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REVIEW ARTICLE

Microplastics as emerging reservoirs of antimicrobial resistance: Clinical relevance and environmental mechanisms

Olabisi Promise Lawal [1], Chinasa Francis Njoba [2], Mary Tomi Olorunkosebi [3], Hycent Jacob [4], Chiamaka Igweonu [3], Jude O. Dilioha [5], Bukola Titilayo Fagbemi [6], Richard Amesimenu [7], Taofeek Saka Jimoh [8], Munachiso Nelson Obiechi [9]*

[1] Department of Medical Laboratory Science, University of Benin, Benin City, NIGERIA

[2] Defence Reference Laboratory, Mogadishu Cantonment, Abuja, NIGERIA

[3] Western Illinois University, Department of Biological Sciences, Macomb, IL, USA

[4] Rowan University, Department of Chemical Engineering, Glassboro, NJ, USA

[5] Department of Environmental Health East Carolina University, USA

[6] Department of Health Sciences, Western Illinois University, Macomb, Illinois, USA

[7] Department of Biochemistry, Chemistry and Physics Georgia Southern University Statesboro, GA, USA

[8] Department of Biological Sciences, Georgia Southern University, Georgia, USA

[9] Department of Optometry, Federal University of Technology Owerri, Imo state, NIGERIA

Correspondence:

Olabisi Promise Lawal

Address: University of Benin, Department of Medical Laboratory Science, Benin City, NIGERIA

Email: lawalolabisipromise@gmail.com

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ABSTRACT

Antimicrobial resistance genes (ARGs) are found in microplastics, which are becoming more widely acknowledged as environmental substrates that may link ecological reservoirs to human illness. These particles create selective microenvironments by adsorbing antibiotics, metals, and biocides, promoting the creation of biofilms, and facilitating horizontal gene transfer. Human exposure through ingestion, inhalation, and skin contact is a problem due to the prevalence of microplastics in aquatic, terrestrial, airborne, and food-chain systems. This review highlights methodological limitations, synthesizes current understanding of the environmental mechanisms and clinical significance of ARGs linked to microplastics, and underscores the need for interdisciplinary surveillance and action. It identifies policy gaps and proposes integrated approaches to mitigate risks at the intersection of plastic pollution and antibiotic resistance within a one health paradigm.

Keywords: microplastics, antimicrobial resistance, biofilms, horizontal gene transfer, clinical microbiology, one health

INTRODUCTION

AMR, one of the biggest public health problems of the 21st century, might kill 10 million people per year by 2050 [1]. Microplastics–plastic particles smaller than 5 mm–have been found in seas, rivers, soils, food, and even human tissues, causing a widespread environmental problem [2]. These two concerns, historically tackled separately, are increasingly interconnected. Microplastics offer unique surfaces for microbial colonization and biofilm development, generating ecological niches that may promote antimicrobial resistance gene (ARG) survival and spread. The combination of antimicrobial resistance (AMR) and microplastic pollution shows how environmental changes might increase microbial hazards to human health [3].

Industrial abrasives, personal care items, and fragmented plastic detritus produce microplastics. Their tiny size, hydrophobicity, and rough surfaces help organic contaminants, heavy metals, and antibiotics adsorb, promoting microbial colonization and stress-induced gene transfer [4]. Using plasmids, transposons, and integrons, microorganisms in these biofilms–called the "plastisphere" –transfer genes horizontally. This process enhances the environmental resistome, which includes all ARGs in microbial communities, expressed or not [5]. The plastisphere is a unique ecological interface where contaminants, microbial populations, and resistance factors interact dynamically.

The clinical importance of these processes is only emerging. Clinically relevant bacteria including Klebsiella pneumoniae, Pseudomonas aeruginosa, and Vibrio species have been found on microplastic surfaces, raising concerns about their potential as opportunistic.

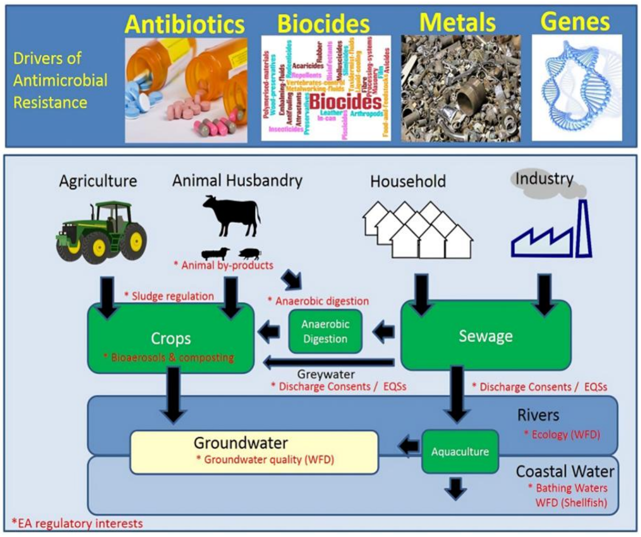

Figure 1. Microplastics as vectors for AMR in the environment Overview of environmental pathways contributing to antimicrobial resistance [8]

infection vectors [6]. Human and animal microplastic ingestion and inhalation offer realistic exposure routes, connecting environmental resistomes to clinical settings. The degree to which microplastic-associated resistomes cause treatment failures, how nanoplastics affect microbial genomes, and whether environmental monitoring can predict clinical AMR onsets are yet unknown [7].

This review synthesizes existing research on microplastics as new AMR reservoirs, focusing on environmental processes and clinical consequences. This one health study integrates environmental microbiology, toxicology, and clinical medicine to demonstrate the necessity of addressing this overlooked interface and the potential for focused research and policy solutions. **Figure 1** from [8] illustrates the complicated relationships between microplastics and antibiotic resistance in environmental and clinical settings. **Figure 1** shows how microplastics preserve ARGs in the environment and clinical settings by forming biofilms and adsorbing antibiotics and heavy metals. While previous reviews have predominantly examined the ecotoxicological effects of microplastics or their environmental role in shaping microbial communities, few have explicitly connected these findings to clinical outcomes and infection control. This review is distinctive in its integration of environmental and clinical dimensions under a one health framework, emphasizing hospital settings, antimicrobial stewardship, and global inequities. By doing so, it addresses the specific knowledge gap of how environmental microplastic reservoirs may translate into tangible risks for patient care and health system resilience.

Figure 1 illustrates the role of microplastics as vectors for AMR in environmental settings. It depicts how microplastics, through processes such as biofilm formation and adsorption of antibiotics and heavy metals, facilitate the persistence and dissemination of ARGs. The diagram emphasizes the interconnectedness of environmental compartments and clinical settings, highlighting the potential pathways through which resistant pathogens can be transmitted to humans [8].

MECHANISMS: MICROPLASTICS AS RESERVOIRS

Microplastics store AMR via physical, chemical, and biological processes. Microplastics are readily colonized by bacteria, allow gene transfer, and interact with antibiotics and metals despite their inert polymeric makeup. These traits make them essential for ARG survival and propagation [9].

The Plastisphere: A Novel Ecological Niche

Microplastics put into aquatic and terrestrial systems are immediately wrapped by a conditioning layer of organic matter, which is then colonized by a variety of microbial communities. This biofilm-covered zone, known as the "plastisphere," is unique from the surrounding free-living microbial assemblages. Biofilms on microplastics include both environmental and therapeutically relevant microorganisms, such as vibrio, pseudomonas, enterobacteriaceae, and staphylococcus species [4, 10]. The plastisphere protects against environmental variations and improves intercellular connections, promoting the survival of resistant species. Importantly, biofilm conditions promote dense microbial growth and tight cell-to-cell contact, which have been shown to enhance horizontal gene transfer (HGT) [11].

Horizontal Gene Transfer

Microplastics promote HGT to the resistome. Biofilms enhance bacterial conjugation, transformation, and transduction of ARGs. Microplastics' rough and hydrophobic surfaces encourage bacteria and extracellular polymeric substances to aggregate, providing microenvironments that increase plasmid transmission [12]. Plasmisphere-associated communities are often found to include mobile genetic elements including transposons and integrons, which typically carry multi-drug resistance determinants. When compared to inert controls like glass beads, laboratory experiments have shown higher rates of conjugative plasmid transfer on microplastic surfaces. These results indicate that microplastics actively increase gene transfer between resistant bacteria [13].

Co-Selection Effects

Microplastics co-select AMR, extending its persistence. Their surfaces absorb antibiotics, heavy metals, and disinfectants, selectively retaining ARGs in microbial populations. Polyethylene, polypropylene, and polystyrene particles absorb tetracycline, sulfonamides, and fluoroquinolones at different rates, boosting local concentrations enough to cause stress. Copper, zinc, and cadmium also attach firmly to plastic particles and select for

Table 1. Microplastics as emerging reservoirs of AMR

Environmental compartment	Sources of microplastics	AMR risks	Additional remarks
Aquatic systems	Industrial effluents, stormwater runoff, WWT plants	Microplastics harbor multidrug-resistant bacteria (e.g., Vibrio, Enterobacteriaceae). Aquaculture systems amplify risks, linking aquatic resistomes to the human food chain.	Risks include human exposure through seafood consumption and contamination of water supplies [19].
Soil systems	Agricultural practices (e.g., sewage sludge, plastic mulch films), wastewater irrigation	Altered microbial communities, enhanced horizontal gene transfer, and persistence of ARGs in soils. Microplastics can re-enter the food chain through crops, livestock, and groundwater.	Soil as a long-term reservoir for ARGs, with significant implications for agriculture and food security [20].
Airborne transmission	Urban air, indoor environments, hospital settings	Airborne microplastics transport bacteria and ARGs over long distances, exposing large populations and raising risks for respiratory infections and hospital-acquired infections.	Airborne microplastics can contribute to the spread of resistant pathogens in healthcare environments [21].
Food chain exposure	Seafood, drinking water, table salt, bottled water, beer	Ingestion of microplastic-contaminated products introduces ARGs into the gastrointestinal tract, potentially disrupting gut microbiota and facilitating gene transfer to pathogens.	Risks are heightened in areas with high seafood consumption and low water treatment infrastructure [22].

metal resistance genes paired with ARGs on mobile genetic elements. Household and hospital biocides adhere to microplastics and increase cross-resistance. Co-selection makes microplastics hotspots where numerous selective agents converge, sustaining multidrug-resistant microbes [3].

Nano vs. Microplastics

Although microplastics are being examined, nanoplastics (particles < 1 μm) may offer even larger dangers owing to their increased surface-to-volume ratio and unique physicochemical features. Nanoplastics may penetrate microbial cell membranes, produce reactive oxygen species, and cause mutagenesis, possibly enhancing spontaneous resistance development [14]. Experimental investigations show that nanoplastics improve transformation efficiency, which occurs when bacteria pick up bare DNA from the environment, including ARGs. These effects contrast from those seen with bigger microplastics, which function largely as passive carriers and scaffolding for biofilms. However, due to methodological hurdles in identifying nanoplastics in real-world settings, their role to AMR remains unknown [15].

Laboratory Data vs. Environmental Observations

Microplastics significantly increase biofilm development, HGT, and selective agent adsorption in controlled lab investigations. However, applying these insights to actual ecosystems is difficult. Environmental observations show ARGs and resistant bacteria on microplastics from rivers, coastal waters, and wastewater, but quantifying their contribution compared to other AMR reservoirs (e.g., sediments, organic matter) is difficult [5]. Laboratory settings with high microplastic concentrations and simplified microbial communities may exacerbate impacts compared to varied natural ecosystems. Due to sampling, detection, and standardization issues, environmental studies may underestimate dangers. Harmonized methods and long-term field studies to confirm experimental findings in real-world scenarios are needed to close this gap [16]. These techniques show that microplastics actively alter microbial relationships, gene exchange, and selection pressures. The plastisphere promotes biofilm specialization, HGT, and co-selection, whereas nanoplastics increase genetic risk. Laboratory and environmental research support these functions, but ecosystem-wide information gaps remain. Understanding these pathways is essential for evaluating microplastic-associated resistomes' clinical significance and creating treatments to reduce their effect [17].

ENVIRONMENTAL COMPARTMENTS AS RESERVOIRS

The ubiquity of microplastics across natural and anthropogenic environments makes them critical reservoirs for AMR. Their distribution in aquatic, terrestrial, atmospheric, and food systems enables the persistence and dissemination of ARGs along interconnected pathways that ultimately reach human populations **Table 1** summarizes the various environmental compartments where microplastics serve as reservoirs for AMR. It outlines the primary sources of microplastics, the associated AMR risks, and additional remarks on the impact of each compartment [18].

Aquatic Systems

Microplastics are mostly deposited in aquatic habitats by industrial effluents, rainfall runoff, and municipal wastewater. Though intended to decrease microbiological and chemical contaminants, wastewater treatment (WWT) facilities only partly retain microplastics. The effluents include plastic particles, antibiotics, disinfectants, and resistant bacteria, making ARG propagation perfect. Biofilms including multidrug-resistant Vibrio and Enterobacteriaceae have been found in marine and freshwater microplastics. Aquaculture in coastal areas increases hazards since fish and shellfish bioaccumulate polluted particles, connecting aquatic resistomes to the human food chain [23].

Soil Systems

Terrestrial habitats are becoming important microplastic and resistant reservoirs. Sewage sludge, animal dung, and plastic mulch films from agriculture contribute substantially. Microplastics and selective agents like antibiotics and metals are introduced by these materials, especially in intensively farmed areas. Microplastics change soil microbial communities and increase biofilm HGT. This cycle is reinforced by irrigation with treated or untreated wastewater, which deposits polymers with resistant microbes. Over time, soils may store ARGs and release them into food production systems via crops, animals, and groundwater pollution [24].

Airborne Transmission

In addition to soil and water, microplastics occur in the sky. Urban air, hospitals, and interior dust contain inhalable microplastic fibers and pieces, according to recent research. Microplastics may spread viable bacteria and ARGs across vast distances, exposing enormous populations. In hospitals with high antibiotic usage, airborne plastics may interact with nosocomial microorganisms, increasing concerns about hospital-acquired illnesses. Inhaled particles enter the respiratory tract, affecting pulmonary microbiota and systemic exposure. Although data are few, the discovery of antibiotic-resistant bacteria on atmospheric microplastics highlights the importance of air as an overlooked transmission channel [25].

Food Chain Exposure

Humans are exposed to microplastics via food and water. Filter-feeding seafood like mussels, clams, and oysters often include microplastic-associated biofilms with resistant bacteria. Table salt, bottled water, and beer contain microplastics, raising concerns about cumulative dietary exposure. These contaminated items transfer plastic particles and ARG-enriched bacteria populations to the gut. This may disturb gut microbiota balance and allow commensal-opportunistic pathogen HGT. The danger is highest among seafood-consuming communities and areas with insufficient water treatment facilities. Microplastics store and transport AMR in many environmental compartments. Aquatic and soil systems support reservoirs, whereas airborne particulates and polluted food chains expose people. The interconnection of these compartments makes identifying microplastic-mediated AMR concerns difficult and emphasizes the need for one health-based integrated monitoring systems [25].

CLINICAL RELEVANCE AND HUMAN HEALTH IMPLICATIONS

Clinical consequences of microplastic-associated AMR are becoming more apparent yet understudied. Ingestion, inhalation, and skin contact with microplastics may introduce ARGs and harmful microorganisms into the body. In sensitive clinical settings, these exposures may modify human microbiomes, transfer resistance, and increase infection risks.

Exposure Routes

The most common method microplastics are ingested via water, shellfish, salt, and food. Microplastics may modify gut microbiota, promote inflammation, and produce HGT microenvironments after ingestion. In addition, commensal bacteria, opportunistic pathogens, and ARGs meet in the gut, which may enhance the gut resistome [26].

Inhalation is another direct exposure method [22]. Microplastics, especially fibers and tiny particles, are found in metropolitan air, interior spaces, and hospitals. Deep in the lungs, these particles may induce local inflammation, hinder clearance, and transport biofilm-associated bacteria [26]. Pathogens including pseudomonas aeruginosa and Klebsiella pneumoniae, which cause respiratory infections and are multidrug-resistant, colonize the lungs.

Dermal contact is poorly investigated but may be significant in occupational contexts (e.g., plastic manufacture, trash handling) and hospital settings with frequent glove and gown usage. Although unbroken skin offers a barrier, micro-abrasions or wounds may enable microplastic-associated bacteria or ARGs into immunocompromised people [27].

Disruption of Human Microbiota and Pathogen Carriage

Emerging data suggests that microplastics may affect host-associated microbiota. The use of contaminated food and water affects the gut microbiome, possibly lowering microbial diversity and resistance. Such disturbances generate ecological niches that resistant species may colonize. Clinically relevant bacteria, such as escherichia coli, enterobacter spp., pseudomonas spp., and staphylococcus aureus, have been identified from microplastic biofilms, highlighting their potential significance as opportunistic disease carriers [5, 28]. Importantly, colonization by these organisms may cause infections in vulnerable hosts, ranging from urinary tract infections to potentially fatal sepsis.

ARG Transfer in Hospital Environments

Hospitals are high-risk for microplastic-mediated AMR. Microplastics from medical disposables, fabrics, and cleaning chemicals are abundant in hospitals. Particles and extensive antibiotic usage generate microhabitats for ARG

Table 2. Comparison of detection methods for microplastic-associated AMR

Detection method	Strengths	Limitations	Relevance to AMR research
FTIR	Non-destructive and rapid analysis; can detect specific plastic polymers and functional groups; high sensitivity for microplastic identification	Limited sensitivity for small particles (< 1 µm); Cannot easily distinguish between microplastics and other organic matter	Useful for identifying microplastics in environmental samples; Helps in characterizing microplastic surfaces in AMR studies [30]
Raman spectroscopy	Provides high-resolution molecular fingerprints; capable of identifying various plastic types; non-destructive	Requires specific sample preparation; Low throughput for large samples	Ideal for characterizing microplastic polymers in AMR research; Can be used to identify contaminants adsorbed on plastics [31]
qPCR	Highly sensitive for detecting specific ARGs; provides quantifiable results; widely available and cost-effective	Limited to known genes of interest; Cannot provide full microbial community profile	Essential for quantifying ARGs on microplastic surfaces; Allows detection of AMR in environmental samples like water, soil [32]
Metagenomics	Provides comprehensive microbial community profiles; can detect a wide range of ARGs and pathogens; allows for discovery of novel resistance genes	Requires advanced computational analysis; High cost and time consumption; Requires large amounts of DNA for sequencing	Crucial for understanding microbial communities on microplastics; Helps in discovering novel AMR genes and pathways linked to microplastics [33]

persistence and exchange. Microplastics may transport ESBL-producing enterobacteriaceae or carbapenem-resistant Pseudomonas in clinical effluent. The return of these organisms into hospital air, surfaces, or water systems increases nosocomial transmission risks. Microplastic-associated microorganisms colonize and infect immunocompromised people, such as those receiving chemotherapy, organ transplantation, or critical care[9].

Synergistic Effects of Co-Exposures

Co-contaminants increase microplastic clinical hazards. Localized "cocktails" of selecting agents favor resistant strains because microplastics absorb antibiotics, metals, and disinfectants. Adsorption of fluoroquinolones or tetracyclines onto polyethylene or polypropylene particles generates gastrointestinal or pulmonary biofilm ARG selecting hotspots. Many co-adsorbed metals like copper and zinc cause metal resistance and ARG co-selection via mobile genetic elements [3]. In clinical settings with high antibiotic doses, these synergistic effects may promote multidrug resistance and complicate infection treatment. From an infection control standpoint, microplastic-associated AMR presents practical challenges. The persistence of resistant biofilms on microplastic surfaces may limit the effectiveness of standard disinfection protocols in hospitals and long-term care facilities. Moreover, the recirculation of resistant bacteria through hospital effluent and air systems can undermine antimicrobial stewardship programs by reintroducing resistant organisms despite optimized prescribing practices. Incorporating microplastic surveillance into hospital wastewater monitoring and indoor air quality assessments could represent a valuable addition to existing infection prevention frameworks.

These routes show that microplastics are clinical vectors as well as environmental nuisances. Microplastics may undermine antimicrobial stewardship and cause nosocomial and community infections by exposing people to resistant bacteria and ARGs, changing human microbiota, and reacting synergistically with antibiotics and metals. Although clear causal linkages between microplastic exposure and clinical outcomes are unknown, environmental, experimental, and clinical investigations suggest a serious and urgent concern. Targeted research, environmental monitoring, and microplastic-AMR integration into infection control and one health efforts are needed to address this problem [9].

METHODOLOGICAL CHALLENGES AND DETECTION

A multidisciplinary toolset is needed to study microplastics as AMR reservoirs, but present methods have substantial limitations that restrict risk assessment. Analytical techniques for microplastic detection use spectroscopic methods like Fourier-transform infrared spectroscopy (FTIR) and Raman to identify polymers and size them. These technologies can identify particles down to a few micrometers, but nanoplastics, which may penetrate cells, are harder to detect. Scanning electron microscopy combined with energy-dispersive X-ray spectroscopy may reveal surface shape and pollutant adsorption, but it is laborious and unstandardized for environmental monitoring [29]. **Table 2** compares important microplastic-associated AMR detection techniques. Each approach for analyzing microplastics in AMR propagation is evaluated for strengths, weaknesses, and significance.

Quantitative PCR (qPCR) and high-throughput metagenomics have been used to characterize microplastic biofilm ARGs. qPCR quantifies particular ARGs, whereas metagenomics profiles microbial populations and resistomes. Both methods must identify intrinsic ARGs carried by colonizing microorganisms from external DNA adsorbed onto plastic surfaces. Without this difference, microplastics' resistance-vector potential is unclear [34].

Standardization is another drawback. Studies use different sampling, particle separation, and detection methodologies, making cross-comparisons challenging. This heterogeneity makes microplastic-associated ARG prevalence estimations unreliable across contexts. Additionally, most experimental research are done under controlled laboratory circumstances with artificially high microplastic concentrations, presenting ecological realism problems [16].

There are many major gaps. Nanoplastics may be more effective in gene transfer and host penetration, but identification is difficult. There are no systematic dose–response connections between microplastic exposure and ARG transfer, making it difficult to use environmental data to human health hazards [35]. Finally, real-world exposure measurement is uncommon, especially in hospital and indoor settings where nosocomial infections may be most critical. These methodological obstacles must be overcome to advance from theoretical worry to actionable proof on microplastic-associated AMR's clinical effect.

Emerging portable and low-cost approaches, such as handheld Raman spectroscopy devices, nanopore sequencing, and simplified microplastic filtration kits, offer promise for application in low- and middle-income countries (LMICs) contexts where laboratory infrastructure is limited. While less precise than advanced metagenomics or FTIR systems, these tools can expand monitoring capacity and support community-level surveillance of microplastic-associated AMR.

ONE HEALTH PERSPECTIVE AND FUTURE DIRECTIONS

Microplastic pollution and AMR are a complex, cross-sectoral issues that can only be handled within a one health framework. This viewpoint shows how microplastics spread ARGs across ecological boundaries by understanding the interconnectivity of human, animal, and environmental health. What starts as plastic garbage in soil or water might become hospital-resistant illnesses, emphasizing the need for coordinated interventions [36].

This issue stems from agricultural intensification. Wastewater irrigation, sewage sludge fertilizer, and plastic mulch cause soil microplastic pollution, which interacts with antibiotic residues and metal pollutants to enhance ARG selection and spread [37]. Frequent antibiotic usage and plastic-derived detritus in aquaculture systems produce biofilm and gene exchange hotspots, increasing the likelihood of resistant bacteria entering the food chain. In LMICs, poor waste management, inadequate regulatory supervision, and high infectious disease loads exacerbate exposure routes [38].

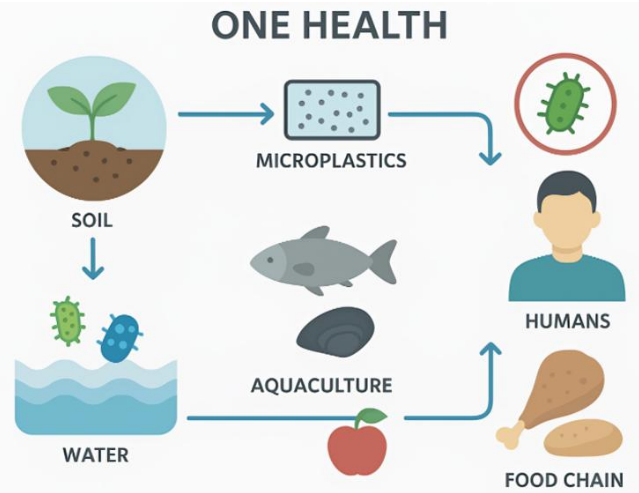

Figure 2. One health transmission pathways of microplastic-associated antimicrobial resistance (Source: Authors' own elaboration)

Thus, future attempts must build comprehensive environmental and clinical monitoring systems beyond standalone studies. Adding metagenomic profiling of microplastic-associated resistomes to AMR monitoring systems might identify resistance fluxes from wastewater, agricultural runoff, and aquaculture into hospitals early. Such initiatives need standardized sampling and data analysis for regional comparability and worldwide risk assessments [39].

Meanwhile, knowledge gaps must be filled. To understand dose–response dynamics, chronic exposure effects, and health concerns in susceptible groups including children, agricultural laborers, and immunocompromised patients, longitudinal and in vivo studies are required. This problem requires concerted stewardship: lowering plastic usage, improving waste infrastructure, and tightening antibiotic laws in human and veterinary medicine [40].

By incorporating microplastic-driven AMR into one health research and policy objectives, the global community may better anticipate and address this growing problem at the intersection of environment, agriculture, and clinical care. **Figure 2** shows how microplastics spread AMR from environmental reservoirs to individuals via one health routes, highlighting the integrative character of this growing problem.

Importantly, the burden of microplastic-driven AMR is not evenly distributed. LMICs face disproportionate risks due to inadequate waste management, reliance on open dumping and burning of plastics, and limited WWT capacity. In many LMICs, aquaculture and seafood constitute essential protein sources, yet these systems often operate in polluted coastal waters with high microplastic and antibiotic loads. At the same time, constrained laboratory infrastructure limits detection of microplastic-associated AMR, leaving major surveillance gaps. These inequities highlight the need for globally coordinated but locally adapted strategies, ensuring that mitigation efforts do not widen existing health disparities.

Figure 2 shows a schematic representation of microplastic-mediated AMR transmission within a one health framework. Microplastics in soil, water, and aquaculture environments act as reservoirs of ARGs, which are transferred along the food chain through crops, seafood, potable water, and livestock. Human exposure occurs via ingestion, inhalation, and dermal contact, with downstream implications for microbiota disruption, infection risk, and nosocomial AMR spread.

To sharpen the research and policy agenda, future directions can be prioritized according to urgency and impact. High-priority clinical needs include dose–response studies of human exposure, investigations into the role of hospital wastewater as a microplastic–AMR hotspot, and integration of microplastic monitoring into infection control programs. Medium-priority environmental research should focus on longitudinal field studies in rivers, aquaculture, and soils to quantify real-world risks. Finally, methodological priorities include standardizing nanoplastic detection techniques and harmonizing protocols for sampling and ARG quantification. Establishing this hierarchy will help align research investments with the most pressing clinical and environmental challenges.

POLICY, MITIGATION STRATEGIES, AND RECOMMENDATIONS

Despite increased acknowledgement of AMR as a global health concern, international and national policies seldom include microplastics as resistance vectors. The WHO Global Action Plan on AMR and many country action plans concentrate on antibiotic stewardship, infection control, and pathogen monitoring but ignore the environmental–plastic interaction. This policy vacuum may ignore a pool of resistance genes that might hinder clinical and public health initiatives [41].

Mitigating plastic pollution and AMR needs a multifaceted strategy. Since traditional plants cannot remove micro- and nanoplastics or neutralize related microbial populations, WWT improvements are crucial. Advanced filtration, membrane bioreactors, and integrated disinfection might minimize environmental burden. Upstream, biodegradable plastics and circular economy models may reduce long-term accumulation, while stronger plastic additive regulation (e.g., antimicrobials, biocides, heavy metals) can reduce co-selection pressures. Also significant are policies that encourage decreased plastic usage in agriculture and aquaculture, such as plastic mulch alternatives and feed practices [42].

Research should prioritize longitudinal environmental monitoring to track resistome evolution and microplastic load. In vivo exposure models are needed to relate microplastic-associated resistomes to unfavorable health outcomes, especially in immunocompromised or high-risk groups. Translational surveillance systems that combine environmental sampling with clinical AMR monitoring may also detect resistance spillovers early, allowing for preventive measures [9].

Beyond identifying risks, advancing our understanding of microplastic–AMR interactions also offers opportunities for targeted interventions. For example, insights into the adsorption properties of different polymers may inform the design of improved biodegradable materials that minimize co-selection pressures. Similarly, knowledge of how microplastics facilitate HGT could guide the development of advanced WWT technologies that disrupt these processes. Incorporating such mechanistic insights into intervention design not only mitigates risks but also transforms a growing environmental threat into an opportunity for innovation in public health protection.

Thus, global governance is needed to address microplastics and AMR. Microplastic-driven AMR threats must be included into international policy frameworks, national stewardship programs, and one health action plans to mitigate this danger and protect antibiotic efficacy.

CONCLUSION

Microplastics are a major environmental contaminant and potential AMR reservoirs and vectors. Microplastics connect ecological dynamics to clinical risks in unexpected ways by promoting HGT, microbial colonization, and resistance co-selection via adsorbed pollutants. Aquatic, soil, airborne, and food-chain compartments show they may connect environmental resistomes to human exposure pathways, boosting infection risk, treatment failure, and public health security issues.

This combined danger demands a paradigm change in environmental science, clinical microbiology, and global health policy. Despite advances in characterizing AMR in pathogens and clinical settings, microplastic-mediated pathways' impact on real-world exposure and patient outcomes is understudied. Similar methodological hurdles in detection, quantification, and causal attribution need urgent innovation [43].

Despite growing recognition of microplastic-associated AMR, critical unknowns remain. We still lack dose–response data linking exposure to health outcomes, standardized methods for detecting nanoplastics, and longitudinal studies to quantify real-world risks. Addressing these gaps–particularly in vulnerable populations and high-risk clinical environments–should be the focus of future research. Prioritizing these areas will be essential to translate one health insight into actionable interventions that safeguard antibiotic efficacy for future generations.

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AI statement: The authors stated that generative AI tools (such as ChatGPT, OpenAI GPT-5) were used only to assist with language refinement, grammar checking, and formatting consistency. No AI system contributed to the conception, analysis, interpretation, or validation of the scientific content. The authors reviewed and verified all text to ensure accuracy and accountability for the final version of the manuscript.

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