

Analysis of the Impact of Environmental Microplastics on Human Health from the Perspective of Modern Environmental Health

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Abstract: Environmental microplastics have become a critical environmental health concern, yet the extent of their impact on human health remains insufficiently resolved due to heterogeneity in particle properties, exposure pathways, and methodological translation. This study aims to synthesize how environmental microplastics may affect human health from the perspective of modern environmental health, with particular attention to exposure realism, plausibility of mechanisms, and uncertainty in risk interpretation. Methodologically, it employs a library-based research design using primary and secondary literature sources related to microplastics, human health, and modern environmental health concepts, followed by content analysis to identify recurring thematic patterns and relationships. The reviewed literature data indicate consistent evidence of multi-route exposure pathways and recurring mechanistic hypotheses such as inflammation and oxidative stress, while significant uncertainty persists in dose estimation, mixture effects, and comparability across studies. The study concludes that microplastics are plausibly health-relevant but require strengthened translational evidence to support decision-grade risk assessments within modern environmental health practice.

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INTRODUCTION

Environmental microplastics have moved from being a niche contamination concern to a central challenge for modern environmental health. They are now detected across diverse ecosystems, including coastal waters, river systems, sediments, soils, and even indoor environments, indicating that human exposure is not limited to specific geographical settings. In parallel, advances in analytical detection have improved researchers' ability to quantify microplastics at low concentrations, revealing that exposure pathways may be more frequent than previously assumed. This growing body of evidence suggests that microplastics are not

merely environmental pollutants but potential contributors to human health risks. Importantly, the problem is compounded by the persistence of microplastics and their ability to travel through environmental media, meaning that exposure can be continuous rather than episodic. From a public health perspective, this creates a pressing need to evaluate how microplastics may interact with biological systems. Moreover, the complexity of microplastics—such as variability in size, shape, polymer type, additives, and surface characteristics—complicates risk assessment. Therefore, clarifying the impact of environmental microplastics on human health becomes a necessary foundation for decision-making in modern environmental health (Li et al., 2023).

While numerous studies confirm the presence of microplastics in environmental compartments, the translation of these findings into a coherent health impact framework remains incomplete. Existing research has offered mechanistic discussions, including possible inflammatory responses, oxidative stress pathways, and the role of particle-mediated transport in the body. However, these theoretical explanations often rely on heterogeneous evidence that varies in experimental design, exposure assumptions, and analytical endpoints. As a result, it is still difficult to establish consistent conclusions about which mechanisms are most relevant in real-world exposure scenarios. Additionally, microplastics are rarely present as a single isolated factor; they often co-occur with other contaminants such as chemical pollutants and biological agents, which can confound causality and attribution. Another limitation in the literature is that many studies focus primarily on detection and characterization rather than linking exposure levels to meaningful clinical or epidemiological outcomes. Furthermore, theoretical approaches sometimes do not fully incorporate the “modern environmental health” perspective, which emphasizes systems thinking, exposure timing, population variability, and the interaction between environmental drivers and health determinants. Consequently, although the literature provides partial answers, it has not yet adequately resolved the central research problem: how to interpret microplastics’ environmental presence into actionable and scientifically grounded implications for human health. This gap motivates the present study to integrate evidence into a more conceptually structured understanding (Ezeh & Agu, 2024).

This study aims to analyze the impact of environmental microplastics on human health through the perspective of modern environmental health. Specifically, it seeks to synthesize how microplastics may influence biological processes, considering exposure pathways, physicochemical properties, and potential toxicological mechanisms. The study also aims to clarify the extent to which current theoretical models can explain human health relevance, particularly when exposed populations face multiple environmental stressors simultaneously. In addition, the research intends to identify where scientific uncertainties remain most significant, such as in exposure assessment accuracy, dose–response interpretation, and real-world relevance of laboratory findings. By framing the analysis within modern environmental health, the study emphasizes not only whether microplastics may be harmful, but also how environmental health practice should evaluate risk, protect vulnerable groups, and guide preventive strategies. The overarching goal is to contribute a structured understanding that can support future research design and inform policy-oriented discussions in environmental health. Ultimately, the study aims to reduce interpretive fragmentation in the literature and provide a clearer rationale for health-focused microplastics research. Through this purpose, the research seeks to move beyond fragmented findings toward a more integrative perspective (Noventa et

al., 2021).

The importance of conducting this research is grounded in the increasing likelihood of sustained human exposure to microplastics and the growing expectation that environmental health sciences should respond with evidence-based risk interpretations. Because microplastics are pervasive and persistent, even low-level exposure could become significant when considered over time and across populations. In this context, relying solely on isolated environmental monitoring results without health-oriented interpretation risks delaying protective actions. Furthermore, the modern environmental health perspective requires that health implications be evaluated in a manner that accounts for real exposure conditions, not only controlled laboratory circumstances. This study is therefore essential to address a gap between environmental detection and human health relevance, allowing researchers and stakeholders to better understand the pathways linking exposure to outcomes. By identifying theoretical limitations in current explanations, the study helps set priorities for future investigations that can generate more decisive evidence. Additionally, a health-centered understanding may strengthen the scientific basis for regulatory considerations, public communication strategies, and preventive measures in environmental management. The research is also important because it provides conceptual clarity that can guide multidisciplinary collaboration across toxicology, environmental science, epidemiology, and public health. Finally, the study's objectives are directly aligned with the need for an integrative framework that supports the development of practical and scientifically credible environmental health responses to microplastic contamination (Sana et al., 2020).

METHOD

This study focuses on the environmental health phenomenon of microplastic contamination and its potential impact on human health. The "object" of the research is therefore not a single location, individual, or experimental cohort, but the broader problem of how environmental microplastics can be interpreted within modern environmental health frameworks. The study examines this phenomenon as it appears across multiple environmental media, including water, soil, sediments, and indoor or occupational contexts, because these settings collectively shape realistic exposure scenarios. In addition, the research treats microplastics not only as particles detected in the environment, but as a complex exposure-related hazard whose properties can vary widely. These properties include particle size distribution, polymer type, chemical additives, and surface characteristics that may influence biological interactions. The chosen object also encompasses the health-relevance question: which human health pathways can plausibly be affected when individuals encounter environmental microplastics through real-world routes. By defining the object in this way, the study can evaluate the phenomenon as an integrative environmental health issue rather than a purely analytical contaminant problem. Ultimately, the object of analysis is the knowledge and explanatory claims that connect environmental microplastics to human health outcomes. This approach enables the study to capture how the phenomenon is conceptualized, evidenced, and discussed in scientific literature (Prathipa et al., 2024).

Type of research and data sources: library-based with primary and secondary literature

This study adopts a library-based research design (penelitian kepustakaan) that relies on documentary materials to address the research objectives. The type of research is grounded in a systematic examination of relevant written sources, including books, journal articles, scientific reports, and peer-reviewed studies. For primary data, the study uses relevant literature that directly addresses microplastics, exposure-health relationships, and environmental health perspectives, particularly those that discuss biological plausibility and health mechanisms. In this context, “primary data” refers to the main scholarly texts and research reports that serve as direct evidence within the literature corpus. Meanwhile, secondary data is constructed from complementary materials that strengthen conceptual framing and keyword-based coverage, such as additional literature that provides definitions, background theories, and contextual evidence regarding microplastics. These secondary sources include scholarly books and research publications that discuss modern environmental health, exposure pathways, risk interpretation, and systems-oriented evaluation. The data collection process is therefore oriented toward assembling an evidence base that is coherent with the study’s research focus. To ensure relevance, the selection of literature is guided by the central keywords, namely microplastics, human health, and modern environmental health. The dataset is not limited by a single discipline because the phenomenon requires cross-cutting insights from environmental science and health sciences. Consequently, the literature corpus is curated to represent the multifaceted nature of microplastic exposure and health interpretation (Mittal et al., 2024).

Foundational theory: sources of information and assumptions

The theoretical foundation in this study is used to guide interpretation and to structure the conceptual relationship between environmental microplastics and human health within a modern environmental health lens. In particular, the study relies on established theoretical and conceptual positions that explain how environmental exposures become health-relevant through biological and systems-level pathways. The theory base functions as both a source of information and an assumption framework, meaning that it provides categories for analyzing evidence in subsequent steps. The theoretical components include the origin of key ideas about environmental exposures, the role of mechanisms in linking exposure to health outcomes, and the emphasis on risk interpretation in real-world contexts. Each theoretical element is operationalized as a lens for reviewing literature content, such as how microplastics may contribute to inflammation-related processes, oxidative stress mechanisms, or transport-mediated effects. The modern environmental health perspective also informs assumptions about variability in exposure timing, susceptibility across populations, and the importance of exposure pathways beyond laboratory conditions. Furthermore, the theory supports the assumption that microplastics should not be treated as a single uniform hazard because their physicochemical diversity can affect biological interactions. The study therefore uses theoretical constructs to evaluate whether the literature provides consistent explanatory pathways and whether uncertainties are acknowledged. Since this is a library-based analysis, theory is not tested experimentally; rather, it is used to interpret and compare claims across studies. Finally, the theoretical foundation is applied to identify how current knowledge aligns with, or fails to meet, the interpretive expectations of modern environmental health. This structure becomes the basis for deriving meaningful conclusions from textual evidence (Azfaralariff et al., 2023).

Research procedure and data collection techniques: literature reading and documentation

The research procedure is designed as a structured sequence for collecting, managing, and interpreting written evidence through documentary study techniques. First, the study conducts a comprehensive reading process to identify relevant materials that directly address environmental microplastics and their health implications. This stage includes reviewing abstracts, introductions, conceptual frameworks, and discussion sections to determine whether the sources align with the central focus of microplastics and human health. Second, the study performs systematic documentation by extracting key information from books, journal articles, reports, and scholarly papers that discuss exposure routes, mechanistic plausibility, and health outcomes. The extraction process is conducted using consistent notes so that information can later be compared across sources without losing contextual meaning. Third, the study ensures that the literature selected for analysis covers not only environmental detection and characterization of microplastics, but also interpretive claims related to human health relevance. Fourth, the study consolidates materials related to modern environmental health concepts, including how such frameworks evaluate risk, vulnerability, and real-world exposure contexts. Fifth, the collection stage includes the identification of recurring themes, such as inflammatory responses, oxidative stress, particle-mediated transport, and the co-occurrence with other environmental stressors. The process also captures how researchers report uncertainties and methodological limitations. Throughout the procedure, data collection is performed exclusively through reading and documentation of written sources, including books, previous studies, papers, journals, articles, reports, and scholarly magazines that are connected to the research problem. This ensures that the study remains faithful to its library-based methodology. Finally, the documented evidence becomes the primary input for the content analysis stage described next (Katyal et al., 2020).

Data analysis technique: content analysis to identify patterns and important information

Data analysis in this study uses content analysis as the central technique for examining the literature corpus. The content analysis process begins with careful reading of selected sources to identify meaning units that correspond to the study's conceptual concerns. These meaning units include statements about exposure pathways, mechanistic explanations, biological plausibility, and reported health implications linked to environmental microplastics. The analysis then involves coding and categorizing textual information into thematic patterns that reflect relationships among microplastics, human health, and modern environmental health perspectives. For example, coded themes may include inflammatory or oxidative stress pathways, the role of particle properties, and the influence of exposure context on risk interpretation. After coding, the study performs synthesis to identify patterns, recurrent explanatory pathways, and areas of inconsistency across the literature. The analysis also seeks to extract important information that appears to be central for understanding the phenomenon, such as how uncertainty is addressed or how studies define limitations. Furthermore, the content analysis process includes comparative examination, meaning that claims across sources are evaluated for alignment with modern environmental health assumptions. This helps the study determine whether the literature provides coherent interpretive links that can support health-focused environmental decision-making. The final stage of analysis involves interpreting

the coded outcomes to produce an evidence-based narrative synthesis, while avoiding unsupported speculation beyond what the literature text explicitly supports. In this manner, the analysis focuses on what the sources say, how they structure evidence, and what gaps are repeatedly revealed. Overall, the use of content analysis enables the study to systematically process qualitative textual materials and transform them into structured findings. Consequently, this analytical technique is appropriate for a library-based investigation of complex environmental health questions(De-la-Torre, 2020).

RESULTS AND DISCUSSION

The literature reviewed in this study consistently positions environmental microplastics as an exposure-relevant environmental factor with plausible pathways to human health impacts. Across the reviewed sources, microplastics are not described merely as passive contaminants, but as particles whose physicochemical attributes may alter how they interact with biological systems. The evidence base shows repeated emphasis on the variability of microplastics, including differences in size, shape, polymer composition, and surface characteristics. These variations are described as determinants of how microplastics may behave in environmental transport and how they may encounter human exposure routes. In addition, the literature indicates that microplastics can be present across multiple compartments, suggesting that exposure may occur repeatedly rather than as a one-time event. As a result, the review reveals that human health relevance should be assessed through a pathway-oriented logic rather than through a purely detection-based logic. The modern environmental health perspective further appears in how sources frame exposure as context-dependent, involving real-world patterns of contact and vulnerability. Importantly, the reviewed texts also identify that microplastics are rarely encountered alone in environmental settings, since co-occurring contaminants may accompany the particle load. Therefore, the collected literature outputs a consistent descriptive picture: microplastics represent a complex exposure domain that requires integrated interpretation to infer health implications. Finally, the results show that the reviewed body of literature provides partial explanatory links, but these links vary in strength and coherence across studies.

A dominant pattern in the reviewed literature is the conceptualization of exposure pathways as the bridge between environmental presence and potential health outcomes. Several sources describe human exposure as mediated through ingestion, inhalation, or dermal contact, with the relative contribution depending on environmental context and population behavior. The review results show that sources frequently discuss how environmental microplastics can enter food chains and drinking water systems, making ingestion a repeatedly cited route. In parallel, inhalation exposure is also emphasized through contaminated air or dust resuspension in indoor and outdoor environments. The documentation from the corpus suggests that indoor exposure may be particularly relevant because microplastics can accumulate in household or occupational spaces. The evidence base also reveals that exposure is influenced by time-related factors, such as duration of residence in microplastics-contaminated environments and repeated daily contact patterns. Within the content analysis, these elements repeatedly appear as contextual modifiers that shape exposure intensity and potential internal dose. Consequently, the results indicate that health interpretation cannot be separated from exposure assessment assumptions. The findings also demonstrate that many reviewed studies are constrained by

variability in how microplastics are measured, reported, and converted into exposure estimates. This creates a recurrent theme: uncertainty in dose estimation becomes a central barrier for stronger health inference. Therefore, pathway results from the literature are present, but they are accompanied by methodological discontinuities. Overall, exposure pathways emerge as the primary structuring concept within the microplastics–health link. Finally, the results suggest that modern environmental health requires translating pathway narratives into decision-relevant risk interpretations.

The content analysis reveals that mechanistic claims are a second major category used to interpret possible human health impacts. Many sources propose that microplastics may influence biological processes through inflammatory responses, oxidative stress, and tissue-level interactions. The reviewed literature also repeatedly discusses the possibility of particle-mediated transport, including how microplastics or associated chemicals may reach relevant biological compartments. Several texts describe that microplastics may carry or adsorb chemical substances, potentially increasing biological relevance beyond the particles alone. The results show that mechanistic statements are often supported by experimental or observational evidence, yet the strength of support differs across mechanistic pathways. In many cases, mechanistic outcomes depend on microplastic characteristics and exposure conditions, reinforcing the idea of heterogeneity. Furthermore, the review results indicate that co-exposure with other environmental stressors may amplify or confound mechanistic interpretations. This produces a consistent result pattern: mechanism is discussed, but causality and real-world relevance are not uniformly established. The content analysis also notes that many studies do not fully operationalize how laboratory concentrations relate to realistic human exposure levels. As a result, mechanistic categories appear as plausible explanations, yet they remain uneven in evidentiary consolidation. This imbalance becomes an important descriptive outcome from the literature synthesis. In addition, the literature outputs repeated attention to biological plausibility as a necessary step for bridging environmental detection to health relevance. Therefore, mechanism becomes a recurring explanatory tool, but it does not always resolve interpretive uncertainty. Overall, the results confirm that mechanistic reasoning is present, but its translation into health impact inference remains limited.

Another prominent finding is the thematic emphasis on uncertainty and methodological limitations within the literature. Across reviewed sources, uncertainty arises from differences in sampling strategies, analytical detection methods, and reporting standards. The content analysis shows that the variability in microplastics identification—such as particle sizing and polymer characterization approaches—can influence comparability across studies. In addition, uncertainty is repeatedly linked to dose estimation, particularly the challenge of converting environmental measurements into internal exposure. The literature also highlights the difficulty of controlling confounding variables when microplastics co-occur with other pollutants. As a result, many sources explicitly recognize that the evidence base is still evolving and that robust causal conclusions remain premature. The results also reveal uncertainty concerning the long-term health relevance of low-dose chronic exposure, which is difficult to assess using short-term studies. Within the modern environmental health lens, such uncertainties are not treated as mere gaps, but as inputs for risk interpretation. Therefore, the results indicate that uncertainty itself is a structured component of how the literature constructs health relevance. The review also shows that studies vary in whether they report uncertainty transparently or assume

interpretive certainty. Consequently, the evidence synthesis suggests that the field is still transitioning from detection-oriented research toward health-relevant risk evaluation. This transitional status becomes a descriptive outcome. Finally, uncertainty emerges as both a methodological and conceptual theme that affects how microplastics health impact claims are interpreted.

A further result is that modern environmental health concepts—such as exposure context, vulnerability, and systems-level framing—appear as interpretive scaffolds in multiple sources. The literature reviewed does not treat microplastics solely as a chemical toxicant; instead, it increasingly frames them as an environmental health challenge involving complex exposure conditions. The content analysis detects repeated references to population heterogeneity, including differences in age, health status, and behavioral patterns that modulate exposure. The sources also emphasize that environmental health decisions require more than demonstrating the presence of hazards, because the hazard must be translated into risk. In this translation, modern environmental health perspectives emphasize realism in exposure assumptions. The review results show that such realism is often limited by measurement-to-dose conversion uncertainties. Even so, the literature attempts to integrate exposure pathways and mechanism into a more coherent risk reasoning. Consequently, the results demonstrate that the modern environmental health perspective is not absent, but its operationalization remains inconsistent. Some sources provide structured reasoning, while others remain descriptive or speculative. This inconsistency becomes a key outcome that shapes the overall interpretation of the evidence base. Additionally, the results show that modern environmental health encourages attention to long-term impacts, not merely immediate effects. Therefore, the literature increasingly supports a chronic risk framing. Overall, the review results identify modern environmental health as a relevant perspective, but also reveal that methodological tools to implement it fully are still developing.

The synthesis also reveals that the co-occurrence of microplastics with other environmental stressors is treated as a significant factor influencing health inference. Many reviewed texts indicate that microplastics may carry additives or adsorb chemicals, potentially increasing biological risk through chemical-particle interactions. The content analysis shows that this creates interpretive challenges because attributing effects exclusively to microplastics becomes difficult. In addition, microplastics co-occur with other pollutants, including heavy metals or persistent organic pollutants in some environmental contexts. This produces a recurring limitation: health impact claims may reflect combined exposures rather than isolated particle effects. The results also show that some studies attempt to address this by focusing on mechanistic pathways that include chemical transport. Nonetheless, the review indicates that such integration is not uniformly executed. Therefore, the field remains at a stage where attribution is scientifically constrained. This is a meaningful result because modern environmental health decision-making requires interpretive caution and transparent reasoning. Furthermore, the literature suggests that future evidence synthesis should adopt frameworks capable of accounting for mixture exposures. Accordingly, the results show that interaction effects and mixture contexts are prominent descriptive themes. Finally, the review outputs that co-occurrence is not a peripheral issue, but a central determinant of how health impacts should be interpreted.

From the content analysis, another result is that the direction of evidence tends to

support plausibility while causal strength remains limited. Several sources provide mechanistic plausibility arguments and describe observed biological responses in experimental contexts. However, the review results show that the translation into human health outcomes lacks consistent epidemiological confirmation. This leads to an evidentiary pattern where plausibility is higher than direct causal demonstration in humans. The reviewed literature indicates that human outcomes may involve multiple intermediate steps, including absorption, distribution, and cellular interactions. Yet, many studies cannot fully track these steps at human-relevant exposure levels. Consequently, the results demonstrate a gap between mechanistic plausibility and population-level health effect estimation. Additionally, the literature indicates that exposure assessment and endpoint selection vary substantially across studies. This affects how strong comparisons can be made. Therefore, the results show that evidence convergence is still developing. Under modern environmental health expectations, such convergence is essential for risk prioritization. The review synthesis also identifies that some sources propose precautionary interpretations, while others emphasize the need for additional robust evidence. Both positions appear in the corpus, indicating scientific uncertainty and disciplinary differences. Overall, the result is a structured evidentiary hierarchy: detection and plausibility are more advanced than definitive human outcome attribution. Finally, this hierarchy becomes central for interpreting what the literature can currently support.

The synthesis further yields a result related to communication implications for environmental health practice. The reviewed texts suggest that public and stakeholder risk communication must be careful because the evidence base is complex and uncertain. Content analysis indicates that explanations often need to balance scientific credibility with public relevance. Some sources highlight that simplified messages may lead to misinterpretation, especially when dose-response relationships are not fully established. The results show that modern environmental health frames communication as part of risk management, not merely dissemination. Therefore, the literature suggests that communication should include the nature of uncertainty and the rationale for precaution. This becomes an interpretive outcome from the corpus. Additionally, the literature indicates that decision-making requires translating scientific findings into actionable priorities, such as monitoring strategies and exposure reduction approaches. The content analysis suggests that microplastics research is increasingly connected to policy discussions, yet the evidence-to-policy pathway remains partially underdeveloped. Consequently, communication emerges as a practical domain where uncertainty must be managed transparently. The review results also reveal that stakeholder expectations may not align with scientific readiness. Therefore, risk communication becomes a site of tension that modern environmental health must navigate. Overall, this result emphasizes that the impact question is not only scientific, but also operational for health protection strategies.

Taken together, the review results support an integrated descriptive conclusion: environmental microplastics show a multi-route exposure profile, plausible mechanistic pathways, and significant uncertainty in translating evidence into definitive human health impacts. The reviewed literature indicates that exposure pathways are central, mechanistic plausibility provides partial biological justification, and uncertainty arises from measurement, dose estimation, mixture effects, and heterogeneity. The modern environmental health perspective provides a conceptual scaffold to structure these elements into risk-relevant reasoning. However, the field's current evidence convergence remains limited, particularly for

direct causal inference in humans. This descriptive synthesis becomes the basis for the subsequent discussion on what the findings imply for research priorities and environmental health practice. Moreover, the review suggests that future research must strengthen methods that connect environmental concentrations to internal doses and clinically meaningful outcomes. The results also indicate that mixture and co-occurrence contexts should be treated as standard rather than exceptional conditions. Additionally, the literature demonstrates that vulnerability and exposure context need deeper operationalization. Therefore, the results collectively indicate that microplastics should be studied as an environmental health concern requiring integrated and cautious interpretation. Finally, the results provide a structured map of how the literature currently supports health relevance while still leaving critical uncertainties unresolved.

Table 1 Variability in Microplastic Characteristics and Exposure Implications

Characteristic	Description	Exposure Relevance Example
Size	Ranges from nanoplastics (<1 µm) to larger fragments	Smaller sizes enable inhalation or translocation across biological barriers
Shape	Fibers, fragments, spheres	Fibers increase retention in lungs via interception
Polymer Composition	PE, PP, PS, PVC, etc.	Influences buoyancy and degradation rates in water/food chains
Surface Characteristics	Biofouling, adsorbed chemicals	Enhances chemical transport into ingestion routes

Table 2 Primary Human Exposure Pathways

Pathway	Key Environmental Compartments	Influencing Factors	Relative Emphasis in Literature
Ingestion	Food chains, drinking water	Daily consumption patterns, contamination levels	High (repeatedly cited)
Inhalation	Air, indoor dust, resuspension	Residence duration, occupational exposure	High (indoor/outdoor focus)
Dermal	Water, soil contact	Skin integrity, activity behaviors	Moderate (less emphasized)

Table 3: Key Uncertainties and Methodological Limitations Captures recurrent barriers to health inference.

Uncertainty Type	Sources of Variability	Implications for Health Assessment
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Sampling/Analytics	Particle sizing, polymer ID methods	Reduces study comparability
Dose Estimation	Environmental-to-internal dose conversion	Weakens causal links to outcomes
Co-Occurrence	Adsorbed chemicals, other pollutants	Confounds attribution to microplastics
Long-Term Exposure	Chronic low-dose effects	Limits from short-term study designs

Discussion

The main contribution of this literature-based analysis is the clarification of how the relationship between environmental microplastics and human health is constructed within modern environmental health reasoning. The results indicate that the literature consistently treats microplastics as an exposure problem with multiple routes, rather than a single-path hazard. This aligns with modern environmental health principles that emphasize exposure pathways, contextual realism, and population variability. The mechanistic themes identified in the reviewed corpus support plausibility, especially through inflammatory and oxidative stress-related interpretations. Yet, the discussion must also acknowledge that plausibility does not automatically translate into definitive human health causality. The evidence hierarchy observed in the results suggests that the scientific community is still progressing from detectability and biological plausibility toward stronger human outcome inference. This gap matters because environmental health decision-making requires risk interpretation, not only mechanistic storytelling. When uncertainty is substantial, modern environmental health frameworks require transparent assumptions and precautionary reasoning. Therefore, the findings collectively suggest that current knowledge is suitable for structured risk consideration, but not yet sufficient for strong causal claims. In this sense, the discussion emphasizes interpretive discipline as a scientific and ethical requirement. Furthermore, the results underline that evidence synthesis must account for heterogeneity in microplastic properties and exposure conditions. This means that the field's conceptual challenge is not merely evidence scarcity, but coherence-building across diverse study designs. Ultimately, the discussion frames the microplastics–health link as a developing knowledge domain that requires integrated methods to mature into decision-grade evidence.

The discussion also addresses why exposure pathways remain the most central concept in connecting environmental microplastics to human health. The results show that ingestion, inhalation, and indoor exposure narratives repeatedly appear as the backbone of human relevance arguments. This indicates that the field recognizes the need to bridge environmental measurements with human contact processes. Modern environmental health perspectives support this bridging by emphasizing real-world exposure contexts rather than abstract hazard presence. However, the literature reveals persistent limitations in how environmental concentrations are converted into internal dose estimates. This limitation affects the strength of mechanistic and health impact claims, because biological effects depend on exposure levels. Therefore, the key “why” behind the observed uncertainty is methodological translation, not only biological complexity. Additionally, the literature suggests that exposure timing and chronicity are essential but under-measured dimensions in many studies. The discussion implies

that without accurate temporal exposure characterization, health interpretation remains incomplete. As a result, research should prioritize exposure assessment frameworks that are compatible with modern environmental health expectations. This includes harmonization of measurement standards and reporting structures to enable comparability across studies. The field's varied detection approaches amplify this translation problem, leading to inconsistencies in dose-related interpretations. Consequently, the results motivate an analytical shift: future work should integrate environmental monitoring, exposure modeling, and biological relevance mapping. Such integration would reduce interpretive fragmentation and improve the credibility of health risk reasoning. In short, exposure pathways are central because they convert environmental presence into human relevance, but their current estimation constraints determine the overall confidence level.

A further aspect of “why” and “for what” relates to mechanistic reasoning and its role as an intermediate interpretive step. The results show that mechanistic pathways such as inflammation, oxidative stress, and particle-mediated interactions are repeatedly discussed across the literature. Mechanistic explanations are valuable because they provide biological plausibility and generate testable hypotheses. However, mechanistic narratives often do not fully align with human-relevant exposure levels and real-world mixture contexts. This misalignment is significant because it may overestimate or misinterpret the degree of health impact under natural exposure conditions. The discussion therefore emphasizes that mechanistic plausibility should be treated as provisional until evidence establishes translational consistency. Modern environmental health frameworks would further require integrating mechanistic endpoints with exposure realism and vulnerability patterns. The results also show that co-occurring contaminants and microplastic additives complicate attribution. Consequently, the discussion suggests that mechanistic research should increasingly adopt mixture-aware designs or analytical approaches that can separate contributions. From a practical standpoint, such mechanistic improvement supports more meaningful risk prioritization. It also improves the clarity of uncertainty communicated to stakeholders. Therefore, mechanistic reasoning is not merely an academic exercise; it is a scaffold for risk interpretation and health protection strategy development. Yet, the current evidence indicates that the scaffold is not fully integrated into a decision-grade evidence structure. This tension explains why stronger causal conclusions remain limited. The discussion ultimately positions mechanistic work as necessary but insufficient without improved translational exposure-to-dose linking and mixture considerations.

The discussion also addresses the modern environmental health “what for” by linking uncertainty to precautionary interpretation and policy relevance. The results indicate that uncertainty emerges from measurement differences, dose estimation challenges, and mixture exposures. Modern environmental health does not treat uncertainty as an obstacle to action, but as a factor shaping risk management decisions. This means that even when causal certainty is incomplete, environmental health practice can still define priorities, monitor exposure, and reduce risk where plausible harm is reasonable. The literature reviewed suggests that risk communication should reflect this uncertainty transparently to avoid misleading simplification. The discussion therefore argues that the value of the present study lies in structuring what is known, what is plausible, and what remains unresolved. Such structuring supports responsible decision-making, including where precaution is scientifically justified and where additional

evidence is required. In this context, the findings can inform monitoring strategy design and research prioritization, particularly by highlighting exposure pathway translation as a key bottleneck. The discussion also implies that stakeholder communication should incorporate the concept of evidentiary hierarchy: detection and plausibility are more established than definitive human causality. Accordingly, communication strategies must align with the evidence level to maintain credibility. The modern environmental health perspective becomes crucial because it integrates science with governance-oriented logic. Therefore, the discussion positions microplastics research as a policy-relevant domain that requires interpretive discipline. Ultimately, the “for what” is to enable evidence-informed risk governance despite uncertainty.

The present analysis contributes to theoretical and practical integration by demonstrating that the literature’s conceptual scaffolding is partially coherent yet operationally fragmented. The results show that modern environmental health concepts are present as interpretive frameworks, but their application differs across studies. Some studies adopt structured exposure-realism reasoning, while others remain descriptive or mechanistic without full translational linkage. This produces fragmentation that limits evidence convergence. The discussion therefore argues that the field requires methodological standardization and conceptual harmonization. Such harmonization includes consistent reporting of microplastic characteristics, standardized exposure assumptions, and improved linkage to health-relevant endpoints. Additionally, the discussion highlights the need to operationalize vulnerability and susceptibility in a way that can be used in risk evaluation. Without such operationalization, modern environmental health remains an aspirational framework rather than a consistently applied model. The results also point to mixture exposure contexts as an under-integrated dimension. Because real environments rarely contain single hazards, mixture-aware approaches would improve external validity and health relevance. Therefore, the discussion recommends that future literature synthesis should not only collect evidence but also evaluate how studies implement modern environmental health criteria. This would strengthen the interpretive quality of the field. In turn, it would support the development of decision-grade conclusions. The study’s contribution, therefore, is to map existing coherence and reveal where integration fails. This mapping becomes essential for advancing the scientific maturity of microplastic health research.

Finally, the discussion outlines the implications and boundaries of this literature-based study. The implication is that environmental microplastics should be treated as a relevant environmental health concern requiring integrated exposure-mechanism-risk reasoning. The study also implies that research priorities should prioritize exposure assessment translation, dose realism, and mixture-aware evaluation to strengthen health inference. Another implication is for communication and governance: uncertainty should be documented and used to guide precautionary risk management rather than to delay action indefinitely. However, the boundary of this study is that, as a literature-based analysis, it does not generate new empirical measurements or establish new causal estimates. The findings therefore represent a synthesis of existing knowledge structures, not a direct measurement of human outcomes. Additionally, the interpretive strength depends on the quality, heterogeneity, and reporting consistency of the included literature corpus. As a result, some uncertainty may remain embedded in the reviewed evidence. Even so, the study provides a coherent narrative structure that can guide future empirical research design. The discussion also suggests that adopting standardized frameworks

for evidence synthesis could reduce fragmentation in the field. In sum, the results support that microplastics plausibly relate to human health through multiple pathways, while uncertainties and translation gaps prevent definitive causal conclusions. The value of this study is in clarifying the nature of these limitations and in translating them into actionable research priorities within modern environmental health.

CONCLUSION

Environmental microplastics emerge from the literature as an exposure-relevant environmental health concern with multiple human exposure routes and plausible mechanistic pathways, yet with substantial translational uncertainty that limits definitive causal inference for human outcomes. The reviewed evidence consistently indicates that exposure pathway realism, variability in microplastic physicochemical properties, and mixture-related factors shape how health relevance is interpreted within modern environmental health frameworks. Mechanistic themes such as inflammation, oxidative stress, and particle-mediated interactions provide important biological plausibility, but they are unevenly supported when linked to human-relevant exposure levels and chronic exposure scenarios. As a result, the current state of knowledge is best understood as a developing evidentiary hierarchy in which detection and plausibility are more established than decision-grade risk quantification. Therefore, future research and environmental health practice should prioritize harmonized measurement and reporting, improved translation from environmental concentrations to internal dose, and mixture-aware designs that better represent real-world exposure conditions.

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