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Microplastic Contamination of Rainwater on the Highway with Different Elevations in Yogyakarta Province Indonesia

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ABSTRACT

Abrasion of vehicle tires produced on highways on the imaginary line of Yogyakarta from Bantul up to Sleman Regency with different elevations has the potential to be a source of microplastics in the air and can contaminate rainwater. This study aims to determine the abundance and characteristics of microplastics in rainwater that falls on highways with different elevations in Yogyakarta Province. The study began with determining the sampling point and taking rainwater samples on the highway around Bantul Market, Tugu Monument, and Kaliurang km 14. Eight samples on different days were taken at each sampling point, as much as 250 mL/sample. Rainwater samples were filtered, microplastic abundance was calculated (particles/L), and grouped based on the shape, color, size, and polymer type. The content of microplastics on highways at different elevations in Yogyakarta Province was not significantly different, with an abundance range ranging from 200 to 484 particles/L. Vehicle density, light intensity, air temperature, and wind speed correlated with the abundance of microplastics in rainwater. The dominant characteristic is black fiber, 101-500 μm, and polyisoprene. Microplastics in rainwater that fell on the highways of Yogyakarta Province with varying elevations did not have different abundances but had the same characteristics.

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1. Introduction

The Special Region of Yogyakarta (Yogyakarta Province) is famous for its imaginary line as a cultural heritage that the Kraton (Palace) Yogyakarta initiated. An imaginary line stretches straight from the southern coast of Bantul Regency, with the lowest elevation (0 m asl), towards the Kraton Yogyakarta (114 m asl), to Mount Merapi, with the highest elevation (2,930 m asl) in Yogyakarta Province (Visiting Jogya, 2020; Balai Pelestarian Cagar Budaya DIY, 2019). The area traversed by the imaginary line has now become an active area for the center of tourism, government, trade, and many settlements have been built up to campus buildings (Samaratungga, 2018). This situation makes human and vehicle activities very high and causes air pollution. Furthermore, abrasion of vehicle tires that rub against the road can also release microplastic particles because tires are made of synthetic rubber, such as polyisoprene and polybutadiene (Klein & Fischer, 2019).
Microplastic is the smallest plastic particle with a size of less than 5000 μm to 1 μm (Hidalgo-Ruz, et al., 2012). Microplastics can spread in the air through the wind at different elevations (Allen, et

al., 2019). The presence of microplastics in the air is at risk of being inhaled and entering the human body, so it can interfere with the performance of the human respiratory organs (Gasperi, et al., 2018). Syafei et al. studied microplastics in the air in Surabaya, West Java, Indonesia (Syafei, et al., 2017). As a result, many microplastic particles have been found in the ambient air of one of the densest urban areas in Indonesia and have entered the human respiratory tract.

Furthermore, microplastic particles in the air can be carried away and mixed with rainwater, contaminating groundwater sources (Rahmatsyah, et al., 2021). It has been proven that microplastics have been found in rivers in Yogyakarta City, such as the Code River, Gadjahwong River, and Winongo River, in their sediments (Utami, et al., 2021). Even so, there has been no measurement of the microplastic content in rainwater that falls on highways in the Yogyakarta area. Of the 50 articles published from 2017 to 2022, microplastic findings in Indonesia are still dominated by aquatic ecosystems (47 articles), and there has been no research on rainwater which should be a source of clean water for life on earth. Moreover, many residents in the north of Yogyakarta Province still collect rainwater and process it for daily consumption (Arief, 2021). These problems are the background for measuring content, especially in the area crossed by the imaginary line as the most densely populated Yogyakarta Province. This study aims to determine the abundance and characteristics of microplastics in rainwater that falls on the highway with different elevations in Yogyakarta Province. This research will be pioneering data with novelty as the first to identify microplastic pollution in rainwater in Indonesia. Hopefully, this research can become information for related agencies such as the Dinas Lingkungan Hidup (DLH) in all regencies and become educational material for the community who use rainwater.

2. Methods

2.1. Location and Time

This research is an empirical study by collecting exploratory data in the field. Microplastics were obtained from rainwater that fell at three sampling points, namely the highway in front of the Bantul Market, in the Tugu Monument of Yogyakarta area, and Kaliurang street km 14. Sampling was carried out from June to July 2022.

2.2. Tools and Materials

The tools used in this study included 250 mL glass bottles, aluminum foil, oven, papers, coolbox, ice gel, filter paper, dropper, glass preparations, cover glass, petri dishes, binocular microscopes, hand counters, camera microscopes, image raster application, Fourier Transform Infrared Spectroscopy, lux meter, thermohygrometer, TDS meter, pH meter, thermometer, and anemometer. In addition, the materials used in this study include rainwater and distilled water.

2.3. Research Procedure

2.3.1. Determination of sampling point and sample collection

Rainwater samples were taken at three sampling points, namely the highway in front of Bantul Market – 48 m asl (A), Tugu Monument of Yogyakarta – 119 m asl (B), and Kaliurang street km 14 – 330 m asl (C) (Figure 1). Determination of the sampling point is done purposively based on the same distance from the coastline of Parangtritis to the top of Merapi Mountain, where between sampling points has a distance of 15-12 km. Rainwater samples were taken at each sampling point eight times (replicates) on eight rainy days. Rainwater samples were collected in a 250 mL glass bottle right from the start of the rain until the bottle was filled. The glass bottle is then covered with aluminum foil so that it is not contaminated with plastic materials. The glass bottle was put into a container containing ice gel at a temperature of less than 4°C (Leslie, et al., 2017) so that the particles inside were not damaged when brought to the laboratory. Tools made of glass are sterilized using an oven for 24 hours before use.

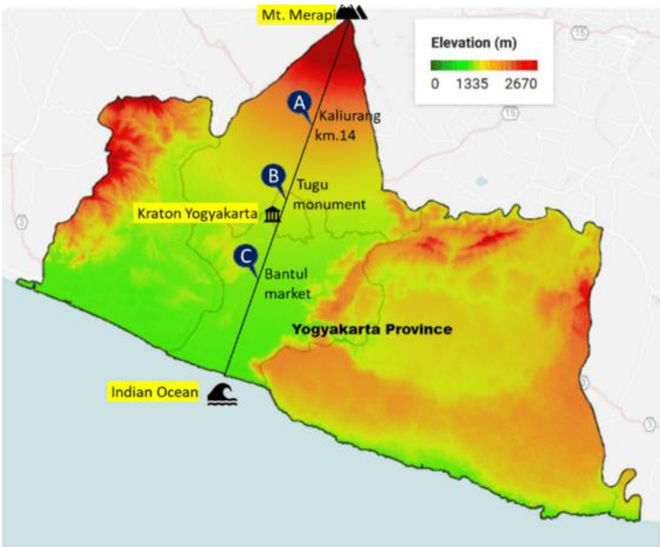


Figure 1. Three sampling points

2.3.2. Measurement of abiotic and vehicle density

Abiotic parameters in rainwater, such as water temperature, water pH, and dissolved particles, and abiotic air parameters, such as air temperature, humidity, light intensity, wind speed, and elevation, were measured at each sampling point for three replications. Rainwater abiotic parameters are measured right after rainwater is collected, while air abiotic parameters are measured when the weather is sunny during the day. In addition, the density of motorized vehicles in three groups (wheel 2, wheel 4, and wheel >4) was also calculated for 1 minute in the busiest hour range, which is between 15.00 and 17.00 WIB. Data collection on the density of motorized vehicles is carried out with the help of a traffic counter application.

2.3.3. Separation and identification of microplastics

In the laboratory, each sample was filtered with 1µm filter paper, then the particles retained on the filter paper were rinsed with distilled water and collected in a petri dish. The sample in a petri dish is then dripped onto a glass slide and covered with a cover glass. The samples were then sorted based on the microplastics' characteristics, including shape, size, and color, using a binocular microscope, then documented through a microscope camera. The length of the microplastic was measured by image raster application. Microplastics are grouped based on the shape of fibers, fragments, films, and granules, based on sizes 1-100 µm, 101-500 µm, 501-1000 µm, 1001-5000 µm, based on blue (dark blue, light blue), green (dark green and light green), black (black, gray), white, yellow, brown, transparent, red (red, pink and purple) [10]. The abundance of microplastics was then calculated in particle/L units, and the standard deviation was also calculated. This method is fast, easy, and inexpensive for separating and identifying microplastics in rainwater samples. To test the accuracy of the type of polymer on the dominance of filtered microplastic particles, a Fourier Transform Infra-Red (FTIR) test was carried out with a wavelength of 450-4000 cm-1 (Utami, et al., 2021).

2.4. Data analysis

The data were analyzed descriptively to compare the average microplastic abundance and percentage of the three sampling points. Microplastic abundance at three sampling points was also analyzed inferentially to test for significant differences in the three data using the krusal wallis test (because the data is not normally distributed). Correlation tests were also carried out to determine the abiotic parameters that were measured to correlate with the abundance of microplastics.

3. Results and Discussion

The results showed the rainwater fell along the Yogyakarta imaginary line contaminated by microplastics in the range of 200 to 484 particles/L. The rainwater that contained the most microplastics was rainwater that fell in the Tugu Monument of Yogyakarta area with an abundance of 393 ± 61 particles/L, then followed by rainwater that fell on the highway in front of the Bantul Market as much as 350 ± 66 particles/L, and last the rainwater that fell on the Kaliurang street km 14 was 322 ± 58 particles/L (Figure 2). The results of the inferential test with Kruskal Wallis significance value > 0.05. This result shows that the abundance of microplastics in rainwater at the three sampling locations showed no significant difference. This analysis proves that the selection along the imaginary line with different elevations does not affect the abundance of microplastics.

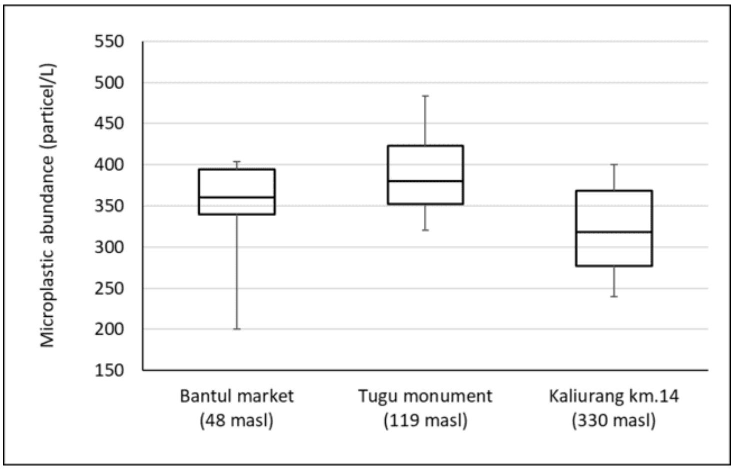


Figure 2. The abundance of microplastics in rainwater at the three sampling points

The results of the correlation test with Pearson (Table 1) show that the parameters that are positively correlated (significance value < 0.05, correlation coefficient +) include air temperature (strong), light intensity (strong), vehicle density (strong), wind speed (weak), while the negative correlation (significance value < 0.05, correlation coefficient -) is air humidity and dissolved particles. Abiotic data collection was taken from June to July 2022 at noon, 2-3 hours before the rain fell. It is estimated that this time is the time for the formation and spread of microplastics in the air. The air temperature during this study ranged from 26 °C-31 °C with a light intensity range of 1,054-5,119 Lux. The direction and speed of the wind when the measurement takes place is 10 to 20 km/hour to the west from the imaginary line of the Yogyakarta Province (Figure 3), so it can be predicted that before being carried away by rainwater, microplastics can be blown and carried to the west of the imaginary line of the Yogyakarta Province. A freshwater ecosystem that rainwater-containing microplastics can potentially pollute is the Progo river. The Progo River is a raw water source for the *Perusahaan Umum Daerah* (Perumda) *Air Minum* in Sleman Regency, Yogyakarta City, and Bantul Regency. Besides the Progo River, the west of Kaliurang street km 14, also has the Banyu Bening Community, which uses rainwater to be processed into drinking water.

Table 1. Correlation between microplastic abundance and abiotic parameters

Parameters	Microplastic abundance	
	Sig. (2-tailed)	**Correlation coefficient**
Air Temperature	0.002	0.600**
Light Intensity	0.000	0.766**
Speed Wind	0.042	0.418*
Air humidity	0.026	-0.454*
Suspended solids	0.050	-0.405*
Water pH	0.997	0.001
Water temperature	0.523	-0.137
Elevation	0.178	-0.285
Vehicle density	0.000	0.666**

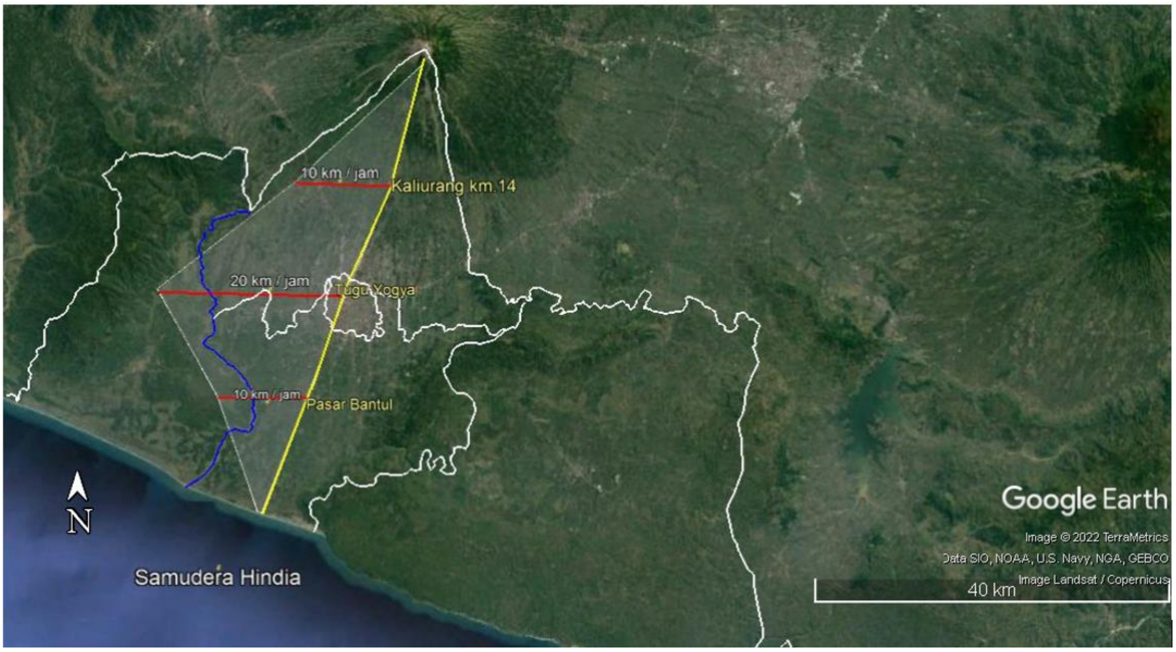


Figure 3. Distribution of microplastics from an imaginary line

Each sampling point is a busy street with varying vehicle densities. Abrasion from vehicle tires is predicted to be a source of microplastics in the air and has the potential to mix with rainwater. The location with the highest vehicle density is the Tugu Monument of Yogyakarta, with 166 vehicles per minute, followed by the highway in front of the Bantul Market, with 113 vehicles per minute, and the lowest on Kaliurang street km 14, with 105 vehicles per minute. The high density of vehicles at the Tugu Monument is due to being at a crossroads that leads to three regencies/cities in Yogyakarta Province, namely Sleman Regency (P. Mangkubumi Road - Magelang Road), Kulon Progo Regency (Wates Street), and Yogyakarta City. The Tugu Monument is also 700 m away from the biggest station in Yogyakarta Province (Yogyakarta Tugu Station), 800 m to the tourist center (*Jalan Malioboro*), and 2 km to Kraton Yogyakarta, making it the center of tourist movement in this tourist city. On the other hand, the Bantul Market also has a high vehicle density because it is a trading center in Bantul Regency and is only 300 meters from the Bantul Regency Government office. Kaliurang street km 14 is close to Mount Merapi and the Indonesian Islamic University (UII), one of the largest private campuses in Yogyakarta with 23,000 active students. This situation creates high vehicle activity, which causes the mobility of students and tourists who want to travel to Mount Merapi.

All microplastics identified at the three sampling points have characteristics that tend to be the same. The dominant form of microplastic in the three locations was fiber, with a range of 46-47%, followed by films with a range of 33-34%, and fragments with a range of 19-20% of the total samples found (Figure 4). Microplastics in the form of fibers were found at all three sampling points and are thought to originate from tire particles that decompose and are carried by the wind into the atmosphere (Klein, M. & Fischer, E.K., 2019). However, based on research carried out by Driss, synthetic textiles in the form of fibers also play a role as the primary source of finding microplastics in the air (Dris, et al., 2016). Fiber particles from textiles will likely be released into the atmosphere from residual discharges in textile mills. On a 6 km radius from each sampling point, recorded five textile factories are located near the Tugu Monument (PT. Rahadja Putra Mulya, PT. Kusumatex, PT. Yogyatex, PT. Sandang Pangan Lantabur, PT. Samitex Sewon), two textile factories are located near with the Bantul Market (PT. Busana Remaja Agracipta, Margaria Group). There is no textile factory in that radius around Kaliurang street km 14.

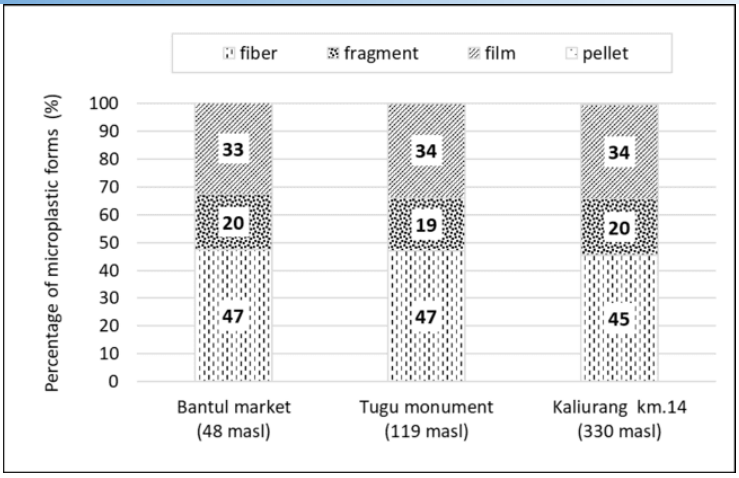


Figure 4. Identified forms of microplastics at the sampling point

At the three sampling points, the most microplastic colors were black, as much as 46-48%, followed by transparent colors, as much as 31-32%, brown, as much as 12-15%, yellow, as much as 6-8%, and red, blue, green as much as 0% (Figure 5). The black color and fiber were dominant when visually observed with a binocular microscope. They indicated vehicle tire abrasion (Panko, et al., 2019) or synthetic fiber fragments from textile factory residues into microscopic sizes. In addition, black microplastics are also the result of the absorption of pollutants in the air as one of the capabilities of additive microplastic particles (Wahdani, et al., 2020). Transparent color becomes the second dominant color, generally accompanied by a film (Figure 6). The characteristics of these microplastics are thought to come from the fragmentation of single-use plastic packaging carried by the wind into the air (Firdaus, et al., 2020). Although the distance from the Piyungan Landfill, which accommodates waste from the three regions of Sleman Regency, Yogyakarta City, and Bantul Regency, is almost 10 km, generally, the three sampling points are close to Temporary Disposal Sites scattered in various areas. Plastic waste is also often found wasted on the sides of the road due to the lack of public awareness to reduce the use of plastic.

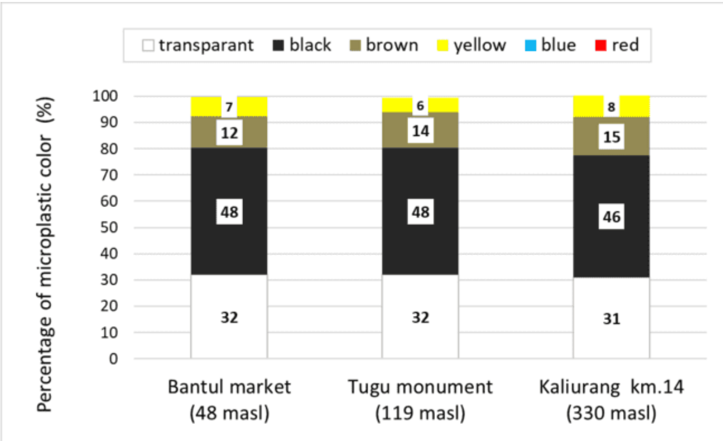
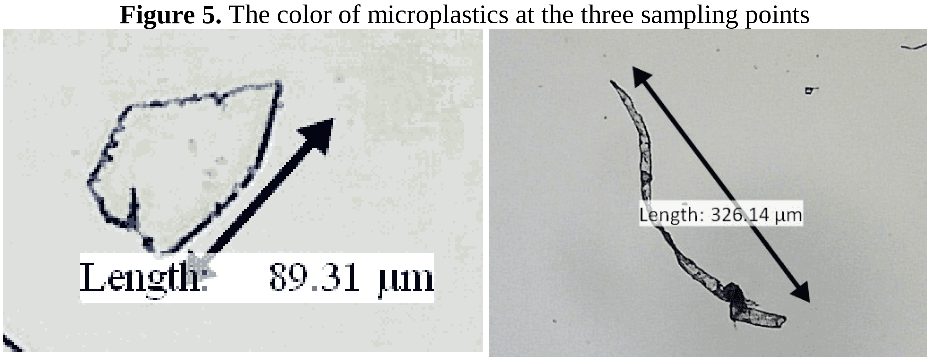
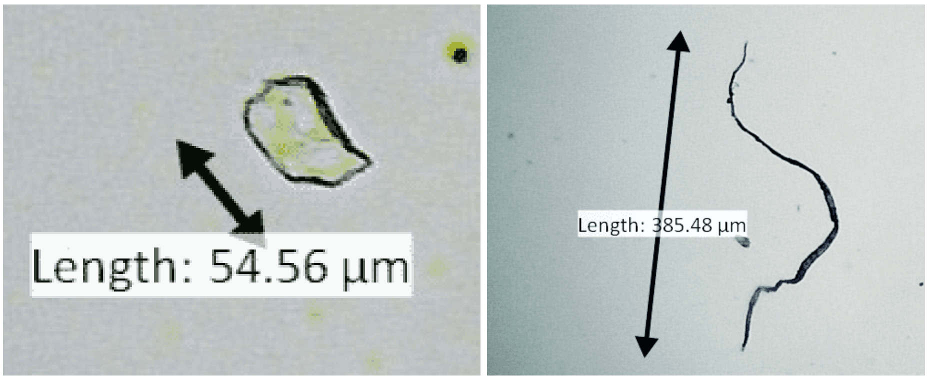


Figure 5. The color of microplastics at the three sampling points



(a) (b)



(c) (d)

Figure 6. Microplastic in the rainwater sample: (a) transparent fragmen; (b) transparent film; (c) yellow fragment; (d) black fiber

Microplastics also have varying size characteristics. Figure 7 shows that the size of 101-500 µm dominates at the three sampling points with a percentage of 32 to 33%, followed by sizes 1-100 µm by 27 to 31%, sizes from 501-1000 µm by 26 to 29%, and sizes from 1001-5000 µm with the smallest percentage of 10 to 12%. This size indicates that microplastics in rainwater are generally (almost 90%) tiny, between 1 µm to 1,000 µm based on Firdaus et al. 2020. This microscopic size is more dangerous to human health because it is easily inhaled and enters the respiratory tract until it enters the digestive tract if rainwater is not treated optimally (Campanale, et al., 2020).

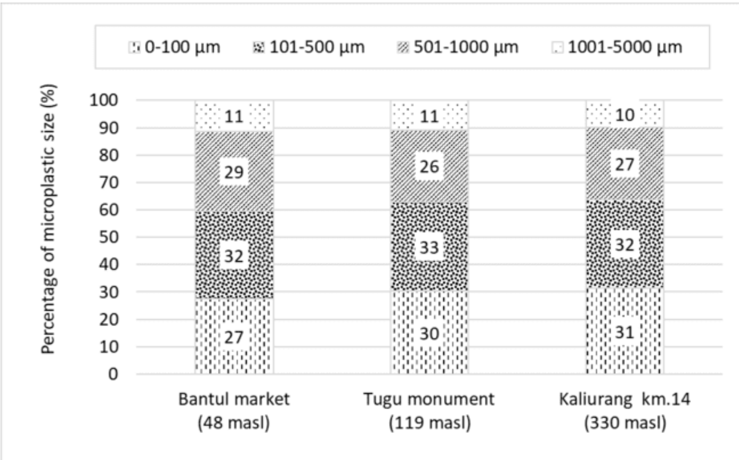
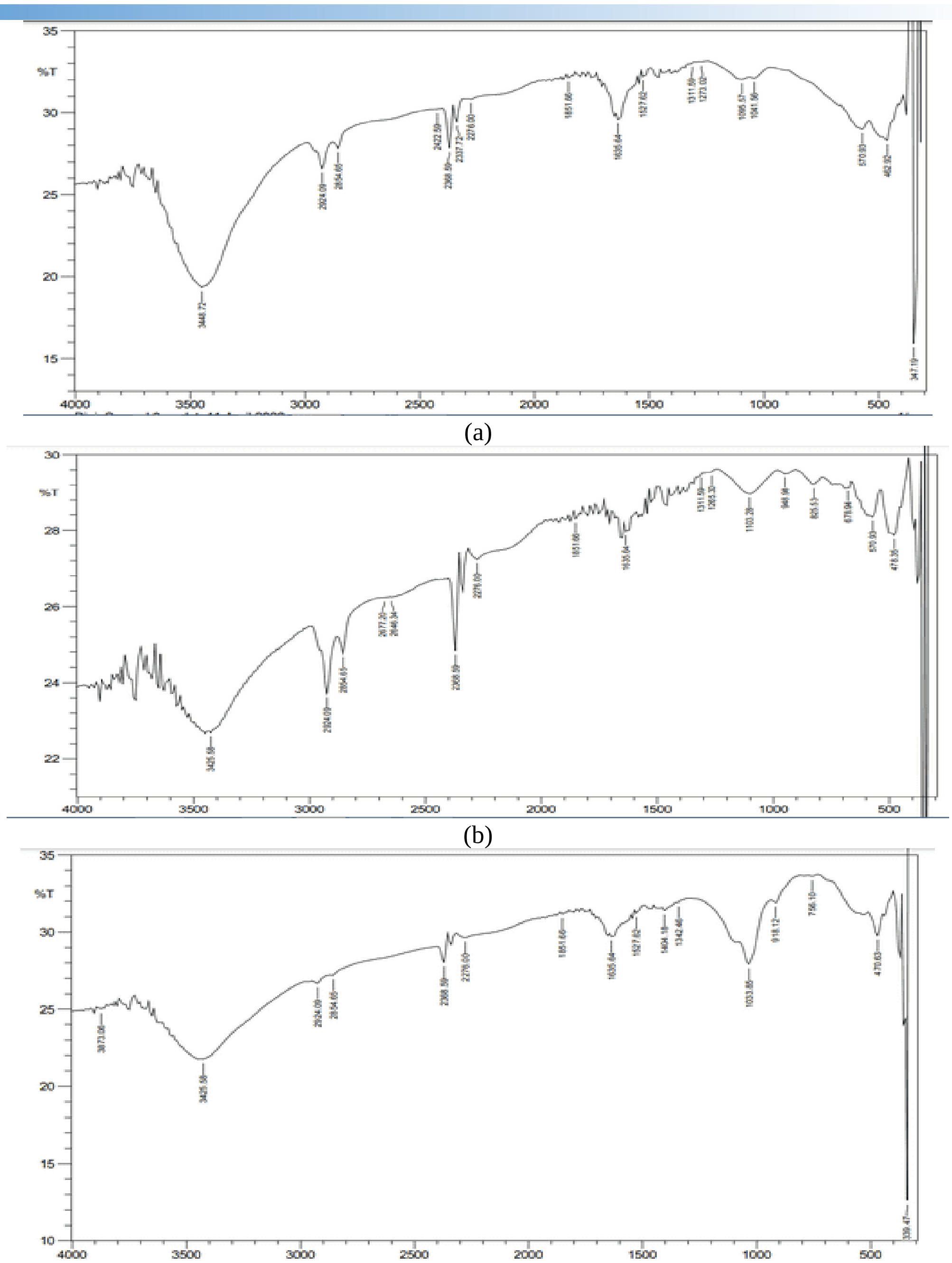


Figure 7. Size of microplastics at the three sampling locations

Based on the results of the FTIR test, it is known that the identified polymer is polyisoprene at the three sampling points. The presence of an O-H group evidence this identification at the wave's peak around 3200 – 3600 cm^{-1}, a monomer and the main constituent of polyisoprene microplastics (Georges et al., 2019). The O-H cluster is shown at the crest of the wave 3448.72 cm^{-1} in the Bantul Market sample test results, 3425.58 cm^{-1} in the Yogyakarta Tugu Monument sample test results, and 3425.58 cm^{-1} in the Kaliurang km 14 road sample test results (Figure 8). Polyisoprene is one of the main constituents of synthetic polymers of all kinds of vehicle tires composed of hydrocarbon compounds and a constituent of thermoplastic elastomeric materials (Deswita, et al., 2006). Particles in the form of transparent films found quite a lot during the observations were predicted to be polyethylene polymers, as the polymer identified in the research of Xie et al. 2022. Although in the FTIR test, the polymer was not identified, it is possible to find a transparent film derived from the fragmentation of single-use plastics and is a polyethylene polymer.



(a) (b) (c)

Figure 8. FTIR test results on (a) Bantul Market, (b) Tugu Monument, (c) Kaliurang km 14

4. Conclusion

The content of microplastics on highways at different elevations in Yogyakarta Province was not significantly different, with an abundance range ranging from 200 to 484 particles/L. Microplastics were found in all rainwater samples, with the highest average abundance in the rainwater that fell in the Yogyakarta Tugu Monument area, with the dominant characteristic being in the form of fibers, black in color, measuring 101-500 m and identified as being formed from polyisoprene polymers. Abiotic parameters such as light intensity, air temperature, air humidity, wind speed, particles dissolved in water, and vehicle density correlated with the abundance of microplastics in rainwater that fell on highways in DI Province, Yogyakarta.

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