Comment

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Time to strengthen the governance of new contaminants in the environment

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Despite existing regulations, many emerging environmental contaminants remain ungoverned, posing serious risks to ecosystems and human health. Here, we outline governance challenges and propose a global roadmap for their regulation. Proactive identification, risk assessment, and international collaboration are urgently needed to close regulatory gaps and ensure a safer, healthier environment for all.

Currently, 219 million chemicals or chemical mixtures have been registered in the Chemical Abstracts Service (CAS) database, and approximately 350,000 widely used chemical substances may enter the environment through their production and application—a number that continues to grow[1–3]. However, the number of contaminants already regulated by international conventions and environmental standards is about 500–1000 (see Supplementary Tables 1 and 2), accounting for less than 1% of those present in the environment, representing merely the "tip of the iceberg" (see Fig. 1). A significant number of contaminants remain unregulated by existing conventions and standards. Due to the absence of a well-established framework for investigating, screening, and regulating those environmental contaminants, the process of identifying high-risk contaminants—from their initial occurrence in the environment to toxic hazard recognition and formal regulation—is commonly protracted. Historically, such extended delay has led to major pollution events, tragedies, and profound ecological and health consequences. For instance, it took nearly a century for polychlorinated biphenyls (PCBs), initially valued for their insulating properties, to be fully recognized as both endocrine disruptors and carcinogens, and to be regulated[4]. The infamous Yusho and Yucheng rice oil poisoning incidents were tragic examples of PCB-related harm[5].

To avert future environmental and public health crises, it is imperative to proactively identify high-risk emerging contaminants, prioritize them based on potential impact, and establish a scientifically grounded and practicable regulatory framework. Such an approach would bridge the persistent gap between scientific discovery and environmental governance, accelerate regulatory response, and mitigate associated ecological and human health risks. We therefore propose that it is time to enhance the governance of "new contaminants in the environment" (ENCs). Here, we define the scope of ENCs, analyze the challenges and issues in their governance, and propose a roadmap for achieving the target (see Fig. 2). We urge global collaboration in the screening, assessment, management, and control of ENCs to identify priority contaminants that demand immediate regulatory focus. These crucial substances should undergo comprehensive risk assessments, be progressively incorporated into relevant international conventions, and be regulated based on environmental standards. Effective measures such as source prevention, process reduction, and systematic governance should be implemented to mitigate their hazards and risks, ultimately contributing to a safe and healthy planet.

Unregulated not equal to unharmful

International conventions, environmental quality standards, emission standards, and priority contaminant control lists constitute fundamental regulatory instruments employed by governments globally to regulate environmental contaminants. Since the landmark 1972 United Nations (UN) Conference on the Human Environment in Stockholm, substantial efforts have been made by the UN, World Health Organization (WHO), and other authorities at both national and regional levels to strengthen the governance of environmental contaminants. For instance, the Basel Convention has addressed 47 categories of hazardous waste through its annexes, the Stockholm Convention has listed 34 persistent organic pollutants (POPs), and the Rotterdam Convention has included 55 chemicals in its hazardous chemicals and pesticides list (see Fig. 1 and Supplementary Table 1).

Importantly, the lack of regulation does not equate to the absence of risk. A significant weakness of existing conventions such as the Stockholm Convention is their reactive, rather than proactive, nature. Contaminants are typically added to regulatory lists only after exposure and ecological harm have been demonstrated through extensive environmental and laboratory studies—often long after the first warning signs have emerged. Meanwhile, sources of unregulated contaminants are diverse, spanning nearly every facet of human life and activity, including chemical manufacturing, pharmaceuticals, textiles, food processing, agriculture, electronics, and construction materials. These contaminants are often ubiquitous in the environment and within living organisms, found everywhere from the deepest ocean trenches to the highest mountain peaks, and present in plants, animals, and even the human body[3,6]. For example, contaminants, such as organophosphate esters (OPEs), per- and polyfluoroalkyl substances (PFASs), and phenolic compounds are widespread, appearing in lakes, oceans, soils, dust, and air, even in remote polar regions[6,7]. Over 10,000 chemicals with known or suspected endocrine-disrupting effects have been monitored in the environment with concentrations ranging from a few parts per quadrillion to hundreds of parts per billion[8]. Microplastics have been found in various human organs, including the brain, placenta, liver, kidneys, lungs, and blood[9].

Those unregulated but frequently detected contaminants may pose significant risks to both ecological and human health. Phototoxic substances derived from oxybenzone in sunscreen, for instance, exert lethal effects on corals[10]. Similarly, N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine quinone (6-PPDQ), formed by the reaction of 6PPD

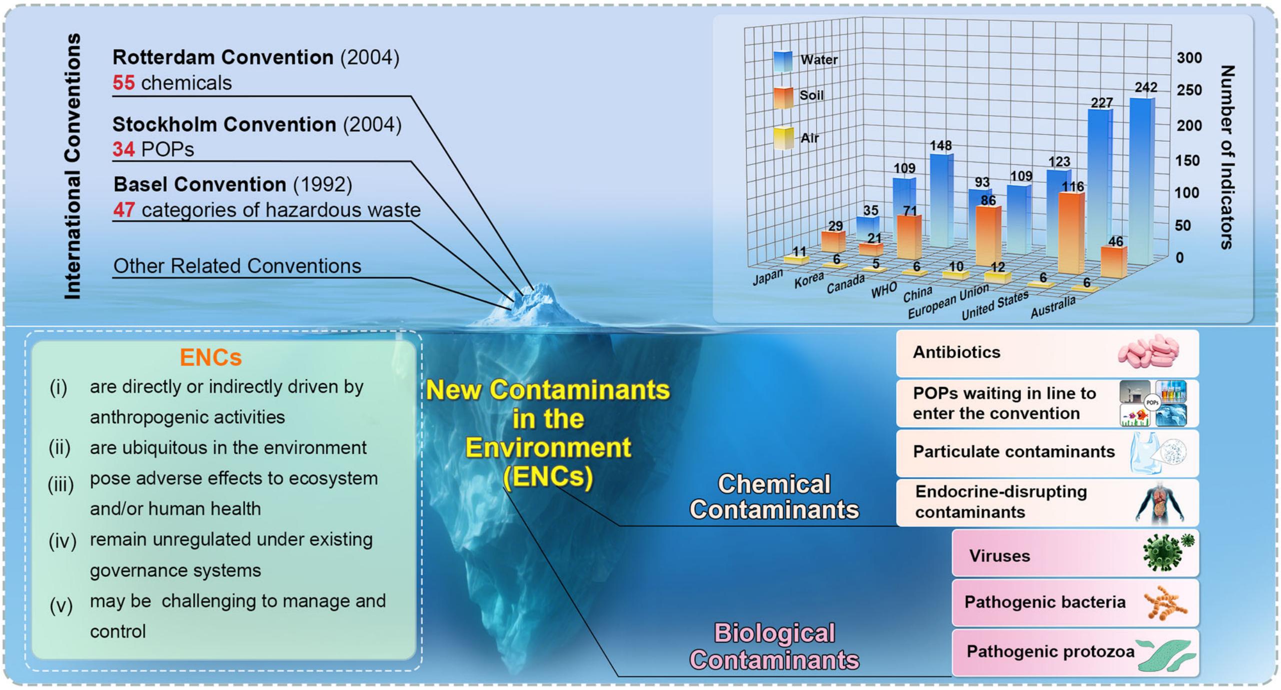

Fig. 1 | Brief concept and characteristics of ENCs. If environmental contaminants are visualized as an iceberg, the tip of the iceberg above the water represents contaminants effectively regulated by international conventions, environmental standards, etc. The majority of the iceberg beneath the surface symbolizes ENCs, which remain unregulated. The bar chart illustrates the number of contaminants currently included in international and regional water, soil, and air quality standards (**see** Supplementary Table 2).

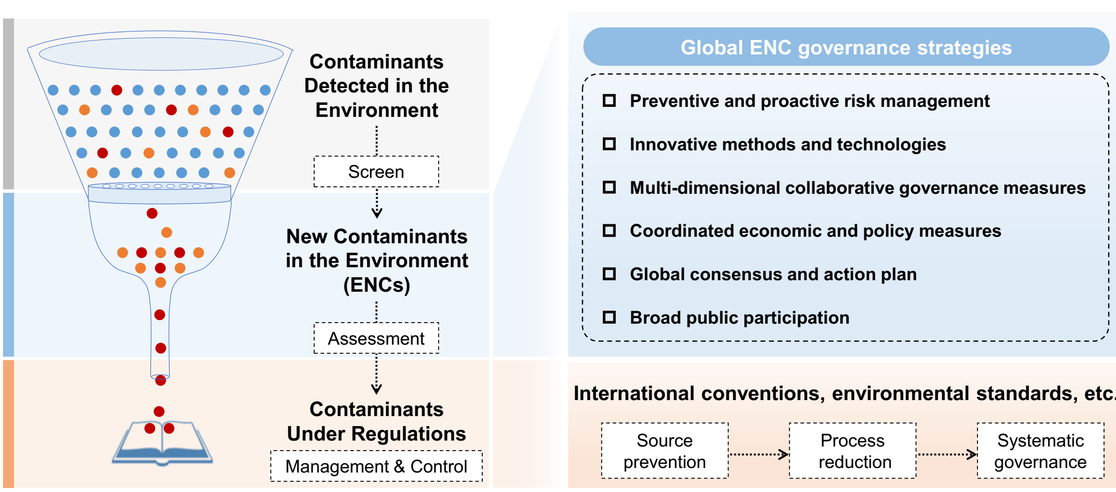

Fig. 2 | Global ENC governance strategies and roadmap. This figure illustrates a comprehensive roadmap for the governance of ENCs. For contaminants in the environment, six strategies are proposed to achieve the screening, assessment, management, and control of ENCs; prevention, reduction, and remediation of ENCs; and progressively incorporation of priority contaminants into regulatory systems and international conventions while establishing a comprehensive proactive management system.

with ozone, induces acute mortality in coho salmon in urban creeks[11]. Meanwhile, the use of neonicotinoid insecticides has contributed to the decline of wild bee populations[12]. Alarmingly, global environmental pollution is estimated to cause approximately 9 million premature human deaths annually, with toxic chemical exposure contributing to over 1.8 million[13], a number that is still rapidly rising. Long-term, low-dose exposure to PFASs has been linked to an increased risk of breast cancer, reproductive dysfunction, birth defects, and metabolic diseases[14]. Notably, the adverse health effects of many unregulated contaminants often emerge after prolonged latency periods. For example, lung cancer resulting from exposure to polycyclic aromatic hydrocarbons may take 10 to 30 years to manifest. This latency is equivalent to delaying the onset of population-level disease burdens by approximately two decades. Taking proactive action on these contaminants now is essential to building a robust foundation for the long-term protection of public health.

Additionally, unregulated contaminants have posed immense socioeconomic and health costs. For example, the estimated social cost of managing PFASs is as high as EUR 16 trillion—approximately 4000 times the net annual profit of the global PFAS industry (around USD 4 billion)[15]. According to a UN Environment Program (UNEP) report, antibiotic resistance directly and indirectly caused approximately 5 million deaths in 2019. By 2050, this figure could rise to 10 million deaths annually—comparable to global cancer deaths in 2020[16]. If left uncontrolled, antibiotic resistance could result in a global Gross Domestic Product (GDP) loss of USD 3.4 trillion annually and push an additional 24 million people into extreme poverty[16], with particularly severe impacts in impoverished regions.

Therefore, it is imperative to strengthen and prioritize the governance of high-risk ENCs. Here, ENCs refer to contaminants that meet all of the following five criteria. ENCs (i) are directly or indirectly driven by anthropogenic activities; (ii) are ubiquitous in the environment; (iii) pose adverse effects to ecosystem and/or human health; (iv) remain unregulated under existing governance systems; and (v) may be challenging to manage and control (see Fig. 1). It is noteworthy that ENCs is an open and dynamic concept that encompasses, but is not limited to, anthropogenic chemical contaminants, such as candidate POPs awaiting regulatory inclusion, particulate contaminants, antibiotics, and endocrine-disrupting chemicals, as well as biological contaminants, such as viruses, and pathogenic bacteria and protozoa. Representative examples of ENCs include liquid crystal monomers, microplastics, nanomaterials, and antibiotic resistance genes. We advocate for a new paradigm, perspective, and approach to mitigating global ecological and health risks from ENCs.

Issues and challenges

Effective and feasible management and control of ENCs need a fundamental transformation in research paradigm, management strategies, and governance framework. The core challenges encompass three critical dimensions: regulatory and strategic priorities, identification and assessment, and technical and health barriers. These dimensions constitute essential pathways for the systematic screening and targeted control of high-risk ENCs.

Regulatory and strategic priorities

Significant disparities exist among nations and regions in their capacity to monitor, manage, and enforce regulations for ENCs. In the European Union (EU), the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulation mandates that chemical substances placed on the EU market be registered and assessed. REACH places the burden of proof for chemical safety on manufacturers and importers, shifting the responsibility for hazard identification, risk mitigation, and safety assurance from governments to businesses[17]. In the United States (U.S.), the Toxic Substances Control Act (TSCA) adopts a risk-based regulatory approach, aiming to identify, assess, and control the risks of toxic chemicals to safeguard public health and ecosystems[18]. The U.S. is also advancing Safer Chemicals Research to generate sufficient information on chemicals needed for informed, risk-based decision-making, including innovative initiatives, such as high-throughput toxicology (HTT), rapid exposure and dosimetry (RED), and virtual tissue models (VTM)[19]. In China, the management of ENCs has been designated as a key area of national basic research and technological innovation, and has taken scientific research and governmental investigation as entry points to systematically screen, assess, manage, and control ENCs[20,21]. However, most countries or regions still lack a systematic and effective regulatory framework for ENCs. In particular, the absence of a comprehensive system for screening and identifying high-risk ENCs for monitoring, risk assessment, and control hinders effective governance. Tackling the challenge is urgent and complex. Key priorities include: (i) integrating existing resources and aligning the environmental risk management of ENCs with regulations for conventional contaminants (e.g., pesticides and cosmetics); (ii) establishing cross-national and cross-departmental coordination among agencies responsible for environmental protection, agriculture, health, customs, science, and finance; and (iii) strengthening legal frameworks and implementing national-level directives with localized accountability mechanisms.

Identification and assessment

Globally, there is a gap in data and knowledge regarding the fundamental characteristics of most ENCs[22]. The combination of high diversity, low environmental concentrations, complex exposure pathways, and variable hazard profiles presents significant challenges in evaluating their ecological and human health risks. Standardized protocols for detecting and quantifying these ENCs are either underdeveloped or nonexistent, while the classification system for prioritizing ENCs for risk assessment and control remains unclear. For instance, commonly used analytical techniques in microplastics research include visual microscopy, Fourier-transform infrared spectroscopy, and Raman spectroscopy. However, inherent heterogeneity in sampling strategies, material selection, and analytical methodologies makes it difficult to compare results across studies. Without more rigorous and internationally harmonized standards, a persistent pattern of misinformation and ineffective regulation may undermine global efforts to protect human health and the environment[23]. Another crucial challenge is the scarcity of toxicity data necessary for the screening and hazard assessment of contaminants. Recent estimates suggest that traditional ecotoxicity tests for a single chemical would cost USD 118,000 in average, and thus it will cost USD 1.18 billion for testing 10,000 chemicals[24]. In terms of time, generating toxicity data meet the requirements of current chemical regulatory frameworks for a single substance would take about two years[25]. If toxicity assessments were performed concurrently for 200 compounds, evaluating 10,000 contaminants would require approximately a century. This is not only impractical but also contradictory to the 3Rs principle (Replacement, Reduction, and Refinement)[26]. Both the financial and time costs associated with traditional toxicity testing present substantial challenges for the regulation of ENCs. To address these challenges, it is beneficial to focus on the following key issues: (i) compiling comprehensive data on the production, use, emissions, and hazard characteristics of ENCs across key industries; (ii) developing targeted, suspect, and non-target screening techniques in priority regions and sectors within existing monitoring networks; (iii) employing new approach methods (NAMs) (e.g., in vitro high-throughput tests and in silico modeling) to rapidly, efficiently, and cost-effectively assess toxicity; (iv) evaluating the long-term (i.e., chronic) effects of low-dose ENC exposure based on preliminary toxicity screening; and (v) establishing comprehensive risk assessments to identify and prioritize high-risk ENCs. Control measures should be based on technical feasibility and socioeconomic impacts, with the ultimate goal of incorporating the identified high-risk ENCs into international conventions and environmental standards.

Technical and health barriers

For most chemical ENCs, the complex chemical structures, low environmental exposure levels, and wide industrial applications make their governance technically demanding, economically challenging, and resource-intensive. Existing pollution control technologies are primarily designed for conventional contaminants, which are insufficient or inappropriate for managing complex ENC mixtures present at low concentrations[27,28]. Important challenges and actions encompass: (i) enforcing prohibitions or restrictions on the production, processing, and trade of high-risk ENCs to reduce their generation at the source; (ii) advancing process control through the promotion of green alternatives and incorporation of ENC emission control into green manufacturing standards; and (iii) reinforcing end-of-pipe treatment at industrial facilities via collaborative governance.

Biological ENCs exhibit high transmissibility and pathogenicity. However, the lack of early warning platforms that integrate ecological, public health, and social behavior data often leads to delayed detection of outbreaks or contamination events, thereby missing the optimal window for intervention[29]. Moreover, such events tend to disproportionately affect vulnerable populations, including children, older adults, and immunocompromised individuals. Inequities in healthcare resource distribution and insufficient public health service capacity further exacerbate disparities in health risks[30], particularly in low- and middle-income countries (LMICs), as defined by the World Bank based on gross national income per capita[31]. To address these challenges, it is important to address the following key issues: (i) strengthening integrated environmental and health surveillance systems to enable early detection across multiple media; (ii) establishing early warning frameworks based on dynamic risk indicators and real-time data; (iii) improving equitable access to public health resources, especially for vulnerable groups; and (iv) advancing a One Health governance framework that integrates environmental, animal, and human health systems to coordinate risk identification, information sharing, and response strategies. These efforts are helpful for building a resilient and sustainable management system for biological ENCs.

Global ENC governance strategies

The above discussions underpin the urgency and global priority of strengthening ENC governance. To tackle the challenge, we propose a governance framework comprising six specific strategies, aiming to mitigate risks posed by ENCs to ecosystems and human health (see Fig. 2).

Preventive and proactive risk management

The governance of ENCs should be initiated from the perspective of reducing risks to ecosystems and human health, requiring a transition from passive response to proactive prevention of risk occurrence[32]. A noteworthy example is China's implementation of the Stockholm Convention[33], which exemplifies an institutionalized framework for systematic contaminant elimination. Over the past two decades, China has achieved significant progress in POPs elimination, encompassing nationwide coordinated efforts for large-scale disposal of historical POPs waste and the phase-out of PCB-containing electrical equipment. To address emissions of dioxins and other hazardous by-products, China has actively promoted the application of Best Available Technologies and Best Environmental Practices in key sectors, such as steelmaking, paper production, and medical waste incineration[34]. These initiatives reflect the integration of risk-based substitution, redesign, and pollution prevention into management frameworks, particularly within high-exposure industries. Specifically, the following measures should be implemented to strengthen ENC governance: (i) strengthen source prevention by enforcing strict elimination or restriction measures, regulating ENC content in products, and preventing environmental release; (ii) enhance process management by improving ENC control during usage to minimize environmental emissions; and (iii) conduct regular investigation and monitoring of key targets (e.g., wastewater systems) to enable early identification and detection of contaminants with potential significant risks. Additionally, it is important to identify priority areas, environmental media, industries, processes, and contaminants for ENC management, establishing a dynamic priority list of contaminants for control. Risk assessments—based on toxicity, prevalence, and other hazard characteristics—can support the development of preventive and proactive management strategies. Overall, ENC governance should be seamlessly integrated into social development planning, policy-making, and various aspects of daily life to ensure effective and sustainable management.

Innovative methods and technologies

Advancing scientific research and fostering innovative technologies are fundamental for effectively addressing global ENC governance challenges. A pivotal innovation involves interdisciplinary and cross-sectoral collaboration, bridging the gap between scientific research and environmental management. This approach strengthens the integration of research, policy formulation, and governance practices, facilitating the translation of extensive research data into actionable policies while reducing socioeconomic costs. The application of the transdisciplinary research (TDR) paradigm is important[35]. For instance, for screening, identifying, and characterizing ENCs, cutting-edge tools such as machine learning and artificial intelligence can be harnessed to develop cost-effective methods. Machine learning-based pseudo-target screening (PTS) leverages integrated mass spectrometry data and experimental parameters to efficiently identify emerging chemical contaminants, markedly reducing the complexity and manual effort associated with traditional non-target screening methods[36]. NAM application offers a more efficient alternative to conventional animal-based toxicity testing, substantially reducing time and financial costs[37–39]. For mitigating ENC-related risks, strategic investment in the research and development of advanced materials and equipment is necessary to achieve cleaner, more economical, and efficient technologies. Detection techniques such as real-time quantitative PCR and biosensors have significantly improved the detection efficiency of biological ENCs in environmental matrices, while also being easy to use[40,41]. Nevertheless, further efforts are needed to overcome current limitations and ensure their broader applicability and sustained effectiveness[38].

Multi-dimensional collaborative governance measures

Effective ENC governance requires multi-dimensional collaboration across regulatory, industrial, and scientific sectors. Key actions to advance governance include: (i) incorporating ENC governance into current regulatory systems and international conventions, establishing environmental quality criteria and standards for high-risk ENCs; (ii) updating regulatory frameworks within international conventions to incorporate specific requirements for ENC risk identification and management, thereby strengthening global governance efforts; (iii) coordinating environmental risk control strategies for ENCs with those of previously regulated contaminants to ensure comprehensive pollution management; (iv) harmonizing pollution control across different environmental media (i.e., air, water, and soil) to minimize cross-media contamination and enhance overall environmental protection; (v) strengthening cross-industry and cross-departmental cooperation, particularly between environmental and health sectors, to ensure a holistic ENC risk management; and (vi) enhancing governance coordination through targeted strategies—such as prohibition, restriction, and treatment measures—while ensuring technical, economic, legal, and policy alignment for effective and sustainable ENC management.

Coordinated economic and policy measures

ENCs exhibit intrinsic linkages with industry and daily life, where socioeconomic policy tools have demonstrated significant efficacy in regulating ENC contamination. Considering the long-term ecological and health impacts, proactive intervention strategies—such as chemical substitution initiatives and preemptive bans—prove more cost-effective than post-contamination remediation. For example, health-related costs associated with PFAS exposure in the U.S. are estimated at USD 37–59 billion annually[42]. A benefit transfer analysis of households affected by PFAS contamination in Italy found that the public is willing to pay for improved water quality, generating approximately EUR 12 million annually in societal benefits[43]. This economic rationale is further underpinned by the U.S. Environmental Protection Agency's 2024 National Primary Drinking Water Regulation (NPDWR) for PFAS, which estimates annual implementation costs of USD 1.5 billion and health benefits of a comparable magnitude[44]. These benefits include the prevention of over 9600 deaths and approximately 30,000 serious illnesses in the coming decades, such as cardiovascular disease, kidney and bladder cancers, and developmental disorders. Additional unquantified gains—such as reduced risks of liver, thyroid, immune, and reproductive conditions—highlight the broader value of early regulatory action. These findings reinforce the long-term economic value of proactive pollution control and underscore its alignment with anticipatory governance, societal priorities, and sustainable economic outcomes. To achieve this, three key actions should be implemented: (i) establish an integrated framework encompassing environmental, economic, and social factors to assess and forecast future policy scenarios; (ii) utilize policy and economic instruments to incentivize industries in developing green products and designs, accelerate digital transformation, and enhance automation and intelligent manufacturing, thereby minimizing the production and use of ENCs; (iii) develop green alternatives by promoting industrial research and innovation in low-carbon green synthesis technologies, efficient production methods, and alternative assessment protocols. This approach ensures that substitutes are economically viable, environmentally sound, and safe for public health, thereby avoiding regrettable substitutions, in which replacement chemicals prove equally or more harmful than the originals. Furthermore, avoiding the unnecessary synthesis and production of new chemicals is essential to the long-term success of ENC governance.

Global consensus and action plan

Given the disparities in development levels and technological capacities across nations and regions, achieving harmonized ENC control objectives necessitates sustained global collaboration and unwavering commitment. To this end, we propose that the UN should establish an International Expert Committee on New Contaminants in the Environment, tasked with providing technical guidance, formulating best-practice principles, and facilitating the development of national pollution control action plans worldwide. International cooperation plays a pivotal role in data sharing, regulatory harmonization, and the provision of financial and technical assistance to countries in need. This initiative encompasses five key elements: (i) fostering international communication, coordination and cooperation, establishing global funding mechanisms and technology transfer programs, and strengthening governance capacity to collectively address the challenges posed by ENCs; (ii) enhancing capacity for ENC monitoring, assessment, and governance to establish international databases and data-sharing platforms on ENC occurrence, toxicity, and regulatory practices; (iii) formulating and promoting harmonized international standards for ENC detection, risk assessment, and regulation; (iv) allocating dedicated funding and policy support from all countries to build regulatory frameworks and integrated platforms for ENC identification, early warning, and risk management; and (v) offering financial aid to LMICs and promoting diverse investment mechanisms for ENC governance at international, national, local, and corporate levels. These international collaborations will enhance synergies across multilateral environmental agreements, particularly the Stockholm Convention, the Basel Convention, the United Nations Framework Convention on Climate Change (UNFCCC), and the Convention on Biological Diversity (CBD).

Broad public participation

The effective governance of ENCs is intrinsically intertwined with the well-being of all human beings, necessitating a collaborative approach among governments, businesses, and individuals. Such a strategy highlights the importance of robust ENC governance, heightened public awareness, and the promotion of sustainable consumption and production practices. National governments should prioritize ENC governance by strengthening legal frameworks and establishing robust regulatory foundations. Regional governments should actively support ENC governance initiatives and lead public awareness campaigns. Businesses play an important role by meticulously assessing the lifecycle impacts of raw materials during product design and development to minimize or eradicate the use of toxic and harmful substances. Moreover, each individual's actions are significant. For instance, citizen science initiatives in Europe and North America have successfully engaged community volunteers in monitoring ENCs, such as pharmaceuticals and pesticides. These initiatives rely on standardized sampling protocols, digital identification tools, and open-access platforms to enhance data transparency and community engagement. This evolution in participatory engagement is further exemplified in the wastewater treatment sector, where recent assessments recommend transitioning from unidirectional public relations to co-creation models—such as citizen juries and deliberative workshops—positioning public knowledge as an indispensable component of effective contaminant governance[41]. The public must deepen their understanding of ENC risks and governance to make informed choices that mitigate ENC pollution. This includes adopting eco-friendly consumption habits, choosing environmentally responsible products, and monitoring pollution control efforts. By collectively embracing these principles and practices, we can foster a more sustainable environment for current and future generations.

Currently, the implementation of these proposed strategies for ENC governance faces challenges, including the lack of foundational data, the absence of standardized risk assessment methodologies, economic and policy barriers, and insufficient international coordination mechanisms. No single country or region can independently and fully address the complex issues posed by ENCs; rather, a coordinated global effort is essential. High-income countries (HICs), as defined by the World Bank[30], can leverage their strengths in scientific research, data infrastructure, and regulatory experience to accelerate the development and sharing of foundational databases, advance research and deployment of cost-effective and efficient detection and treatment technologies, and develop practical and science-based risk assessment methodologies. Moreover, through technology transfer, resource sharing, and capacity-building initiatives, HICs can assist LMICs in enhancing their ENC governance capabilities. At the same time, LMICs, based on their national contexts, can prioritize addressing the most pressing local contamination challenges and adopt context-appropriate, cost-effective control measures to gradually improve their data collection systems and regulatory frameworks and progressively incorporate high-risk ENCs into effective regulation. For instance, China has not only released an action plan on controlling ENCs[20] but has also launched a national major special initiative with a planned investment of approximately USD 300 million. Looking ahead, China aims to mobilize joint investments from government, industry, and international partners to advance research, foster innovation, and develop practical solutions for ENC governance.

Conclusions

Despite notable international endeavors to tackle inadequately regulated contaminants, the attention towards ENC governance remains far from adequate. This presents a multifaceted challenge for scientists, governments, industries, and the public. We advocate for global collaboration to craft a comprehensive framework for ENC governance, revolutionize research methodologies, bolster international partnerships, and enhance public awareness. These initiatives aim to mitigate the risks and adverse impacts of ENCs and propel the advancement of the UN Sustainable Development Goals (SDGs), such as SDG 3, 6, 12, 13, 14, and 15. Through these collective actions, we can better address the challenges posed by ENCs and advance toward a cleaner and healthier environment for all.

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Competing interests
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Additional information

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