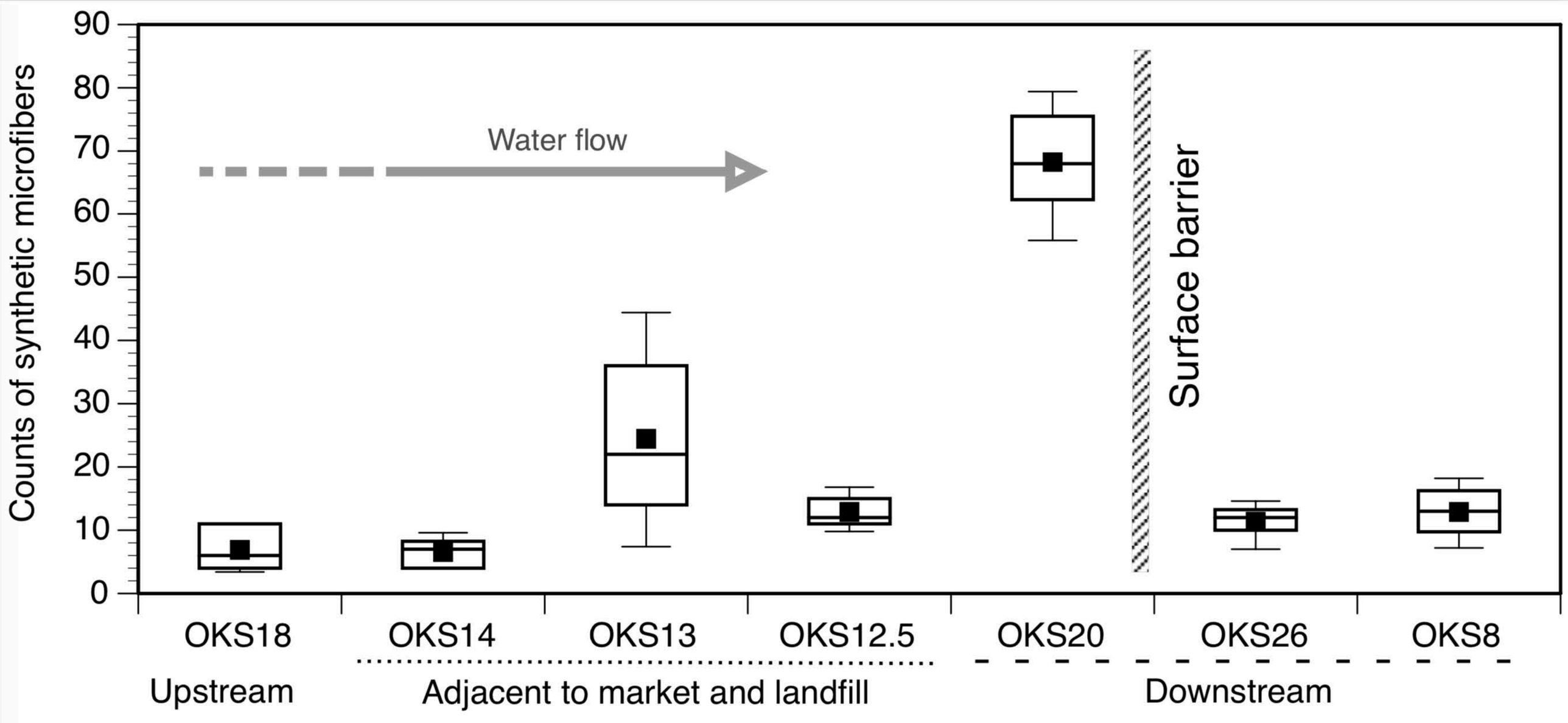

Amount of microparticle (μg/m3)
200
180
160
140
120
100
80
60
40
20
0
Market/Landill
1km off Market
5km off Market
KM, 5m (PM2.5)
KM, 5m (PM10)
KM, 10m (PM2.5)
KM, 10m (PM10)
HQ, 12m (PM2.5)
HQ, 12m (PM10)
OSU, 2m (PM2.5)
OSU, 2m (PM10)
PurpleAir stations location


Sat May 6, 2023
75 min rain
16mL of rainwwater
Market open hours (0200-1800)
Sun May 14, 2023
105 min rain
40mL of rainwwater
Market open hours (0200-1800)
Thurs May 25, 2023
165 min of rain
160mL of rainwwater
Market open hours (0200-1800)
Amount of microparticle (μg/m3)
Time (min)
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440

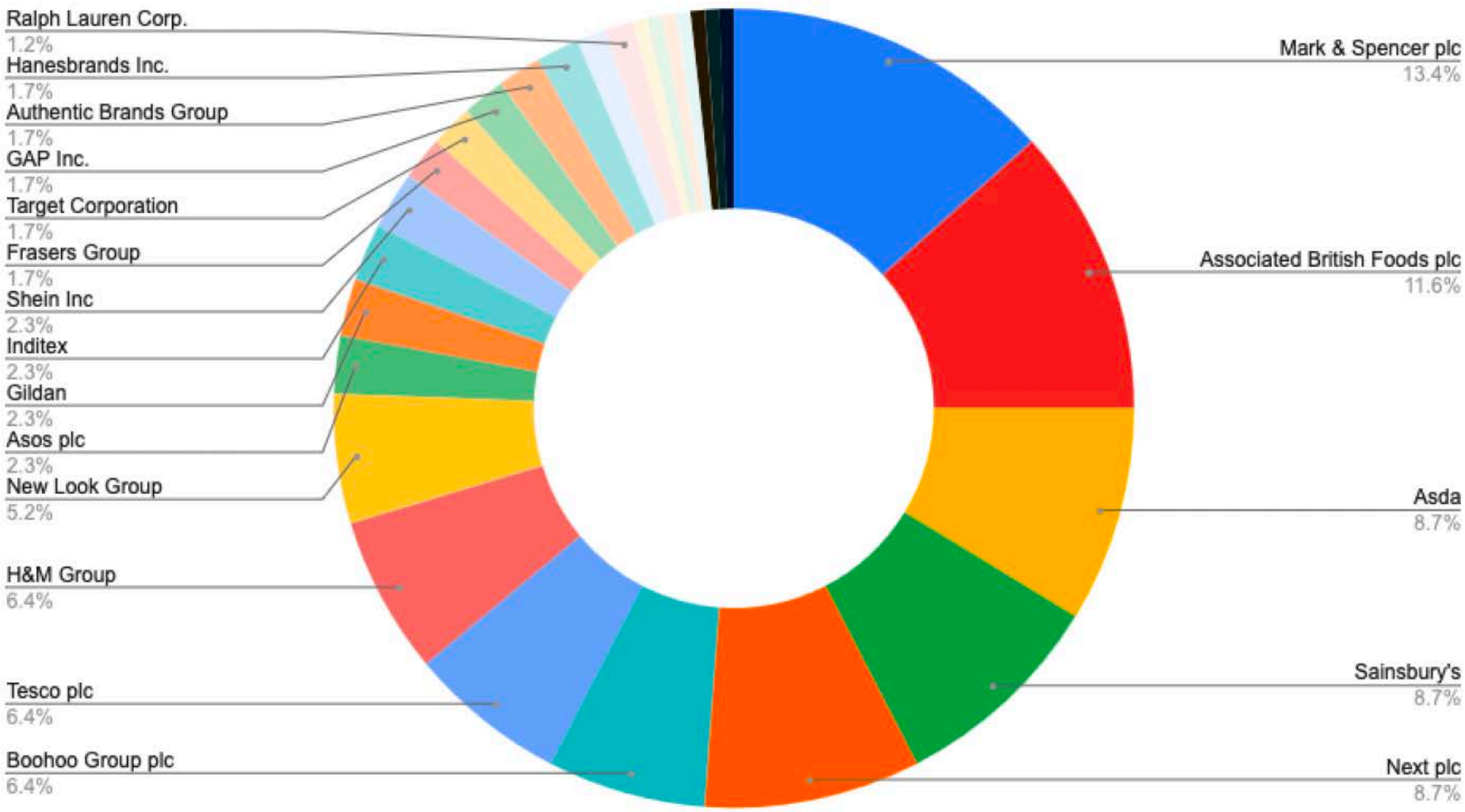
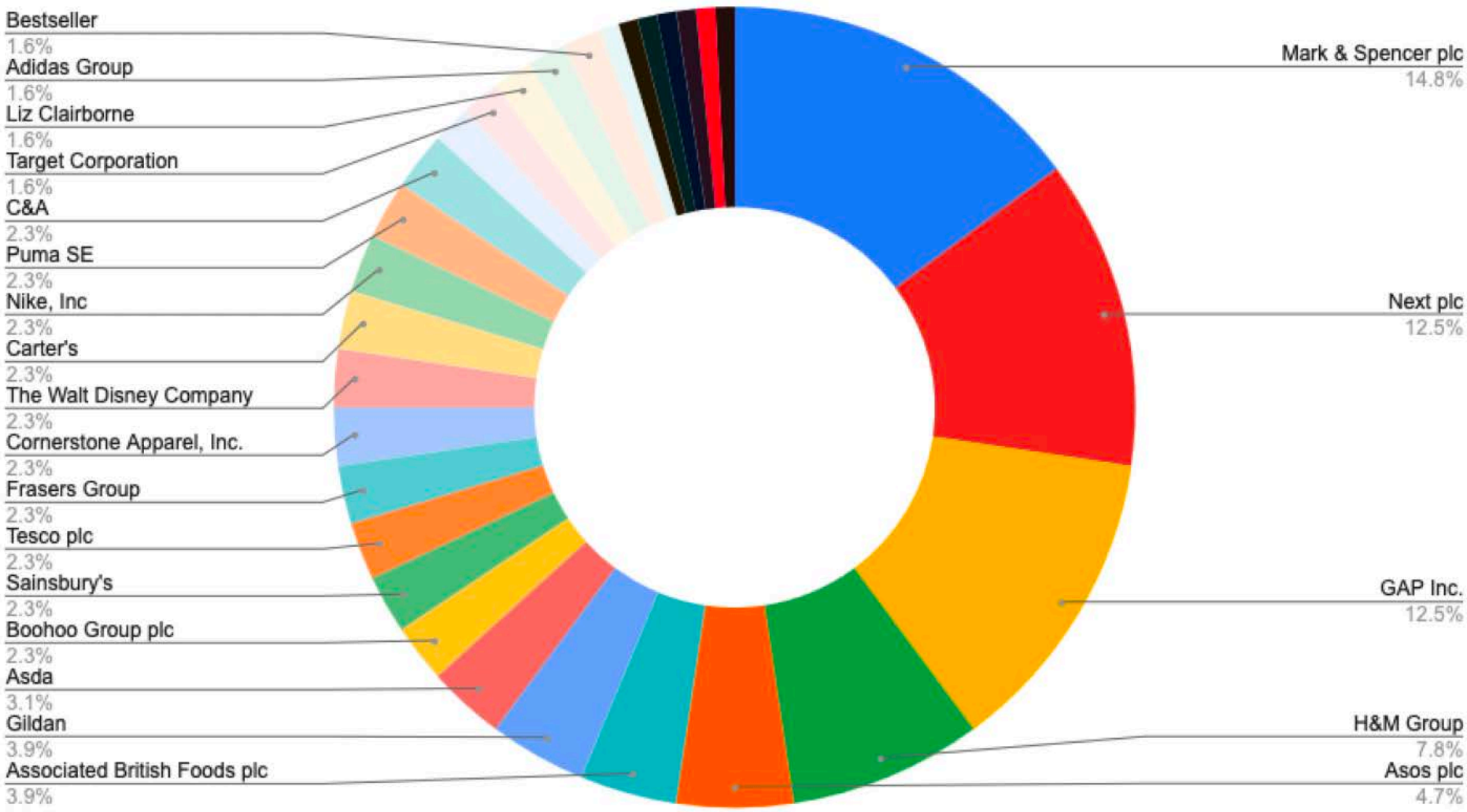

Counts of synthetic microfibers
200
180
160
140
120
100
80
60
40
20
0
HQ, 12m
WH, 5m
WH, 10m
KM, 5m
KM, 10m


Counts of synthetic microfibers
300
250
200
150
100
50
0
16
20
20
*
40
70
160
180
185
190
200
Volume of rain water per event (mL)


Counts of synthetic microfibers
300
250
200
150
100
50
0
1
2
2
3
3
3
3
4
6
7
Number of days since last rain


Counts of synthetic microfibers
90
80
70
60
50
40
30
20
10
0
Water flow
Surface barrier
OKS18
OKS14
OKS13
OKS12.5
OKS20
OKS26
OKS8
Upstream
Adjacent to market and landfill
Downstream

Market Waste Known Conglomerate %



Beach Waste Known Conglomerate %