



The Environmental Exposome: Toxicity of Air, Water, Food, and Agricultural Pollutants and Emerging Strategies for Detoxification, Holobiotics, Environmental Hygiene, and Healthy Longevity



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Abstract

Background: Environmental pollution has emerged as a major determinant of global disease burden. Continuous exposure to airborne pollutants, contaminated water, pesticides, microplastics, heavy metals, and ultra-processed foods contributes significantly to chronic disease, premature aging, and mortality.

Objective: To review major environmental toxicants and evaluate current approaches to exposure reduction, detoxification, microbiome restoration, and healthy longevity.

Methods: A narrative review of recent literature was performed using published evidence from toxicology, environmental health, microbiome research, preventive medicine, and public health. Emphasis was placed on contemporary topics including PFAS, microplastics, regenerative agriculture, and holobiotic therapies.

Results: Environmental toxicants contribute to respiratory disease, metabolic syndrome, cardiovascular disorders, neurodegeneration, endocrine dysfunction, infertility, and cancer. Emerging evidence indicates that microbiome-targeted interventions may enhance host resilience against toxic insults. Holobiotics, including prebiotics, probiotics, postbiotics, and synbiotics, demonstrate promising effects on intestinal barrier integrity, inflammation, immune homeostasis, and toxicant metabolism.

Conclusion: Reducing environmental exposures while promoting microbiome health and sustainable living may become a cornerstone strategy for improving health span and longevity in the twenty-first century.

Keywords: Toxicology; Exposome; Air Pollution; PFAS; Microplastics; Microbiome; Probiotics; Postbiotics; Regenerative Agriculture; Longevity

Abbreviations

PM: Particulate Matter; PFAS: Per- and Polyfluoroalkyl Substances; VOCs: Volatile Organic Compounds; WHO: World Health Organization; SCFA: Short Chain Fatty Acids; MPs: Microplastics; NCDs: Non-Communicable Diseases; ROS: Reactive Oxygen Species; GI: Gastrointestinal; EPA: Environmental Protection Agency

Introduction

The concept of the environmental exposome has transformed modern toxicology by recognizing that health outcomes arise from lifelong cumulative exposures to environmental agents rather than isolated toxic events [1].

Air pollution alone contributes millions of premature deaths annually and remains among the foremost global health threats [2]. Environmental contaminants now encompass particulate matter, volatile organic compounds, heavy metals, industrial chemicals, persistent organic pollutants, pesticides, endocrine-disrupting compounds, pharmaceutical residues, and microplastics [3].

Parallel advances in microbiome science have demonstrated that humans exist as meta-organisms or holobionts, in continuous interaction with trillions of microorganisms influencing metabolism, immunity, and detoxification [4].

Recent concerns regarding PFAS ("forever chemicals"), microplastics, nanoplastics, glyphosate exposure, antimicrobial residues, and industrial pollutants have intensified global calls for environmental stewardship and preventive interventions [5].

This review evaluates the major environmental toxic exposures affecting human health and explores practical and biological approaches to increase resilience through environmental hygiene, improved food systems, water and air purification, and microbiome-centered interventions.

Materials and Methods

A narrative review methodology was adopted.

Databases reviewed included: PubMed, Scopus, Web of Science, WHO publications, ATSDR reports, CDC resources and Environmental toxicology journals

Keywords used: Toxicology, Air pollution, PFAS, Microplastics, Heavy metals, Water contamination, Regenerative agriculture, Probiotics, Postbiotics, Microbiome and Longevity

Publications from 2015–2026 were preferentially evaluated, with landmark references included where necessary.

Results

Air pollution

Major airborne toxicants include: Particulate Matter, PM_{2.5} and PM₁₀ arise from: Traffic emissions, Industrial combustion, Biomass burning and Wildfires.

Health impacts include: COPD, Asthma, Pulmonary malignancy, cardiovascular disease and Stroke

Toxic gases

Important pollutants include: Sulfur dioxide, Nitrogen oxides, Carbon monoxide and Ozone.

These compounds contribute to oxidative stress, systemic inflammation, endothelial dysfunction, and accelerated atherosclerosis [2].

Water contamination

Water toxicants include:

Heavy metals: Lead, Arsenic, Mercury and Cadmium

Industrial chemicals

PFAS have become a global concern because of environmental persistence and bioaccumulation. Associations have been reported with immunological dysfunction, metabolic disease, reproductive toxicity, thyroid disorders, and renal pathology [5]. [atsdr.cdc.gov], [who.int]

Pharmaceutical residues

Antibiotics and endocrine-active compounds increasingly contaminate drinking water systems.

Food toxicology

Ultra-processed foods: Modern diets frequently contain: Artificial preservatives, Emulsifiers, Flavor enhancers and Excess refined carbohydrates.

These compounds contribute to chronic inflammation and dysbiosis.

Food packaging: Bisphenols and phthalates represent significant endocrine-disrupting exposures.

Agricultural Toxicants

Agricultural chemicals include: Organophosphate pesticides, Carbamates, Glyphosate and Neonicotinoids.

Potential toxic effects: Neurotoxicity, Endocrine dysfunction, Reproductive impairment and Carcinogenesis.

Microplastics: The emerging toxicological threat.

Microplastics have been identified in: Blood, Feces, Placenta and Breast milk.

Current evidence suggests that microplastics alter microbial diversity, short-chain fatty acid production, intestinal permeability, and inflammatory pathways (Table 1).

Discussion

Modern toxicology increasingly recognizes that health consequences arise not from isolated exposures but from cumulative interactions between multiple toxicants and host biological susceptibility [1].

The exposome concept highlights how chronic environmental insults contribute to non-communicable diseases. Air pollution, PFAS, heavy metals, pesticides, and microplastics share common mechanistic pathways involving oxidative stress, mitochondrial dysfunction, inflammation, and endocrine disruption [2, 5].

Microplastics represent one of the most rapidly evolving areas of environmental health research. Evidence suggests disruption of gut microbial composition, reduction in beneficial bacterial taxa, impairment of SCFA production, and promotion of chronic inflammatory states [pmc.ncbi.nlm.nih.gov], [pmc.ncbi.nlm.nih.gov], [frontiersin.org].

Table 1: Major environmental toxicants and health effects.

Source	Major Toxicants	Major Health Effects
Air	PM _{2.5} , VOCs	Asthma, COPD, CVD
Water	PFAS, heavy metals	Kidney, endocrine disorders
Food	Preservatives, additives	Obesity, dysbiosis
Agriculture	Pesticides	Neurotoxicity, infertility
Plastics	Microplastics	Dysbiosis, inflammation

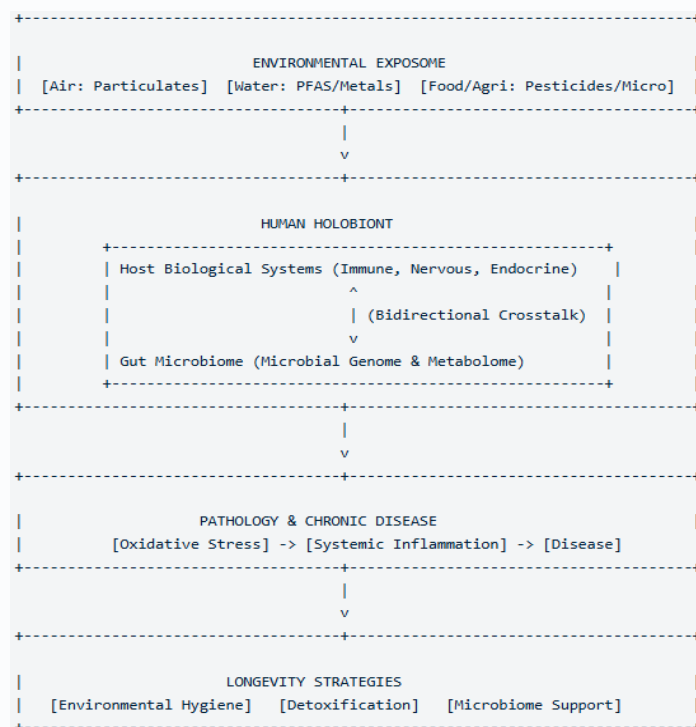


Figure 1: The environmental exposome and its impact on the human holobiont. Major environmental toxicants from air, water, food, and agricultural sources converge on host biological systems and the gut microbiome, leading to oxidative stress, inflammation, and chronic disease. Environmental hygiene, detoxification strategies, and microbiome support may promote healthy longevity.

Recent WHO and ATSDR assessments emphasize growing concerns surrounding PFAS exposure and long-term adverse health outcomes. [atsdr.cdc.gov], [who.int].

Environmental detoxification strategies

Air purification: Evidence-based approaches include: HEPA filtration, Improved ventilation, Indoor pollutant reduction, Smoke-free environments.

Water purification: Recommended technologies: Reverse osmosis, Activated carbon filtration and UV sterilization.

Food-based detoxification: Foods supporting phase I and phase II detoxification include: Brassica vegetables, Garlic, Onion, Turmeric and High-fiber foods.

Organic and regenerative agriculture

Regenerative agriculture emphasizes: Soil biodiversity, Reduced chemical dependence, Carbon sequestration and Improved nutrient density.

Health benefits include reduced chemical exposure and improved food quality.

Holobiotics and microbiome restoration

A major contemporary development is the emergence of holobiotics.

Prebiotics

Promote growth of beneficial microorganisms through non-digestible substrates.

Probiotics

Potential benefits include: Reduced intestinal permeability, Anti-

inflammatory effects and improved metabolic regulation.

Postbiotics

Microbial metabolites such as butyrate provide anti-inflammatory benefits without requiring live organisms.

Synbiotics

Combined prebiotic-probiotic formulations may provide synergistic protection against environmental stressors.

Emerging evidence suggests microbiome-targeted interventions may influence xenobiotic metabolism, immune modulation, and resilience against toxic exposures (Table 2).

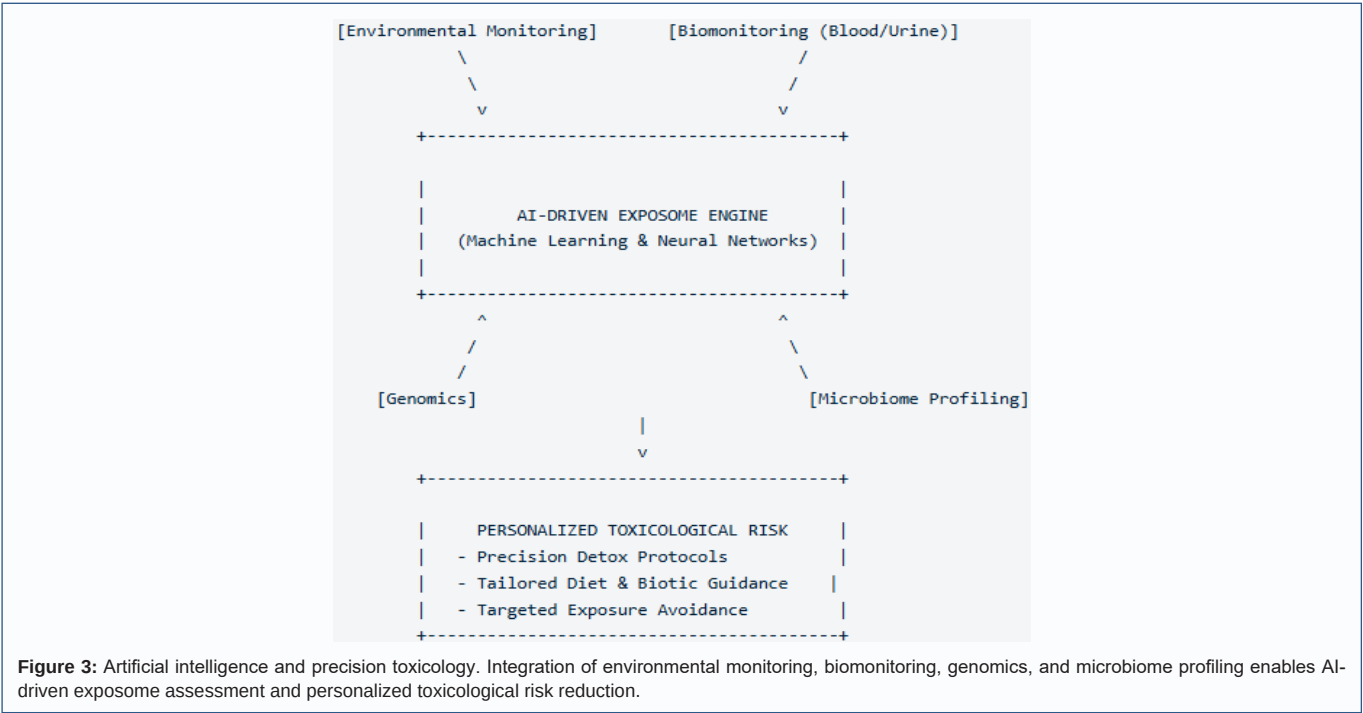
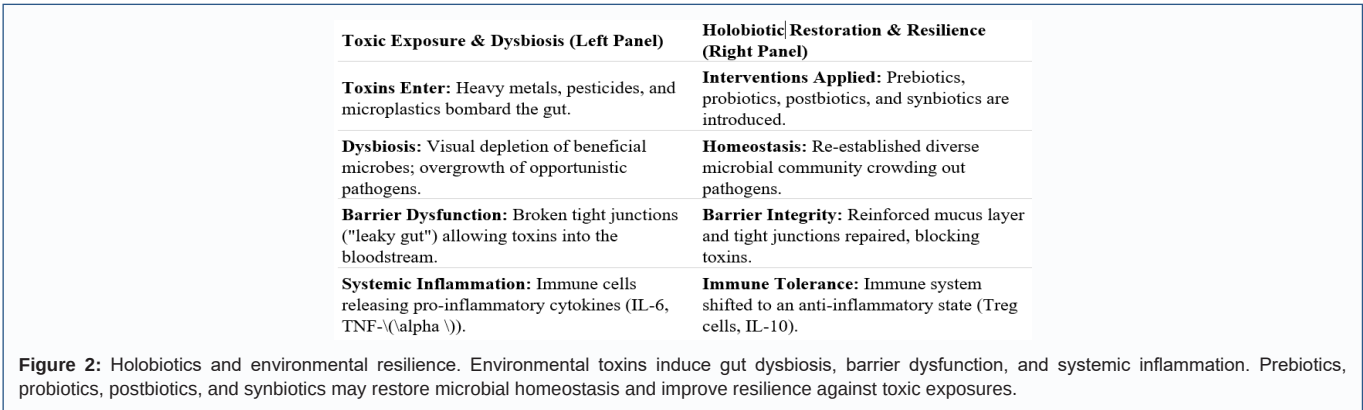
Children are disproportionately vulnerable to environmental toxicants because of their developing organ systems, immature detoxification pathways, higher respiratory rates, greater food and water consumption per kilogram of body weight, and longer lifetime exposure horizon [6-10].

Developmental origins of toxic disease

The Developmental Origins of Health and Disease (DOHaD) hypothesis proposes that environmental exposures during fetal life, infancy, and childhood can program susceptibility to disease later in life. Prenatal and early-life exposure to air pollution, heavy metals, endocrine-disrupting chemicals, and pesticides has been associated with: Neurodevelopmental disorders, Autism spectrum disorders, Attention-deficit/hyperactivity disorder, Allergic diseases, Obesity, Metabolic syndrome, Reduced cognitive performance.

Lead toxicity

No level of lead exposure is currently considered safe in children. Chronic exposure is associated with: Reduced IQ, Learning



disabilities, Behavioral abnormalities and Long-term socioeconomic consequences.

Microplastics in childhood

Recent studies have demonstrated microplastic contamination in infant feeding bottles, formula preparation systems, placental tissue, and breast milk. The long-term impact on immune development, neurodevelopment, and gut microbiome maturation remains incompletely understood but represents an important emerging research priority [8].

Prevention strategies in children

Recommended measures include: Breastfeeding whenever possible. Avoidance of plastic food containers and bottles exposed to heat, Reduction of pesticide exposure, Regular monitoring of indoor air quality, Promotion of outdoor activity in low-pollution environments.

Endocrine disruptors: The silent toxicants

Endocrine-Disrupting Chemicals (EDCs) are exogenous compounds capable of interfering with hormonal signaling at extremely low concentrations.

Major endocrine disruptors

Bisphenols: Bisphenol A (BPA) and Bisphenol S (BPS)

Found in: Plastic bottles, Food containers, Thermal receipts.

Phthalates

Present in: Food packaging, Cosmetics and Medical devices.

PFAS

Persistent environmental chemicals increasingly linked to metabolic and endocrine dysfunction [atsdr.cdc.gov], [who.int].

Agricultural compounds include Atrazine, Glyphosate and Organophosphates

Health consequences

Potential effects include:

Reproductive health: Reduced fertility, Endometriosis, Polycystic ovarian syndrome, Reduced sperm quality.

Metabolic disease

Obesity. Diabetes and insulin resistance.

Table 2: Holobiotic strategies for environmental resilience.

Intervention	Example	Potential Benefit
Prebiotic	Inulin	Increased SCFA production
Probiotic	Lactobacillus	Barrier protection
Postbiotic	Butyrate	Anti-inflammatory effects
Synbiotic	Combined formulation	Enhanced microbiome resilience

Thyroid dysfunction

Altered thyroid hormone synthesis and Neurodevelopmental consequences in children.

Cancer

Associations have been reported with: Breast cancer, Testicular cancer, Prostate cancer and Thyroid malignancies.

The endocrine disruptor concept has challenged traditional toxicological assumptions because biological effects may occur at extremely low doses and during critical windows of development.

Climate toxicology: The emerging discipline

Climate change is increasingly recognized as a toxicological multiplier rather than solely an environmental phenomenon.

Heat-driven toxicity

Rising global temperatures influence: Pollutant concentration, Ozone formation, Wildfire frequency, industrial chemical volatilization.

Extreme heat can amplify toxicant absorption and biological susceptibility.

Wildfire toxicology

Wildfires release: PM2.5, Carbon monoxide, Polycyclic aromatic hydrocarbons, and Heavy metals.

Repeated exposure has been associated with chronic respiratory disease and cardiovascular events.

Climate and water toxicology

Climate-driven flooding can increase: Heavy metal contamination, Waterborne pathogens and Agricultural runoff.

Drought conditions may concentrate contaminants within shrinking water supplies.

Food security and toxic exposure

Climate change indirectly affects toxicology through: Increased pesticide utilization, altered fungal contamination, Mycotoxin accumulation and reduced agricultural biodiversity.

Climate toxicology is likely to become one of the most important fields of environmental health over the coming decade.

Artificial intelligence and environmental monitoring

Artificial Intelligence (AI) is revolutionizing environmental toxicology through enhanced detection, prediction, and prevention of toxic exposures.

AI-Based air quality surveillance

Machine learning algorithms now integrate: Satellite imaging, Meteorological data, Ground sensors and Traffic patterns to predict pollution events with increasing accuracy.

Table 3: Emerging toxicological threats in the twenty-first century.

Emerging Threat	Principal Sources	Potential Health Effects
Microplastics	Food, water, air	Dysbiosis, inflammation
PFAS	Water, food packaging	Endocrine disruption
Nanoplastics	Consumer products	Cellular toxicity
Climate-related pollutants	Wildfires, industry	Respiratory disease
Endocrine disruptors	Plastics, pesticides	Reproductive dysfunction
Ultra-processed foods	Modern food systems	Obesity, metabolic syndrome

Table 4: Intervention strategies for reducing environmental toxic burden.

Domain	Intervention	Expected Benefit
Air	HEPA filtration	Reduced particulate exposure
Water	Reverse osmosis	Reduced chemical contaminants
Food	Organic food selection	Lower pesticide burden
Agriculture	Regenerative farming	Improved ecosystem health
Microbiome	Holobiotics	Enhanced resilience
Lifestyle	Exercise and sleep	Improved detoxification capacity

Applications include: Urban planning, Health advisories and Environmental regulation.

Water quality monitoring

AI-assisted systems can detect: Heavy metals, PFAS contamination, Microbial pollutants, Industrial chemical leak in real time.

Precision toxicology

Emerging "precision toxicology" combines: Genomics, Epigenomics, Metabolomics, Microbiomics, and Environmental exposure data allowing individualized risk assessment.

AI and the human exposome

Future systems may continuously integrate: Wearable sensor data, Personal air monitoring, Dietary records and Biomarker data to provide dynamic exposure maps for individuals (Table 3 and 4).

Conclusion

Environmental toxicants arising from polluted air, contaminated water, processed foods, agricultural chemicals, PFAS, and microplastics are increasingly recognized as major drivers of chronic disease. Modern preventive toxicology must move beyond single-agent paradigms toward a holistic understanding of cumulative exposures within the exposome framework.

Environmental hygiene, air and water purification, organic and regenerative agriculture, and microbiome-centered interventions offer complementary approaches to reducing toxic burden. Holobiotics, including prebiotics, probiotics, postbiotics, and synbiotics, represent promising emerging tools that may enhance resilience against environmental insults and help improve healthspan and longevity.

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