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One Health Perspectives on Microplastic Pollution: Environmental Fate, Cross-Species Health Risks, Microbial Interactions, and Future Mitigation

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Abstract

Background: Microplastics are ubiquitous contaminants that affect environmental, animal, and human health through multiple exposure pathways and complex biotic interactions. A One Health approach—bridging disciplines and sectors—is essential to understand and mitigate these multifaceted risks.

Objective: This review synthesizes literature (2015–2022) on microplastic occurrence, exposure pathways, biological impacts, microbial interactions, mitigation technologies, and policy responses through a One Health lens. It highlights major findings, methodological gaps, and priority actions for research, surveillance, and governance.

Methods: We organized thematic evidence from a comprehensive literature selection and citation-chaining process that prioritized interdisciplinary studies connecting toxicology, ecology, epidemiology, and policy. Key topics include exposure pathways (ingestion, inhalation, dermal), trophic transfer and bioaccumulation, microplastic-associated biofilms and antibiotic-resistance gene (ARG) dissemination, sentinel species monitoring, mitigation approaches (source reduction, waste management, bioremediation, filtration), and policy frameworks. Strengths and limitations of current studies are critically examined.

Results: The literature documents pervasive microplastic contamination across terrestrial, aquatic, and atmospheric compartments, with demonstrated bioaccumulation and trophic transfer. Microplastics act as vectors for chemical additives, pathogens, and ARGs, with biofilms playing dual roles in pathogen transmission and biodegradation potential. Proposed mitigation strategies emphasize source reduction, circular-economy interventions, improved waste management—including pandemic-related biomedical waste controls—and technological innovations such as microbial biodegradation and advanced filtration. However, empirical evaluations of mitigation effectiveness are limited, methodologies are heterogeneous, and longitudinal human-health data are scarce.

Keywords: microplastics; One Health; plastisphere; antibiotic resistance genes; monitoring; mitigation; biodegradation; waste management.

1. INTRODUCTION

Research on the One Health approach to mitigate microplastics effects on human health, animal health, and environmental pollution has emerged as a critical area of inquiry due to the pervasive and multifaceted impacts of microplastics across ecosystems and biological systems (Allen et al., 2022; Morrison et al., 2022). Over the past decade, the field has evolved from recognizing microplastics as marine pollutants to understanding their ubiquity in terrestrial, atmospheric, and aquatic environments, affecting organisms from microbes to humans(Kim et al., 2022; Kiran et al., 2022). The significance of this research is underscored by alarming statistics, such as the presence of microplastics in over 80% of aquatic species and their detection in human tissues, highlighting urgent environmental and public health concerns (Kibria et al., 2022; Silva et al., 2022)The One Health framework, emphasizing the interconnectedness of human, animal, and environmental health, has gained prominence as a holistic strategy to address these complex challenges(Prata, 2022; Redford et al., 2022).

The specific problem addressed is the insufficient integration of multidisciplinary knowledge to fully understand and mitigate microplastic pollution's health risks across biological and ecological scales (Dang et al., 2022; Koelmans et al., 2022). Despite extensive studies on microplastic occurrence and toxicity, critical knowledge gaps remain regarding their bio-nano interactions, exposure pathways, and cumulative effects on microbiomes and ecosystems(Molina & Benedé, 2022; Perković et al., 2022).Controversies persist over the extent of microplastics' toxicity, with some studies emphasizing physical and chemical hazards, while others highlight biological vectors and microbial interactions (Zolotova et al., 2022). The lack of standardized methodologies and comprehensive risk assessments hampers effective policy and intervention development, potentially exacerbating environmental degradation and health outcomes (Blackburn & Green, 2022).

This review adopts a conceptual framework grounded in the One Health paradigm, defining microplastics as persistent environmental contaminants that interact with biological systems at molecular, organismal, and ecosystem levels (Meaza et al., 2021; Morrison et al., 2022) It integrates concepts of microplastic pollution, microbial biodegradation, and health risk assessment to elucidate the complex interrelations influencing human, animal, and environmental health(Grande-Tovar et al., 2022; Koelmans et al., 2022). This framework supports the systematic evaluation of microplastic impacts and mitigation strategies within a transdisciplinary context.

The purpose of this systematic review is to synthesize current evidence on the One Health approach to mitigating microplastic effects, identify key findings and knowledge gaps, and propose integrated solutions to protect human, animal, and environmental health (Brack et al., 2022; Redford et al., 2022). By bridging disciplinary divides and highlighting emerging research, this review adds value by informing policy, guiding future research, and fostering holistic interventions aligned with global sustainability goals (Courtene-Jones et al., 2022).

The review methodology involves a comprehensive literature analysis of peer-reviewed studies published between 2019 and 2022, selected based on relevance to microplastic pollution, health impacts, and One Health strategies (Grande-Tovar et al., 2022; Morrison et al., 2022).Analytical frameworks include risk assessment, ecological impact evaluation, and biodegradation mechanisms, with findings organized thematically to address sources, effects, and mitigation of microplastics within the One Health context.

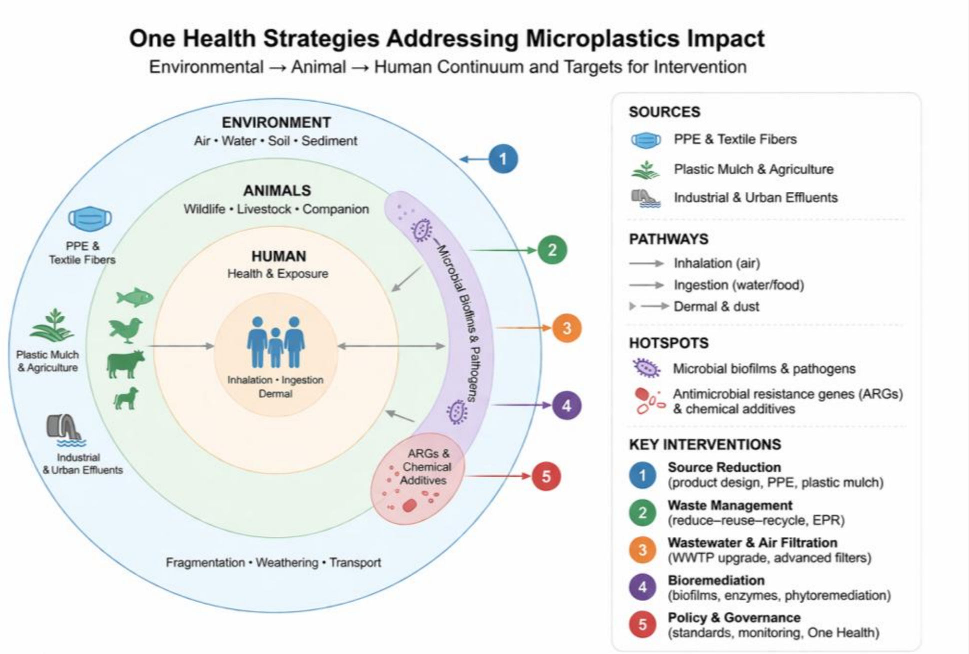

Figure 1. One Health conceptual schematic illustrating microplastic pathways, environmental reservoirs, and cross-domain impacts. Sources include primary microplastics, secondary fragmentation, industrial discharges, agricultural inputs, and pandemic-related biomedical waste. Environmental compartments comprise marine, freshwater, soil, and atmospheric systems, connected by transport processes such as runoff, wind dispersal, and wastewater effluent. Exposure routes to animals and humans include ingestion (seafood and crops), inhalation of airborne particles, dermal contact, and occupational pathways. Arrows denote trophic transfer and feedback loops between the environment, animals, and humans. Insets highlight microplastic-associated biofilms, the carriage of

chemical additives and antibiotic-resistance genes (ARGs), and potential microbial biodegradation. The schematic identifies key points for management interventions, including source reduction, waste management, filtration technologies, and bioremediation, and summarizes the integrated One Health framework applied throughout this review.

2. METHODS: Literature Identification, Selection, and Synthesis

This review employed a narrative synthesis approach to integrate interdisciplinary evidence on microplastics within a One Health framework. We transformed the initial research question into multiple targeted queries to capture toxicological, ecological, epidemiological, and policy-oriented literature, then implemented iterative searches across bibliographic databases and institutional repositories. Studies published between 2015 and 2022 were prioritized to reflect contemporary advances; backward and forward citation chaining was used to capture foundational and emergent work. Inclusion criteria emphasized empirical studies, systematic reviews, meta-analyses, and policy analyses that explicitly addressed microplastic occurrence, exposure pathways, bioaccumulation, microbial interactions, or health/ecological impacts. Exclusion criteria removed studies outside the date range, non-peer-reviewed opinion pieces lacking empirical grounding, and works not addressing at least one One Health domain. Retrieved records were screened for relevance and methodological rigor, then scored and ranked to select highly pertinent studies for synthesis. Thematic coding and comparative analysis were applied to extract cross-cutting themes, identify data gaps (standardization, longitudinal human exposure, inhalation/dermal routes), and highlight mitigation and policy recommendations within a One Health perspective. This narrative approach enabled integration across scales (molecular to ecosystem) and disciplines while acknowledging heterogeneity in methods and geographic coverage.

3. ENVIRONMENTAL OCCURRENCE AND FATE OF MICROPLASTICS

3.1 Sources and major pathways

Microplastics originate from primary sources (manufactured micro-sized particles such as microbeads and industrial abrasives) and secondary sources resulting from fragmentation of larger plastic items (consumer packaging, fishing gear, agricultural mulch, and biomedical waste) that enter the environment via waste mismanagement, runoff, atmospheric deposition, and wastewater effluents. The COVID-19 pandemic exacerbated inputs from single-use medical and protective equipment, elevating biomedical waste as a notable contributor in recent years. Agricultural practices (e.g., sewage sludge application, plastic mulch) and urban runoff are major terrestrial inputs that bridge to aquatic systems, while industrial discharges and stormwater mobilize particles into rivers and coastal zones(Yang et al., 2022). These diverse inputs underscore the multi-sectoral sources relevant to One Health interventions.

3.2 Transport and compartmentalization: aquatic, soil, atmospheric reservoirs

Once released, microplastics partition among aquatic (freshwater and marine), terrestrial (soils and sediments), and atmospheric compartments. Hydrological transport moves particles downstream to estuaries and oceans, while atmospheric processes can redistribute small particles and nanoplastics over long distances, depositing them onto land and water. In soils, microplastics accumulate through sludge application, littering, and agricultural inputs and can be retained or mobilized depending on particle size, shape, and soil structure. Aquatic sediments act as sinks, while benthic resuspension events and bioturbation can reintroduce particles to the water column(Kim et al., 2022). These compartmental dynamics influence exposure routes for wildlife and humans and dictate where mitigation efforts (e.g., wastewater treatment upgrades, land management) are most effective.

3.3 Persistence, fragmentation, and transformation

Microplastics are persistent due to polymer durability and environmental resistance. Physical, chemical, and biological processes fragment larger plastics into micro- and nanoplastics, with factors such as UV exposure, mechanical abrasion, and microbial colonization influencing rates of degradation and size distribution. Weathering alters surface chemistry, increases sorption capacity for organic pollutants and metals, and enhances surface roughness that promotes biofilm formation. Transformation processes produce a continuum of particle sizes and altered reactivity, complicating detection and risk assessment, particularly for nanoplastics which are currently difficult to quantify reliably. The persistence and evolving properties of particles underpin long-term ecological accumulation and potential human exposure via multiple pathways.

4. EXPOSURE PATHWAYS AND BIOACCUMULATION ACROSS SYSTEMS

4.1 Human exposure: food, water, air, occupational routes

Humans are exposed to microplastics chiefly through ingestion (contaminated seafood, drinking water, food crops grown on contaminated soils)(Bansal & Singh, 2022), inhalation of airborne particulates (urban dust, indoor aerosols), and occupational contact in certain industries (textile manufacturing, plastic recycling). Seafood consumption is a prominent ingestion pathway due to trophic transfer and bioaccumulation in marine organisms; crops may accumulate particles via soil–plant transfer and irrigation with contaminated water. Drinking water (tap and bottled) and processed foods have documented microplastic contamination. Inhalation exposure is an emerging concern, with smaller particles and fibers detected in air and indoor environments; dermal uptake is less well characterized but may be relevant for occupational or cosmetic exposures(Vethaak & Leslie, 2016). Quantitative exposure estimates remain uncertain due to methodological heterogeneity and limited longitudinal human data.

4.2 Animal exposure: ingestion, inhalation, entanglement; sentinel species

Wildlife and domestic animals encounter microplastics through ingestion (feeding on contaminated prey or substrates), inhalation, and, in some cases, entanglement or physical entrapment. Aquatic species, seabirds, marine mammals, and benthic invertebrates have been widely documented as ingesting microplastics, with demonstrable physiological effects. Terrestrial species can be exposed via contaminated soil or food sources. Sentinel species (e.g., mussels, seabirds, fish) are useful for monitoring environmental loading and for linking ecosystem contamination to potential human health risks in a One Health context. Biomonitoring using sentinel organisms helps trace trophic transfer and can inform exposure mitigation strategies(Brack et al., 2022).

4.3 Terrestrial and aquatic food-web transfer and trophic accumulation

Microplastics can transfer across trophic levels via ingestion and assimilation pathways. Primary consumers ingest particles that are then consumed by predators, facilitating trophic accumulation and potential biomagnification of associated chemical additives or sorbed pollutants. Evidence demonstrates particle retention in digestive systems and, for smaller particles, potential translocation to tissues; however, the extent of true biomagnification versus trophic dilution varies across systems and particle types. Soil–plant pathways allow terrestrial entry into food webs through crop uptake, herbivore exposure, and subsequent transfer to higher trophic levels, establishing food-chain routes for human exposure(Kim et al., 2022).

4.4 Dermal and inhalation exposures: emerging evidence and uncertainties

Dermal absorption of intact microplastics remains poorly characterized; potential exposure via cosmetics and personal-care products is a plausible concern for localized skin interactions and for small particles penetrating compromised skin. Inhalation pathways are increasingly recognized: airborne microplastic fibers and particles have been detected in indoor and outdoor air and may deposit in the respiratory tract, with nano-sized plastics more likely to translocate across epithelial barriers. Major uncertainties include particle-size–dependent deposition, clearance mechanisms, dose metrics for health effects, and the relative contribution of inhalation versus ingestion to total human burden(Zhang et al., 2020). Standardized sampling and exposure assessment methods are needed to close these gaps.

5. BIOLOGICAL AND HEALTH IMPACTS

5.1 Physical and mechanical effects

At organismal scales, ingested microplastics can cause gastrointestinal obstruction, reduced feeding efficiency, and tissue abrasion. In aquatic animals, physical blockage and reduced energy reserves have been observed; in extreme cases, entanglement and mechanical injury are reported. The severity of mechanical effects depends on particle size, shape (e.g., fibers vs. fragments), and load relative to organism physiology. These mechanical stressors can cascade to affect growth, reproduction, and survival, with implications for population and ecosystem-level health(Deng et al., 2017; Zhang et al., 2020).

5.2 Chemical toxicity: additives, sorbed pollutants, and leaching

Microplastics carry intrinsic chemical risks via polymer additives (plasticizers, flame retardants, stabilizers) and by sorbing persistent organic pollutants and metals from the environment. These chemicals can desorb under biological conditions, potentially producing endocrine disruption, developmental toxicity, and other systemic effects. The combined exposure to particle-associated chemicals, environmental contaminants, and the plastic matrix poses complex mixture toxicities that are difficult to disentangle in laboratory and field studies(Biamis et al., 2021). Chemical-mediated effects are a central pathway by which microplastics may impact animal and human health beyond purely physical interactions.

5.3 Cellular and molecular effects: oxidative stress, genotoxicity, endocrine disruption

Experimental studies report particle-induced oxidative stress, inflammatory responses, and molecular perturbations (e.g., altered gene expression, cellular damage) across taxa. Nanoplastic fractions are of particular concern for cellular uptake and possible genotoxicity. Observed endpoints include increased reactive oxygen species, DNA damage markers, altered endocrine signaling, and mitochondrial dysfunction in laboratory models. Translating these mechanistic findings to population- or human-level health risk is constrained by dose metrics, exposure realism, and interspecies differences, yet these cellular effects provide plausible mechanistic linkages between environmental contamination and adverse health outcomes(Brack et al., 2022; Hussain, 2014; Redford et al., 2022; Rillig et al., 2017; Xia et al., 2008).

5.4 Microbiome and immune impacts: dysbiosis and systemic effects

Microplastics act as substrates for microbial colonization, forming biofilms that may harbor pathogens and antibiotic resistance genes (ARGs). Ingestion of particle-associated biofilms can alter gut microbiota composition, leading to dysbiosis, inflammatory responses, and downstream systemic effects. Aquaculture and natural aquatic systems have reported biofilm-mediated pathogen transfer, raising One Health concerns where animal health, ecosystem health, and human food safety intersect. Conversely, microbial communities also include plastic-degrading taxa that could be harnessed for remediation; however, mechanistic understanding of microplastic–microbe interactions and their net health implications remains incomplete and requires standardized, cross-disciplinary study designs(Cholewińska et al., 2022; Grande-Tovar et al., 2022).

Table 1: Summary of reviewed studies on microplastics within a One Health framework, highlighting impact scope, exposure pathways, management strategies, microbial interactions, and multidisciplinary integration. The table provides an overview of current evidence and key research trends.

Impact Assessment Scope	Exposure Pathway Characterization	Mitigation Strategy Effectiveness	Microbial Interaction Analysis	Integration of Multidisciplinary Evidence	Study
Comprehensive across molecular to ecosystem levels	Identifies multiple environmental compartments and transport mechanisms	Proposes One Health-based integrated solutions	Highlights plastics as vectors for microbes and chemicals	Strong integration of biological scales and health domains	(Morrison et al., 2022)
Focus on nanoplastics risks to environment and humans	Emphasizes environmental exposure and bio-nano interactions	Calls for multidisciplinary One Health risk mitigation	Notes microbial roles but limited detailed analysis	Advocates for robust multidisciplinary evidence generation	(Dang et al., 2022)
Animal health impacts in aquaculture systems	Details microplastic migration from terrestrial to aquatic environments	Urges urgent reduction of microplastic influx	Examines biofilms harboring pathogens on plastics	Links environmental, animal, and human health via One Health	(Cholewińska et al., 2022)
Reviews ARGs and microplastics in multiple environments	Covers aquatic, terrestrial, and atmospheric pathways	Discusses removal strategies for contaminants	Highlights biofilm-mediated ARG transfer on microplastics	Emphasizes One Health perspective for risk management	(Niu et al., 2022)
Evaluates cumulative xenobiotic impacts including microplastics	Focuses on dietary and environmental exposure routes	Suggests integration of microbiome biomarkers in mitigation	Discusses microbiota modulation by xenobiotics	Integrates toxicology, microbiology, and risk assessment	(Ortiz et al., 2022)

Water contamination impacts on human, animal, environment	Identifies diverse contaminants including microplastics in water	Recommends integrated One Health water management	Notes pathogen transmission via contaminated water	Integrates sociocultural and environmental health factors	(Prata, 2022)
Broad environmental and human health impacts of plastics	Discusses plastics as vectors for chemicals and pathogens	Advocates system approaches for plastic pollution solutions	Reviews biofilm formation and pathogen carriage	Calls for integrative system-level research and policy	(Courtene-Jones et al., 2022)
Ecosystem-level ecotoxicological impacts of micro/nanoplastics	Describes occurrence in air, soil, water, food chains	Reviews detection and mitigation strategies	Notes microbial biofilms on microplastics	Synthesizes ecological and toxicological perspectives	(Kiran et al., 2022)
Animal health effects across aquatic and terrestrial species	Summarizes ingestion and exposure routes in animals	Notes experimental data gaps and variability	Discusses microplastic-induced oxidative stress and damage	Combines ecological and biomedical evidence	(Zolotova et al., 2022))
Human health risks from micro/nanoplastics in food	Identifies physical, chemical, biological hazards	Notes lack of exposure level data and risk quantification	Mentions potential microbiome and immune effects	Calls for comprehensive risk assessment frameworks	(Molina & Benedé, 2022)
Comparative microplastic exposure in humans, marine mammals, turtles	Examines ingestion, inhalation, dermal exposure routes	Highlights need for prolonged exposure studies	Reports immune and oxidative stress responses	Integrates toxicology with environmental health data	(Meaza et al., 2021)
Marine sentinel species for environmental and public health	Focuses on shared toxicity mechanisms across species	Uses sentinel monitoring for exposure assessment	Explores bioinformatics for pathway elucidation	Combines ecotoxicology, genomics, and One Health	(Biamis et al., 2021)
Environmental and human health consequences of microplastics	Details cellular and genetic damage, microbial transport	Urges urgent environmental recovery actions	Notes microplastics as microbial transport surfaces	Synthesizes environmental toxicology and health impacts	(Silva et al., 2022)
COVID-19 protective equipment as emerging microplastic source	Describes pollution in aquatic, terrestrial, atmospheric media	Recommends sustainable management and research priorities	Highlights animal harm via entanglement and ingestion	Links pandemic waste to One Health pollution concerns	(Yang et al., 2022)
Soil microplastic pollution effects on	Details sources like sludge, mulching,	Discusses impacts on soil biota and human toxicity	Examines microplastic vector role for pollutants	Combines soil science, toxicology, and health risk	(Bansal & Singh, 2022)

microbes, crops, humans	irrigation				
Microplastic accumulation and bioremediation in agricultural soils	Describes sources, accumulation, and bio-toxicity	Reviews extraction and bioremediation strategies	Notes trophic transfer to humans via food chain	Integrates agronomy, ecology, and health sciences	(Yadav et al., 2022)
Microplastic contamination in global agro-ecosystems	Details sources, mobility, fate, and toxicity in soils	Calls for pollution control and sustainable policies	Highlights contaminant transport by microplastics	Synthesizes soil science, ecology, and policy frameworks	(Uwamungu et al., 2022)
Global science-policy call for chemical and waste management	Emphasizes One Health risks from chemicals and wastes	Advocates international science-policy interface body	Addresses chemical mixtures and ecosystem risks	Promotes systems thinking and solution-oriented assessments	(Brack et al., 2022)
Ten-year micro/nanoplastic research milestones and effects	Summarizes sources, fate, and environmental impacts	Reviews analytical advances and exposure pathways	Notes bioaccumulation and ecosystem effects	Synthesizes multidisciplinary research progress	(Allen et al., 2022)
Environmental fate and biological impacts of microplastics	Describes sources, persistence, and ecological consequences	Calls for new technologies and stricter policies	Notes endocrine disruption and cellular effects	Integrates ecology, toxicology, and policy analysis	(Reeves et al., 2022)
Human health risks from microplastics and antibiotic resistance in soils	Reviews contamination sources and exposure pathways	Highlights knowledge gaps and monitoring needs	Discusses microbial interactions and resistance spread	Combines soil science, microbiology, and health risk	(Perković et al., 2022)
Meta-analysis of micro/nanoplastics effects on plants	Evaluates species-specific toxicity and exposure duration	Identifies research gaps in trophic transfer and accumulation	Notes limited mechanistic insights	Integrates plant science, toxicology, and environmental risk	(Azeem et al., 2022)
Meta-analysis of macro/microplastics on crop growth and soil health	Quantifies negative impacts related to plastic content and type	Provides policy-relevant findings for sustainable agriculture	Notes time-dependent effects on soil and plants	Combines agronomy, toxicology, and policy implications	(Gao et al., 2022)
Microplastics in Great Lakes: environmental and health implications	Reviews occurrence, exposure routes, and socioeconomic impacts	Discusses policy and circular economy remedies	Notes vector role for pollutants and pathogens	Integrates environmental science, public health, and policy	(Fuschi et al., 2022)

Bibliometric study of micro/nanoplastics and microorganisms	Maps research trends and microbial biodegradation	Identifies need for standardized methodologies	Details microbial roles in degradation and pathogen spread	Integrates bibliometrics, microbiology, and environmental science	(Grande-Tovar et al., 2022)
Microplastic sources, routes, and organism effects	Reviews terrestrial, atmospheric, aquatic pathways	Discusses ecological impacts on animals, plants, microbes	Notes oxidative stress and growth inhibition	Combines environmental science and ecotoxicology	(Kim et al., 2022)
Microplastic accumulation and impacts on ecosystems and health	Analyzes global distribution and toxic chemical additives	Reviews detection methods and pyrolysis treatment	Notes chemical toxicity and ecosystem disruption	Integrates environmental chemistry and toxicology	(Korinenko, 2022)
One Health framework linking biodiversity and human health	Emphasizes cross-sectoral and transdisciplinary approaches	Calls for inclusive, multidisciplinary conservation efforts	Highlights ecosystem and microbial health links	Integrates conservation biology and One Health policy	(Redford et al., 2022)
Systems approach to plastic pollution risk and mitigation	Highlights complexity of social, economic, environmental factors	Advocates integrative frameworks for policy development	Notes need for stakeholder engagement	Combines systems science, policy, and environmental health	(Courtene-Jones et al., 2022)
Ecological pathology and One Health pollutant effects	Explores pollutant impacts on microbes, insects, fish, humans	Emphasizes ecosystem-level One Health interactions	Discusses synergistic pollutant effects	Integrates pathology, ecology, and One Health	(Haschek et al., 2019)
Sustainable management of micro/nanoplastics in environment	Reviews ecotoxicological impacts and circular economy approaches	Evaluates waste management and policy needs	Highlights source reduction and valorization	Integrates environmental management and policy	(Redford et al., 2022)
Human health effects of microplastics: knowns and unknowns	Summarizes exposure routes and potential toxic effects	Notes limited clinical evidence and research gaps	Discusses immune and reproductive toxicity	Integrates toxicology and human health risk	(Blackburn & Green, 2022)
Microplastic contamination in seafood and human health risks	Reviews ingestion rates, polymer types, and pollutant transfer	Highlights chemical additive leaching and human exposure	Notes trophic transfer and DNA damage risks	Combines marine biology, toxicology, and public health	(Kibria et al., 2022)
Risk assessment framework for	Reviews particle diversity and effect	Proposes probabilistic exposure and effect	Discusses unique microplastic properties vs	Integrates risk assessment and environmental toxicology	(Koelmans et al., 2022)

microplastic particles	mechanisms	thresholds	natural particles		
Evidence-based commentaries on microplastic environmenta l health	Highlights need for detection and mitigation methods	Notes emerging contaminant presence in human tissues	Calls for robust evaluation of health impacts	Integrates environmental health and policy	(Gross & Enck, 2021)
Integrated approach to emerging contaminant risk mitigation	Reviews hard and soft engineering tools for pollution control	Emphasizes human factor and surveillance systems	Discusses economic instruments and public engagement	Combines engineering, policy, and health risk	(Gwenzi et al., 2022)
Assessment of emerging plastics on environment and health	Evaluates micro/nanopl astic risks and treatment technologies	Reviews biodegradable plastics and recycling approaches	Discusses agroecosyste m impacts and prevention	Integrates environmental engineering and health sciences	(Joo, 2022)

6. MICROBIAL INTERACTIONS, BIOFILMS, AND ANTIMICROBIAL RESISTANCE

6.1. Biofilm formation on plastic surfaces: composition and dynamics

Microplastics rapidly acquire surface conditioning films upon environmental exposure, promoting colonization by diverse microbial consortia that form biofilms. These plastisphere communities typically comprise bacteria, archaea, fungi, and protists whose composition depends on polymer type, particle size and shape, environmental compartment (freshwater, marine, soil, air), and local physicochemical conditions (temperature, nutrient availability, salinity). Biofilm development proceeds through sequential stages—initial adsorption of organic molecules, pioneer colonizer attachment, extracellular polymeric substance (EPS) production, and successional replacement—yielding structured microenvironments with gradients in oxygen, pH, and substrate availability. Such heterogeneity fosters niche partitioning and potential selection for taxa adapted to hydrophobic surfaces or pollutant-utilizing metabolisms. The plastisphere can differ markedly from surrounding planktonic or benthic communities, with implications for biogeochemical processing, contaminant transformation, and host exposure routes(Cholewińska et al., 2022; Grande-Tovar et al., 2022).

6.2. Microplastics as vectors for pathogens and antibiotic-resistance genes (ARGs)

Because biofilms concentrate cells and facilitate horizontal gene transfer, microplastics can act as vectors for pathogenic and opportunistic microorganisms and for dissemination of antibiotic-resistance genes (ARGs). Evidence documents pathogen enrichment on plastic surfaces in aquaculture and natural waters, raising concerns for animal and human health via contaminated seafood, water, or contact with contaminated environments. The close proximity of diverse microbes within EPS matrices enhances conjugation and other gene-exchange mechanisms, potentially accelerating ARG spread across environmental reservoirs. The vector role of microplastics is compounded when particles sorb chemical pollutants that may co-select for resistance or stress-adaptive traits, amplifying public-health-relevant risks. Nevertheless, studies vary in scope and methods, and quantification of vectoring capacity across ecosystems remains incomplete(Niu et al., 2022; Perković et al., 2022).

6.3. Microbial biodegradation potential: taxa, enzymes, and bioremediation prospects

Microbial degradation of some plastics has been reported under laboratory and environmental conditions, implicating taxa across bacteria and fungi that express depolymerizing enzymes (e.g., hydrolases, esterases, cutinases, laccases) capable of attacking certain polymer backbones. Research highlights examples of biodegradation potential—especially for more labile polymers and in engineered systems—but rates are often slow and context-dependent. Bioprospecting and omics-driven discovery of degradation pathways, coupled with enzyme engineering and microbial consortia optimization, offer promising routes for bioremediation and circular-economy technologies. However, scalable field application faces challenges including heterogeneity of environmental plastics, competing ecological interactions, and uncertainty about by-products and their ecotoxicity. Realistic deployment will require rigorous environmental risk assessments and integration with broader waste-management strategies(Reeves et al., 2022).

6.4. Knowledge gaps in microbial mechanism studies and standardization

Significant methodological heterogeneity hampers cross-study comparison of plastisphere composition, pathogen prevalence, ARG dynamics, and biodegradation potential. Key gaps include standardized sampling and molecular protocols for microbial community characterization, limited in situ longitudinal studies that capture successional dynamics, sparse mechanistic work on gene transfer rates within biofilms on plastics, and insufficient evaluation of degradation by-products and their toxicity. The interplay between chemical sorbates, microbial communities, and host organisms—central to One Health risk assessments—remains undercharacterized. Addressing these gaps requires harmonized methods, integrative omics and culture-based approaches, and interdisciplinary field experiments linking microbial ecology to ecotoxicology and public health outcomes(Allen et al., 2019; Blackburn & Green, 2022; Molina & Benedé, 2022).

7. MONITORING, BIOMONITORING, AND SENTINEL SPECIES

7.1. Sentinel species approaches in marine and terrestrial systems

Sentinel species (e.g., mussels, bivalves, certain fish, seabirds, and selected terrestrial invertebrates) provide practical indicators of microplastic presence and biological effects because they integrate exposure over time, are relatively tractable to sample, and can reflect local or regional pollution. Marine mussels and filter feeders have been widely used for monitoring because their feeding mode concentrates suspended particles, enabling comparisons across sites and temporal trends. Terrestrial sentinels—soil invertebrates, earthworms, or crop plants—can indicate soil microplastic burdens and ecological impacts. Sentinel-based biomonitoring supports One Health aims by linking environmental contamination to ecological endpoints and potential human exposure via shared resources (e.g., seafood, crops). Standardizing sentinel selection, sampling frequency, and biomarkers (e.g., particle loads, physiological stress markers, microbiome shifts) is essential to maximize comparability and utility for policy and public health surveillance(Biamis et al., 2021; Meaza et al., 2021).

7.2. Biomonitoring methods and indicators for One Health surveillance

Biomonitoring employs a suite of indicators ranging from particle counts and polymer identification (via spectroscopy or thermal methods) to biological endpoints such as tissue burdens, biomarkers of oxidative stress or inflammation, and microbiome composition. Integrative surveillance frameworks align environmental sampling (water, sediment, soil, air) with biomonitoring of sentinel organisms and human exposure proxies (e.g., drinking water, seafood, stool or sputum analyses). Effective One Health monitoring emphasizes harmonized analytical protocols, validated exposure biomarkers, and linkage of environmental measures to health-relevant outcomes. Advances in analytical chemistry and molecular diagnostics enhance detection sensitivity but require cross-laboratory validation and accessible capacity building for wide deployment(Courtene-Jones et al., 2022; Morrison et al., 2022).

7.3. Gaps and regional disparities in monitoring capacity

Monitoring is unevenly distributed geographically, with data-rich regions dominating the literature and substantial gaps in Africa, Latin America, and parts of Asia. Limitations include insufficient laboratory infrastructure, lack of standardized methods, and constrained funding for longitudinal surveillance. These disparities impede equitable risk assessment and global policy coordination. Building global monitoring networks, technology transfer, and capacity building—together with harmonized protocols and open data sharing—are critical to generate representative, comparable evidence that supports transboundary mitigation and equitable One Health interventions.

8. MITIGATION STRATEGIES AND TECHNOLOGICAL INTERVENTIONS

8.1. Source reduction and product design: upstream measures and circular economy

Upstream interventions—reducing single-use products, redesigning materials for durability and recyclability, adopting circular-economy principles, and promoting alternatives to problematic polymers—are foundational to lowering microplastic inputs. Product design changes (e.g., replacing microbeads, using biodegradable or truly compostable materials validated under realistic conditions) and policy measures (bans, producer responsibility schemes) can reduce generation of secondary microplastics. Behavioral interventions and market incentives are necessary complements to regulatory measures to shift consumption and manufacturing patterns. Integrated life-cycle thinking ensures that substitution and circular solutions do not create unintended environmental trade-offs(Redford et al., 2022).

8.2. Waste management, recycling, and biomedical-waste controls (COVID-19 implications)

Improved waste collection, segregation, and high-quality recycling reduce mismanaged plastics that fragment into microplastics. The COVID-19 pandemic highlighted vulnerabilities: surges in biomedical and single-use protective equipment increased plastic loads and underscored the need for targeted biomedical-waste controls, safe disposal infrastructure, and adapted recycling streams. Strengthening informal sector inclusion, investing in municipal waste systems, and updating guidance for healthcare waste are critical to mitigate pandemic-related and routine biomedical contributions to microplastic pollution. Policy coherence across public health and environmental management domains is required for effective implementation(Yang et al., 2022).

8.3. End-of-pipe technologies: filtration, wastewater treatment upgrades, air filtration

End-of-pipe solutions include improved wastewater treatment (tertiary filtration, membrane technologies, advanced coagulation) to capture microplastics before discharge; stormwater controls to reduce runoff transport; and air filtration systems (in industrial and indoor settings) to limit airborne exposure. While effective at reducing environmental release and human exposure at point sources, these technologies vary in cost and energy demand and may generate concentrated residues requiring safe handling and disposal. Pilot implementations indicate potential benefits, but scaling requires economic appraisal and integration with upstream measures to achieve sustainable reductions(Brack et al., 2022).

8.4. Bioremediation and biodegradation: microbial and engineered approaches

Biotechnological strategies leverage microbial degraders and engineered enzymes to accelerate breakdown of susceptible polymers. Promising laboratory and pilot studies demonstrate partial depolymerization and potential for valorization of breakdown products, but field-scale efficacy and environmental safety remain to be proven. Combining biodegradation with physical removal and circular processing could form part of a multi-pronged mitigation portfolio, yet careful evaluation of by-products, unintended ecological effects, and socio-economic viability is necessary before widescale adoption(Yadav et al., 2022).

8.5. Socio-economic considerations and stakeholder engagement in intervention design

Successful interventions require socio-economic feasibility, stakeholder buy-in, and context-sensitive design. This includes addressing informal recycling sectors, aligning incentives for producers and consumers, and tailoring measures to local infrastructure and cultural practices. Engagement of communities, industry, public health authorities, and regulators enhances legitimacy and adoption of mitigation measures. Cost–benefit analyses, co-design processes, and equitable transition pathways are pivotal to balance environmental goals with livelihoods and development priorities.

8.6. Evidence on mitigation effectiveness: pilot projects and evaluation gaps

Although many mitigation approaches are proposed, empirical evaluations of their effectiveness are limited; most remain theoretical or at pilot stages. There is a need for rigorous monitoring and assessment of interventions (technological, policy, behavioral) including environmental outcomes, health impacts, cost-effectiveness, and scalability. Standardized metrics and long-term studies are necessary to move from promising pilots to validated, policy-ready solutions within One Health frameworks.

9. POLICY, GOVERNANCE, AND ONE HEALTH IMPLEMENTATION

9.1. Existing regulatory landscape and international policy calls

Policy responses include national regulations (e.g., bans on microbeads and certain single-use plastics), regional strategies on marine litter, and international calls for coordinated action on chemical and waste management. Scientific and policy communities advocate for a stronger global science–policy interface to address microplastics within the broader context of chemical pollution and planetary health. However, the regulatory landscape is fragmented and often sector-specific, limiting comprehensive control across the life cycle of plastics. Integrative policies that bridge waste, chemical, public health, and agricultural sectors better align with One Health objectives.

9.2. Science–policy interfaces and the need for integrative governance bodies

Several analyses urge establishment or empowerment of international science–policy mechanisms to synthesize evidence, set standards, and coordinate transboundary responses. Integrative governance bodies can harmonize monitoring standards, guide risk assessment frameworks that incorporate ecological and human health data, and mobilize resources for capacity building in data-poor regions. These interfaces should facilitate stakeholder engagement, transparent evidence translation, and adaptive governance responsive to evolving science.

9.3. Surveillance, reporting standards, and capacity building

Effective governance depends on harmonized surveillance systems, common reporting standards for microplastic monitoring, and investments in laboratory and human capacity globally. Standardized protocols for sampling, polymer identification, and biological indicators will improve comparability and policymaking. Capacity building should prioritize regions with limited data and align surveillance outputs with policy-relevant indicators to inform regulatory action and public health protection.

9.4. Equity, data-poor regions, and transboundary challenges

Addressing microplastics equitably requires attention to data gaps and infrastructure constraints in low- and middle-income countries, where the burden of mismanaged waste can be high. Transboundary transport of microplastics complicates national control efforts and necessitates international cooperation. Policies must consider differential capacities, provide technical and financial support, and ensure that global strategies do not disproportionately shift burdens onto vulnerable populations. Equitable One Health governance balances global coordination with local adaptation and capacity strengthening.

10. METHODOLOGICAL LIMITATIONS AND RESEARCH GAPS

10.1. Heterogeneity in sampling, extraction, and analytical methods

Across environmental compartments, studies employ diverse collection strategies, particle size cutoffs, extraction protocols, and analytical platforms (e.g., visual sorting, Fourier-transform infrared spectroscopy, Raman spectroscopy, pyrolysis-GC/MS), producing datasets that are difficult to compare or synthesize. This methodological heterogeneity affects detection limits—especially for small micro- and nanoplastics—quantification accuracy, polymer identification fidelity, and repeatability. Differences in sample pre-treatment (digestion, density separation), contamination controls, and reporting units (particle counts, mass, surface area) further complicate meta-analysis and risk extrapolation. The lack of common quality-control standards and interlaboratory validation undermine confidence in cross-study comparisons and obstructs regulatory thresholds grounded in robust exposure data. Harmonized sampling frameworks, validated laboratory protocols, and proficiency testing are needed to produce comparable, policy-relevant evidence and to enable robust global monitoring networks.

10.2. Lack of standardized exposure metrics and dose–response data

The literature lacks consensus on exposure metrics that meaningfully link environmental measurements to biological dose and adverse outcomes. Studies vary in reporting particle number versus mass, differ in particle size classes, and seldom contextualize external environmental concentrations in terms of internal dose or biologically effective exposure. Consequently, dose–response relationships for key endpoints (inflammation, oxidative stress, reproductive outcomes, microbiome perturbation) are poorly defined, limiting quantitative risk assessment. Experimental work often uses unrealistically high particle concentrations, non-environmental particle types, or single-endpoint assays, resulting in limited ecological and human health relevance. Establishing harmonized exposure units, validated biomarkers of internal dose (including particle burden, chemical additive biomarkers, and microbiome signatures), and benchmark dose–response data across taxa are essential prerequisites for meaningful One Health risk modelling and regulatory guidance.

10.3. Shortcomings in longitudinal and human epidemiological studies

Most evidence derives from cross-sectional, laboratory, or short-term exposure studies, producing limited insight into chronic, cumulative, or delayed effects of microplastics on humans and wildlife. There is a conspicuous scarcity of well-designed longitudinal cohorts or case-control studies linking measured exposure biomarkers to health outcomes over time, including immune, metabolic, developmental, and microbiome endpoints. Human epidemiological data remain sparse and often rely on indirect exposure estimates rather than measured internal burdens, constraining causal inference and public-health decision-making. Similarly, few long-term ecological field studies capture life-history consequences or population-level impacts in sentinel species. Investment in prospective human cohorts, integrated animal sentinel monitoring, and multi-year ecosystem studies is necessary to establish temporal exposure–effect relationships critical for One Health interventions.

10.4. Gaps in socio-economic and implementation research

While technical mitigation options are increasingly described, there is limited empirical evidence on socio-economic feasibility, cost–benefit outcomes, stakeholder acceptance, and implementation pathways—particularly in low- and middle-income regions. Few studies assess impacts on informal recycling sectors, employment, or equity implications of policy measures (e.g., bans, producer responsibility) and technological upgrades (wastewater treatment, advanced filtration). The COVID-19 pandemic exposed practical governance and infrastructural vulnerabilities (e.g., surges in biomedical waste) but systematic analyses of pandemic-related policy responses, behavioral drivers, and scalable operational protocols are limited. To ensure equitable and practicable One Health interventions, research must incorporate implementation science, socio-economic modelling, participatory approaches, and evaluation frameworks that measure real-world effectiveness and co-benefits across communities(Morrison et al., 2022).

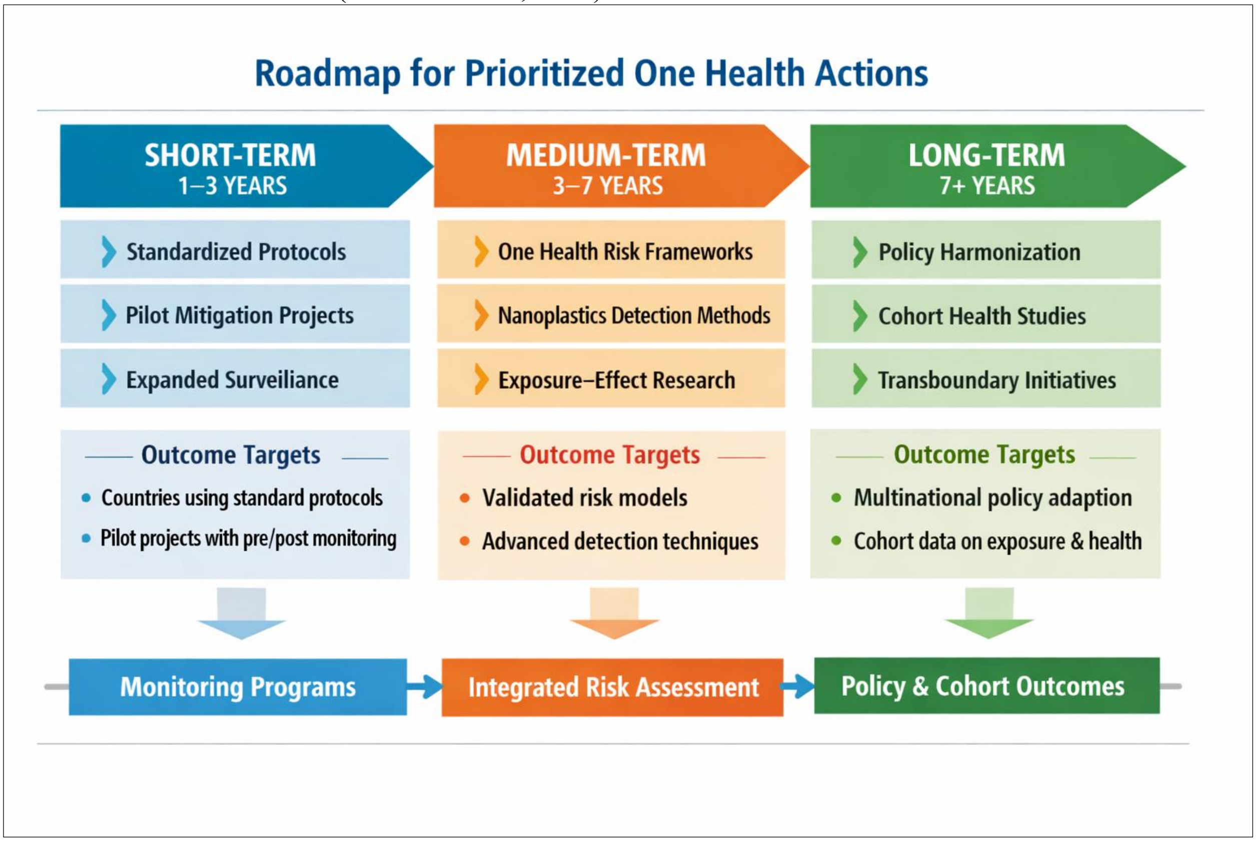

Figure 2. Roadmap for prioritized One Health actions to address microplastic pollution. The figure outlines short-, medium-, and long-term strategies, including standardized monitoring, improved waste management and filtration technologies, development of risk-assessment frameworks, and long-term policy and health studies. Arrows indicate links between research, surveillance, and policy, highlighting coordinated actions across environmental, animal, and human health systems.

11. RECOMMENDATIONS AND A ROADMAP FOR ONE HEALTH ACTION

11.1. Research priorities: standardized protocols, integrated risk models, longitudinal cohorts

- Standardize methods: Develop and promulgate harmonized protocols for sampling, particle isolation, polymer identification, and quality control across matrices (water, sediments, soil, air, biota), including agreed particle size classes and reporting units to facilitate comparability and meta-analysis.
- Integrated risk models: Build mechanistic, cross-scale models that couple environmental fate and transport, plastisphere microbial dynamics (including ARG exchange), exposure-dose conversion, and toxicological endpoints across humans, animals, and ecosystems. Models should explicitly handle chemical co-contaminants and mixtures.
- Longitudinal cohorts and sentinel networks: Establish prospective human cohorts with validated exposure biomarkers alongside coordinated sentinel species monitoring and environmental surveillance to link exposures to health outcomes over time. Prioritize inclusion of underrepresented regions and vulnerable populations.
- Analytical innovation: Invest in sensitive, cost-effective detection methods for small micro- and nanoplastics and standardized biomarker assays (e.g., internal particle burden, additive biomarkers, microbiome signatures).

These research priorities are aligned with the review's identified needs to improve comparability, mechanistic understanding, and policy relevance.

11.2. Policy and regulatory priorities: source controls, monitoring frameworks, pandemic-waste protocols

- Source control: Prioritize upstream measures such as bans on primary microplastics (e.g., microbeads), product redesign for reduced fragmentation, extended producer responsibility, and circular-economy incentives.
- Monitoring frameworks: Implement harmonized monitoring and reporting standards (environmental and biomonitoring) integrated into national surveillance and international reporting, with standardized indicators tied

to One Health outcomes.
- Pandemic and biomedical-waste protocols: Develop and mainstream protocols for safe handling, segregation, and disposal of biomedical plastics that anticipate surge scenarios (e.g., pandemics), coupled with contingency plans to prevent plastic leakage into the environment.
- International coordination: Support science–policy interfaces and governance bodies to harmonize standards, mobilize technical assistance to data-poor regions, and foster transboundary cooperation.
These priorities respond to the literature's call for integrated policy approaches that cross waste, chemical, public health, and agricultural sectors.

11.3. Technical and operational priorities: pilot evaluations, scalable biodegradation, treatment upgrades
- Pilot evaluations: Fund multi-site pilot projects that rigorously evaluate technical interventions (wastewater tertiary filtration, stormwater controls, community recycling schemes), including environmental outcomes, costs, and social impacts.
- Scalable biodegradation: Advance safe, well-controlled research into microbial and enzymatic degradation, emphasizing environmental safety, by-product characterization, and integration with circular processing streams before field deployment.
- Treatment upgrades: Prioritize cost-effective treatment upgrades (e.g., targeted filtration in high-risk discharges, hospital effluents) with guidance on management of captured residues.
- Implementation science: Integrate operational research to identify barriers, optimize logistics, and tailor solutions to local contexts.
These operational priorities address the literature's note that many promising solutions remain unproven at scale and require rigorous evaluation.

11.4. Cross-sectoral collaboration, public engagement, and capacity building
Cross-sectoral platforms: Create national and regional One Health task forces to coordinate environment, health, agriculture, and waste management sectors for coherent policy and operational responses.
Public engagement: Co-design interventions with communities and stakeholders (including informal sector actors) to ensure acceptability, sustainability, and equitable outcomes.
Capacity building: Invest in laboratory infrastructure, workforce training, and technology transfer—especially for underrepresented regions—to enable standardized monitoring and evidence-based policy.
Open data and knowledge exchange: Foster data sharing, centralized repositories, and collaborative networks to accelerate learning and harmonize practice.
These actions align with calls for inclusive governance and capacity strengthening to make One Health approaches operational globally.

12. DISCUSSION
12.1. Synthesizing evidence across human, animal, and environmental domains
The integrated literature demonstrates that microplastics are pervasive across compartments and can affect biological systems from microbes to humans through multiple exposure routes (ingestion, inhalation, dermal). Microplastics serve both as stressors (physical and chemical) and as ecological vectors (microbial biofilms, ARGs), yielding complex pathways to health impacts. Synthesizing evidence requires harmonized metrics and cross-disciplinary translation so environmental measurements can be meaningfully linked to biological dose and outcomes. While conceptual One Health frameworks are well established, operationalizing them demands bridging methodological divides and generating longitudinal, transdisciplinary datasets to enable coherent risk assessment and targeted mitigation.

12.2. Translating One Health science into practice: barriers and enablers
Barriers include methodological heterogeneity, regional disparities in monitoring capacity, limited socio-economic evidence, and fragmented governance across sectors. Enablers are: standardized protocols, empowered science–policy bodies, pilot-tested interventions with documented socio-economic co-benefits, and stakeholder co-design. Scaling effective practices will require aligning incentives across stakeholders (industry, municipalities, healthcare, communities), sustained funding for long-term monitoring and implementation research, and adaptive governance that can respond to emerging evidence. The COVID-19 experience illustrates both risks (surge in biomedical plastics) and the need for resilient waste systems that integrate public health and environmental protection.

12.3. The role of transdisciplinary research and stakeholder partnerships
Transdisciplinary research—and meaningful partnerships among scientists, policymakers, industry, civil society,

and affected communities—is essential to translate mechanistic understanding into feasible interventions. Co-produced research agendas, shared monitoring platforms, and participatory evaluation methods can ensure interventions are context-appropriate, socially acceptable, and scientifically robust. Cross-sectoral training programs and joint funding mechanisms will catalyze the integration required to advance a practical One Health response to microplastic risks.

13. CONCLUSIONS

13.1. Key takeaways

Microplastics are ubiquitous across environmental matrices and biological taxa and act as physical stressors, chemical carriers, and microbial vectors that can affect human, animal, and ecosystem health.

Major methodological and data gaps—heterogeneous sampling and analysis, limited exposure metrics, paucity of longitudinal human and ecological studies, and scarce socio-economic implementation research—constrain quantitative risk assessment and policy development.

Priority actions include standardizing methods, establishing longitudinal cohorts and sentinel networks, piloting and evaluating mitigation technologies, strengthening waste and pandemic-waste protocols, and building cross-sectoral governance and capacity. These actions are fundamental to making One Health approaches operational and effective.

13.2. Urgency and the path forward for One Health mitigation of microplastic risks

Given the evidence of pervasive contamination and plausible pathways to adverse health and ecological outcomes, there is an urgent need to move from conceptual frameworks to coordinated action. This requires investing in harmonized science, pilot-tested interventions, governance mechanisms that cross disciplinary and sectoral boundaries, and equitable capacity building to ensure global representativeness. A pragmatic, phased roadmap—combining upstream source reduction, targeted treatment upgrades, validated biodegradation research, standardized monitoring, and stakeholder engagement—offers a feasible pathway to reduce microplastic risks to human, animal, and environmental health at scale.

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Abbreviations

ARGs – Antibiotic Resistance Genes
EPS – Extracellular Polymeric Substances
FTIR – Fourier-Transform Infrared Spectroscopy
GC/MS – Gas Chromatography–Mass Spectrometry
One Health – One Health Framework
PPE – Personal Protective Equipment
QC – Quality Control
UV – Ultraviolet

References

1. Allen, S., Allen, D., Karbalaei, S., Maselli, V., & Walker, T. R. (2022). Micro(nano)plastics sources, fate, and effects: What we know after ten years of research. Journal of Hazardous Materials Advances, 6, 100057. https://doi.org/10.1016/j.hazadv.2022.100057
2. Allen, S., Allen, D., Phoenix, V. R., Le Roux, G., Durántez Jiménez, P., Simonneau, A., Binet, S., & Galop, D. (2019). Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nature Geoscience, 12(5), 339–344. https://doi.org/10.1038/s41561-019-0335-5
3. Azeem, I., Adeel, M., Ahmad, M. A., Shakoor, N., Zain, M., Yousef, N., Yinghai, Z., Azeem, K., Zhou, P., White, J. C., Ming, X., & Rui, Y. (2022). Microplastic and Nanoplastic Interactions with Plant Species: Trends, Meta-Analysis, and Perspectives. Environmental Science & Technology Letters, 9(6), 482–492. https://doi.org/10.1021/acs.estlett.2c00107
4. Bansal, O. P., & Singh, A. (2022). A REVIEW ON MICROPLASTIC IN THE SOILS AND THEIR IMPACT ON SOIL MICROBES, CROPS AND HUMANS. International Journal of Research - GRANTHAALAYAH, 10(9), 245–273. https://doi.org/10.29121/granthaalayah.v10.i9.2022.4812
5. Biamis, C., Driscoll, K. O., & Hardiman, G. (2021). Microplastic toxicity: A review of the role of marine sentinel species in assessing the environmental and public health impacts. Case Studies in Chemical and Environmental Engineering, 3, 100073. https://doi.org/10.1016/j.cscee.2020.100073
6. Blackburn, K., & Green, D. (2022). The potential effects of microplastics on human health: What is known and what is unknown. Ambio, 51(3), 518–530. https://doi.org/10.1007/s13280-021-01589-9
7. Brack, W., Barcelo Culleres, D., Boxall, A. B. A., Budzinski, H., Castiglioni, S., Covaci, A., Dulio, V., Escher, B. I., Fantke, P., Kandie, F., Fatta-Kassinos, D., Hernández, F. J., Hilscherová, K., Hollender, J., Hollert, H., Jahnke, A., Kasprzyk-Hordern, B., Khan, S. J., Kortenkamp, A., … Zuccato, E. (2022). One planet: one health. A call to support the initiative on a global science–policy body on chemicals and waste. Environmental Sciences Europe, 34(1), 21. https://doi.org/10.1186/s12302-022-00602-6
8. Cholewińska, P., Moniuszko, H., Wojnarowski, K., Pokorny, P., Szeligowska, N., Dobicki, W., Polechoński, R., & Górniak, W. (2022). The Occurrence of Microplastics and the Formation of Biofilms by Pathogenic and Opportunistic Bacteria as Threats in Aquaculture. International Journal of Environmental Research and Public Health, 19(13), 8137. https://doi.org/10.3390/ijerph19138137
9. Courtene-Jones, W., Clark, N. J., & Thompson, R. C. (2022). Plastic pollution requires an integrative systems approach to understand and mitigate risk. Emerging Topics in Life Sciences, 6(4), 435–439. https://doi.org/10.1042/ETLS20220018
10. Dang, F., Wang, Q., Huang, Y., Wang, Y., & Xing, B. (2022). Key knowledge gaps for One Health approach to mitigate nanoplastic risks. Eco-Environment & Health, 1(1), 11–22. https://doi.org/10.1016/j.eehl.2022.02.001
11. Deng, Y., Zhang, Y., Lemos, B., & Ren, H. (2017). Tissue accumulation of microplastics in mice and biomarker responses suggest widespread health risks of exposure. Scientific Reports, 7. https://doi.org/10.1038/srep46687
12. Fuschi, C., Pu, H., MacDonell, M., Picel, K., Negri, M., & Chen, J. (2022). Microplastics in the Great Lakes: Environmental, Health, and Socioeconomic Implications and Future Directions. ACS Sustainable Chemistry & Engineering, 10(43), 14074–14091. https://doi.org/10.1021/acssuschemeng.2c02896
13. Gao, H., Liu, Q., Yan, C., Mancl, K., Gong, D., He, J., & Mei, X. (2022). Macro-and/or microplastics as an emerging threat effect crop growth and soil health. Resources, Conservation and Recycling, 186, 106549. https://doi.org/10.1016/j.resconrec.2022.106549
14. Grande-Tovar, C. D., Carrascal-Hernández, D. C., Trilleras, J., Mora, K., & Arana, V. A. (2022). Microplastics' and Nanoplastics' Interactions with Microorganisms: A Bibliometric Study. Sustainability, 14(22), 14761. https://doi.org/10.3390/su142214761
15. Gross, L., & Enck, J. (2021). Confronting plastic pollution to protect environmental and public health. PLOS Biology, 19(3), e3001131. https://doi.org/10.1371/journal.pbio.3001131
16. Gwenzi, W., Muhoyi, E., & Mukura, T. J. (2022). Health risk assessment and mitigation of emerging contaminants: A call for an integrated approach. In Emerging Contaminants in the Terrestrial-Aquatic-Atmosphere Continuum: (pp. 325–342). Elsevier. https://doi.org/10.1016/B978-0-323-90051-5.00021-3
17. Haschek, W. M., Berenbaum, M., Hinton, D. E., Cora, M., Chernoff, N., Travlos, G., Liu, C.-W., Lu, K., & Law, M. (2019). Pathology in Ecological Research With Implications for One Health: Session Summary. Toxicologic Pathology, 47(8), 1072–1075. https://doi.org/10.1177/0192623319880530
18. Hussain, S. , S. S. , A. S. M. , S. R. J. , M. J. D. , R. A. B. , & B. J. C. (2014). Inflammasome activation in airway epithelial cells exposed to engineered nanoparticles. Particle and Fibre Toxicology, 11(38).
19. Kibria, G., Nugegoda, D., & Haroon, A. K. Y. (2022). Microplastic Pollution and Contamination of Seafood (Including Fish, Sharks, Mussels, Oysters, Shrimps and Seaweeds): A Global Overview (pp. 277–

322). https://doi.org/10.1007/978-3-030-89220-3_14

20. Kim, N., Kim, B., & Lee, E.-H. (2022). Source and Route of Microplastics in Terrestrial, Atmospheric, and Aquatic Environments, and Effects of Microplastics on Organisms. Journal of Korean Society of Environmental Engineers, 44(11), 453–467. https://doi.org/10.4491/KSEE.2022.44.11.453
21. Kiran, B. R., Kopperi, H., & Venkata Mohan, S. (2022). Micro/nano-plastics occurrence, identification, risk analysis and mitigation: challenges and perspectives. Reviews in Environmental Science and Bio/Technology, 21(1), 169–203. https://doi.org/10.1007/s11157-021-09609-6
22. Koelmans, A. A., Redondo-Hasselerharm, P. E., Nor, N. H. M., de Ruijter, V. N., Mintenig, S. M., & Kooi, M. (2022). Risk assessment of microplastic particles. Nature Reviews Materials, 7(2), 138–152. https://doi.org/10.1038/s41578-021-00411-y
23. Meaza, I., Toyoda, J. H., & Wise Sr, J. P. (2021). Microplastics in Sea Turtles, Marine Mammals and Humans: A One Environmental Health Perspective. Frontiers in Environmental Science, 8. https://doi.org/10.3389/fenvs.2020.575614
24. Molina, E., & Benedé, S. (2022). Is There Evidence of Health Risks From Exposure to Micro- and Nanoplastics in Foods? Frontiers in Nutrition, 9. https://doi.org/10.3389/fnut.2022.910094
25. Morrison, M., Trevisan, R., Ranasinghe, P., Merrill, G. B., Santos, J., Hong, A., Edward, W. C., Jayasundara, N., & Somarelli, J. A. (2022). A growing crisis for One Health: Impacts of plastic pollution across layers of biological function. Frontiers in Marine Science, 9. https://doi.org/10.3389/fmars.2022.980705
26. Niu, L., Liu, W., Juhasz, A., Chen, J., & Ma, L. (2022). Emerging contaminants antibiotic resistance genes and microplastics in the environment: Introduction to 21 review articles published in CREST during 2018–2022. Critical Reviews in Environmental Science and Technology, 52(23), 4135–4146. https://doi.org/10.1080/10643389.2022.2117847
27. Ortiz, P., Torres-Sánchez, A., López-Moreno, A., Cerk, K., Ruiz-Moreno, Á., Monteoliva-Sánchez, M., Ampatzoglou, A., Aguilera, M., & Gruszecka-Kosowska, A. (2022). Impact of Cumulative Environmental and Dietary Xenobiotics on Human Microbiota: Risk Assessment for One Health. Journal of Xenobiotics, 12(1), 56–63. https://doi.org/10.3390/jox12010006
28. Perković, S., Paul, C., Vasić, F., & Helming, K. (2022). Human Health and Soil Health Risks from Heavy Metals, Micro(nano)plastics, and Antibiotic Resistant Bacteria in Agricultural Soils. Agronomy, 12(12), 2945. https://doi.org/10.3390/agronomy12122945
29. Prata, J. C. (2022). A One Health perspective on water contaminants. Water Emerging Contaminants & Nanoplastics, 1(3), 15. https://doi.org/10.20517/wecn.2022.14
30. Redford, K. H., da Fonseca, G. A. B., Gascon, C., Rodriguez, C. M., Adams, J., Andelman, S., Barron, D. H., Batmanian, G., Bierbaum, R., Daszak, P., Daugherty, C., Griffin, J., Kemper, K., Lee, A., Long, B., Lovejoy, T. E., McCauley, D., Romanelli, C., Paxton, M., … Zambrana-Torrelio, C. (2022). Healthy planet healthy people. Conservation Letters, 15(3). https://doi.org/10.1111/conl.12864
31. Reeves, A., Chaudhuri, P., & Chakraborty, S. (2022). Fate and consequences of microplastics in the environment and their impact on biological organisms. In Microbial Biodegradation and Bioremediation (pp. 69–79). Elsevier. https://doi.org/10.1016/B978-0-323-85455-9.00010-2
32. Rillig, M. C., Ingraffia, R., & De Souza Machado, A. A. (2017). Microplastic incorporation into soil in agroecosystems. Frontiers in Plant Science, 8. https://doi.org/10.3389/fpls.2017.01805
33. Silva, J. dos S., Rodrigues, J. R. P., Sá, R. A. de Q. C. de, Oliveira, M. B. M. de, Silva, S. M. da, Souza, K. S., Silva, M. R. F. da, Araújo, L. C. A. de, Pereira, E. S., Bezerra, A. Â., & Barros, A. V. de. (2022). Environmental pollution by microplastics and its consequences on human health. Research, Society and Development, 11(13), e520111335863. https://doi.org/10.33448/rsd-v11i13.35863
34. Uwamungu, J. Y., Wang, Y., Shi, G., Pan, S., Wang, Z., Wang, L., & Yang, S. (2022). Microplastic contamination in soil agro-ecosystems: A review. Environmental Advances, 9, 100273. https://doi.org/10.1016/j.envadv.2022.100273
35. Vethaak, A. D., & Leslie, H. A. (2016). Plastic Debris Is a Human Health Issue. Environmental Science & Technology, 50(13), 6825–6826. https://doi.org/10.1021/acs.est.6b02569
36. Xia, T., Kovochich, M., Liong, M., Zink, J. I., & Nel, A. E. (2008). Cationic Polystyrene Nanosphere Toxicity Depends on Cell-Specific Endocytic and Mitochondrial Injury Pathways. ACS Nano, 2(1), 85–96. https://doi.org/10.1021/nn700256c
37. Yadav, V., Dhanger, S., & Sharma, J. (2022). Microplastics accumulation in agricultural soil: Evidence for the presence, potential effects, extraction, and current bioremediation approaches. Journal of Applied Biology & Biotechnology, 38–47. https://doi.org/10.7324/JABB.2022.10s204
38. Yang, S., Cheng, Y., Liu, T., Huang, S., Yin, L., Pu, Y., & Liang, G. (2022). Impact of waste of COVID-19 protective equipment on the environment, animals and human health: a review. Environmental Chemistry

Letters, 20(5), 2951–2970. https://doi.org/10.1007/s10311-022-01462-5
39. Zhang, Q., Xu, E. G., Li, J., Chen, Q., Ma, L., Zeng, E. Y., & Shi, H. (2020). A Review of Microplastics in Table Salt, Drinking Water, and Air: Direct Human Exposure. Environmental Science & Technology, 54(7), 3740–3751. https://doi.org/10.1021/acs.est.9b04535
40. Zolotova, N., Kosyreva, A., Dzhalilova, D., Fokichev, N., & Makarova, O. (2022). Harmful effects of the microplastic pollution on animal health: a literature review. PeerJ, 10, e13503. https://doi.org/10.7717/peerj.13503

APPENDICES

Appendix 1: Critical Analysis and Synthesis

Aspect	Strengths	Weaknesses
Interdisciplinary Integration	The literature robustly embraces the One Health framework, effectively linking human, animal, and environmental health impacts of microplastics. Several studies provide comprehensive overviews that integrate toxicological, ecological, and epidemiological data, facilitating a holistic understanding of microplastic pollution and its cascading effects across biological scales(Morrison et al., 2022)(Dang et al., 2022)(Redford et al., 2022). This integration supports the identification of shared mechanisms of toxicity and cross-species health outcomes, advancing the conceptual foundation for One Health interventions.	Despite the conceptual strength, practical interdisciplinary integration remains limited. Many studies focus predominantly on either environmental or human health aspects without fully bridging these domains. The lack of standardized methodologies across disciplines hampers data comparability and synthesis, limiting the operationalization of One Health approaches in microplastic research("Harmful effects of the microplastic poll...", 2022)(Molina & Benedé, 2022)(Koelmans et al., 2022). Furthermore, the complexity of integrating diverse data types often results in fragmented evidence that challenges comprehensive risk assessments.
Exposure Pathways and Bioaccumulation	Research has elucidated multiple exposure routes for microplastics, including ingestion, inhalation, and dermal contact, across terrestrial, aquatic, and atmospheric systems. Studies document bioaccumulation in various organisms and trophic transfer, highlighting the pervasive nature of microplastics in food chains and environments (Cholewińska et al., 2022) (Meaza et al., 2021) (Kim et al., 2022). This detailed characterization of exposure pathways informs risk identification and prioritization of intervention points.	However, quantitative data on exposure levels and bioaccumulation remain sparse and inconsistent. Variability in particle size, polymer type, and environmental matrices complicates exposure assessment. Many studies rely on laboratory models with limited ecological validity, and there is a paucity of longitudinal human exposure data, impeding accurate risk quantification (Molina & Benedé, 2022) (Blackburn et al., 2021) (Koelmans et al., 2022). Additionally, the influence of microplastic-associated chemicals and additives on bioaccumulation dynamics is insufficiently addressed.
Microbial Interactions and Pathogen Dynamics	The role of microplastics as vectors for microbial communities, including pathogenic and opportunistic bacteria, is well recognized. Research highlights biofilm formation on microplastics facilitating pathogen transmission in aquaculture and natural ecosystems, linking environmental contamination to animal and human health risks(Cholewińska et al., 2022)(Esteve-Núñez, 2022)(Grande-Tovar et al., 2022). This microbial	Despite growing interest, mechanistic understanding of microplastic-microbe interactions remains limited. Studies often lack standardized protocols for microbial characterization and fail to capture the complexity of microbial consortia in diverse environments(Grande-Tovar et al., 2022). The implications for antimicrobial resistance gene dissemination and long-term ecological consequences are underexplored. Moreover, the potential for microbial biodegradation of microplastics is promising but not yet sufficiently harnessed or understood for

	dimension enriches the One Health perspective by elucidating indirect health impacts mediated through microbiota.	practical mitigation.
Mitigation Strategies and Risk Management	Several studies propose integrated mitigation approaches combining source reduction, improved waste management, and technological innovations such as biodegradation and advanced filtration(Dang et al., 2022)(Lamichhane et al., 2022)(Griffin & Hynes, 2022). The emphasis on circular economy principles and sustainable practices aligns with global environmental goals and offers pathways for reducing microplastic pollution at multiple scales.	Nonetheless, empirical evaluations of mitigation fectiveness are scarce, and many proposed rategies remain theoretical or at pilot stages(Clark Ghosh, 2022)(Griffin & Hynes, 2022). There is a otable gap in assessing socio-economic feasibility nd stakeholder engagement, which are critical for uccessful implementation. Additionally, the edominance of end-of-pipe solutions overlooks pstream interventions and the human behavioral ctors essential for comprehensive risk duction(Nelson, 2022).
Policy Frameworks and One Health Implementation	The literature underscores the necessity of incorporating One Health principles into policy frameworks to address microplastic pollution comprehensively(Werner et al., 2022)(Werner et al., 2022)(Redford et al., 2022). Calls for global science-policy bodies and integrative governance highlight the recognition of microplastics as a planetary health issue requiring coordinated international action.	However, current policies often lack integration ross sectors and fail to address the complexity of icroplastic risks holistically(Fuschi et al.,)22)(Clark & Ghosh, 2022). There is insufficient anslation of scientific evidence into enforceable gulations, and monitoring systems are inadequate r comprehensive risk assessment(Perković et al.,)22). The uneven distribution of data-rich regions ersus data-poor areas further complicates global olicy harmonization and equitable intervention.
Methodological Robustness and Data Quality	Advances in analytical techniques have improved detection and characterization of microplastics across environmental compartments, enhancing data quality and enabling more precise exposure assessments(Kiran et al., 2022)(Allen et al., 2022)(Fuschi et al., 2022). Meta-analyses and bibliometric studies provide valuable insights into research trends and knowledge gaps, supporting evidence-based prioritization.	Despite these advances, methodological eterogeneity persists, including variability in mpling, extraction, and identification otocols(Koelmans et al., 2022)(Azeem et al.,)22). This inconsistency undermines omparability and meta-analytic synthesis. Many udies rely on short-term or laboratory-based cperiments that may not reflect real-world omplexities, limiting the external validity of ndings("Harmful effects of the microplastic oll...", 2022)(Blackburn et al., 2021). Furthermore, e lack of standardized dose metrics and effect resholds impedes risk characterization.
Knowledge Gaps and Research Needs	The literature collectively identifies critical knowledge gaps, including long-term health effects of microplastic exposure, interactions with chemical contaminants, and the role of the microbiome in mediating	However, the pace of research addressing these aps is slow relative to the urgency of the problem. imited longitudinal human studies and insufficient terdisciplinary collaboration constrain ogress(Dang et al., 2022)(Molina & Benedé,)22). Additionally, the complexity of microplastic

	toxicity(Molina & Benedé, 2022)(Jiménez-Arroyo et al., 2022)(Blackburn et al., 2021). Recognition of these gaps guides future research priorities and the development of more comprehensive risk assessments.	ixtures and environmental variability poses ıallenges for experimental design and data terpretation, necessitating innovative ethodological approaches.

Appendix 2: Limitations of the Literature

Area of Limitation	Description of Limitation	Papers which have limitation
Methodological Constraints	Many studies rely on laboratory or in vitro models that may not accurately replicate real-world environmental conditions, limiting external validity. This affects the generalizability of findings to complex ecosystems and human exposures.	("Harmful effects of the microplastic poll...", 2022) (Yang et al., 2022) (Blackburn et al., 2021) (Meaza et al., 2021)
Fragmented and Incomplete Data	Research often presents fragmentary and controversial data due to variability in plastic types, particle sizes, doses, and exposure modes, weakening the consistency and comparability of results across studies.	("Harmful effects of the microplastic poll...", 2022) (Molina & Benedé, 2022) (Reeves et al., 2022)
Limited Long-term Exposure Studies	There is a scarcity of long-term and chronic exposure studies, which restricts understanding of cumulative and delayed effects of microplastics on health and ecosystems, thus limiting comprehensive risk assessment.	(Meaza et al., 2021) (Blackburn et al., 2021) (Perković et al., 2022)
Lack of Standardized Methods	Absence of standardized protocols for sampling, classification, quantification, and characterization of microplastics, especially smaller sizes, impedes reproducibility and comparability across studies, affecting reliability of conclusions.	(Yang et al., 2022) (Grande-Tovar et al., 2022) (Lamichhane et al., 2022)
Geographic Bias	Most research is concentrated in data-rich regions, with limited studies from Africa, Latin America, and parts of Asia, reducing the global representativeness and applicability of findings to diverse environmental and socio-economic contexts.	(Werner et al., 2022) (Uwamungu et al., 2022) (Grande-Tovar et al., 2022)
Insufficient Integration of Multidisciplinary Data	Studies often lack comprehensive integration of toxicological, ecological, and epidemiological data, hindering holistic understanding of microplastic impacts across human, animal, and environmental health domains.	(Dang et al., 2022) (Morrison et al., 2022) (Clark & Ghosh, 2022)
Understudied Exposure Routes	Research has predominantly focused on ingestion, with limited investigation into inhalation and dermal exposure pathways, which may underestimate total human and animal exposure and associated risks.	(Meaza et al., 2021) (Blackburn et al., 2021)
Limited Ecotoxicological Studies in Terrestrial Systems	Terrestrial ecosystems, especially soil and agroecosystems, remain underexplored compared to aquatic systems, limiting understanding of microplastic impacts on soil health, plants, and terrestrial organisms.	(Bansal & Singh, 2022) (Yadav et al., 2022) (Dhevagi et al., 2022) (Uwamungu et al., 2022)
Insufficient Data on Microbial Interactions	The complex interactions between microplastics and microbial communities, including biofilm formation and pathogen transmission, are inadequately characterized, limiting insights into ecological and health consequences.	(Cholewińska et al., 2022) (Grande-Tovar et al., 2022) (Jiménez-Arroyo et al., 2022)

Emerging Contaminants Complexity	The multifaceted nature of microplastics combined with other emerging contaminants like antibiotic resistance genes complicates risk assessment and mitigation, with current studies often addressing these factors in isolation.	(Niu et al., 2022) (Perković et al., 2022) (Nelson, 2022)

Appendix 2: Gaps and Future Research Directions

Gap Area	Description	Future Research Directions	Justification	Research Priority
Standardization of Microplastic Exposure Assessment	Lack of standardized methodologies for quantifying microplastic exposure levels and bioaccumulation across environmental compartments and species.	Develop and validate standardized protocols for sampling, extraction, and quantification of microplastics in diverse matrices; establish harmonized dose metrics for exposure and effect thresholds.	Current variability in methods limits comparability and synthesis of exposure data, impeding accurate risk assessment and policy formulation (Molina & Benedé, 2022) (Grande-Tovar et al., 2022) (Koelmans et al., 2022).	High
Mechanistic Understanding of Microplastic-Microbe Interactions	Insufficient knowledge on microbial community dynamics on microplastics, including pathogen transmission and biodegradation mechanisms.	Conduct in situ and controlled studies to characterize microbial consortia on microplastics; elucidate mechanisms of antimicrobial resistance gene transfer and microbial degradation pathways; standardize microbial assessment methods.	Microbial interactions critically influence health risks and ecological impacts but remain poorly understood, limiting mitigation potential (Cholewińska et al., 2022) (Grande-Tovar et al., 2022) (Jiménez-Arroyo et al., 2022).	High
Longitudinal Human Health Impact Studies	Scarcity of long-term epidemiological and clinical studies assessing chronic health effects of microplastic exposure in humans.	Design cohort and case-control studies to monitor microplastic exposure biomarkers and health outcomes over time; integrate microbiome and immune function analyses.	Most human health data are extrapolated from models; direct evidence is needed to confirm risks and inform public health interventions (Molina & Benedé, 2022) (Blackburn et al., 2021) (Jiménez-Arroyo et al., 2022).	High
Evaluation of One Health-Based Mitigation Strategies	Limited empirical evaluation of the effectiveness, socio-economic feasibility, and stakeholder engagement in One Health integrated mitigation approaches.	Implement pilot projects applying One Health frameworks for microplastic pollution control; assess outcomes, cost-benefit, and community participation;	Proposed strategies are often theoretical; practical validation is essential for successful implementation and policy uptake (Morrison et al., 2022) (Clark & Ghosh, 2022) (Griffin & Hynes, 2022).	High

		develop guidelines for scalable interventions.		
Integration of Multidisciplinary Data into Risk Frameworks	Challenges in synthesizing toxicological, ecological, epidemiological, and policy data into comprehensive risk assessment models.	Develop integrative risk assessment frameworks incorporating multi-scale data; employ systems modeling and probabilistic approaches to capture complexity and uncertainty.	Fragmented data and methodological heterogeneity hinder holistic understanding and decision-making (Morrison et al., 2022) (Werner et al., 2022) (Koelmans et al., 2022).	Medium
Microplastic Exposure via Emerging Sources (e.g., COVID-19 Waste)	Emerging microplastic sources such as pandemic-related protective equipment lack detailed exposure and risk characterization.	Investigate environmental fate, exposure pathways, and toxicological effects of microplastics derived from biomedical waste; develop targeted removal and recycling technologies.	New sources exacerbate pollution and pose unknown risks, requiring urgent research to guide management (Yang et al., 2022) (Masud et al., 2022).	Medium
Role of Microplastics in Chemical and Pathogen Vectoring	Insufficient quantification of microplastics as vectors for chemical additives, persistent organic pollutants, and pathogens across ecosystems.	Quantify sorption/desorption dynamics of contaminants on microplastics; assess vectoring capacity in food webs; evaluate implications for human and animal health.	Vectoring amplifies microplastic toxicity and complicates exposure scenarios, yet remains under-characterized (Esteve-Núñez, 2022) (Kibria et al., 2022) (Silva et al., 2022).	Medium
Soil Microplastic Impact on Agroecosystems and Food Safety	Limited understanding of microplastic accumulation effects on soil health, crop productivity, and trophic transfer to humans.	Conduct long-term field studies on microplastic-soil-plant interactions; evaluate remediation and bioremediation strategies; assess human exposure via food chains.	Soil contamination threatens agricultural sustainability and human health but is less studied than aquatic systems (Bansal & Singh, 2022) (Yadav et al., 2022) (Azeem et al., 2022).	Medium
Policy Integration and Global Governance for Microplastic Risks	Current policies lack cross-sectoral integration and global coordination incorporating One Health principles.	Develop international science-policy bodies focused on microplastic and chemical pollution; promote harmonized regulations and monitoring systems; foster transdisciplinary stakeholder collaboration.	Effective governance is critical to address complex, transboundary microplastic challenges (Werner et al., 2022) (Fuschi et al., 2022) (Clark & Ghosh, 2022).	High
Advancement of	Need for improved	Innovate sensitive,	Analytical limitations	Medium

Analytical Techniques for Micro- and Nanoplastics	detection, characterization, and quantification methods, especially for smaller-sized particles in complex matrices.	cost-effective analytical tools; standardize quality control and validation procedures; expand capabilities for real-time monitoring.	constrain exposure assessment accuracy and hinder regulatory enforcement (Lamichhane et al., 2022) (Kiran et al., 2022) ("Life Cycle Assessment\nof Microplastics...", 2022).	