

Health Implications of Microplastic Exposure in Pregnancy and Early Childhood: A Systematic Review

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Abstract: Microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as a significant environmental pollutant, raising concerns about their potential health risks. Emerging evidence shows that MPs can reach human tissues, including the placenta, causing oxidative stress, inflammation, and endocrine disruption. These issues are particularly concerning for vulnerable populations like pregnant women and infants, where exposure could negatively impact fetal development and health outcomes. This systematic review, adhering to PRISMA guidelines, aimed to identify and evaluate studies on the impact of microplastic exposure on pregnancy outcomes and early childhood development. A comprehensive search of databases, including Scopus, Web of Science, Medline, and others, along with grey literature and citation searches, was conducted. The review focused on peer-reviewed articles published within the last decade involving human subjects such as newborns, infants, and pregnant women. The systematic search initially identified 328 studies, of which 200 were screened after removing 128 duplicates. From these, 64 full-text articles were assessed for eligibility, and ultimately, 13 studies were included in the final review. Among these, six studies had a low risk of bias, five a moderate risk, and two a high risk of bias. The sample sizes across the studies ranged from 2 to 43 participants, and the most frequently analysed biological material was the placenta (10 out of 13 studies). Microplastics such as polyethylene (PE) and polypropylene (PP) were most detected, appearing in 11 and 10 studies, respectively. Significant associations were observed between microplastic exposure and adverse health outcomes, including reduced birth weight, shortened gestational age, and altered microbiota composition. Methodological variability and potential biases were identified as limitations. Given the increasing global prevalence of microplastic pollution, understanding its health impacts on vulnerable populations such as pregnant women and infants is critical, providing the first comprehensive synthesis of evidence in this area.

Keywords: microplastic, placenta, microbiota, fetal development, toxicity

Introduction

Plastics have become ubiquitous in modern society due to their versatility, durability, and low cost. However, their extensive use has led to significant environmental pollution, with microplastics (MPs) emerging as a critical concern. MPs are defined as plastic particles smaller than 5 mm, which result from the degradation of larger plastic debris or are manufactured for specific industrial applications.¹ These MPs can enter the human body through ingestion, inhalation, and dermal exposure. A landmark study found MPs in human stools, indicating widespread human exposure.² Their persistence in the environment and potential to enter the human food chain have raised concerns about their impact on human health, particularly vulnerable populations such as pregnant women, newborns, and infants.

Plastic pollution has become a pervasive global environmental issue, affecting terrestrial, freshwater, and marine ecosystems across all continents. MPs, mainly less than 5 mm in size, have been detected in air, soil, drinking water, food chains, and even human tissues, raising concerns about ecological and public health impacts. The ubiquity and persistence of plastic waste underscore the urgent need for coordinated global efforts in waste management, the development of sustainable alternatives, and policy interventions to mitigate its growing threat. Understanding the health



impacts of MPs is particularly important given the rising levels of plastic pollution globally. The production of plastics has increased exponentially, with estimates suggesting that by 2050, plastic production could reach 1,100 million tonnes annually.³ Consequently, the potential for human exposure to MPs is likely to increase, underscoring the need for urgent research into their health effects.

Previous studies have shown that MPs can translocate from the environment into human tissues, including the placenta, raising the possibility of fetal exposure during pregnancy.⁴ The presence of MPs in human breast milk further suggests that infants may be exposed postnatally.⁵ Emerging evidence suggests that MPs may exert toxic effects through various mechanisms, including oxidative stress, inflammation, and endocrine disruption. For instance, oxidative stress induced by MPs has been shown to cause cellular damage and apoptosis, which can affect fetal development and organogenesis.⁶ Inflammation, another consequence of microplastic exposure, can lead to adverse pregnancy outcomes such as preterm birth and intrauterine growth restriction (IUGR).⁷ Furthermore, MPs have been implicated in endocrine disruption, which can interfere with hormone signalling and impact growth, development, and metabolism.⁸

Furthermore, infants and pregnant women are particularly vulnerable to environmental toxins due to their unique physiological conditions. During pregnancy, the placenta acts as a critical interface between the mother and the fetus, facilitating nutrient and waste exchange. The presence of MPs in the placenta could potentially disrupt this process, leading to adverse fetal outcomes.⁹ Similarly, infants, due to their rapid growth and development, may be more susceptible to the toxic effects of MPs compared to adults.

The increasing prevalence of MPs in the environment and their potential health risks necessitate a comprehensive evaluation of their impact on early childhood development and pregnancy outcomes. This review aims to address this need by systematically analyzing the available evidence, identifying gaps in knowledge, and providing recommendations for future research and public health policies. Understanding the health implications of MPs is crucial for protecting vulnerable populations and mitigating the potential long-term consequences of plastic pollution.

Previous reviews have primarily focused on the environmental prevalence of MPs and their ecological impacts, as well as their general effects on human health, such as inflammation and oxidative stress.^{5,10,11} While some studies have explored the health effects of MPs, there is a lack of comprehensive reviews specifically addressing their impact on pregnancy outcomes and early childhood development. This significant gap in the literature underscores the importance of conducting a focused review to synthesize existing evidence and provide a clearer understanding of the risks posed by MPs to these vulnerable populations. This review aims to address this gap and offer valuable insights into the specific health implications of microplastic exposure for pregnant women and young children, including its impact on developmental milestones, health markers, adverse pregnancy outcomes, and fetal development.

Methods

Research Question

What is the impact of microplastic exposure on pregnancy outcomes and early childhood development, specifically focusing on developmental milestones, health markers, adverse pregnancy outcomes, and fetal development issues?

Study Design

A systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent and comprehensive approach. This review aims to consolidate existing evidence on the impact of MPs exposure on early childhood development and pregnancy outcomes.

Eligibility Criteria

Inclusion criteria mainly focussed on peer-reviewed journal articles, including observational studies, randomized controlled trials (RCTs), and cohort studies. Studies involving human subjects, specifically newborns, infants, and pregnant women, were included. Research assessing the impact of MPs exposure, including ingestion through breastmilk and formula or general exposure to MPs via ingestion, were also considered. Studies that report on at least one of the following outcomes got major consideration: developmental milestones, health markers, adverse

pregnancy outcomes, fetal development issues, preterm birth, IUGR, birth weight, placental health, cognitive development, motor skills, oxidative stress, inflammation, or endocrine disruption. Only studies published in English and within the last ten years were included to ensure relevance to current environmental conditions and research standards.

Exclusion criteria were non-peer-reviewed articles, editorials, commentaries, and reviews. Studies involving only animal subjects or in vitro experiments were also excluded. Research not focusing on MPs exposure also excluded. Articles not available in English and studies published more than ten years ago were also excluded.

Search Strategy

The primary databases searches included Scopus, Web of Science, Google Scholar, Medline, Global Health (GH), CINAHL, Embase, and PubMed. Additional sources include reference lists of relevant articles, grey literature, and conference proceedings to capture unpublished or hard-to-find studies. The search queries were: “MPs”, “plastic particles”, “newborn”, “infant”, “pregnant woman”, “pregnancy”, “breast milk”, “infant formula”, “ingestion”, “exposure”, “developmental milestone”, “health marker”, “adverse pregnancy outcome”, “preterm birth”, “IUGR”, “fetal development”, “birth weight”, “placental health”, “cognitive development”, “motor skill”, “oxidative stress”, “inflammation”, and “endocrine disruption”. Boolean operators were used to combine these search terms appropriately, ensuring a comprehensive and targeted search.

Study Selection

The study selection followed a two-step process. First, titles and abstracts of identified studies were screened for relevance. Second, full-text articles of potentially eligible studies were reviewed in detail. Covidence, an online systematic review management tool, was utilized to streamline the review process and manage the workflow.

Data Extraction

A standardized data extraction form was developed to ensure consistency and comprehensiveness in data collection. Key information extracted include study characteristics (author(s), year of publication, country, study design), population details (sample size, age, and demographic characteristics), exposure details (type and source of MPs, methods of exposure assessment), outcomes measured (developmental milestones, health markers, pregnancy outcomes), results (main findings related to MPs exposure and specified outcomes), and risk of bias.

Quality Assessment

The quality of all selected studies was evaluated using the Joanna Briggs Institute’s (JBI) Critical Appraisal Checklists for Studies. The JBI checklist consists of 8 items, each rated with a score of yes (1), no (0), or unclear/not applicable (0). The total score for each study was converted into a percentage, and studies were categorized based on their risk of bias: high risk (20–50% of items scored yes), moderate risk (50–80% of items scored yes), and low risk (80–100% of items scored yes). Any disagreements between the two independent reviewers were resolved through discussion and consensus.¹²

Of importance, the methodological quality of all included studies was assessed independently by two reviewers using the Joanna Briggs Institute (JBI) critical appraisal checklists appropriate to each study design. Any disagreements between reviewers were first discussed to reach a consensus. If consensus could not be achieved, a third reviewer was consulted to provide an independent assessment and resolve the conflict. This process ensured consistency, transparency, and rigor in evaluating the quality of evidence included in the review.

Data Synthesis

A qualitative synthesis was conducted for all included studies to summarize the findings. This synthesis was structured around the key outcomes of interest, including developmental milestones, health markers, adverse pregnancy outcomes, and fetal development issues.

Results

Search Results

The systematic review process, as depicted in the PRISMA flow diagram in Figure 1, involved a thorough and comprehensive selection of studies to assess the impact of microplastic exposure on pregnancy outcomes and early childhood development. The initial search identified a total of 307 studies from various databases, including Google Scholar, Scopus, CINAHL, Embase, MEDLINE, Web of Science, PubMed, and GH. An additional 21 studies were identified through citation searching and grey literature. After removing 128 duplicates, 200 studies were screened for relevance.

Following the initial screening, 21 studies were excluded, and 179 full-text articles were sought for further evaluation. Of these, 115 studies could not be retrieved. Subsequently, 64 studies were assessed for eligibility, with 51 studies being excluded for not meeting the inclusion criteria due to irrelevant population, exposure, outcome, or study design. Specifically, most excluded studies are usually conducted on non-humans, ie, rats and dolphins. Ultimately, 13 studies were included in the final review.^{3,4,9,12,13}

Risk of Bias

The risk of bias across the studies varies, with five studies classified as having a moderate risk of bias, three studies identified with a high risk of bias, and six studies marked with a low risk of bias. The main sources of bias stem from the lack of information about the inclusion and exclusion criteria of the sample, insufficient description of study subjects and settings, inadequate identification and strategies to deal with confounding factors, and issues with appropriate statistical analysis in a few studies.

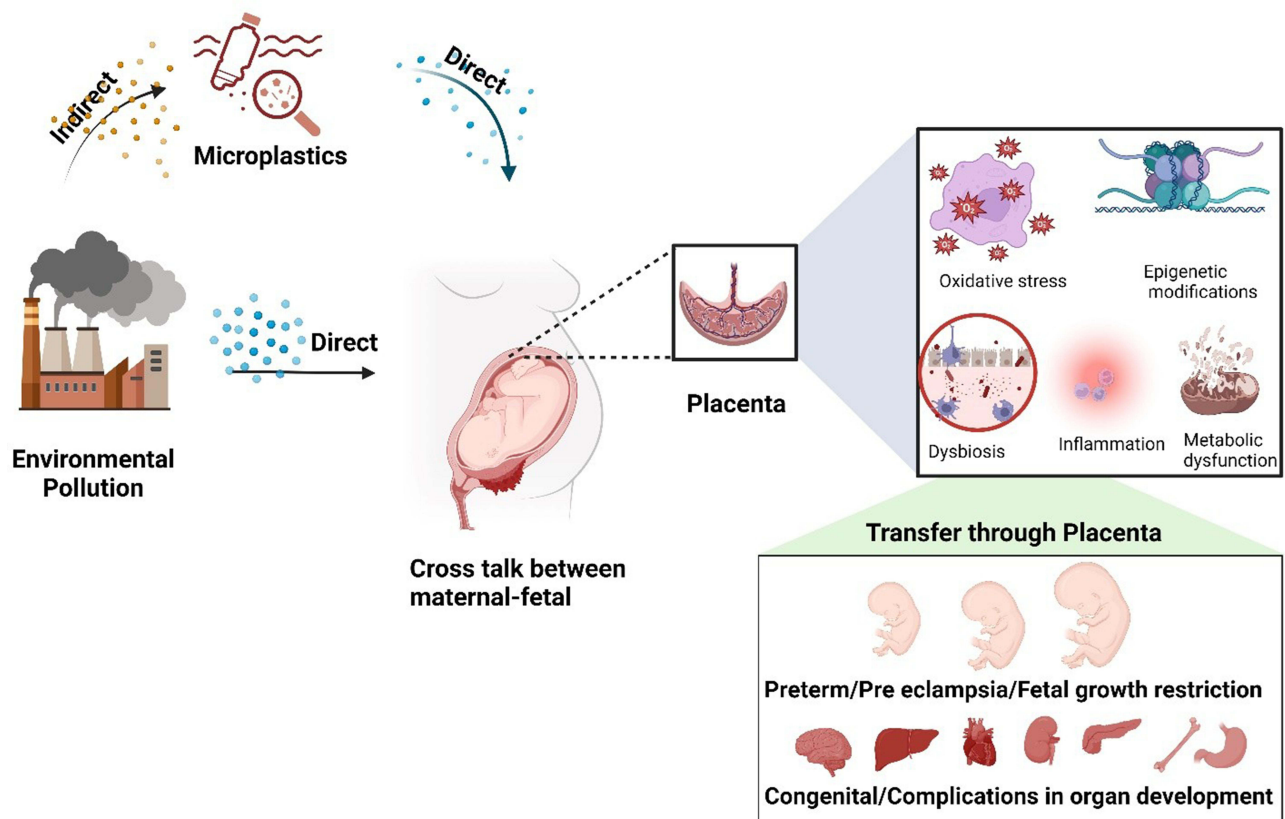


Figure 1 Summary of the impact of microplastic exposure and environmental toxicants on the maternal placenta and their subsequent effects on fetal growth. The figure illustrates how these toxicants induce oxidative stress, trigger epigenetic modifications, cause dysbiosis, and provoke inflammation and metabolic disruptions in the placenta. These pathological changes are associated with adverse pregnancy outcomes, including fetal growth restriction, preeclampsia, preterm birth, and complications in fetal organ development. The figure highlights the complex interplay between environmental toxicants and placental function, emphasizing the potential risks for congenital abnormalities and long-term health issues in the fetus.

Study Characteristics

This review encompassed studies from a diverse array of countries, as seen in Table 1, underscoring the global interest in understanding the effects of microplastic exposure on pregnancy and infant development. The countries represented in this review include China (three studies), Italy (two studies), Germany, the United States, Iran, the Czech Republic,

Table 1 Summarised Table Showing Previously Conducted Study on the Role of Environmental or Microplastic Toxicity Effect on Maternal-Fetal Growth

Author, Year	Country	Sample Size	Sample Type	Method of Analysis	Particle Size	Types of MPs Identified	Risk of Bias
(Braun et al, 2021) ¹⁴	Germany	2	Placenta, maternal stool, and meconium	Fourier-transform infrared (FTIR) microspectroscopy	> 50 μm	PE, PP, PU, PS	Moderate
(Ragusa et al, 2021) ³	Italy	6	Placenta	Raman XploRA Nano Microspectrometer	5 - 10 μm	PP	High
(Zhang et al, 2021) ¹⁵	US	6 infants, 3 newborns	Meconium and infant stool	Chemical quantification	>150 μm	PET, PC	Low
(Amereh et al, 2022) ¹⁶	Iran	43	Placenta	Digital Microscopy 220X and Raman microspectroscopy	Normal: 7.3–27.6 μm UGR: 2.9–34.5 μm	PE, PS, PET, PP	Low
(Ragusa et al, 2022) ⁹	Italy	10	Placenta	Variable pressure scanning electron microscope with dual energy dispersive X-ray spectroscopy detectors	4.8–3.7 μm	Not specified	Moderate
(Halfar et al, 2023) ¹⁷	Czech Republic	10	Placenta and amniotic fluid during pregnancy and delivery	Fourier transform infrared spectroscopy on a Nicolet iN10 device with integrated microscope using the attenuated total reflectance (ATR) method	Width: 6.8 μm - 260 μm Height: 7.4 μm - 245.2 μm	CPE, PE, PE-HD	High
(Liu et al, 2023) ⁴	China	18	Placenta and meconium	Agilent 8700 LDIR Chemical Imaging System	20–500 μm	PA, PU, PE, PET, PP, PVC, POM, EVA, PTFE, CPE, Polybutadiene, PC, PS, PMMA, PLA, Polysulfones	Moderate
(Liu et al, 2023) ¹⁸	China	18	Placenta, meconium, infant feces, breast milk, and infant formula sample (at 6 months of age)	Agilent 8700 LDIR	20–50 μm	PP, PE, PS, PET, PVC, PU	Low
(Weingrill et al, 2023) ¹⁹	Hawaii	30	Placenta	Raman Spectroscopy	1-44 μm	PP, PES, PU, PVC, PVA, PET, PE, PA, PAN	Low
(Zhu et al, 2023) ²⁰	China	17	Placenta	LD-IR chemical imaging system	20->200 μm	PVC, PP, PBS, PET, PC, PS, PA, polyester fiber, PE, PAM, PSF	High

(Continued)

Table 1 (Continued).

Author, Year	Country	Sample Size	Sample Type	Method of Analysis	Particle Size	Types of MPs Identified	Risk of Bias
(Hasanah et al, 2024) ¹³	Indonesia	30	Maternal stools	Fourier Transform Infrared (FTIR) microspectroscopy	200-4900 μm	PET, HDPE, Polyamide, Polyethylene chlorinated, Ethylene propylene	Moderate
(Xue et al, 2024) ²¹	Shanghai	40	Amniotic fluid	LD-IR imaging spectrometer	20.34–467.85 μm	PE, CPE, PA, PU, PP, EVA, SBS, PET, PVC	Low
(Zurub et al, 2024) ²²	Canada	10	Placenta	Raman microspectroscopy	2-60 μm	PE, PP, PS, PVC, PMMA	Low

Indonesia, and Canada. The sample sizes of these studies ranged from 2 to 43 participants. The types of samples analysed were notably diverse, with the majority of studies (10 out of 13) focusing on the placenta. Other sample types included maternal stool, meconium, infant stool, amniotic fluid, infant feces, breast milk, and infant formula. The analysis methods used in the studies varied, with several techniques employed across the different studies. The most commonly used methods were Fourier Transform Infrared Spectroscopy (FTIR), the Agilent 8700 laser infrared imaging spectrometer (LDIR), and the Raman Microspectrometer.

There were also a wide range of microplastic particle sizes in these studies, categorized into small (<10 μm), medium (10–100 μm), and large (>100 μm) particles. Small particles were analyzed in four studies, medium particles in five studies, and large particles in eight studies (up to 4900 μm). Polyethylene (PE) was the most common microplastic being studied, appearing in 11 studies. Polypropylene (PP) is the second most frequent (10 studies), followed by polyurethane (PU) and polystyrene (PS), each present in 6 studies. Polyethylene terephthalate (PET) is included in 8 studies, while polyvinyl chloride (PVC) appears in 7 studies. Other MPs such as polycarbonate (PC), chlorinated polyethylene (CPE), polyamide (PA), and several others are less frequently reported.

Braun et al conducted a pilot study to establish a protocol for detecting MPs in the human placenta, maternal stool, and fetal meconium during real-life clinical settings.¹⁴ This study focused on term pregnancies that ended in caesarean delivery due to breech presentations. MPs were found in two out of three placental samples, 1 out of 2 meconium samples, and all three stool samples, with approximately two polyethylene (PE) and one polystyrene (PS) particles per 20 g of maternal stool. The study noted the limitation of a very small sample size (only two participants).

Ragusa et al performed a pilot observational descriptive preclinical study to detect MP fragments in human placenta samples from six consenting patients with uneventful pregnancies.³ Participants were selected based on strict exclusion criteria to avoid confounding factors like gastrointestinal diseases, severe pathologies, substance abuse, specific diets, and certain medications. MPs were found in 4 out of 6 placental samples, total in twelve fragments: five in the fetal side portions, four in the maternal side portions, and 3 in the chorioamniotic membranes. The study highlighted the variability in MP detection due to physiological conditions, genetic characteristics, diverse food habits, and lifestyle factors among patients.

In their study, Zhang et al, quantitatively determined the concentrations of PET and PCMPs in three meconium and six infant stool samples.¹⁵ They found PET MPs in the ranges of 5700–82,000 ng/g (median: 36,000 ng/g dry weight) and PC MPs in the ranges of 49–2100 ng/g (median: 78 ng/g dry weight) in infant feces. Among meconium samples, PET MPs were detected at concentrations of 12,000 and 3200 ng/g dry weight in two samples and PC MPs at 110 ng/g dry weight in one sample. The estimated average daily exposure doses via dietary sources to PET and PC MPs in one-year-old infants were 83,000 and 860 ng/kg-bw/d, respectively. The study underlined the need for caution to eliminate contamination sources during feces collection, especially from baby diapers, which were not assessed for MP contamination in this study.

Amereh et al explored the presence of MPs in human placentas and their association with fetal growth.¹⁶ They found MPs in 4 out of 30 normal placenta samples and in all 13 samples from pregnancies with IUGR, with a total of 308 MPs extracted. The study observed that the measured load of MPs was significantly higher in individuals who used bottled water and consumed plastic-packaged takeaway food compared to those using boiled tap water and home-cooked meals. The analysis revealed a negative association between MPs load and birth outcomes, including birth weight, neonatal length, head circumference, and one-minute Apgar scores. The results underscored the adverse impact of MP exposure on fetal growth, with significant correlations between higher MP levels and poorer neonatal health metrics.

The objective of Ragusa et al was twofold: to locate MPs within the intra/extracellular compartments of the human placenta and to assess whether their presence was associated with structural changes in cell organelles.⁹ The study also included participants with gestational diabetes not treated with insulin and excluded those with specific conditions like gastrointestinal diseases, recent antibiotic use, and certain dietary restrictions. The study finally involved ten term placental samples from mothers with a median age of 34.5 years who had vaginal or cesarean deliveries. They found that all ten placental samples contained MPs.

Halfar et al investigated the presence of MPs and additives in amniotic fluid and placenta samples, providing the first evidence of their simultaneous presence in both matrices. The study included pregnancies ranging from 24 to 42 weeks of gestation. They identified MPs in 9 out of 10 placenta samples and 6 out of 10 amniotic fluid samples. The number of particles in amniotic fluid varied from 0 to 8 (median: 1; average: 1.5), and in placental samples from 0 to 10 (median: 2; average: 2.8). MPs included chlorinated polyethylene, calcium zinc PVC stabilizer, and polyethylene. The study noted limitations due to the size of detectable particles and variations in methodologies for MP determination.¹⁷

Liu et al examined microplastic (MP) exposure in placentas and meconium samples, exploring its potential correlation with microbiota.⁵ The study excluded subjects with HIV, gastrointestinal disease, or cancer. They finally involved 18 mother-infant pairs, with the mothers having a median age of 32.5 years and all undergoing term vaginal deliveries. They detected a median of 18.0 MP particles/g in placentas and 54.1 particles/g in meconium. The study found that the microbiota at the phylum level in both placenta and meconium were mainly composed of Proteobacteria, Bacteroidota, and Firmicutes. Significant differences in β -diversity and gut composition between placenta and meconium microbiota were noted, with polystyrene and polyethylene showing consistent inverse correlations with several microbiota genera.¹⁸

Another study by Liu et al aimed to assess MP exposure in various biological samples, including placenta, meconium, infant feces, breast milk, and infant formula. Samples were collected from participants with a median age of 32.5 years who underwent vaginal deliveries. Results indicated that all 18 samples contained MPs, with the highest median abundance detected in meconium (54.1 particles/g) and the lowest in infant milk (17.3 particles/g). Participants who consumed more than 2000 mL of water daily or frequently used plastic products had higher MP levels. The study faced limitations, including small sample size, potential contamination, and loss of MPs during sample preparation.¹⁸

Weingrill et al investigated temporal exposures to MPs in placentas collected over a 15-year period using Raman spectroscopy.¹⁹ The study involved 30 placentas from term pregnancies delivered via cesarean section. The study excluded placentas with known medical conditions or sent to pathology for clinical indications. MPs detected an increasing trend over the years: 4.1 MPs/50g in 2006, 7.1 MPs/50g in 2013, and 15.5 MPs/50g in 2021. Despite being the largest study of its kind, limitations included the retrospective collection of older samples and a small sample size, which hindered correlations between MP exposure and maternal-fetal health outcomes.

Zhu et al evaluated the presence and characteristics of MPs in 17 placentas using laser direct infrared (LD-IR) spectroscopy.²⁰ Participants' ages ranged from 23 to 36 years. MPs sized 20–200 μm were detected in all samples, with an average abundance of 2.70 ± 2.65 particles/g. The types of MPs found included PVC, PP, PBS, PET, PC, PS, PA, polyester fiber, PE, PAM, and PSF. The study highlighted the widespread occurrence of MPs in placentas but emphasized the need for more comprehensive data to fully understand MP presence and its implications for maternal and fetal health.

Hasanah et al investigated the presence of MPs in the stools of pregnant women, examining the impact of contaminated food consumption.¹³ The study involved 30 stool samples from pregnant women, predominantly in their second trimester (56.7%) and multigravida (77%). They detected 359 MPs across all samples, with particle sizes ranging from 200 to 4900 μm . A significant proportion of the participants regularly consumed seafood (>75%), with most

consuming small fish. Another risk factor identified was the use of plastic bowls with hot food, though this practice was less common (two-thirds rarely engaged in it).

Xue et al explored the levels of MPs in maternal amniotic fluid (AF) and their associations with fetal growth metrics.²¹ Exclusion criteria encompassed pregnant women with complications like hypertension and diabetes. The study included 40 pregnant women, averaging 30.18 ± 2.35 years, who underwent cesarean sections. MPs were detected in 32 out of 40 AF samples, with an average concentration of 2.01 ± 4.19 particles/g. The study found a significant negative correlation between maternal MPs levels and gestational age ($\beta = -0.46$) and birth weight ($\beta = -35.60$ g), indicating that higher MPs levels were associated with reduced gestational age and birth weight. Additionally, a strong positive correlation was observed between seafood intake frequency and MPs abundance in AF, particularly with polymers like PE and CPE.

Zurub et al aimed to characterize the accumulation of plastic and non-plastic particles (NPP) in term human placentas. Exclusion criteria for the study were comprehensive, including any obstetrical complications, multiple pregnancies, and language barriers (participants who did not understand English or French). The study involved 56 term placentas from vaginal deliveries (34 ± 3.71) and cesarean sections (33 ± 2.55). There were 31 MPs identified across 8 out of 10 placenta samples, with an average of 1 ± 1.2 MP/g of placental tissue.²²

Discussion

The systematic review identified significant levels of MPs in the placenta, maternal stool, meconium, infant stool, amniotic fluid, and breast milk across multiple studies. Findings in this review are supported by other studies, such as Schwabl et al (2019), who detected MPs in human stool samples from participants across different countries.² In a similar vein, a study by Gignac et al (2021) found MPs in the blood of 17 out of 22 healthy adult volunteers, further suggesting that MPs can penetrate various biological barriers and enter systemic circulation.²³

The review also demonstrated the global prevalence of MP contamination but with varying levels of exposure. Geographical location and demographic factors appear to play a significant role in the levels of MP exposure observed across different studies. For instance, studies conducted in industrialized regions, such as the United States and China, reported higher concentrations of MPs compared to those conducted in less industrialized regions. Zhang et al (2021) conducted their study in New York State, a highly urbanized area, where the highest concentrations of PET MPs in infant feces reached up to 82,000 ng/g.¹⁵ In contrast, Hasanah et al (2024) conducted their study in Indonesia, finding lower but still significant levels of MPs in maternal stool samples, with an average of 359 MPs detected across all samples.¹³ These differences may reflect variations in local environmental pollution levels, waste management practices, and dietary habits, which are influenced by socioeconomic status and urbanization.

Further, studies conducted in urban areas tended to report higher MP levels than those in rural settings, likely due to higher pollution levels and greater use of plastic products in urban environments. For instance, the study indicated higher MP concentrations in samples from urban populations who used more plastic products and consumed more bottled water.⁵ This is corroborated by Wright and Kelly (2017), who found that urban populations are more exposed to MPs through both direct ingestion and environmental exposure due to higher plastic waste production and inadequate waste management systems.⁵

Primary Routes of Microplastic Exposure

In general, ingestion appeared to be the most significant route of MPs exposure, particularly through the consumption of contaminated food and water. Studies also found high concentrations of MPs in food items and bottled water, suggesting that dietary intake is a major source of exposure.¹⁵ This aligns with the findings of Cox et al (2019), who estimated that humans consume over 50,000 MP particles annually through food and beverages alone.²⁴

Inhalation of airborne MPs also emerged as a critical exposure route, particularly in urban areas with high levels of environmental pollution. The study by Wright and Kelly (2017) indicated that airborne MPs could be inhaled and deposited in the respiratory tract, contributing significantly to overall exposure.⁵ This was further supported by Gasperi et al (2018), who found substantial levels of airborne MPs in both indoor and outdoor environments, highlighting the omnipresence of MPs in the air we breathe.²⁵

Dermal contact, while less studied, is also a potential exposure route, particularly through personal care products containing MPs and synthetic fibers from clothing. A recent study identified MPs in human skin samples, emphasizing the need for further research on transdermal absorption and its implications.

Comparison of Exposure Levels in Breastfed vs Formula-Fed Infants

This review found that MPs were detected in both human breast milk and commercial infant formula, though the concentration levels and types of MPs vary significantly between the two due to the composition and packaging of infant nutrition sources. Breast milk, naturally derived from the mother, can be contaminated with MPs through maternal ingestion and inhalation, subsequently passing these particles to the infant. However, the concentrations found in breast milk tend to be lower compared to formula, primarily due to the natural filtration processes in the human body.²⁶ One study analyzing breast milk samples from various regions identified PE and PP as the predominant MPs, with concentrations ranging from 1 to 10 particles per liter, similar to the findings of this review.²⁷

Conversely, infant formula, especially when packaged in plastic containers or prepared with bottled water, often exhibits higher microplastic concentrations. A study examining different brands of infant formula found microplastic levels as high as 4,000 particles per liter, significantly surpassing those in breast milk.²⁸ The heating and mechanical shaking involved in formula preparation can further exacerbate microplastic release from packaging materials.²⁹

Furthermore, breastfed infants benefit from bioactive compounds and immunological factors in breast milk that may mitigate some adverse effects of microplastic exposure. In contrast, formula-fed infants lack these protective elements, potentially facing higher risks of gastrointestinal and developmental issues linked to microplastic ingestion.³⁰ This disparity underscores the importance of promoting breastfeeding and improving the safety of infant formula packaging and preparation practices.

The Impact of Microplastic Exposure on Pregnancy

The placenta, a crucial organ for nutrient and gas exchange between mother and fetus, has been found to contain MPs according to our systematic review (Figure 2). The presence of these particles in the placenta could impair nutrient and oxygen delivery to the fetus, leading to conditions such as Intrauterine growth restriction (IUGR) and preeclampsia.³¹ Furthermore, exposure to MPs has been associated with increased oxidative stress and inflammation in placental tissues, which are critical factors contributing to adverse pregnancy outcomes.³²

Animal studies corroborate these findings, indicating that maternal exposure to MPs can result in lower birth weights and shorter gestational periods. For instance, Liu et al (2021) found that pregnant mice exposed to polystyrene MPs had offspring with significantly lower birth weights and disrupted gestational development.³³ Another study showed that microplastic exposure during pregnancy led to placental inflammation and oxidative stress, which are known to negatively impact fetal growth and increase the risk of preterm birth.³⁴

Human observational studies further highlight these risks. One of the studies included in our systematic review reported a correlation between higher microplastic levels in the placenta and reduced birth weights, lower Apgar scores, and smaller head circumferences in newborns.¹⁶ These findings suggest that environmental pollutants pose significant public health to pregnant women.

Based on the studies included in our review and supporting literature, ingestion is the most prominent exposure pathway for both populations. This is primarily due to dietary intake through contaminated food and water, including infant formula prepared in plastic bottles or warm liquids stored in plastic containers. Inhalation is also relevant, particularly in indoor environments where airborne microplastics from textiles and household dust are prevalent. While dermal exposure is considered a less significant route due to limited skin permeability, it cannot be entirely ruled out, especially in infants with more sensitive skin.

Microplastic Exposure Impact on Early Childhood Development

Our study has found MPs in the placenta, indicating that these particles can cross the placental barrier and potentially affect fetal development.³ These exposures during critical windows of development may interfere with physical growth, cognitive abilities, and motor development.

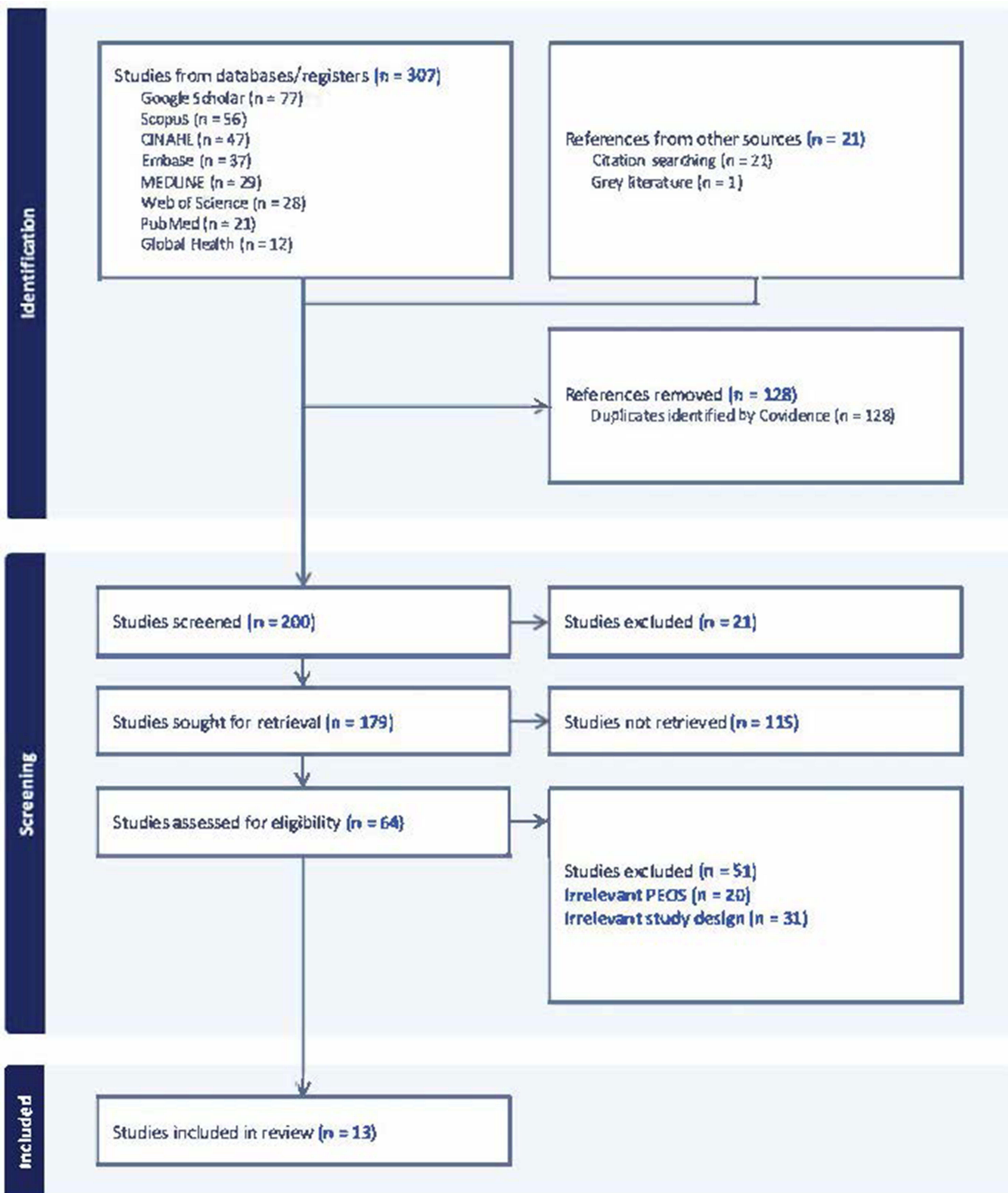


Figure 2 PRISMA flow diagram showed the summary of selection and criteria of study.

Animal studies further found that exposure to MPs during pregnancy could induce oxidative stress and inflammation, leading to cellular damage and apoptosis in fetal tissues. This was evident in multiple studies that observed increased cellular damage in both the placenta and fetus, leading to defective neurodevelopment and cognitive functions following exposure to smaller nanoplastics compared to larger ones.^{26,35} Animal studies further support these findings. In one study,

pregnant mice exposed to polystyrene MPs showed impaired motor skills and reduced exploratory behavior in their offspring, suggesting neurotoxic effects.³⁶ In addition, another study also demonstrated that exposure to MPs can alter gut microbiota, which is critical for the development of the immune system and neurodevelopment in early life.

Furthermore, another study demonstrated that exposure to polystyrene MPs resulted in disrupted immune balance in the placenta and fetal tissues, altering macrophage polarization and cytokine secretion, which are essential for normal fetal development. Maternal exposure to MPs also caused fetal growth restriction and reduced umbilical cord length, both indicators of compromised fetal health.³⁷

Additionally, MPs have been linked to endocrine disruption, which can interfere with hormonal regulation critical for fetal development. Studies have indicated that MPs can mimic or block natural hormones, leading to developmental abnormalities and long-term health issues. For example, Liu et al (2019) reported that maternal exposure to MPs resulted in altered metabolic homeostasis and endocrine function in offspring, highlighting the transgenerational effects of microplastic exposure.³³

As far as the MPs detection methodologies are concerned, The Fourier Transform Infrared Spectroscopy (FTIR) and Raman spectroscopy are the most commonly used methods for microplastic detection. While FTIR is widely accessible and practical for identifying larger particles (>20 μm), it has limitations in detecting smaller particles and can be influenced by sample impurities. Raman spectroscopy offers higher spatial resolution, enabling the detection of smaller particles (<1 μm), but it is more sensitive to fluorescence interference and requires longer analysis times. These methodological inconsistencies affect comparability and highlight the need for standardized protocols in microplastic research.

The evidence highlighting the presence of microplastics in maternal and infant biological samples underscores the need for proactive public health interventions. These findings can inform targeted educational campaigns aimed at pregnant women and caregivers, promoting behavioral changes to minimize plastic exposure, such as avoiding plastic food containers, especially when exposed to heat, and opting for safer alternatives. Additionally, the results support the development of regulatory policies to limit plastic use in packaging for infant formula and baby food, as well as to promote transparent labeling of microplastic content. Integrating such measures into maternal and child health programs could play a crucial role in reducing early-life exposure and its potential health impacts.

Strengths and Limitations of the Review

The review process benefited from a comprehensive and robust search strategy, ensuring the inclusion of a wide array of relevant studies. The diversity of geographical location, advanced analytical techniques, and various sample types analyzed in the included studies, such as placentas, meconium, maternal and infant stools, amniotic fluid, breast milk, and infant formula, provided a holistic perspective on MP exposure during pregnancy and early childhood.

However, several limitations were identified across the included studies. Many studies had small sample sizes, which limits the generalizability of the findings. The reliance on pilot studies and observational designs, which are less robust compared to RCTs, further limits the strength of the evidence. Variability in methodologies for detecting and quantifying MPs led to inconsistencies in exposure assessment, as different studies used different techniques, affecting the comparability of results. There was also a lack of standardized outcome measures across studies, making it challenging to synthesize and compare results. Potential contamination during sample collection and analysis was a concern, potentially leading to over- or underestimation of microplastic levels. Additionally, several studies did not adequately control for confounding factors such as diet, lifestyle, and environmental exposures, contributing to potential bias. The inclusion and exclusion criteria varied, and some studies lacked detailed descriptions of study subjects and settings, further complicating the assessment of bias.

Of note, to minimize bias and strengthen the empirical evidence, future studies should prioritize standardized methodologies for microplastic (MP) detection and quantification, including uniform protocols for sample collection, contamination control, and analytical techniques. Larger, multicentre cohort studies with clearly defined inclusion criteria and rigorous control of confounding variables, such as diet, socioeconomic status, and environmental exposures, are essential to improve generalizability and reduce bias. Longitudinal research is particularly needed to evaluate the long-term effects of MP exposure during pregnancy and early childhood. Moreover, the inclusion of randomized controlled trials, where ethically feasible, and the development of validated outcome measures will enhance the strength of causal

inferences. Collaboration across regions and disciplines can also help harmonize study designs and ensure more comprehensive and comparable data on MP exposure and health impacts.

Conclusion

The systematic review underscores the pervasive presence of MPs in biological samples from pregnant women and infants, revealing a potential public health concern with significant implications for maternal and fetal health. The detection of MPs in placental tissues, maternal and infant stools, meconium, amniotic fluid, and breast milk across diverse geographic locations highlights the widespread nature of this exposure. Despite variations in methodologies and sample sizes, the consistent finding of common plastics such as polyethylene and polypropylene in these studies points to a significant environmental and dietary source of microplastic exposure.

Healthcare providers should be aware of the potential risks of MP exposure and advise pregnant women on strategies to minimize their exposure. Public health initiatives should focus on reducing MP contamination in food and water and promoting safer alternatives to plastic use, particularly among vulnerable populations like pregnant women and infants. Future research should focus on longitudinal studies to assess the chronic health impacts of microplastic exposure, the development of standardized detection and quantification methods, and public health intervention effectiveness studies to reduce exposure and mitigate health impacts.

This review highlights emerging evidence of microplastic presence in maternal and infant biological samples, raising concerns about potential health risks during critical periods of development. While some consistent associations were observed, particularly relating to oxidative stress, endocrine disruption, and developmental outcomes, the limited number of studies, small sample sizes, and variability in methodologies necessitate cautious interpretation. To advance this field, future research must adopt standardized analytical techniques, control for confounding variables, and expand both human and supporting animal studies. Addressing the complex challenge of microplastic exposure requires interdisciplinary collaboration, bringing together experts in environmental science, toxicology, clinical medicine, public health, and policy. Practical frameworks are also necessary to translate findings into actions, for example, by informing healthcare providers, educators, and community leaders about strategies to reduce exposure, particularly among pregnant women and infants. Until stronger evidence emerges, promoting preventive measures and supporting informed decision-making remain essential components of public health response.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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