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Spatial Distribution of Microplastics and Mesoplastics in Sediments Across Hsinchu, Taiwan

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ABSTRACT

Microplastics are becoming a major environmental concern, as they are ubiquitous, but their harm is not fully understood. Since research on microplastics in sediments in urban areas is scarce, this study aimed to uncover where microplastics may be the most abundant. City center, city border, and outer city sites were examined. One city center site was chosen (Gongshiyi Park), three city border sites were chosen (Touqian River North Bank, Touqian River South Bank, and Shixing Air Quality Purification Zone), and one outer city site was chosen (Shibajian Mountain). In each site, 25 samples were collected from an area of 10x10 cm and a depth of 2 cm, and plastic particles were filtered out using a 1mm sieve. The highest abundance of microplastics was at the city border (413.3 microplastics/m^2), followed by the outer city (200 microplastics/m^2), and lastly, the city center (100 microplastics/m^2). Similarly, mesoplastics were collected and counted from the same samples, displaying a different trend with the highest abundance at the city border (273.3 mesoplastics/m^2), followed by the city center (80 mesoplastics/m^2), and lastly, the outer city (40 mesoplastics/m^2). Contrary to previous research which showed a decrease in microplastic abundance from rural to urban areas, the findings of this study suggest that external anthropogenic variables, such as effective maintenance regimes, may have altered microplastic dispersal. Future studies should include a larger sample size, span over a longer period of time, and include a more complete land use analysis.

Introduction

With its numerous applications, plastic is omnipresent in modern society. 19 to 23 million metric tons of plastic waste generated in 2016 entered aquatic ecosystems (Borelle et al., 2020). Most plastics are thrown away after a single use and pile up in landfills or enter water bodies; these plastics then break down into smaller pieces through exposure to “biological, chemical and environmental elements. (Yee et al., 2021)” Microplastics are pieces of plastic 5mm or less (Wu et al., 2019, Isobe et al., 2021, Yee et al., 2021, Wang et al., 2021). Primary microplastics are plastics manufactured to be less than 5mm in size and are usually found in personal care products such as toothpaste. Secondary microplastics are plastics broken down from larger items such as packaging or clothing. Since microplastics have a low density but are hard to break down, they are easily transported across the globe through wind and ocean currents, while freshwater ecosystems such as lakes and rivers are transporters of microplastics from terrestrial to marine environments (Ma et al., 2022). In total, there are 24.4 trillion pieces of microplastics in the world’s upper oceans, which weighs 82,000 to 578,000 tons (Isobe et al., 2021). Although previous research on atmospheric microplastics is scarce, fallout of airborne microplastics have been observed, and they can also pollute aquatic and terrestrial ecosystems (Wang et al., 2021).

Once in the environment, microplastics have multiple ways to enter the human body. The three main ways are inhalation, ingestion, and skin contact; seafood and the environment pose the greatest risk of exposure to microplastics "due to long-term weathering of polymers, leaching of polymer chemical additives, residual monomers, exposure to pollutants and pathogenic microorganisms all being active in these environments" (Yee et al., 2021). Although the omnipresence and mass consumption of microplastics have been firmly established in the literature, the extent of their impacts on human health are still being debated. Yee et al. (2021) find "scant research into their impact on the human body at subcellular or molecular levels. In particular, the potential of how nanoplastics [plastics < 0.1 μm] move through the gut, lungs and skin epithelia in causing systemic exposure has not been examined thoroughly." Although the extent to which each category harms the human body is ambiguous, the potential damage is still evident. For instance, additives such as bisphenol A (BPA),which are common in plastic products, are known to cause various health problems, and the United States Food and Drug Administration has raised concerns that BPA could be linked with hormonal and cardiovascular issues (US FDA, 2014). Moreover, the chemical composition of and pollutants in microplastics have been found to negatively impact the health of marine organisms (Yu et al., 2020).

Urban environments, driven by high human activity, are considered a significant source of microplastics, with common contributors including "tire wear, landfill and sewage treatment, construction, industrial activity, [and] household laundry (Qiu et al. 2020)." In fact, microplastic pollution suddenly increases from rural to urban areas, and the majority of them are "generated in residential and industrial areas" (Kunz et al. 2023). After entry into the environment, microplastics can easily be transported due to their light weight. As a result, they have been detected in the "urban atmosphere, ground surface dust or soil, and municipal rivers" (Qiu et al. 2020).

Multiple studies have examined the distribution of microplastics within cities as well. Ma et. al (2022) conducted a study on the Songhua River and urban centers throughout northern China found that city centers had more microplastics in the river compared to the upper areas of the rivers. The levels of microplastics varied randomly as the river flowed from the city center to the lower areas, due to urbanization and anthropogenic activities. Rafique et al. (2020) studied the distribution of microplastics in various urban environments in Lahore, Pakistan. They found that "the highest concentration of microplastics was present in the parks while the lowest numbers of microplastics were enumerated in soil from dumping sites," and the average concentration in Lahore district was 4483 ± 2315 microplastics/kg. As for the types of parks, playgrounds could have a higher concentration of microplastics, possibly due to the play structures' plastic composition (Koutnik et al., 2023).

Regarding the distribution of microplastics across rural and urban areas, most studies agree that urbanized areas generally have a higher microplastic concentration than rural areas. Kunz et al. (2023)–who conducted their study in Taichung, Taiwan–found through land use analysis that the number of microplastics suddenly increases from rural to urban areas but that the strength of this phenomenon depends on the strength of the rural to urban gradient. Specifically, in the catchment areas, microplastic pollution was directly correlated with "the size of industrial, residential and traffic areas." Additionally, microplastic pollution was negatively correlated with the size of forest areas. Kunz et al. (2023) also specified that exceptions to their findings should be scrutinized since other factors such as population density, land use, and urbanization could affect the correlations. One such exception was Yin et al.'s (2020) discovery that microplastic pollution actually decreased when going from rural to urban areas in East Dongting Lake, in Hunan Province, China. However, as Kunz et al. (2023) explained, there must have been extraneous factors influencing the results, which Yin et al. (2020) acknowledged by attributing the contrast to "effective control measures" within the urban areas.

Counterintuitively, areas with a greater flow of people do not necessarily correlate with higher concentrations of microplastics. Fernandes et al. (2022), found a negative correlation between the flow of people and the concentration of microplastics in Santo André (SP), Brazil. This was due to the fact that a greater flow of people meant increased maintenance and cleaning, resulting in less microplastics, while places with less people had less maintenance, and therefore, more solid waste and microplastics. Thus, it is also crucial to note the difference between urbanized areas and areas with a greater flow of people.

This study aims to examine the concentration of microplastics in urban centers, urban borders, and out-urban areas in Hsinchu, Taiwan, an area where microplastics' pathways have not been thoroughly examined.

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Examining pathways is critical to mitigation and could help to answer questions like whether or not current control measures are effective, as highlighted by Yin et al. (2020).

Methods

Survey Sites

The goal of this study was to determine the concentrations of microplastics across outer city, city center, and city border locations. Sample sites in Hsinchu were selected for each location. For the outer city site, Shibajian Mountain (**十八尖山**) was chosen and is located at around 24.791431, 1z20.986539. The city center site was a small park outside an apartment building, named Gongshiyi Park (**公十一公園**) and located at around 24.825430, 121.010774. Finally, there were three sites chosen for the city border. The first two sites were on the north and south banks of Touqian River (**頭前溪**) (24.813519, 121.014675 and 24.820342, 120.998994; respectively), while the third site was at Shixing Air Quality Purification Zone (**世興空氣品質淨化區**) at 24.812683, 121.039583. For the sake of clarity and simplicity, this paper will refer to each site by their English names. The category of each location was decided by determining whether or not said point was inside/outside/on the border of a white area on Google Maps, which represents cities, and by visually observing the density of buildings in the surrounding area. Although Shibajian Mountain would have been categorized as a city border site, the surrounding area had much fewer buildings compared with the other sites, so it was categorized as an outer city site.

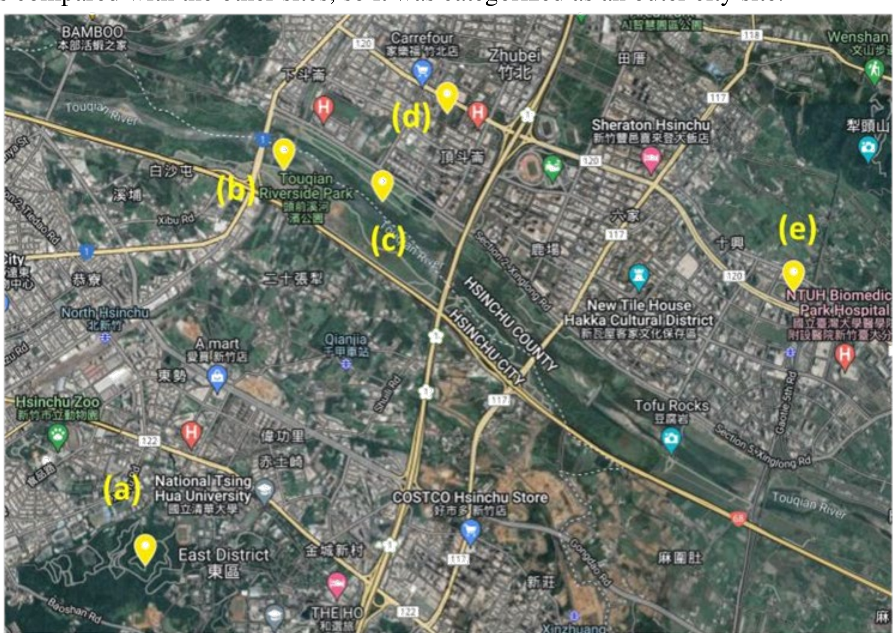

Figure 1. Satellite map of all the sites. (a) Shibajian Mountain–Outer City (b) Touqian River–City Border (southern bank) (c) Touqian River–City Border (northern bank) (d) Gonshiyi Park–City Center (e) Shixing Air Quality Purification Zone–City Border.

As for the terrain characteristics, the site in Shibajian Mountain was a hiking trail with an asphalt path in the middle and soil on its two sides. The samples were collected randomly on both the left and right sides, which were dense with vegetation. The southern bank of Touqian River had a section consisting of more vegetation and an asphalt path, as well as another section with flatter terrain that was mostly covered by grass and a dog park section that was inaccessible during the experiment. The eastern site of Touqian River and the Shixing Air

Quality Purification Zone both had moderate vegetation. Gonshiyi Park was the smallest site and had the least amount of vegetation, with mostly grass cover and a few large trees.

Sample Collection, Preparation, and Analysis

This study's methodology was partly based on The Big Microplastic Survey, a global collaborative citizen project run by the charity Just One Ocean and the University of Portsmouth, which aims to collect microplastics samples on beaches around the world. In this study, all samples were collected from the period 31-May-2023 to 14-July-2023. In each sampling site, five spots were chosen randomly. Within each spot, five holes were dug randomly (each approximately 10 cm wide and 2 cm deep), and each hole was approximately one meter apart from one another. The samples were collected with a steel shovel and the sediment was temporarily deposited in plastic buckets. All samples from the same sites were deposited into the same bucket.

After collection, the samples were sieved for both microplastics (1-5mm) and mesoplastics (5-10mm). The bucket of sediment for each site was removed until only approximately a third of the sediment was left while the rest of it was set aside in a separate container. Then, the bucket containing the sediment was filled with saltwater (30g of salt per liter of water) to allow the plastic to float up while the unwanted sediment remained at the bottom. Salt was added to give additional buoyancy for the plastic particles. The mixture was then poured through a 1 mm kitchen sieve into a separate plastic bucket of the same size, until all the liquid and particles floating on the surface were removed and only the sediment was left. The particles were then set aside on a paper plate. This process was repeated until all the sediment had been filtered. After the particles were put on the plate, vegetation and other objects that were visibly not plastic were manually removed with a tweezer and discarded.

Samples from each site were placed on separate paper plates. Each site's microplastics and mesoplastics were counted, and the particles were categorized as mesoplastics or microplastics by manually measuring the particles with a clear plastic ruler and determining the sizes of each particle. Both the recording of the number of plastic particles and the calculation for the average particle per square meter was done through Google Sheets. To convert the number of particles to the average number of particles per square meter, the raw number was multiplied by a unit conversion of $100^2/500$, since there was a total of 500 cm^2 worth of soil collected from each site.

The particles were then classified as ones that came from the city center, city border, or the outer city. Since three different sites were used to survey the city border, the average was taken for the number of mesoplastics and microplastics found across all three border sites in order to compare them with the city center and city border, which only had one site each.

Results

Microplastics and Mesoplastics Across Outer, Inner, and Intermediate Sites

Overall, the number of plastic particles was greatest at the city border sites. The site with the greatest number of plastic particles was Shixing Air Quality Purification Zone, with 49 individual particles and 980 particles/m^2 (Figure 2, 3). This was followed by the north and south banks of Touqian River, which both had 27 individual particles, or 540 particles/m^2 (Figure 2, 3). The outer city site, Shibajian Mountain, had the second most plastic particles, with 12 plastic particles or 240 particles/m^2, and the city center site had the least particles, with only 180 particles/m^2 or 9 particles (Figure 2, 3).

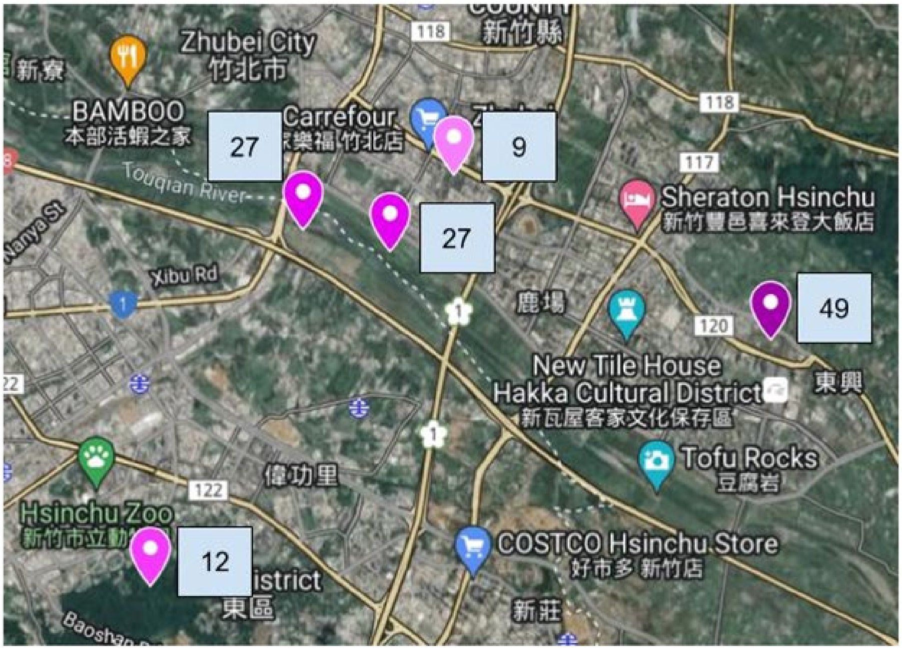

Figure 2. Number of particles (mesoplastics and microplastics) in each site. The darker the color, the more plastics there were in the given site.

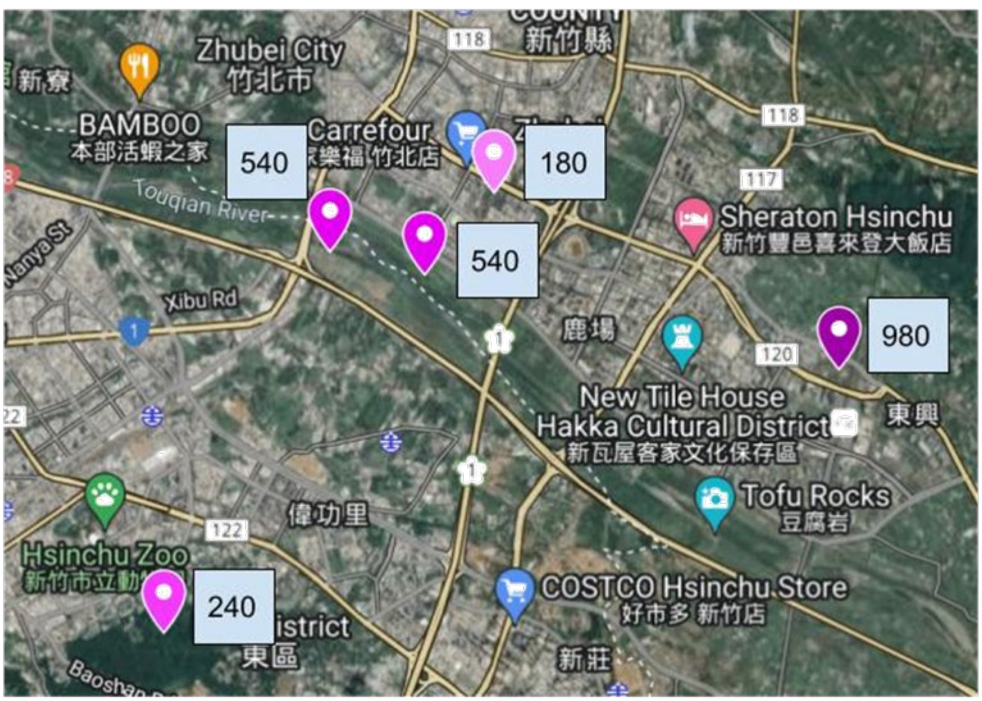

Figure 3. Particles (mesoplastics and microplastics) per meter in each site. The darker the color, the more plastics there were in the given site.

The rankings were slightly different when the number of microplastics and mesoplastics were recorded separately. Since three sites were selected as the city border sites, the average number of plastics was found for the three locations; this number was then taken as the “raw” data for the city border and then converted into particles/m^2 after performing the same calculations as done with the other sites. The raw data shows that the city border generally had the most plastics, which was followed by the outer city and the city center. However, the outer city site had less mesoplastics than the city center site (Table 1).

Table 1. Number of microplastics and mesoplastics particles of all types of sites.

Type of Particle	**City Center**	**City Border**	**Outer City**
Microplastics	5	20.7	10
Mesoplastics	4	13.7	2

As for the particles per square meter, the result of the city border sites was calculated to be 413.3 microplastics/m^2 and 272.4 mesoplastics/m^2 (Table 2). The outer city site had more microplastics than the city center site, but the opposite was true for mesoplastics. The outer city site had 200 microplastics/m^2 and 40 mesoplastics/m^2, while the city center site had 100 microplastics/m^2 and 80 mesoplastics/m^2 (Table 2).

Table 2. Microplastics and mesoplastics per square meter of all types of sites.

Type of Particle	**City Center**	**City Border**	**Outer City**
Microplastics	100	413.3	200
Mesoplastics	80	273.3	40

Breakdown of the Types of Plastics and Their Locations

Of the five sites, Shixing Air Quality Purification Zone had the most microplastics/m^2 (n=660). Touqian River North Bank had the second most microplastics/m^2 (n=380), followed by Touqian River South Bank and Shibajian Mountain, which both had 200 microplastics/m^2 (Table 2). In general, the city border sites had the most microplastics, as seen by the colors on the map (Figure 4). However, Touqian River South Bank only had 100 microplastics/m^2 more than the amount in Gongshiyi Park and it had the same amount as Shibajian Mountain. Touqian River North Bank and Shixing Air Quality Purification Zone had 180 and 460 more microplastics/m^2, respectively, than Touqian River South Bank (Table 2).

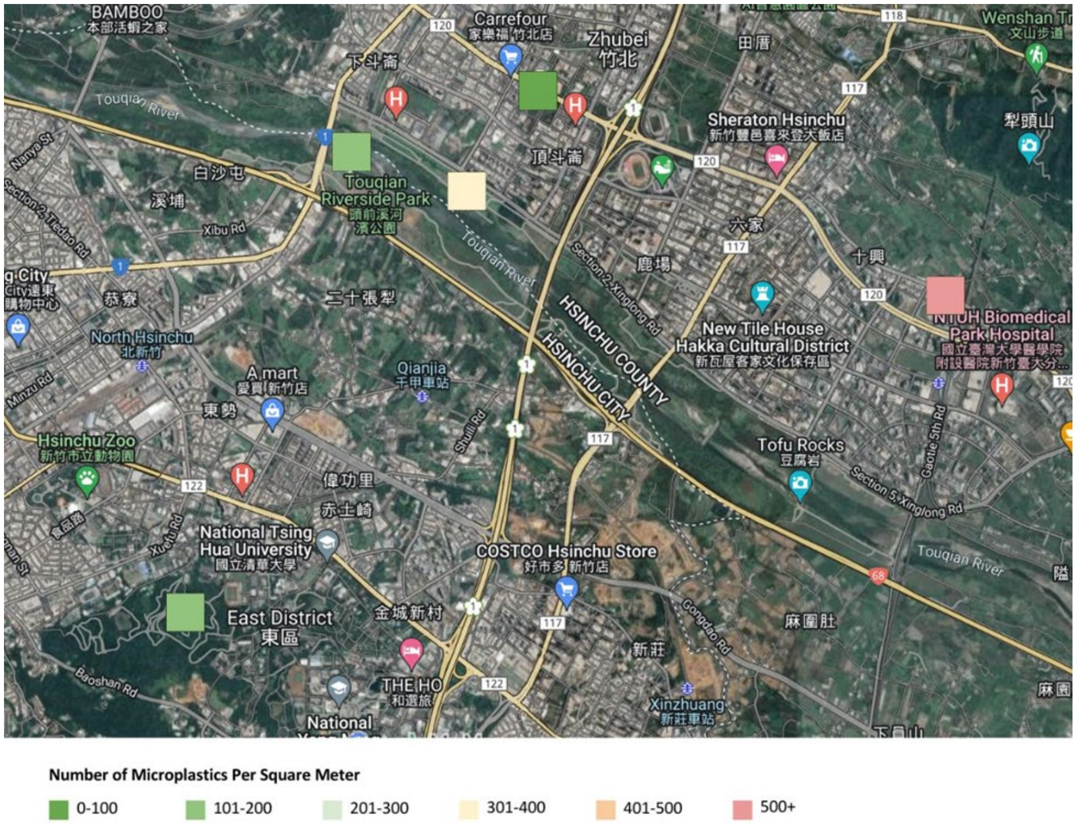

Figure 4. Each sample site labeled with the number of each type of microplastic pinned on the locations.

Mesoplastics also tended to concentrate at the city border sites. For instance Touqian River South Bank had 340 mesoplastics/m^2, making it the site with the most mesoplastics (Table 2). Shixing Air Quality Purification Zone came in second, with only 20 fewer mesoplastics/m^2 than Touqian River South Bank (Table 2). Touqian River North Bank had the third most mesoplastics/m^2, with a calculated density of 160 mesoplastics/m^2 (Table 2). Thus, unlike the density of microplastics in the border sites, all three border sites had mesoplastic densities consistently greater than the city center and outer city sites. To this end, Gonshiyi Park only had 80 mesoplastics/m^2 and Shibajian Mountain only had 40 mesoplastics/m^2 (Table 2).

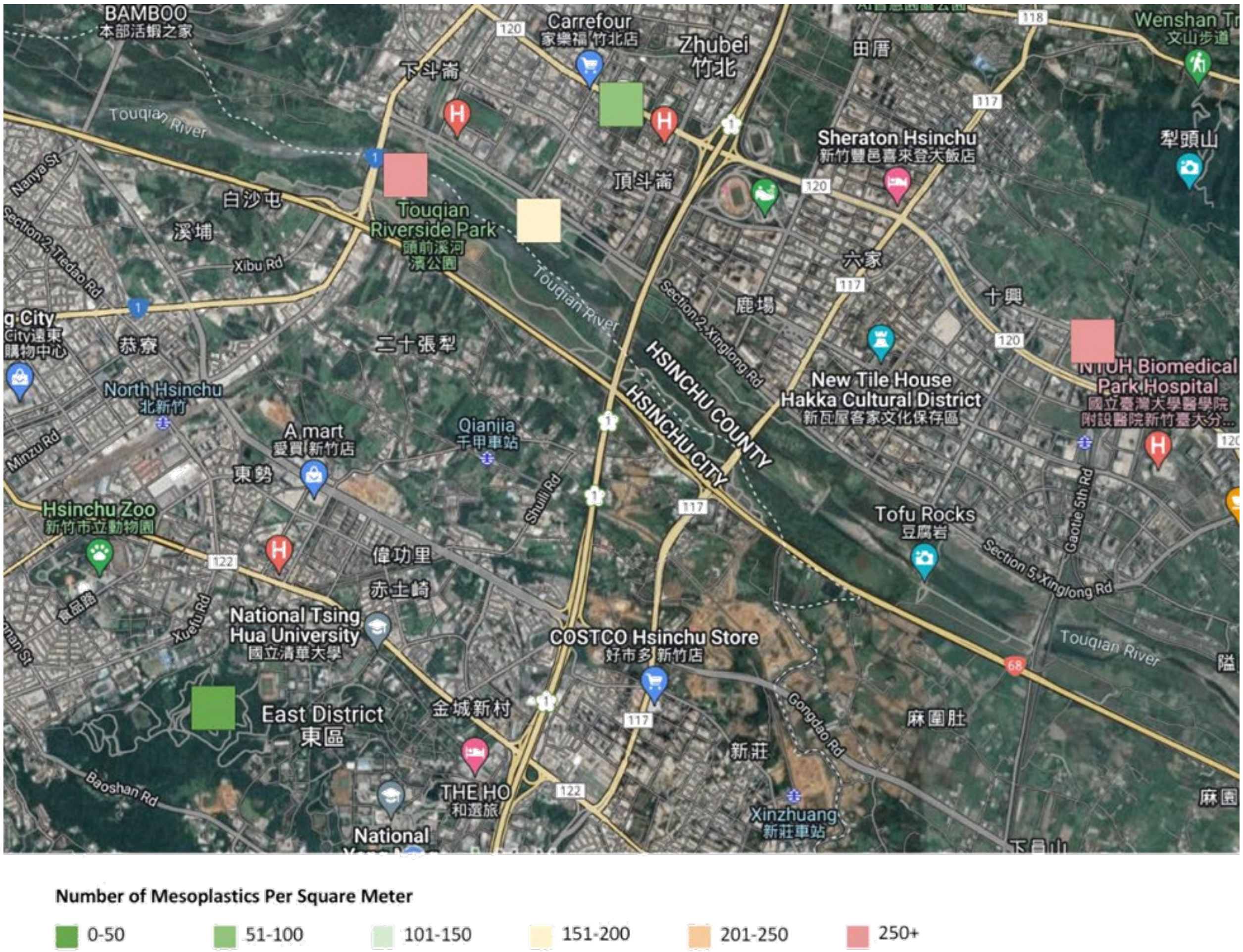

Figure 5. Each sample site labeled with the number of each type of mesoplastic pinned on the locations.

Discussion

Spatial Distribution of Microplastics & Mesoplastics

According to Kunz et al. (2023), the prevalence of microplastics should generally increase when moving from a rural to urban area, but they did specify that anthropogenic factors could influence this trend. Results from the present study break this trend–there were the most microplastics on the city border (n=20.7), while the outer city had the second most overall microplastics (n=10), and the city center had the least amount of microplastics (n=5)–which suggests that anthropogenic factors influenced the results. As Yin et al. (2020) pointed out, effective control measures within the city could have been the reason why they found more microplastics in rural areas than in urban areas. Fernandes et al. (2022) also noted that a greater flow of people in Santo André, Brazil correlated with greater maintenance efforts and thus negatively correlated with the amount of microplastics. Therefore, the relatively low number of microplastics found in the city center in this experiment could also be explained by anthropogenic factors such as effective policymaking or maintenance efforts.

All of the city border sites in this experiment were public parks. Rafique et al. (2020) found that public parks tended to have the highest amount of microplastics, and noted that the lack of awareness of the effects of single-use plastics combined with the fact that the parks were among the busiest locations in Lahore meant that single-use plastic products were bought by people, left in parks, and broken down by animals, especially the plastic products containing food. The authors further pointed out that parks may have more microplastics because they are open environments and thus more prone to the aerial deposition of microplastics. Although Gongshiyi Park, the city center site in this experiment, is also a park, it may have had less microplastics because it was less trafficked and may have had a better maintenance regime.

The outer city site had the second least amount of microplastics and fewer microplastics than the city center site, even though it was the most rural site. This could be due to a number of reasons. Firstly, the local culture of the hikers could have influenced their behaviors in producing less waste in hiking areas, resulting in a smaller amount of microplastics. Furthermore, Kunz et al. (2023) noted that the amount of microplastic pollution correlated negatively with the size of forest areas. Since Shibajian Mountain was the most dense with vegetation and was the largest forest area, this may have been why it had such a low amount of microplastics.

Conclusion

On average, there were 100 microplastics/m^2 in the city center, 413.3 microplastics/m^2 in the city border, and 200 microplastics/m^2 in the outer city. There were 80 mesoplastics/m^2 in the city center, 273.3 microplastics/m^2 in the city border, and 40 microplastics/m^2 in the outer city. Most of the literature indicates that microplastic abundance tends to decrease when moving from rural to urban areas. However, anthropogenic factors in the present study such as good maintenance in some areas may have influenced the results. For instance, the low concentration of microplastics found in the city center could be explained by efficacious policymaking and maintenance. The reason why the outer city was found to have less microplastics may have been due to the fact that the chosen site was dense with vegetation, which may have acted as a barrier for the plastic particles. Future studies should examine the city with a greater sample size and over a longer period. More detailed land use analysis should also be carried out. As more literature on the pathways of microplastics and mesoplastics in urban areas in Hsinchu is created, the data could eventually support efforts to mitigate microplastic pollution.

Limitations

This paper has several limitations that must be noted. Firstly, there is a limited sample size, and only the city border location included more than one site. 5 locations were surveyed in each site, with 5 samples each, making a total of 25 samples per site. The randomness of the sampling technique may also be flawed. These locations where samples were collected were picked manually at the location of the sites, and not randomized beforehand, which could result in potential biases. Future experiments could randomize the sample locations beforehand or use techniques such as quadrant sampling.

All samples were collected during the period of 5/31/23 to 7/14/22. However, Warrier et al. (2022) found an increase in the concentration of microplastics in a Southern Indian lake during the Monsoon Season, suggesting that rainfall could have an effect on microplastic abundance. Thus, future studies could look at these sample sites with a more diverse time range, examining both periods with scarce rainfall and periods with abundant rainfall, or a shorter time range, perhaps within 1 or 2 days.

After the collection of the samples and during their preparation, there may have been some plastic particles that did not float up to the surface of the buckets but instead stayed trapped within the sediment. If so, they would not have been transported onto the paper plates and counted. Stirring of the sediment during the process was done in an attempt to prevent this issue, but some particles may have still remained stuck. Furthermore, the saltwater solution added into the sediment only had a salinity of 30 g/L, meaning that plastic pieces with a higher density than that of salt water may not have floated to the surface. As a result, the number of microplastics could have been slightly underestimated.

Lastly, it is difficult to determine the true and precise causes of why some areas may have a greater plastic particle density than others or why a certain type of microplastic is more abundant in some areas compared to others. A more detailed examination of the environment, including the analysis of factors such as land use, population density, the flow of people, the degree of urbanization, and other anthropogenic factors should be examined more carefully before drawing strong conclusions.

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