SYSTEMATIC REVIEW

The Method, Occurrence, Health Risk, and Prevention of Airborne Microplastics in Indonesia: A Systematic Review

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ABSTRACT

Introduction: Microplastics originate from production in small forms (micro) and degraded plastic waste. Initially, most research on microplastics focused on their presence in oceans and lakes. Recently, researchers have begun investigating airborne microplastics, as their size, ranging from 500 to 2000 μm, allows them to be carried by the wind. There is a paucity of research on airborne microplastics conducted in Indonesia. This study aims to evaluate the current level of airborne microplastic research in Indonesia. **Materials and methods:** The method involved searching the literature that included the terms "airborne," "atmospheric," or "ambient microplastics" in Indonesia, following PRISMA guidelines. Data sources used the Google Scholar database from 2019 to 2024 and search papers from May 15, 2024, until August 12, 2024. A total of 15 studies were reviewed. **Results:** All studies reviewed confirmed the presence of airborne microplastics, with fibers and fragments being the most common forms, varying in size, and polyethylene terephthalate (PET), polyethylene (PE), and polyester being the most frequently identified polymers. **Conclusion:** The sampling methods used were active and passive; variations in location, time, duration, and equipment can influence the outcomes. Additionally, factors such as weather conditions, research site characteristics, and human activities also have an impact. The health risks associated with the tiny size of microplastics are similar to those of particulate matter, which can easily enter the respiratory system and cause non-communicable diseases. There is a need to establish threshold levels for microplastic concentrations in the air, both indoors and outdoors.
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Keywords: Airborne microplastic, Method, Occurrence, Health risk, Prevention

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INTRODUCTION

The issue of plastic pollution was first raised many years ago, (1) with the initial discovery of plastic fragments of plastic in the stomachs of *albatrosses*, an arge seabird (2). Ingestion of plastics occurs in fish, seabirds, marine animals, and various food chain members (3). These instances involve not only the toxicity of plastics but also physical interference, such as entanglement in nets and lines, choking after consuming plastic debris, or ingesting plastic, which can lead to a false sense of fullness and ultimately starvation (1). The term "microplastics" (4) was first introduced in 2004, referring to granular and fibrous plastic particles with a diameter of 20 μm collected from Currently, microplastics are prevalent in various environments, particularly beaches and the ocean. Microplastics have been recognised as a significant contributor to biodiversity loss and were included in the UNEP Year Book 2014 as one of ten emerging environmental issues (5).Currently, microplastics are prevalent in various environments, particularly in the oceans (4), the deep ocean (6), freshwater lakes (7), rivers (8–10), and terrestrial ecosystems (11,12).

The global expansion in plastic manufacturing over the past few decades has led to a significant increase in the quantity of microplastic pollution in the environment, a trend that is expected to persist (13). Improperly managed plastic waste can ultimately find its way into water bodies. Each year, millions of tons of plastic waste from 192 coastal nations enter the ocean, and this figure is anticipated to rise in tandem with increasing plastic production. (14,15). According to a study conducted across 192 countries, Indonesia ranks second in contributing plastic waste to marine environments (11). Plastic particles can become trapped in or on bubbles formed at the surface due to wave action, and when these bubbles burst upon contact with the air, they release contaminants, including plastic particles, into the atmosphere (16). Once in the atmosphere, plastic particles can be transported by the wind over considerable distances, similar to dust, sand, or sea salt (17). Depending on their density and weight, microplastics can be carried by air or water currents throughout the environment (18).

Airborne microplastics were first identified by Dris in Paris, France, in 2015, confirming the presence of microplastics in freshwater, sewage, and atmospheric fallout in urban environments (19). Subsequent research has been conducted across Europe, including studies in France (Paris (20,21), Pyrenees Mountains (22); UK in London (23), Nottingham (24), Yorkshire (25); Germany in Hamburg (26); Denmark in Aarhus (27); Spain in Barcelona (28); Portugal in Aveiro (29); US in California (30); Australia in Sydney (31), Victoria (32); Asia: China in Dongguan (33), Yantai (34), Shanghai (35–37), Beijing (38), Wenzhou (39); Iran in Tehran (40), Asaluyeh (41), Bushehr port and Shiraz (42); Turkey in Sakarya (43); India in Chennai (44), Nagpur (45); Nepal in Kathmandu (46); Japan in Kusatsu (46); and the Arctic regions of the Swiss Alps and Bremen, Bavaria (47). Research on airborne microplastics in Southeast Asia has also been conducted in several countries, including Vietnam, in Da Nang (46)Ho Chi Minh (48); Malaysia in Klang, Petaling and Gombak (49), Kuala Lumpur (50), Kuala Lumpur (51), Trengganu (52); and Thailand in Bangkok, Pathum Thani, and Samut Prakan (53), Pathum Thani (54), Nakhon Si Thammarat (55), Pathum Thani (56), Bangkok (57).

In addition, several studies have investigated the differences in airborne microplastics between indoor and outdoor environments (21,29,30,39,57), as well as between urban and suburban areas (20,26,32,39,45). Research has also focused on the atmospheric deposition rates of microplastics (19,20,23,31,33–35,52,56), their abundance in the air (19,20,36–42,44–46,21,47,48,51,55,57,22,25,26,28–30,32), and their various shapes (19,20,30–36,38–40,22,41–47,49–51,23,52–55,57,24–29). Additionally, studies have examined the sizes (19,20,39,40,45–47,50,53–56,22,57,23,26,27,30,31,34,38), and colors (34,35,52,55,40,41,43,45,46,49–51) of these polymer particles (20,21,33–36,40,42–46,23,47,53,57,25–28,30–32).

Airborne microplastics can easily disperse and contribute to air pollution, as well as exacerbate global warming and climate change. It is noted that many airborne microplastics may increase the risk of global warming and climate change (58). These microplastics are so minuscule that they can be readily ingested and inhaled by living organisms (33,39). Numerous studies have examined microplastics in water, food, the sea, and lakes. Unfortunately, research on airborne microplastic in Indonesia remains limited, particularly concerning the quantification of airborne microplastics, their sources, and their impact on human health. Furthermore, policies related to microplastics, waste management, and both indoor and outdoor pollution are not sufficiently regulated. As the fourth most populous country, Indonesia ranks as the seventh-largest producer of waste globally. This study aims to evaluate the existing research on airborne microplastics in Indonesia, focusing on methods, prevalence, health risks, and prevention strategies.

MATERIALS AND METHODS

Source

All published, peer-reviewed journal articles focusing on microplastics were systematically searched using Boolean operators following PRISMA guidelines.

Formulation of the Research Question

The research question for this systematic review was formulated using the PICO framework. A modified version of PICO, referred to as Problems, Interest, and Context, was employed. The review of studies must include three primary components: microplastics in the air (problems), their shapes, sizes, colors, and polymers (interest), and the geographical context of Indonesia.

Eligibility Criteria

Papers written in both English and Indonesian were included in the search; however, mini-theses and theses were excluded.

Information Sources

To locate published papers on airborne microplastics in Indonesia, a web search was conducted using Google Scholar, focusing on publications from the past five years (2019–2024). Google Scholar was chosen to broaden the search for relevant papers that align with the research criteria, given the study's exclusive focus on Indonesia.

Search Strategy

The database search was conducted using the following search phrases with Boolean operators: "Airborne AND Microplastic AND in Indonesia," "Atmospheric AND Microplastic AND in Indonesia," "Ambient AND Microplastic AND in Indonesia," and "Mikroplastik di Udara AND Indonesia," yielding approximately 1,940 results, 6,250 results, 2,120 results, and 857 results, respectively.

Selection Process

A preliminary screening based on titles was conducted on all retrieved publications. Duplicate papers were removed, and those that were not freely accessible were excluded from this analysis (N = 27). A total of 22 free full-text papers were downloaded. Further screening led to the exclusion of additional papers, resulting in 15 articles available for review. The data presented are categorized by location of study, sampling methods, identification and quantification of microplastics, occurrence of airborne microplastics—including shapes, sizes, colors, and polymers—atmospheric microplastic deposition rates, total suspended particles (TSP), PM10, PM2.5, and microplastic concentrations; as well as health risks and prevention strategies. Figure 1. illustrates a diagram of the literature selection process.

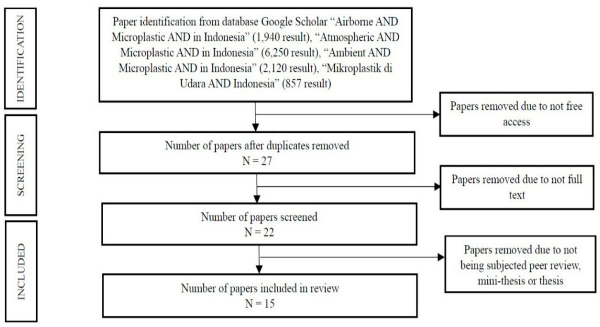


Figure 1: PRISMA Flow Chart

RESULTS

Location Site

Research on airborne microplastics has been conducted in six major cities across Indonesia: 13 sites on Java Island and two on Sumatra Island. The study on Java Island included Jakarta, Bandung, Surabaya, Yogyakarta, Sidoarjo, Mojokerto, and Gresik, while the Sumatra Island locations were Medan and Bandar Lampung. This research took place from 2019 to 2023. The geographical distribution of the study locations across Indonesia is depicted in Figure 2.

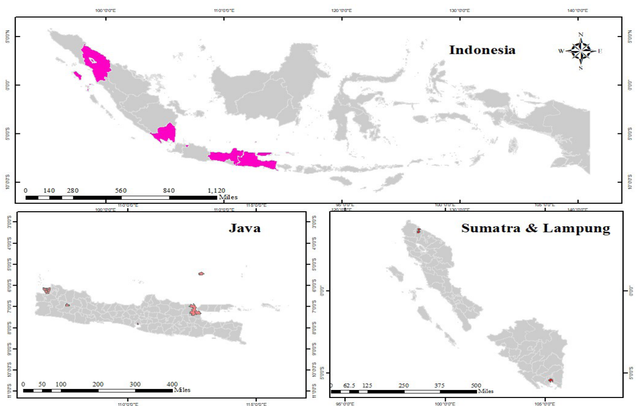


Figure 2: Location Site (Pink province level; Orange city level)

In Jakarta, microplastic sampling was conducted in Ancol, North Jakarta, adjacent to Jakarta Bay. The sampling occurred at a high elevation to capture atmospheric microplastics without interference from trees or buildings (59). In Bandung, in 2019 (60), sampling was first conducted in Sarana Olahraga Ganesha (SARAGA), a green belt area designed to mitigate debris from passing traffic. The monitoring area was chosen due to its bowl-like topography and central location, which restricts horizontal air circulation, leaving vertical convection as the primary mechanism for air movement. That same year (61), a comparison of airborne microplastics was undertaken in two distinct spatial typologies within the Bandung Metropolitan Area: the Lebak Siliwangi area, representing an urban area, and the Cibabat area, representing a suburban area. In the following year (2022-2023), sampling occurred on the roof of an 8- story building at the Institute of Technology Bandung (ITB) and was compared to Osaka in 2021 on the roof of a 3–story building at Osaka Metropolitan University (62). This study was conducted across two cities in two nations: Bandung, Indonesia, and Osaka (Sakai City), Japan. Airborne microplastic research in Yogyakarta (63) and Surabaya (64, 64,65) was carried out along roads with high vehicle congestion due to microplastics produced from rubber tire friction (66). In Yogyakarta, sampling took place at four locations along the intersections of Yogyakarta' s arterial road, known as the ring road (north, south, east, and west). In Surabaya (2019), sampling was performed on three streets: Urip Sumoharjo Street, representing a road with high vehicle congestion; Mayjend Sungkono Street, representing a road with medium congestion; and Embong Malang, representing a road with low congestion. Other studies (67, 67,68) were conducted indoors in three different settings (office, school, and apartment) to analyze the quantity of microplastics and the number of inhabitants in various indoor spaces. In Medan (69), sampling was conducted in six industrial areas to analyze outdoor airborne microplastics. Meanwhile, in Bandar Lampung (70), sampling was carried out near three roads representing different environments: industrial areas, residential zones, busy roads such as provincial roads, and the city center. In Sidoarjo, Gresik, and Mojokerto (71–74), sampling took place at various sites, including a tofu industry, a plastic waste recycling plant, a waste treatment industry incinerator, a temporary landfill, and a Waste to Energy Power Plant.

Sampling

There are two types of sampling methods: active and passive (75). Active sampling methods were employed in Bandung, Yogyakarta, Surabaya, Medan, and Bandar Lampung. All devices used were High Volume Air Samplers (HVAS) with different sampling durations: 24 hours (HVAS SIBATA HV 1000F) (61,63), 8 hours (70), and 3 hours (60). The flow rates varied among studies, including 68.82 m3/h (60), 20 L/min (62), 1.2

m3/second (63), 207.38 mL/min, and 446.93 mL/min (64,65). Vacuum pumps (Vacuubrand pumps) and a vacuum cleaner (Krisbow Turbo Tiger) were used in Surabaya (64,65,67,68). In Bandung, the sampling aimed to measure both microplastics and Total Suspended Particulate (TSP) (60,61). In both Bandung and Osaka, a multi-nozzle cascade impactor sampler (Tokyo Dylec) was used to collect three size fractions of ambient aerosols (PM2.5, PM10, and TSP) on Teflon-coated glass fiber filters (TX40HI20-WW, Pallflex) (62). In Yogyakarta, TSP, PM10, and PM2.5 were measured (63), while in Medan, only PM2.5 was assessed (69).

In Jakarta, for instance, 10 mL of distilled water is added to the rain gauge to collect atmospheric microplastics. This water is tested using the blank method to ensure it is free of microplastics. The rain gauge, with its mouth opening angled at 15° against the wall, operates for ninety-six hours (59). Sampling involves cutting Whatman filter paper to fit petri dishes with diameters of 12 or 15 cm. The coated petri dishes are then placed in various locations according to the cardinal directions. In Sidoarjo, Gresik, and Mojokerto, the passive sampling methods are employed not only to measure microplastics but also PM2.5 levels (71–74).

Identification and Quantification of Microplastics

The identification of microplastics was conducted using various microscopes, including a binocular microscope (69,70), a Leica M205C (59), an Olympus UTV0.5XC-3 (63,64), a DinoLite AM2111 digital microscope (60,61,67,68), a stereo microscope (71,72,74) and a trinocular digital microscope Dw-tc-y Black edition (73). The occurrence of airborne microplastics, including shapes, sizes, colours, polymers, as well as the atmospheric microplastic deposition rate, Total Suspended Particles (TSP), PM10, PM2.5 and microplastic concentration is presented in Table I.

Table I: Occurrence of Airborne Microplastic in Indonesia 2019 – 2024

Study Location	Shape	Size	Colour	Polymer	TSP Concentration	Deposition Rate	Concentration	Year	Reference
Jakarta	foam<fragment<fibres	500–1000 µm < 300–500 µm	N/A	•Polyester, •Polystyrene (PS), •Polybutadiene, and •Polyethylene (PE).	N/A	•3-40 particles/m^2/d, average of 15 ± 13 particles/m^2/d •The highest mean in the rainy season (23.422 ±9.065 particles/m^2/d), and the lowest in the dry season (5.745 ± 1.984 particles/m^2/d).	N/A	2022	(52)
Bandung	Fibres in an urban area is greater than in the suburban area	•Fibres size in urban samples is 1000–1400 µm •Fibres size in suburban area, the range is 600–1000 µm.	•Black, •brown, •red, •green, and •transparent	N/A	•Urban area TSP average: 186.52 ± 45.76 µg/m^3 •Suburban area TSP average: 154.30 ± 74.02 µg/m^3	N/A	•Urban: 0.3–0.6 particles/m^3 •Suburban: 0.1–0.3 particles/m^3	2022	(53)
Bandung	Fibres and fragment	N/A	N/A	N/A	TSP: 78.28 + 2.50 µg/Nm3	N/A	N/A	2019	(54)

CONTINUE

Table I: Occurrence of Airborne Microplastic in Indonesia 2019 – 2024 (CONT.)

Study Location	Shape	Size	Colour	Polymer	TSP Concentration	Deposition Rate	Concentration	Year	Reference
Bandung and Osaka	Bandung and Osaka: Fragment, granule, fibres (<fragment)	•Bandung: 3.14 - 512 µm •Osaka: 3.50 - 728.15 µm	N/A	Bandung: •Ethylene Vinyl Acetate (EVA), •Polybutadiene Rubber (PBR), •Polycaprolactone (PCL), •Polydially Phthalate (PDAP), •Polyethylene (PE), •Polyethylene Terephthalate (PET), and •Polyvinyl Acetate (PVA). Osaka: •Ethylene Vinyl Acetate (EVA), •Polyethylene (PE), •PE/Polypropylene (PP) Copolymer, •Polyethyl Methacrylate (PEMA), •Polyethylene Terephthalate (PET), •Polymethyl Methacrylate (PMMA), •Polypropylene (PP), •Polystyrene (PS), and •Polyvinyl Chloride (PVC).	N/A	N/A	•Bandung:1.03 to 14.27 particles/m^3 •Osaka:0.63 to 3.29 particles/m^3 Average: •Bandung: 6.64 particles/m^3 •Osaka:1.65 particles/m^3	2023	(55)
Yogyakarta	Fibres< film<fragment	N/A	•Black, •Blue, •Brown, •Clear/ Transparent, •Green, •Orange, •Purple, •Red, And •Yellow	N/A	N/A	N/A	Four locations (road) are •0.86 particles/ Nm^3 •0.82 particles/ Nm^3 •0.59 particles/ Nm^3 •0.42 particles/ Nm^3	2024	(56)
Surabaya	Fibres, fragments and film	N/A	N/A	•Polyethylene Terephthalate (PET), •Polyester, and •Cellophane	N/A	N/A	•First location: 174.97 and 130.50 particles/ m^3 •Second location: 131.75 and 68.36 particles/m^3 •Third location: 94.69 and 55.93 particles/m^3	2019	(57,58)

CONTINUE

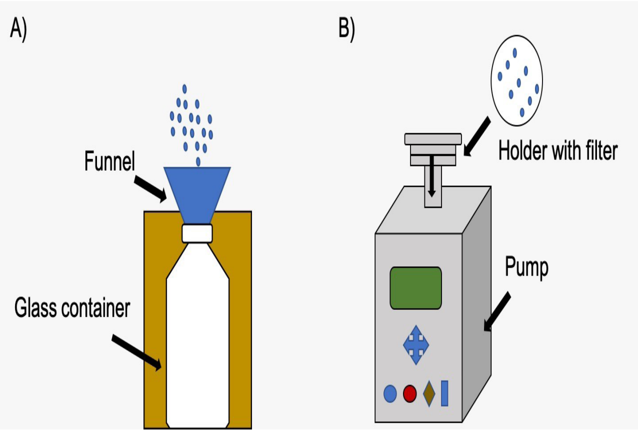
Table I: Occurrence of Airborne Microplastic in Indonesia 2019 – 2024 (CONT.)

Study Location	Shape	Size	Colour	Polymer	TSP Concentration	Deposition Rate	Concentration	Year	Reference
Surabaya	Film<fragment<fibres	3000–3500 μm	N/A	N/A	N/A	N/A	Amount of microplastics Office: 1.334 particles on a weekday 242 particles on a weekend 2.351 particles on a weekday 252 particles on a weekend School 1.290 particles on a weekday and 239 particles on a weekend 2.321 particles on a weekday and 257 particles on a weekend Apartment 1.133 particles on a weekday and 127 particles on a weekend 2.108 particles on a weekday and 95 particles on a weekend	2020	(60)
Surabaya	Office: fibres and fragments School and apartment: fibres	N/A	N/A	•Cellophane, •Clipboard, •Alkyd Resin, •Polyester, •Polyethylene Terephthalate (PET)	N/A	N/A	Office: •709.09 particles/m^3 on Monday and Tuesday, •1186.36 particles/m^3 on Thursday and Friday, •509.09 particles/m^3 on weekend. School: •1004.55 particles/m^3 on Monday and Tuesday, •590.09 particles/m^3 on Thursday and Friday •227.27 particles/m^3 on weekend. Apartment: •595.45 particles/m^3 on Monday and Tuesday, •231.82 particles/m^3 on Thursday and Friday, •236.36 particles/m^3 on weekend	2020	(61)

CONTINUE

Table I: Occurrence of Airborne Microplastic in Indonesia 2019 – 2024 (CONT.)

Study Location	Shape	Size	Colour	Polymer	TSP Concentration	Deposition Rate	Concentration	Year	Reference
Medan	N/A	N/A	N/A	N/A	$PM_{2.5}$ concentrations in Medan range from 25.78 – 60.36 µg/m^3.	N/A	The amount of microplastics at 6 locations: 1.78 2.41 3.41 4.39 5.27 6.97 particles Abundance of microplastics at six locations: 1.1.18 2.0.62 3.0.6 4.0.57 5.0.41 6.1.4 particles/m^3	2024	(62)
Bandar Lampung	Fragment<fibres	•500-1000 µm (42%), •100-500 µm (29%), •1000-1500 µm (15%), •1500-2000 µm (6%), •2000-2500 µm (4%), and •>2500 µm (4%)	•Blue, •Grey, •Black, •Brown, •Red, •Green, •Purple, •Pink, •Light Blue, •Yellow, •Orange, and •Trans parent	Polyethylene Terephthalate (PET)	$PM_{2.5}$: 25.78 – 60.36 µg/m^3	N/A	Abundance of microplastics 0.0021-0.0199 particles/m^3 Average 0.008 ± 0.005 particles/m^3 of air or 49.812 ± 31.435 particles/day.	2024	(63)
Sidoarjo	Fragment<-film<fibres	N/A	N/A	N/A	$PM_{2.5}$: 1. 29 µg/m^3 2.1876 µg/m^3	N/A	Amount of microplastics 1.1243 particles 2. 15 particles	2021	(64)
Sidoarjo, Gresik, Mojokerto	Fragment, fibres, film	N/A	N/A	N/A	$PM_{2.5}$: 1. 44 µg/m^3 2. 821 µg/m^3 3. 36 µg/m^3 4. 50 µg/m^3 5. 58 µg/m^3 6. 40 µg/m^3	N/A	Amount of microplastics at 6 locations: 1. 10 particles 2. 4 particles 3. 3 particles 4. 3 particles 5. 9 particles 6. 4 particles	2021	(65)
Sidoarjo	Fibres<-fragment<-film	N/A	N/A	N/A	$PM_{2.5}$: 1. 96 µg/m^3 2.224 µg/m^3 3.153 4.302	N/A	Amount of microplastics at 4 locations: 911 particles	2023	(66)
Sidoarjo	Fragment<-film<fibres	N/A	N/A	N/A	N/A	N/A	Location 1.3.7 particle/gr 2.7.8 particle/gr 3.8.9 particle/gr 4.17.2 particle/gr	2023	(67)



Figue 3: Illustration Passive (A) and Active (B) Sampling Method

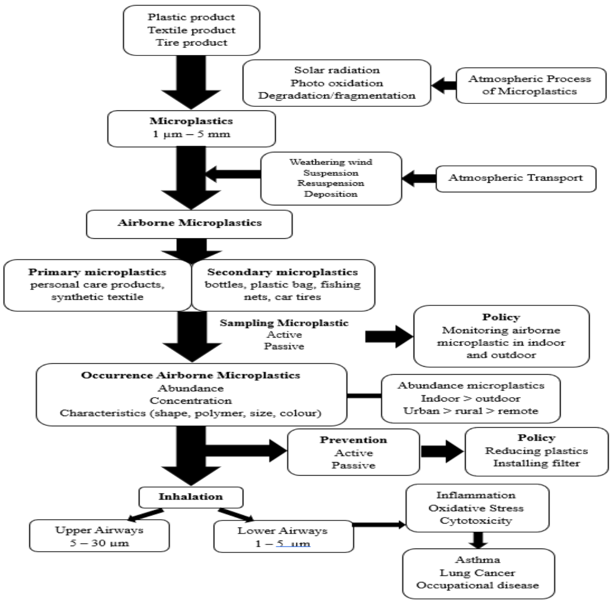


Figure 4: Schematic Representation of Occurence Airborne Microplastic, Prevention, and Health Risk

DISCUSSION

Location Site

All cities mentioned are provincial capitals in Indonesia, except for Sidoarjo, Gresik, and Mojokerto. The largest population in Indonesia is located in West Java, particularly in the cities of Depok, Bogor, and Bandung. Surabaya, in East Java, has the second largest population. Meanwhile, Jakarta, as the country's capital, experiences congestion that is twice as high during the day due to its status as an economic and government center. Medan ranks fourth in terms population size in Indonesia. Additionally, microplastic levels in urban areas are significantly higher than in suburban areas (19,23), attributed to the greater density of buildings and a higher volume of activities involving plastics and textiles (20,76,77).

Sampling

Due to variations in the form and density of particles, different types of microplastics in the air can be identified using various sampling techniques. Furthermore, the concentration levels of microplastics and other empirical variables may be influenced by these different methods. Active sampling techniques necessitate the use of pumping sampler devices, which draw a fixed volume of air over a designated area. As air passes through the sampler, particulate matter is collected on a substrate or filter. Passive sampling methods are considered to be the most effective for atmospheric microplastic deposition due to their simplicity, affordability, ease of use, and reliance oncommon laboratory equipment. Additionally, since passive sampling techniques do not require electricity or other power sources, they can be employed for extended outdoor sampling that lasts for weeks or even months (75).

Identification and Quantification of Microplastics

Microscopes enabled for the identification of microplastic shapes (fiber, foam, granule, and fragment), sizes of microplastics (<300 µm, 300–500 µm, 500–1000 µm, and >1000 µm), and colors (transparent, crystalline, white, clear-white-cream, red, orange, blue, opaque, black, gray, brown, green, pink, tan, yellow, and pigmented) (33,78).

Microplastics primarily exist in three forms: pellets, fragments, and other generic types. Pellets typically exhibit shapes such as cylinders, disks, flats, ovoids, and spheres. In contrast, fragments are most commonly found in angular, subrounded, rounded, and subangular shapes. Generally, microplastics are characterized by their elongated, uneven, and rough surfaces, often featuring broken edges (33). The diameter of microplastics could be accurately measured using Image-J software (60–62,70,79). One effective method for assessing minute variations in microplastic size while minimizing background noise is through image analysis (80,81).

For Fourier Transform Infrared (FTIR) analysis, particles that were extracted from the filter were selected at random (82,83). FTIR analysis with the Nicolet iS10 from Thermo Fisher Scientifics. FTIR analysis was conducted using the Nicolet iS10 from Thermo Fisher Scientific. By analyzing the spectrum of the functional groups generated, this process determined the composition of each sample. The generated spectra were compared with those found in the Thermo Fisher Scientifics Nicolet databases (64,68). The concentration and properties of microplastics, including their shape, physical diameter, and polymer type, were examined using Micro-Fourier Transform Infrared (µ-FTIR) spectroscopy (Spotlight 400/Spectrum 3 PerkinElmer). The detector operated within a wave number range of 4,000–695 cm-1. Initially, the infrared peak bands of C-H stretching (3,000–2,700 cm–1) and C=O stretching (1,740–1,710 cm–1) were identified to screen for microplastic candidates (84). Raman Spectroscopy was employed to characterize the polymer (70).

Occurrence of Airborne Microplastics

Shapes

The findings indicate that the most common shapes of microplastics are fibers and fragments. Fibers are particularly prevalent due to their high production and waste rates, with an annual production rate of 6.6% (85). Furthermore, they are typically generated from activities such as the garment industry, washing, laundry, and clothing (20,76,77,86), and are often associated with dust from PET, a primary polymer used in textile production (19,87,88). Fibrous microplastics are classified as secondary microplastics; they rarely disintegrate in the environment. The primary concern regarding fibrous microplastics is their potential to disperse over vast distances (41).

Both indoor and outdoor environments predominantly contain fibers, which are released from textiles, carpets, laundry, synthetic clothing during washing, and automobile abrasion (primarily from tire treads) (87,88). Sixty-seven percent of indoor fibers are composed of natural materials (21). The concentration of fibers indoors is higher than that outdoors, as people spend over 70% of their time inside, where conditions are influenced by airflows, ventilation, and room layout. Consequently, elevated concentrations of indoor microplastics are often a result of inadequate air renewal rates (89). Furthermore, outdoor fiber concentrations are significantly lower than indoor levels, likely due to the migration of outdoor microplastics into the buildings caused by wind and air movement (29). During the rainy season, fiber concentrations are higher than in the dry season, probably because rainfall enhances the deposition of atmospheric microplastics (20,21). Varirous factors, including the materials used in clothing, bedding, carpets, and furniture, the methods and frequency of cleaning, and the turbulence and filtration of airflow caused by human activity and ventilation systems, are proposed account for the geographic variance of indoor airborne microplastics (21,37,90). Although fiber particles found in surface dust and airborne particles belong to the same category, fibers in surface dust are generally larger than those in the air. This observation suggests that fibers larger than 20 µm are less likely to remain airborne for extended periods, indicating that this size range is particularly significant (38).

Fibers are predominantly found in various locations around the world, including in Europe: France, the UK (London, Yorkshire, Nottingham), Portugal (Aveiro), Spain (Barcelona), Turkey (Sakarya); the US (California – indoor building); Australia: Sydney, Victoria; and Asia: China (Dongguan, Yantai, Shanghai, Beijing), Japan (Kusatsu), Vietnam (Ho Chi Minh, Da Nang), Nepal (Kathmandu), India (Nagpur), Iran (Bushehr and Shiraz); as well as the Arctic regions, including the Swiss Alps and Bremen, Bavaria (19,20,37,38,42,43,45–48,21,23–25,32–34,36). Fragments are primarily found in Europe: France, Germany (Hamburg), the US: California – outdoor building), and Asia: Iran (Tehran), China (Shanghai, Wenzhou), and India (Chennai) (22,26,30,35,39,40,44). The most prevalent forms of non-fibrous microplastics are fragments and films. Potential sources of fragments include thicker plastic products that can be recycled and disposable plastic bags (33). These items can develop from the physical abrasion and mechanical crushing of larger polymers over time, particularly those commonly found in construction materials and billboards (42). Since plastics constitute the majority of the materials discussed above, frequent exposure to heat and sunlight causes them to deteriorate (91). The breakdown of polyethylene and polypropylene bags and wrappings is typically the primary source of microplastic films (92). Expanded polystyrene (PS) products have the potential to emit foam microplastics (33).

Sizes

In most studies, the size of microplastics in Indonesia ranges from 300 – 1000 µm. Fiber sizes reported in other studies range from 200 – 400 µm, 400 – 600 µm, and up to 750 µm, with these sizes being predominant; fibers in larger size ranges are considered rare. Some microplastics are smaller than 20 µm, with additional size categories including 20 to 25 µm and 50 to 200 µm (20,22,23,28,31,38,47). Fragments sizes are reported as less than 63 µm, 63 to 300 µm, and more than 300 µm, µm, variation variations 10 – to 1,000 µm (22, 28). smaller than 100 µm dominated airborne microplastics (39). The prevalence of smaller airborne microplastics suggests that size plays a crucial role in controlling the mobilization and transportation of these particles in the atmosphere. Generally, particles remain suspended in the air longer if it is smaller (93). Smaller size fractions of microplastics dominate the airborne microplastics samples; larger microplastics tend to settle rapidly due to gravity, whereas smaller microplastics remain in the atmosphere for longer. On air sample filters, larger plastic fibers are more noticeable than tiny pieces, fragments, which might be why fibers have frequently drawn greater attention (39).

As size increases, the relative quantity of fibers decreases. The majority of research on indoor airborne microplastics supports this trend (21,27,39). Hartmann et al. (94) reported that the dominant size range varies across studies, indicating that multiple factors impact the size distribution. Among these variables are the sampling location, sampling technique, identification method, and visual detection threshold. The primary determinant of plastic particles' destiny in the environment and their ability to penetrate biological organisms is their size (93).

Colors

It has been reported that airborne microplastics are found in a wide range of colors. Transparent, white, and black are the most common colours among them (95). The varying sizes and colors of microplastics originate from a diverse array of industrial, automotive, and household sources (41). One possible explanation for the prevalence of lighter-colored microplastics is the widespread use of various disposable plastics, such as plastic bags, in both residential and commercial settings (42).

Polymer

The most commonly found polymers were PET, PE, PS, and polyester. PET was the predominant polymer in most of the fibers, polyethylene was primarily found in fragments, and polystyrene was mainly used in foams (34). PET is a plastic polymer extensively used to producetextiles, fabrics, and synthetic fibers (22,34). PE, PS, polyester fibers were more prevalent in residences where carpet served as the primary flooring material (31). Polystyrene is frequently used in the fast-food industry as a packaging material and for thermal insulation (96). Polyethylene is the most widely produced type of plastic and is also extensively used as a packaging material (97).

The Atmospheric Microplastic Deposition Rate and Microplastic Concentration

These results showed that the atmospheric microplastic deposition rate and microplastic concentration differed across several locations. Variations in the quantity of airborne microplastics between urban and rural areas were also linked to changes in population and land-use variables (21). The transport and dispersion of airborne microplastics can also be influenced by various meteorological factors, such as temperature, precipitation, wind speed, wind direction, and the vertical gradient in pollutant concentration, which can affect how microplastics behave and move through the atmosphere and surroundings (98).

The "urban heat island effect" significantly influences the distribution of air pollutants in urban areas. (93), which may also affect the dispersion of airborne microplastics. Compared to rural residents, urban inhabitants face a higher risk of inhaling microplastics due to the elevated concentration of these particles in metropolitan environments. Additionally, the amount of accumulated rainfall may be a crucial climatic factor to consider for future monitoring, as indicated by the temporal dynamics of microplastic abundances (32).

In indoor areas, microplastics can be released by various sources, including carpets, toys, clothes, cleaning methods, and furniture made of synthetic materials (39,90). Indoor microplastics may accumulate as a result of air conditioning systems (39). The placement of buildings, human activity, and population density similarly affect the concentration and size of microplastics. Conversely, outdoors, the concentration of microplastics is impacted by heavy traffic volume and the presence of industrial and workshop units (99). Because arid-windy conditions favor the atmospheric transport of particles, climate and wind patterns are expected to influence the concentrations of microplastics in the air. Greater air microplastic deposition would occur in regions downwind of a recognized source area (such as big cities) than in areas upwind (39).

Consequently, microplastics are likely being released into the environment via several sources, such as exposed plastic that degrades in open landfills, or plastic debris that wears down during garbage transfer and processing processes (23). These studies carried out at waste recycling plants, waste treatment industry incinerators, temporary landfills, and Waste to Energy Power Plants had caused air pollution, which is called a false solution to plastic management (71–74).

This finding is similar across various countries, as all citizens use plastic intentionally in a variety of activities. Moreover, microplastics likely travel through the air due to wind deflation. Compared to a remote, pristine environment, the predicted mobility in the prior research was lower (22), indicating that microplastics may have traveled up to 95 km. However, the differing settings probably experience distinct climatic conditions due to varying assumptions (size/aerodynamic equivalent diameter and density) made about the particles. Additionally, considering the small sample size, the results of the current and earlier studies should be evaluated cautiously, and further research is suggested to strengthen this body of data. Airborne microplastics should be considered alongside particulate matter (as coarse, fine, or ultra-fine particles), which are regarded as significant air pollutants, in addition to SOx, NOx, and COx emissions. These have been closely monitored for some time and should therefore be carefully examined for their effects on human health. As a result, although it is difficult to pinpoint exactly how much microplastics a location should have, it is conceivable to state that the atmosphere does contain some of them, albeit at varying levels. (43).

Health Risk

Microplastic exposure can increase the risk of non-communicable diseases such as asthma and cancer. In Indonesia, the prevalence of asthma and cancer in 2023 was 1.8% and 1.2%, respectively (100). In recent years, human exposure to microplastics has grown into a serious problem. Chronic exposure to airborne particulates through skin contact, inhalation, and ingestion negatively affects one's health (89). The most significant ways that microplastics are encountered are through ingestion and inhalation (31,101). Fibres are more prevalent (90%) and smaller (5–250 μm) (21,25) and are found in a wide variety of manufactured and natural materials used in daily living, such as furniture and textiles. The sorts of fibres that are most likely to infiltrate the human body can disrupt its physiological processes (21,25). They can enter the human lungs by inhalation (102), are durable (103), and 20 μm in length cannot be cleansed by the human lungs (104). Although the discovered fibres are allegedly too large to be breathed, exposure can nonetheless occur through ingestion, especially for young infants. When inhaled, microplastics build up in the human lungs and directly contact respiratory organs, potentially causing long-term discomfort.

A recent study has identified disorders associated with plastics and their derivatives (86). Particles lodged in the nasal and pulmonary mucus can be expelled through sneezing, coughing, blowing the nose, and spitting out or swallowing the mucus. One of the most significant aspects of atmospheric microplastics is their potential for inhalation and subsequent passage through the alveoli of the lungs (breathable particles). The inhalability of particles is influenced by their size and shape; it appears that only fibrous particles and those smaller than 5 μm can become lodged in the deep lung (85). While mucociliary clearance in the upper airways effectively removes larger inhalable particles, some particles manage to evade this process and reach the deep lung. Particularly with longer fibers, these particles tend to evade clearance (105) and demonstrate remarkable resilience in physiological fluids, likely continuing to accumulate with ongoing inhalation (103).

There is a significant chance that occupational workers who handle para-aromatic amides, polyesters, or nylon fibers may experience coughing, dyspnea, and a reduction in lung capacity. (86) Several employees at plastic processing plants have suffered from respiratory and health issues (such as wheezing, coughing, dyspnea, and occupational asthma), potentially caused by long-term exposure to microplastics. (105) These health considerations suggest that regularly consuming organic fibers can lead to inflammation by triggering localized biological responses. (85,106) Greim et al. (107) proposed that the interaction of cells with vitreous fibers or particles could serve as an approximate measure of toxicity. They discovered that this interaction can release cytotoxic substances and intracellular messengers, which may promote lung inflammation. The ongoing production of reactive oxygen species can subsequently result in secondary genotoxicity (85,107), which can cause oxidative DNA damage (102,108) and is also a factor inducing cancer (105). Previous studies identified the presence of synthetic fibers, including cellulosic, cotton, nylon, polyamide, and plastic fibers (like polyester) in human lungs (102,103). Notably, 97% of malignant lung specimens contained fibers (21), all polymeric particles in the microplastics found in human lung tissues taken during autopsies were less than 5.5 μm, and the fibers varied in size from 8.12 to 16.8 μm. Polyethylene and polypropylene were the most frequently identified polymers. (109)

Prevention

Indirect and direct methods are employed to reduce the presence of microplastics in the environment. Examples of indirect solutions include installing appropriate filters in both new and existing ventilation or air conditioning systems, as well as utilizing air purifiers in private homes that lack air conditioning or are used infrequently. (110). The direct method involves reducing the sources of microplastics. (111). Public education and awareness regarding microplastics are essential, as is collaboration in minimizing or eliminating plastic usage.

Moreover, to strengthen efforts in reducing the sources of microplastics, the government needs to establish policies on airborne microplastics. The framework involves implementing proper waste management, the 3R principles (reuse, reduce, and recycle), regulating quality standards both indoors and outdoors, and monitoring airborne microplastics alongside particulate matter from indoor and outdoor areas. Indoor area monitoring is more focused on high-activity times and occupants on weekdays than on weekends, while outdoor area monitoring primarily targets the streets. Industries can recycle plastics to minimize the generation of existing plastic waste. These strategies will succeed through collaboration between the government, industry players, and the community.

CONCLUSION

It described the presence of airborne microplastics in our environment and daily lives, with common shapes being fibers and fragments of varying sizes. The predominant polymers identified were PET, PE, and polyester. The duration of data collection (measurement), measurement device, meteorological conditions, location (indoor or outdoor, suburban or urban), human activity, and surrounding goods impacted these research findings. Most research was conducted on Java Island. Several cities and districts, such as Surabaya, Bali, and Banjarmasin, have implemented bans on plastic bags in groceries. This policy could minimize plastic use. Moreover, it is important to formulate these policies nationally to address airborne microplastics, to set thresholds for the concentrations of microplastics both indoors and outdoors, and to monitor their presence. It requires commitment from the government, industry, and the community. The health effects of non-communicable disease relate to the size, shape, and polymer of microplastics, but exact exposures could not be determined. Further research on the link between airborne microplastics and health effects on at-risk populations should be conducted.

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