New
Contaminants

Editorial

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New contaminants: existence and knowledge gaps

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Accelerating technological developments result in increasing emissions of a suite of elements and compounds that have received scant scientific attention. These "new contaminants" (NCs) have surged to the forefront of environmental research priorities. While lacking comprehensive regulation, NCs may be persistent, mobile, and bioaccumulative, posing substantial threats to both ecological security and public health. Their emergence underscores humanity's profound imprint on Earth's ecosystems as well as critical gaps in current scientific understanding.

NCs derive from agriculture, household products, and high-tech industries, and often follow convoluted environmental pathways. Examples include pharmaceutical residues, microplastics, and electronic waste from manufacture through to recycling and disposal. New contaminants are broadly classified as: (a) chemical pollutants, including persistent organic pollutants, pharmaceuticals and personal care products, endocrine disruptors, disinfection by-products, and organometallics; (b) micro- and nanomaterials, such as microplastics and engineered nanoparticles; (c) biological contaminants, including antibiotic-resistant microorganisms, antibiotic resistance genes, pathogens, and viruses; and (d) other incompletely characterised substances. Though NCs may only be present at trace concentrations, they may bioaccumulate through food webs, show synergistic toxicity, disrupt endocrine and reproductive functions, and exacerbate antibiotic resistance. These effects threaten ecological and human health.

Research on NCs has progressed from detection to characterisation and mitigation. Technological advances allow trace-level identification of previously undetectable compounds. This helps elucidate their sources, occurrence, and temporal trends. These findings demonstrate complex multimedia transport and transformation processes, leading to bioaccumulation across diverse biological taxa. Current research prioritises the identification of toxicological mechanisms. Integrating evidence from multi-omics, cellular assays, animal models, and epidemiological studies advances our understanding of the health impacts. Emerging cleanup technologies, such as advanced oxidation, membrane separation, engineered adsorption, and bioremediation, show potential in managing NCs. Efficient and sustainable remediation requires the integration of resource recovery with cleanup processes. Predictive tools using big data, machine learning, and lifecycle analysis will improve risk forecasting, policy formulation, and prevention strategies. Current research targets a limited set of representative contaminants but lays the groundwork for a more comprehensive and accurate environmental health risk management framework.

Research on NCs is in its infancy and there are critical knowledge gaps. The fluid definitions and classifications of NCs highlight the growing inadequacy of conventional toxicology and environmental monitoring methods to understand these complex and multifaceted risks. A lack of consistent identification protocols and analytical standards hampers the comparability of research, data integration, and collaboration. For instance, there is limited international consensus on the morpho-chemical characterisation of microplastics. This impedes source tracing and risk assessment. Current research predominantly focuses on acute and single contaminant's effects and overlooks complex interactions. Consequently, there is a lacuna in out understanding of synergistic mixtures, transgenerational impacts, and epigenetics, which are required for reliable health-related early warning systems. High costs, scalability challenges, and the risks of secondary contamination constrain practical remediation technologies, such as advanced oxidation and soil washing. Inconsistent research methodologies, ineffective translation of identification data, and insufficient integration of scientific insights compound these limitations.

Working towards "zero pollution" can be accelerated by focusing on NC research through five pathways, as described below.

Advanced identification and analytical methods

Developing robust methods to identify and quantify new contaminants across diverse environmental matrices is a challenge for risk assessment. This requires adaptable, standard contaminant-specific analytical frameworks. Priorities include developing high-resolution, and high-sensitivity analytical platforms (e.g., advanced liquid chromatography–mass spectrometry) to detect the variants and transformation products of mobile, persistent contaminants like per- and polyfluoroalkyl substances. Other priorities include advancing

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particle characterisation technologies for precise size measurement and polymer identification in complex environmental and biological samples. Implementing multidimensional separation with selective detectors can resolve the issues associated with co-eluting signals from complex mixtures of industrial additives (e.g., plasticisers), particularly in co-contamination scenarios. Optimising extraction and storage methods for trace-level analysis of NCs facilitate the quantification of hydrophobic, volatile, and structurally labile substances. Using nucleic acid-based tools integrated with high-throughput sequencing allows the genetic-level detection of biological contaminants such as antimicrobial resistance genes.

Environmental behaviour and migration pathways

Understanding the transport, transformation, and degradation mechanisms of NCs across environmental compartments is critical for predicting exposure pathways and developing remediation strategies. Research must delineate the contaminant release pathways from household, agricultural, and industrial waste streams, and quantify their environmental fate. For instance, antimicrobial resistance genes enter wastewater systems with untreated sewage, persist through the treatment stage, and enter agricultural systems through the application of biosolids. Research priorities include identifying drivers of the transport mechanisms and interfacial processes of NCs across atmospheric, aquatic, terrestrial, and biological compartments. Research should qualify multiscale dispersion dynamics, with a focus on transport pathways and spatial distribution within watershed, atmospheric circulation patterns, and hydrological processes. Investigation of co-contamination scenarios is imperative, including the synergistic transport and enrichment effects of NCs. The environmental impacts of NCs depend on their degradation potential and transformation pathways under diverse conditions, driven by photochemistry, redox reactions, and biotransformation. Understanding their environmental behaviour requires elucidating the interdependence between the contaminants' stability and reactivity across different media and characterising their degradation mechanisms and transformation products.

Human and ecological health implications

Research should systematically identify the health and ecological threats posed by NCs and elucidate their toxicity mechanisms in humans and ecosystems. Priorities include elucidating the interactions between NCs and biomolecules across biological scales and deciphering NC-induced disruptions to endocrine, immune, neurological, and genetic functions, particularly pathways that impair reproduction or accelerate antimicrobial resistance. It is important to determine how direct toxicity, sublethal stress, and long-term bioaccumulation affect the nutritional balance of microbial communities and keystone species, and to investigate ecological disruption, including any impacts on population dynamics, biodiversity, and ecosystem functioning. Long-term effects of exposure in vulnerable systems such as wetlands, estuaries, and soil–plant systems require special attention due to the risk of irreversible ecological change.

Sustainable solutions and policy innovations

Effective remediation strategies, tailored to NCs' properties and persistence, are essential for management and achieving "zero pollution" goals. Research strategies must be tailored to specific contaminant categories. Advanced oxidation processes can degrade stable and soluble compounds such as per- and polyfluoroalkyl substances and pharmaceuticals. Novel separation techniques or functional materials can remove persistent particulate or hydrophobic contaminants like microplastics. Biologically mediated methods, such as bio- and phytoremediation, can degrade or remove contaminants that are resistant to chemical treatment. A dynamic monitoring-based regulatory framework should be developed to establish and refine emission standards. This will translate scientific advances into management practices.

Modelling and data analysis

Data modelling and analysis are essential for understanding NCs' behaviour and optimising management decisions. Research priorities should include building big data models to track contaminant pathways from microscale reactions to global dispersion. Artificial intelligence could be developed to predict the ecotoxicity or degradation of unknown contaminants and to update priority control lists. Big data-driven simulations could model NCs' dynamics, establish risk quantification frameworks, and inform both emergency responses and long-term control strategies.

The journal *New Contaminants* is a platform for global researchers to exchange findings in this field. This interdisciplinary hub connects environmental science, engineering, public health, and policy research to advance knowledge and create solutions. This journal's cultivation of international collaboration will advance contaminant science, leading to safer ecosystems and improved human health.

Declarations

Competing interests

The authors declare that they have no conflict of interest.

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