Ecotoxicol. Environ. Contam., v. 21, n. 1, 2026, 59- 77
doi: 10.5132/eec.2026.01.06

ECOTOX BRASIL
SOCIEDADE BRASILEIRA DE ECOTOXICOLOGIA

EEC

Review Article

Chemical Contaminants in Urban Rivers: Ecotoxicological Risks To Aquatic Life and Human Health

Janisi Sales Aragão[1], Ana Millene dos Santos Silva[1], Victor Soares Rodrigues[2], Katerin Fuentes-Lopez[3], Karuane Saturnino da Silva Araújo[4], Bruno Machado Araújo[4], Jéssica Antonia Cardoso Mendes[4], Irwing Carlo Neres da Silva[5], Thiago Machado da Silva Acioly[6]

[1]Federal Institute of Education, Science, and Technology of Ceará (IFCE), Juazeiro do Norte, CE, Brazil.
[2]State University of Montes Claros (Unimontes), Montes Claros, MG, Brazil.
[3] Environmental and Computational Chemistry Group. Functional Toxicology Group. School of Pharmaceutical Sciences, Zaragocilla Campus, University of Cartagena, Cartagena, Colombia.
[4]State University of Maranhão (UEMA), São Luís, MA, Brazil. [5]State University of the Tocantina Region (UEMASUL). Imperatriz, Maranhão, Brazil.
[6]Federal Institute of Education, Science and Technology of the Sertão Pernambucano (IFSertãoPE), Campus Floresta, Floresta, PE, Brazil.

Received January 20, 2026; Accept July 15, 2026

Abstract

The discharge of waste and effluents into water bodies, driven by rapid urbanization and industrial development, has been closely linked to the degradation of aquatic ecosystems and the disruption of essential ecosystem services, particularly in urban rivers. These rivers are frequently contaminated with antibiotics that promote the emergence of resistant bacterial strains, as well as potentially toxic elements (PTEs), polycyclic aromatic hydrocarbons, and pesticides. This review examines the ecotoxicological impacts of contaminants on urban rivers, evaluating their effects on ecosystem health and potential risks to human populations. The study was conducted as an integrative literature review following PRISMA guidelines, using the descriptors ‘Urban River’ AND ‘Ecotoxicology’ across the databases Science Direct, Scopus, and Web of Science. A total of 245 records were initially identified. After applying inclusion and exclusion criteria, as well as screening and eligibility assessment, 24 articles were selected for full-text reading and critical analysis. The study identifies major pollution sources and hazardous chemicals in urban rivers. In Brazil, pollution from antibiotics and PTEs continues to degrade aquatic habitats and compromise water quality, while public policies for river restoration remain in early stages, requiring broader implementation and coordinated actions across government levels. These patterns reflect a global challenge, as urban rivers worldwide face similar pressures from industrialization, urban runoff, and inadequate wastewater management.

Keywords: Anthropogenic pollution; freshwater ecosystems; toxic substances; environmental management; biomonitoring.

*Corresponding author: janisi.aragao@ifce.edu.br

INTRODUCTION

Rapid urban and technological growth has led to a progressive deterioration in the quality of aquatic ecosystems, which often receive untreated domestic, agricultural, and industrial wastewater (Bunke *et al*., 2019; Haarstrick & Sharma, 2024; Guabloche *et al*., 2024). The presence of organic and chemical substances, including trace metals, pesticides, and emerging pollutants such as antibiotics and pharmaceuticals, poses significant risks to both human health and aquatic biota, as contaminated water can lead to waterborne diseases that adversely affect communities and healthcare systems (Acioly *et al*., 2024; Singh *et al*., 2024; Thakur *et al*., 2025). These pollutants accumulate in aquatic environments, which function as sinks for diverse contaminants (Materon *et al*., 2020), leading to excessive algal growth and the mortality of fish and other aquatic organisms. This imbalance disrupts ecosystems, threatens public health, and contributes to secondary soil contamination, among other negative effects.

In their natural state, rivers form a dynamic mosaic of habitats constantly shaped by water flow and sediment transport. The interaction between hydrological, vegetative, and geomorphological processes supports biodiversity and maintains ecological integrity. However, the accumulation of pollutants and increasing urban development have deeply altered these ecosystems, modifying hydrology and sediment regimes, fragmenting river systems, and disrupting the connectivity between rivers and their floodplains. These changes degrade urban river ecology, leading to what is commonly known as the "urban stream syndrome" (Gurnell, Lee & Souch, 2007). Urbanization's impact on rivers is profound, as many cities historically developed around them due to the resources they provide, such as water, energy, and transportation (Mishra *et al.*, 2024; Wu *et al.*, 2024). However, the expansion of impermeable surfaces, channel modifications, and increasing water demand have caused many urban rivers to lose the ecosystem services that once supported the flourishing cities around them. As aquatic ecosystems deteriorate, there is an urgent need to restore and manage these water bodies sustainably, recognizing the essential benefits that healthy rivers provide to society (Sharma & Birman, 2024; Xiong *et al.*, 2024).

The issue of urban river pollution is particularly critical in developing countries, where access to basic sanitation services is often limited or absent. In the Médio Tocantins River, located in northeastern Brazil (state of Maranhão), untreated wastewater is directly discharged into the river, worsening pollution levels in both water and sediments (Acioly *et al*., 2024; Machado da Silva Acioly *et al.*, 2024). Rapid urban growth further exacerbates these problems and highlights the urgent need for robust public policies focused on improving sanitation infrastructure and fostering a culture of environmental responsibility (Olguín *et al*., 2010; Kryston *et al*., 2024).

While urbanization drives economic growth, it also presents major challenges related to housing, infrastructure, and basic services. This expansion increases the use of land and natural resources, accounting for approximately two-thirds of global energy consumption and more than 70% of greenhouse gas emissions. Moreover, 1.8 billion people currently live in flood-prone areas, making them increasingly vulnerable to disasters. Today, more than half of the world's population, over 4 billion people, resides in cities, and this figure is expected to reach nearly 70% by 2050. Alarmingly, around 45% of this urban population lives in flood-prone areas, especially in rapidly urbanizing river plains and coastal regions of developing countries (World Bank, 2025). Therefore, effective coordination between local and national governments is essential for achieving sustainable urbanization and building greener, more inclusive, and more resilient cities.

The growing contamination of urban rivers should also be considered within the One Health framework, which recognizes the close interconnection between environmental, animal, and human health. Chemical contaminants released into aquatic ecosystems, including heavy metals, pharmaceuticals, and antibiotic-resistant microorganisms, can adversely affect aquatic organisms through toxicity and bioaccumulation while increasing human exposure via contaminated water and aquatic food webs (Sharma *et al*., 2023; Mills *et al.*, 2024). Consequently, protecting water quality requires an integrated approach that considers both ecosystem integrity and public health. In this context, ecotoxicological assessments are essential because they identify biological effects that may not be detected by physicochemical analyses alone, supporting environmental risk assessment, water quality management, and evidence-based decision-making for the protection of ecosystem and human health (Caixeta *et al*., 2022; Pereira et al., 2026).

Urban rivers must be recognized for their vital role in maintaining ecological balance and enhancing urban quality of life. They provide essential water resources and offer economic, social, and environmental benefits, supporting ecosystems and promoting human well-being (Zingraff-Hamed *et al.*, 2021; Sousa et al., 2025). Therefore, this article reviews the ecotoxicological of urban rivers, assessing ecosystem health and the potential impacts of contaminants on human populations. In this context, it provides a comprehensive overview of ecotoxicological studies conducted in urban rivers in recent years (2014 to 2024), aiming to analyze the health effects on aquatic biota and to establish relationships between contaminant exposure in river systems and potential human health risks. By addressing these issues, this review contributes to the advancement of several United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 14 (Life Below Water), by promoting knowledge that supports sustainable water management and the protection of aquatic ecosystems in urban environments (United Nations, 2015).

METHODOLOGY

This study is an integrative review of broad scope, designed to compile and synthesize the main findings of the existing scientific literature, following the recommendations of PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The protocol was structured based on a checklist and flow diagrams covering the following stages: formulation of a guiding question, selection of databases, choice of keywords, definition of eligibility criteria, data collection, listing and presentation of information, and discussion and publication of the results. The guiding question of this research was: "What has the literature addressed regarding ecotoxicological impacts in urban rivers?".

To answer this question, the descriptors Urban River and Ecotoxicology were combined using the Boolean operator AND, with the terms applied in English in the databases Science Direct, Scopus, and Web of Science. In Scopus, the search was restricted to titles, abstracts, and keywords, whereas in Science Direct and Web of Science, the descriptors were searched throughout the text. These descriptors were intentionally selected because they directly reflect the scope of the review, focusing specifically on ecotoxicological studies conducted in urban river environments. Preliminary searches using broader combinations of keywords retrieved a substantial number of studies unrelated to the research question, including investigations of non-urban aquatic ecosystems and general water quality assessments. Therefore, the selected descriptors were considered the most appropriate to maximize the relevance and specificity of the retrieved literature. Studies published in English between 2014 and 2024 were selected. This time frame was chosen to provide an up-to-date overview of the most recent advances in urban river ecotoxicology, considering the rapid emergence of new contaminants, analytical methodologies, and ecological risk assessment approaches over the last decade.

Inclusion criteria comprised original open-access studies addressing ecotoxicological aspects and impacts in urban rivers. Exclusion criteria included studies not related to the topic, outside the scope of the research question, paywalled content, case reports, monographs, theses, dissertations, opinion papers, reviews, and duplicates. Articles were considered outside the scope if they did not address ecotoxicological studies in urban rivers or examined non-urbanized environments without clear evidence of urban impacts.

For article selection, a preliminary screening of titles and abstracts was performed to verify whether each study met the predefined criteria. The screening and eligibility assessment were independently conducted by two reviewers based on the predefined inclusion and exclusion criteria. Any disagreements regarding study selection were resolved through discussion until consensus was reached. The screening process was not blinded, as information regarding authors, journals, and institutions was available during the selection process. Subsequently, the eligible studies were read in full, allowing the extraction of data that composed the results of this research. To facilitate data interpretation, a summary table was prepared, containing the ecotoxicological approach, observed impact, and geographical location of the investigated river. Additional literature relevant to the topic was consulted exclusively to provide background information and support the discussion of specific concepts. These complementary references were not included in the PRISMA selection process and were not considered part of the evidence synthesis.

A total of 245 articles were identified after applying the year and language filters across the selected databases: Science Direct (76.33%), Scopus (12.65%), and Web of Science (11.02%). After removing 21 duplicate records, 224 articles remained for preliminary screening based on titles and abstracts. Following this stage, 65 articles were selected for full-text assessment, of which 41 were excluded for being outside the scope of the study. Consequently, 24 articles were included in the final review, as illustrated in Figure 1.

A limitation of this review is that a formal risk-of-bias assessment of the included studies was not performed. As an integrative review, the focus was on synthesizing the available evidence rather than evaluating the methodological quality of individual studies using standardized risk-of-bias tools.

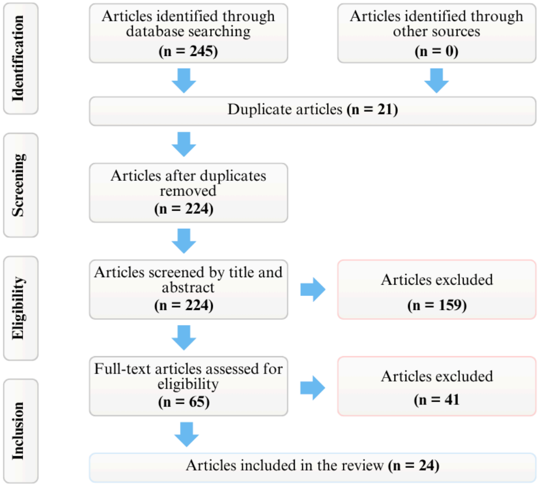

Figure 1. PRISMA 2020 flow diagram illustrating the literature search, screening, eligibility assessment, and study selection process used in this integrative review.

RESULTS AND DISCUSSION

Overview of Contaminants in Urban Rivers

Environmental ecotoxicology is a broad and evolving field, and its importance continues to grow with the increasing complexity of chemical transformations in the environment. Isolated chemical analyses alone cannot accurately capture the environmental impact of contaminants, as they fail to demonstrate their true ecological effects (Cheng *et al.*, 2024; Magalhães & Ferrão-Filho, 2008). A clear example of this limitation is the growing presence of emerging contaminants in water bodies, which cause multiple environmental problems, particularly affecting aquatic biota. Numerous studies have reported the occurrence of these contaminants in urban rivers and documented their impacts on different aquatic organisms (Table 1).

Environmental contaminants in urban rivers encompass a wide variety of chemical classes, including pharmaceuticals, pesticides, metals, plasticizers, and microplastics (Table 1). Their widespread presence in multiple environmental compartments, such as water, sediment, and biota, has been extensively documented (Gillis, 2012; Sanchez & Porcher, 2014; Wang *et al.*, 2016; Tu *et al.*, 2018; Barreto *et al.*, 2020; Tang *et al.*, 2024). These pollutants are typically introduced through untreated industrial effluents, domestic sewage, urban runoff, and diffuse agricultural discharges, posing cumulative and long-term risks to aquatic ecosystems. Taken together, these findings indicate that urban rivers act as integrative systems for multiple contamination sources, resulting in complex exposure scenarios that cannot be fully understood through isolated chemical measurements alone.

Emerging Contaminants and Ecotoxicological Risks

Studies conducted in different geographic regions consistently demonstrate that emerging contaminants, particularly pharmaceuticals and personal care products, are among the compounds most frequently detected in urban rivers worldwide. Arsand *et al.* (2023) evaluated the ecological risk of emerging contaminants, including nonsteroidal anti-inflammatory drugs (NSAIDs), analgesics, and antipyretics, in the Dilúvio Stream (Porto Alegre, Brazil), focusing on freshwater organisms such as fish, invertebrates, and algae. The study revealed that paracetamol exhibited high toxicity to the tested organisms, while sulfamethoxazole and trimethoprim posed risks to algae, and caffeine affected crustaceans.

These findings indicate that such compounds present a high intrinsic hazard to aquatic organisms; however, the actual ecological risk depends on environmental concentrations, exposure frequency, organism size (weight), and species-specific sensitivity. Furthermore, Arsand *et al.* (2023) detected caffeine, metoprolol, paracetamol, propranolol, sulfamethoxazole, and trimethoprim in all analyzed samples, suggesting continuous inputs from domestic sewage and insufficient removal during wastewater treatment processes.

Similarly, Tamura *et al.* (2017) conducted chemical analyses and toxicity tests on water samples collected from urban streams in Tokushima, Kyoto, and Saitama, Japan, heavily influenced by wastewater effluents. A total of 63 pharmaceuticals and 36 personal care products were investigated, of which 50 and 18 compounds, respectively, were detected in at least one sample. Caffeine was identified as the most abundant pharmaceutical, being detected in all analyzed samples at concentrations reaching 11,000 ng/L, whereas 2-phenoxyethanol was the predominant personal care product compound, with concentrations up to 14,000 ng/L. Reported LOD and LOQ values ranged from 1–10 ng/L and 5–50 ng/L, respectively, depending on the analyzed compound.

The high environmental concentrations of these compounds reinforce their persistence and widespread consumption, making them reliable indicators of anthropogenic contamination in urban aquatic systems. Toxicity assays demonstrated that linear alkylbenzene sulfonates (LAS) were most toxic to *Ceriodaphnia dubia* (8-d EC25 = 0.13–1.9 mg L^{-1}), followed by *Danio rerio* (9-d EC10 = 0.40–7.6 mg L^{-1} for hatching and larval mortality) and *Raphidocelis subcapitata* (72-h EC10 = 1.7–26 mg L^{-1}), highlighting differences in species sensitivity among aquatic taxa.

Table 1. Summary of studies evaluating ecotoxicological impacts in urban rivers

Author / Year	Ecotoxicological Approach	Observed Impact	River / City / Country
Arsand *et al.* (2023)	Ecological risk assessment of emerging contaminants (non-steroidal anti-inflammatory drugs — NSAIDs, analgesics, and antipyretics).	Paracetamol showed high ecological risk for algae, crustaceans, and fish (RQ = 2.84–8.06), with low EC50/LC50 values (0.124–0.352 mg L^{-1}). Sulfamethoxazole and trimethoprim also posed elevated ecological risk to algae (RQ = 50 and 1.78, respectively), while caffeine presented higher risk to aquatic crustaceans (RQ = 2.27).	Dilúvio Stream – Porto Alegre, Brazil.
Tamura *et al*. (2017)	Chemical analysis and toxicity tests of pharmaceuticals and personal care products, including linear alkylbenzene sulfonates (LAS).	The most abundant pharmaceutical detected was caffeine, whereas 2-phenoxyethanol was the predominant personal care product. LAS compounds were most toxic to *Ceriodaphnia dubia* (8-d EC25 = 0.13–1.9 mg L^{-1}), followed by *Danio rerio* (9-d EC10 = 0.40–7.6 mg L^{-1}) and *Raphidocelis subcapitata* (72-h EC10 = 1.7–26 mg L^{-1}). Very low EC10 values were also reported for algae exposed to triclosan (0.00054 mg L^{-1}) and clarithromycin (0.0037 mg L^{-1}).	Urban streams in Tokushima, Kyoto, and Saitama – Japan.
Domínguez-García *et al.* (2024)	Risk Quotient (RQ) and feeding/survival bioassay with *Daphnia magna*.	RQ assessment and *D. magna* bioassay. Most pharmaceuticals showed RQ < 1; atorvastatin and chlorpromazine exceeded toxicity thresholds. No mortality occurred, although sublethal feeding effects were observed in D. magna. LOQ ranged from 2.0 to 71.9 ng L^{-1}.	Besòs and Llobregat Rivers – Catalonia, Spain.
Biswas, Vellanki and Kazmi (2022)	Risk Quotient (RQ).	RQ of six out of ten target compounds in surface water exceeded 1, implying moderate to high risk for freshwater organisms.	Yamuna River – India.
Prasad, Shukla, and Ahammad (2024)	Contaminants in the Ganges River and Risk Quotient (RQ).	Metformin, triclosan, triclocarban, diclofenac, and methylparaben were the most abundant compounds. Maximum RQ in water: triclocarban, 17α-ethinylestradiol, diclofenac, and triclosan; in sediment: triclocarban, followed by 17α-ethinylestradiol, 17β-estradiol, triclosan, and diclofenac.	Ganges River – India.
Murrell *et al*. (2024)	Enzymatic activities of microbial communities.	Inhibition of protease, phosphatase, and lipase activities, and increased catalase activity in response to oxidative stress.	Urban and rural rivers – Cuba.
Rapp-Wright *et al.* (2023)	Risk Quotient (RQ) for emerging contaminants	Most compounds in the river were classified as low ecological risk.	Urban river – Ireland.
Zhang *et al.* (2020)	Mixture Risk Quotient (MRQ) of antibiotics.	Average MRQ values were 3.4 in water and 2.7 in sediments, indicating moderate ecological risks from antibiotic mixtures, particularly for algae. Synergistic effects were observed for some antibiotic combinations, and LOQ values ranged from 0.10 to 3.5 ng g^{-1}.	Chaobai River – Beijing, China.

Table 1 - continued

Author / Year	Ecotoxicological Approach	Observed Impact	River / City / Country
Marques *et al.* (2023)	Presence of azithromycin (AZI), ivermectin (IVE), and hydroxychloroquine (HCQ) in urban rivers; environmental Risk Quotient (RQ); evaluation of individual and combined effects on cyanobacteria (*Synechococcus elongatus*) and microalgae (*Chlorella vulgaris*).	AZI and HCQ posed environmental risks to cyanobacteria and microalgae, while IVE mainly affected *C. vulgaris*. Combined exposure altered growth and photosynthesis, and AZI + IVE induced cyanobacterial mortality. LOQ values ranged from 0.02 to 0.50 µg L^{-1}.	Barigui, Belém, and Iguaçu Rivers – Curitiba, Brazil.
Won- Ki, Atique, An (2020)	DNA damage in zebrafish (*Danio rerio*).	Embryonic developmental delays, distal head and tail necrosis, heart morphology differences, and altered heart rate.	Geum River – Daejeon, South Korea.
Mata *et al.* (2020)	Toxicity using benthic crustaceans (*Heterocypris incongruens*)	Ecotoxicological assays showed 100% mortality after 6 days of sediment exposure, indicating severe sediment toxicity associated with high concentrations of toxic metals exceeding sediment quality guidelines.	Kinshasa – Democratic Republic of Congo.
Sharma *et al.* (2022)	Chromium presence in water, sediment, plants (*Eichhornia crassipes*), and fish (*Labeo rohita*).	Chromium concentrations exceeded WHO permissible limits in water and sediments. Bioconcentration factors (BCF) were highest in fish gills (6.42) and lowest in kidneys (1.04), indicating tissue-specific bioaccumulation. HPI and MQI values revealed severe chromium contamination and ecological risk in the Yamuna River ecosystem.	Yamuna River – India.
Urmi *et al.* (2023)	Risk Quotient (RQ) for phthalate esters.	RQ values followed the order DEHP > BBP > DBP > DEP > DMP. DEHP posed high ecological risk to sensitive aquatic organisms, particularly algae (RQ = 60.1 in Savar and 20.4 in Tongi), while BBP showed high risk to invertebrates. Risk assessment was based on LC50/EC50 and NOEC-derived PNEC values.	Tongi and Savar – Bangladesh.
Wang *et al*. (2019)	Ecotoxicological risks of polychlorinated biphenyls (PCBs) in sediments.	PCBs in most sediment samples exceeded TEL (Threshold Effect Level) but were below PEL (Probable Effect Level).	Pearl River – China.
Barreto *et al*. (2020)	Embryo-larval development of native fish (*Salminus brasiliensis*, *Prochilodus lineatus*, *Pseudoplatystoma corruscans*, *Rhamdia quelen*).	Most species showed high frequency and severity of deformities depending on tested concentrations.	Atuba River – Curitiba, Brazil.
Mwanamoki *et al.* (2014)	Sediment chemical analysis and toxicity using benthic crustaceans (*Heterocypris incongruens*)	Ecotoxicological assays showed 100% mortality in exposed benthic organisms, indicating severe sediment toxicity associated with contaminant exposure.	Congo River basin and Lake Ma Vallée – Kinshasa, DRC.

Table 1 - continued

Author / Year	Ecotoxicological Approach	Observed Impact	River / City / Country
Truong *et al*. (2023)	Ecological risk assessment.	Risks ranged from low to medium for aquatic organisms.	Urban rivers and lakes – Hanoi, Vietnam.
Alves *et al*. (2021)	Fish toxicity.	Swim bladder inflation failure, delayed hatching, insufficient mouth protrusion, blood stasis, underdeveloped pectoral fins.	Capibaribe River – Brazil.
Gemusse *et al*. (2021)	Health assessment of tilapia (*Oreochromis niloticus*).	Negative impacts on fish health.	Iguaçu River – Paraná, Brazil.
Santana *et al* (2018)	Chemical analysis of tilapia muscles (*Oreochromis niloticus*).	High levels of metals; hepatic alterations (necrosis and inflammatory processes).	Iguaçu River – Paraná, Brazil.
Gillis, Higgins and Jorge (2014)	Urban-derived contaminants in wild freshwater mussels (*Lasmigona costata*).	Physiological effects from chronic exposure to complex urban inputs; some biomarkers responded cumulatively to municipal wastewater effluents and road runoff.	Grand River – ON, Canada.
Kumari *et al*. (2023)	Presence of microplastics in wild fish.	Fish captured near effluent discharge points were more susceptible to microplastic contamination; fish feeding in the water column were particularly affected.	Ganges River – Patna, Bihar, India.
An *et al.* (2022)	Presence of microplastics in water and benthic snail (*Bellamya aeruginosa*).	Relatively high abundance of microplastics in surface water and snails (mean 28.13 ± 4.18 particles per individual).	Qing River – Beijing, China.
Hou *et al.* (2024)	Concentrations and distribution of imidacloprid and thiamethoxam after heavy rainfall events.	Chronic ecological risk assessment (RQ and joint probability curves) showed moderate to significant risks of imidacloprid and thiacloprid to aquatic organisms, especially insects and crustaceans. Chronic HC5-derived criteria were 0.006 and 0.012 µg/L, respectively; chronic risk probabilities affecting 5% of species reached 97% and 68%. LOD/LOQ: 0.01/0.03 ng/L.	Licun River – Qingdao, China.

Very low EC10 values were reported for algae exposed to triclosan (0.00054 mg L^{-1}) and clarithromycin (0.0037 mg L^{-1}), indicating high sensitivity to these compounds. These findings highlight differences in species sensitivity across trophic levels, with aquatic invertebrates showing greater susceptibility to surfactants, potentially affecting food web dynamics and ecosystem stability.

Environmental risk assessment is an essential tool for estimating the probability of adverse ecological effects resulting from exposure to environmental stressors, including chemical substances, land-use changes, and invasive species. The Risk Quotient (RQ) is widely applied for this purpose, where $RQ < 1$ indicates negligible risk, $1 \leq RQ < 10$ indicates low potential for adverse effects, $10 \leq RQ < 100$ represents moderate potential, and $RQ \geq 100$ indicates a high potential for adverse ecological effects (EPA, 2018, cited in Domínguez-García *et al.*, 2024).

This approach integrates both exposure and toxicity, allowing a more realistic assessment compared with analyses based solely on intrinsic hazard. An example is the study conducted by Domínguez-García *et al.* (2024), who applied the RQ method to evaluate pharmaceuticals in water samples from the Besòs and Llobregat rivers in Catalonia, Spain. Most pharmaceuticals presented RQ values lower than 1, indicating low environmental risk. Although no mortality was observed in *Daphnia magna*, sublethal effects on feeding behavior were detected. These findings highlight the importance of considering sublethal endpoints, since behavioral and physiological alterations may precede population-level effects and contribute to ecological imbalances under chronic exposure scenarios.

In India, Biswas, Vellanki, and Kazmi (2022) reported that six out of the ten compounds detected in surface waters of the Yamuna River exhibited RQ values greater than 1, indicating moderate to high risks for freshwater organisms. This contrast with studies reporting low RQ values suggests that environmental risk varies substantially according to local conditions, including population density, wastewater treatment efficiency, and hydrological characteristics. Similarly, Prasad, Shukla, and Ahammad (2024) identified metformin, triclosan, triclocarban, diclofenac, and methylparaben as the most abundant contaminants in the Ganges River. Triclocarban showed the highest ecological risk, followed by 17α-ethinylestradiol, diclofenac, and triclosan in water samples, whereas sediments exhibited higher risks associated with triclocarban and steroidal estrogens.

The elevated risks associated with sediments indicate that these environmental compartments may act as secondary sources of contamination, gradually releasing pollutants over time and increasing the exposure of benthic organisms. Emerging contaminants also affect microbial communities by inhibiting protease, phosphatase, and lipase activities, while simultaneously increasing catalase activity as a response to oxidative stress, as observed by Murrell *et al*. (2024) in urban and rural rivers in western Cuba. These biochemical alterations suggest that contaminants may impair essential ecosystem functions, including nutrient cycling and organic matter decomposition, potentially reducing ecosystem resilience. Overall, the studies analyzed reveal a consistent global pattern in which emerging contaminants are continuously introduced into urban rivers, persist across different environmental compartments, and induce both lethal and sublethal effects at multiple trophic levels.

Despite regional differences in contaminant concentrations and profiles, the recurrent detection of compounds such as caffeine, antibiotics, and personal care products indicates common contamination sources associated with urbanization and the discharge of domestic wastewater. However, it is important to emphasize that many studies do not report essential analytical parameters, such as limits of detection (LOD) and limits of quantification (LOQ), which restricts the comparability, reproducibility, and robustness of environmental monitoring data. Furthermore, although pharmaceuticals are widely discussed in the literature, pesticides are also frequently introduced into urban rivers through surface runoff, particularly during rainfall events, representing an important yet still underexplored source of ecotoxicological risk.

Mixtures of Contaminants and Synergistic Effects

Rapp-Wright *et al.* (2023) monitored more than 140 emerging contaminants in rivers and wastewater treatment plants in Ireland. The authors reported that the overall environmental risk of contaminants detected in river waters was lower than that observed in effluent samples, with most compounds classified as low risk, suggesting a dilution effect along the river course. Only twelve compounds were quantified in the urban river samples.

These findings suggest that, although dilution processes may reduce contaminant concentrations in receiving water, they do not eliminate ecological risks, particularly under scenarios of continuous input in which contaminants are persistently introduced into aquatic systems. Furthermore, the lower number of quantified compounds in river samples compared with effluents may reflect both dilution effects and analytical limitations, reinforcing the importance of comprehensive monitoring strategies.

In Beijing, Zhang *et al*. (2020) applied the Mixture Risk Quotient (MRQ) approach to evaluate nine antibiotics in the Chaobai River. This One Health perspective recognizes the interconnection between environmental, animal, and human health, highlighting that contamination of aquatic ecosystems may directly and indirectly affect human populations. Representative aquatic organisms, including algae, invertebrates, and fish, showed moderate environmental risk due to the high concentrations, toxicity, and synergistic effects of antibiotic mixtures (Zhang *et al.*, 2020). Macrolides and sulfonamides were detected at higher concentrations in water samples, whereas tetracyclines and fluoroquinolones predominated in sediments. This compartmentalization of contaminants indicates that different classes of antibiotics exhibit distinct environmental behaviors, influencing their bioavailability and exposure pathways across trophic levels. Moreover, the moderate risk associated with contaminant mixtures highlights that combined effects may amplify ecological impacts beyond those predicted from assessments of individual compounds alone.

Marques *et al.* (2023) investigated three pharmaceuticals widely used during the COVID-19 pandemic—azithromycin, ivermectin, and hydroxychloroquine—in water samples collected from three urban rivers in Curitiba, Brazil. The study included Risk Quotient (RQ) assessment and the evaluation of individual and combined effects on cyanobacteria (*Synechococcus elongatus*) and microalgae (*Chlorella vulgaris*). Concentrations of azithromycin (up to 2.85 μg/L) and hydroxychloroquine (up to 2.97 μg/L) showed significant environmental risks, whereas ivermectin (up to 3.2 μg/L) affected only *C. vulgaris*.

Marques *et al*. (2023) observed that exposure to the azithromycin + ivermectin combination caused cyanobacterial mortality and reduced growth and photosynthetic activity when all three pharmaceuticals were combined. Although the growth of *C. vulgaris* was not significantly affected, its photosynthetic performance was negatively impacted. These findings demonstrate that the toxicity of contaminant mixtures cannot be inferred solely from the effects of individual compounds, since combined exposure may result in additive or synergistic interactions capable of altering both organism survival and physiological processes. The differential responses observed between cyanobacteria and microalgae further highlight species-specific sensitivity, emphasizing the complexity of predicting ecological outcomes under scenarios involving exposure to multiple contaminants.

Due to the occurrence of contaminants as complex mixtures, the isolated assessment of individual compounds may underestimate actual environmental risks. This limitation is particularly relevant in urban rivers, where multiple contamination sources simultaneously contribute to the chemical composition of water and sediments. Furthermore, the persistence of many emerging contaminants results from their resistance to both abiotic and biotic degradation processes.

Pharmaceuticals may exert biological activity at very low concentrations, easily cross biological membranes, and remain active long enough before being excreted in feces and urine (Bereda, 2022; Bhavani & Subbulakshmi, 2025). These characteristics increase their potential to interact with other compounds, thereby elevating the likelihood of mixture effects and cumulative toxicity in aquatic environments. Examples include oxolinic acid, cyclophosphamide, flumequine, oxytetracycline, clofibric acid, and ivermectin, which are known to resist degradation in aquatic environments, soils, sediments, and wastewater treatment plants (Bottoni, Caroli, & Barra-Caracciolo, 2010; Gwenzi *et al*., 2022; Lavrukhina *et al.*, 2024).

The persistence of these compounds contributes to their continuous accumulation and increases the probability of interactions with other contaminants, reinforcing the importance of considering long-term exposure scenarios in ecotoxicological assessments. Inadequate wastewater treatment, insufficient sanitation infrastructure, and improper pharmaceutical disposal further intensify the persistence and accumulation of these contaminants in aquatic systems. Together, these factors promote the formation of complex contaminant mixtures that may produce additive, synergistic, or even antagonistic effects, complicating environmental risk assessment and management strategies. Overall, the studies analyzed indicate that evaluating isolated compounds is insufficient to fully understand ecotoxicological risks in urban rivers, since real-world scenarios involve simultaneous exposure to multiple contaminants with interactive effects. Therefore, incorporating mixture-based approaches, such as the Mixture Risk Quotient (MRQ) and multispecies toxicity testing, is essential to improve the accuracy and ecological relevance of environmental risk assessments.

Ecotoxicological Effects of Metals, Emerging Contaminants, and Persistent Pollutants

Bae, Atique, and An (2020) conducted an ecological risk assessment in two urban streams (Gap Stream and Miho Stream) belonging to the Geum River watershed in the metropolitan region of Daejeon, South Korea. Using fish biomarkers, the authors analyzed DNA damage through the comet assay (single-cell gel electrophoresis) and physiological responses based on the activity of the enzymes 7-ethoxyresorufin-O-deethylase (EROD) and acetylcholinesterase (AChE).

The results revealed that fish from impacted areas exhibited DNA damage levels 2 to 3.6 times higher than those from the control site, in addition to alterations in nuclear morphology and increased enzymatic activity, indicating exposure to chemical contaminants originating from industrial discharges and wastewater treatment plants. These biomarkers reflect early sublethal effects, allowing the detection of chemical stress before impacts occur at the population level, thereby reinforcing their importance in ecotoxicological assessments.

The study by Bae, Atique, and An (2020) highlighted the usefulness of these biomarkers as early warning tools for evaluating the ecological health of urban streams contaminated by heavy metals such as Zinc (Zn), Chromium (Cr), Cadmium (Cd), Arsenic (As), and Copper (Cu). Although these elements naturally occur in the environment, elevated concentrations represent a high intrinsic hazard, while the actual ecological risk depends on bioavailability, exposure conditions, and species sensitivity. Exposure of benthic crustaceans (*Heterocypris incongruens*) to sediments from the Congo River in Kinshasa, Democratic Republic of Congo, resulted in 100% mortality after six days, demonstrating sediment toxicity likely associated with high metal concentrations (Mata *et al*., 2020).

Similarly, Mwanamoki *et al*. (2014) observed that sediments influenced by anthropogenic activities, urban runoff, and domestic and industrial effluents exhibited the highest metal concentrations in the Congo River basin. These findings demonstrate that sediments act as important contaminant reservoirs, functioning as secondary sources of exposure for benthic organisms over time. Sharma *et al*. (2022) evaluated chromium levels in water, sediments, plants (*Eichhornia crassipes*), and fish (*Labeo rohita*) in Mathura and Agra along the Yamuna River in India. Metal pollution was extremely high in Mathura, and bioconcentration factors in fish tissues varied according to organ and sampling location, being higher in gills in Agra and lower in kidneys in Mathura.

These variations indicate that bioaccumulation depends not only on organism physiology but also on local environmental conditions, reflecting differences in exposure pathways and metabolic regulation capacity. These regions are frequently visited for religious activities, while the waters receive inputs from tanneries, welding industries, electroplating facilities, paint factories in Mathura, and an oil refinery in Agra. Living organisms require trace metals to sustain metabolic and physiological functions. However, when concentrations or bioavailability exceed optimal levels, these elements become toxic.

The biological effects resulting from metal exposure depend on physicochemical properties, environmental concentration, exposure duration, routes of entry, and the developmental stage of exposed organisms, making risk assessment highly dependent on environmental context. Essential metals such as Fe, Cu, and Mn may disrupt cellular homeostasis and alter gut microbiota at elevated concentrations, whereas toxic metals such as Pb, Cd, As, and Hg are harmful even at trace levels due to their bioaccumulation potential and interference with antioxidant systems (Zhu *et al.*, 2024; Jomová *et al.*, 2025). Carvalho *et al.* (2017) demonstrated that even low concentrations of Zn and Cd altered reproductive patterns in *Ceriodaphnia dubia*, compromising freshwater ecosystems. Similarly, Novais *et al*. (2018) reported that Cu and Ni negatively affected species development and ecosystem homeostasis, as evidenced by morphological alterations in the hepatic tissues of *Danio rerio*. These studies indicate that, even at sublethal levels, metals may induce chronic effects that impair reproduction, growth, and ecological functioning, reinforcing the importance of considering endpoints beyond mortality alone.

Emerging contaminants (ECs), including pharmaceuticals, personal care products, PFAS, microplastics, and endocrine-disrupting chemicals (EDCs), are increasingly detected due to anthropogenic activities. These compounds interfere with endocrine regulation and may cause reproductive, developmental, and metabolic disorders, while also exhibiting persistence, bioaccumulation potential, and the capacity to induce oxidative stress, genotoxicity, and endocrine disruption across multiple trophic levels (Boahen *et al.*, 2025; Wang *et al*., 2024). These properties increase their environmental risk potential, particularly when combined with other contaminants present in aquatic systems, contributing to cumulative and interactive effects.

Phthalates (phthalic acid esters), widely used as plasticizers since the 1930s, are present in polymers, personal care products, and cosmetics, and are continuously released into the environment (Godwin, 2023; Etuk & Inyang, 2024). They accumulate in water, soil, and biota, posing risks related to endocrine disruption, reproductive toxicity, and developmental abnormalities (Skelly, Li, & Braslau, 2021; Srinivasulu *et al.,* 2024; Khalid & Abdollahi, 2021; Singh, Gosu, & Subbaramaiah, 2025). Their widespread environmental distribution, combined with their persistence, reinforces the need for continuous monitoring and the development of safer alternatives. Persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and organochlorine pesticides, are synthetic compounds characterized by high environmental persistence, lipophilicity, and resistance to natural degradation. Their ability to bioaccumulate in adipose tissues and biomagnify throughout food webs represents serious ecological and human health risks. These characteristics favor trophic transfer and increase the exposure of organisms at higher trophic levels, including humans. Exposure to these compounds has been associated with endocrine disruption, reproductive and immunological disorders, and other chronic toxic effects in aquatic organisms and humans (Miglioranza *et al.*, 2022; Najam & Alam, 2023; Aladl *et al.*, 2025). In Brazil, PCB management was strengthened through the "Projeto PCB Responsável," approved in December 2021. Developed through a partnership between the Ministry of the Environment and Climate Change (MMA) and the United Nations Development Programme (UNDP Brazil), with support from the Global Environment Facility (GEF), the project aims to ensure the safe elimination of contaminated materials by 2027.

This initiative represents an important advance in mitigating environmental and human health risks associated with persistent contaminants. Polycyclic aromatic hydrocarbons (PAHs) are hydrophobic compounds that accumulate in lipid-rich tissues, favoring bioaccumulation and toxicity across trophic levels. In particular, high molecular weight PAHs exhibit greater mutagenic, carcinogenic, and immunotoxic potential, reinforcing their relevance as priority contaminants in aquatic environments. Studies have demonstrated that these compounds can affect essential cellular pathways by inducing oxidative stress and impairing immune function (Wang *et al.*, 2024; Patel *et al.*, 2020; Othman *et al.*, 2022).

Collectively, the studies analyzed indicate that metals, emerging contaminants, and persistent pollutants exhibit distinct mechanisms of toxicity, yet share characteristics such as persistence, bioaccumulation, and the potential to induce sublethal and chronic effects. These factors, combined with environmental and biological variability, make ecotoxicological risk assessment highly complex and reinforce the need for integrated approaches that consider multiple environmental compartments, diverse organism groups, and multiple toxicological endpoints.

Ecotoxicological Impacts and Management of Water Quality in Urban and Coastal Areas

Regarding organophosphate esters (OPEs), Truong *et al*. (2023) investigated their occurrence and ecological risk in surface waters from urban rivers and lakes in Hanoi, Vietnam.

The analysis of 37 water samples collected from six rivers and 17 lakes revealed the presence of different OPE compounds (triesters and diesters) in all samples, with concentrations ranging from below the detection limit to 6,138 ng L^{-1}. Risk assessments based on the Risk Quotient (RQ) across different trophic levels (algae, crustaceans, and fish) indicated low to moderate ecological risks, suggesting that combined industrial and domestic effluents are the main contamination sources. These findings indicate that, even when risk levels are classified as low to moderate, continuous exposure may result in cumulative effects, particularly in ecosystems subjected to multiple pollution sources.

Similar concerns regarding surface water contamination have also been reported in Brazil, where both rural and urban river stretches are increasingly exposed to chemical pollution (de Morais *et al*., 2023; Alves *et al.,* 2021). The Capibaribe River, which supplies water to approximately 1.7 million people, receives runoff from agricultural areas as well as industrial and domestic discharges along its 280 km extension. Alves *et al.* (2021) reported frequent developmental abnormalities in fish exposed to these waters, including delayed hatching, underdeveloped jaws, blood stasis, and underdeveloped pectoral fins. These alterations indicate important sublethal effects that may compromise species survival, growth, and reproductive success, ultimately affecting population dynamics over time. In agreement with these findings, Morais *et al.* (2024) reported increasing ecotoxicological stress in the Iguaçu River associated with rising chemical loads from urban, industrial, and agricultural sources, combined with inefficient wastewater treatment. Gemusse *et al*. (2021) also demonstrated significant negative effects in *Oreochromis niloticus*, including histopathological damage, oxidative stress, and genotoxicity, highlighting the risks of aquatic contamination to both biota and human populations. This evidence highlights the connection between environmental and human health, emphasizing the importance of integrated approaches, such as the One Health concept, in assessing risks associated with water quality.

Additional studies corroborate these results. Santana *et al.* (2018), for example, chemically analyzed tilapia muscle tissues collected from reservoirs impacted by industrial activities and observed elevated metal concentrations and hepatic alterations, including necrosis and inflammatory processes. In Canada, chronic exposure of freshwater mussels (*Lasmigona costata*) to urban contaminants revealed physiological Higgins, & Jorge, 2014). In the Brazilian Legal Amazon, Araújo *et al*. (2024) reported that both water samples and tambacu (*Colossoma macropomum* × *Piaractus mesopotamicus*) tissues failed to meet national quality standards, with evidence of *E. coli* bioaccumulation, representing a significant risk to human health.

The occurrence of microbiological contaminants together with chemical compounds highlights the complexity of risks in aquatic systems, involving multiple stressors and distinct exposure pathways. Regarding microplastics, their small size and increasing abundance in aquatic environments enhance their bioavailability compared with macroplastics, particularly at lower trophic levels. These particles are readily ingested by zooplankton, macroinvertebrates, and small fish, facilitating their entry into food webs (Wright *et al.*, 2013; Benson *et al.*, 2022). This characteristic promotes trophic transfer and intensifies cumulative effects throughout the food chain.

Studies have shown that high surface area, low density, and reduced particle size are key factors facilitating microplastic ingestion by organisms occupying lower trophic levels (Wright *et al.*, 2013; Ugwu *et al.*, 2021). The presence of these contaminants has already been documented from planktonic organisms to fish, highlighting their potential for trophic transfer and ecological impacts (Benson *et al.*, 2022). Kumari *et al.* (2023) confirmed the occurrence of microplastics in fish collected from the Ganges River, with slightly higher levels detected in farmed fish. The authors attributed these findings to the use of plastic containers in aquaculture and to the lentic characteristics of farming environments.

Fish collected near effluent discharge points exhibited greater susceptibility to microplastic contamination, particularly species feeding within the water column. Such findings suggest that both environmental conditions and management practices may influence microplastic exposure. An *et al.* (2022) identified high abundances of microplastics in water samples and benthic gastropods (*Bellamya aeruginosa*) from the Qing River in Beijing, with an average of 28.13 ± 4.18 particles per individual. Among the identified polymers, polypropylene, polyamide, and polyethylene were the most frequently detected. Poor sanitation infrastructure, inefficient wastewater treatment, inadequate solid waste disposal, and improper management of domestic and industrial effluents further intensify environmental risks. These conditions facilitate contaminant transport into aquatic

stress responses, with biomarkers showing cumulative responses to municipal effluents and road runoff (Gillis, systems through surface runoff and atmospheric deposition, thereby increasing their spatial distribution.

Mwanamoki *et al*. (2014) highlighted that water quality degradation in urban rivers is strongly associated with stormwater runoff, untreated industrial discharges, and uncontrolled urbanization. Hou *et al.* (2024) demonstrated that rainfall events significantly increased concentrations of imidacloprid and thiacloprid, with levels approximately 1.93 times higher in surface runoff than in river water. This finding underscores the critical role of stormwater runoff as a transport pathway for contaminants and highlights the importance of incorporating hydrological dynamics into environmental risk assessments.

Ecotoxicological assessments may also provide valuable support for integrated watershed management. Kanzari *et al.* (2014) suggested that sediment data can serve as important references for biodiversity conservation and sustainable water resource management. Barreto *et al.* (2020) emphasized the relevance of ecotoxicological testing for biodiversity conservation, demonstrating the high sensitivity of early fish life stages to pollution. These results highlight the importance of incorporating ecotoxicological tools into public policy development and environmental monitoring strategies. More broadly, water quality assessments in watersheds require not only the identification of contamination sources, but also consideration of hydrological factors such as precipitation, which strongly influence pollutant dynamics.

Many metropolitan regions are also located within coastal zones, resulting in the continuous discharge of contaminants into marine and estuarine environments. These inputs extend the impacts observed in urban rivers, increasing ecological risks and affecting highly sensitive coastal ecosystems. In Brazil, studies have shown that coastal environments are heavily impacted by untreated sewage, industrial effluents, and urban runoff, resulting in eutrophication, pathogen contamination, and biodiversity loss (Fistarol *et al.,* 2015; Martinez *et al.*, 2021). Taken together, these patterns reflect a global environmental issue and highlight the urgent need for integrated coastal management policies and improvements in sanitation infrastructure.

CONCLUSION

According to the studies included in this review, insufficient wastewater management and limited pollution control were recurrently identified as major challenges affecting urban river quality. The discharge of domestic and industrial effluents, combined with urban stormwater runoff, consistently introduces a wide systems. These pollutants generate various adverse effects on aquatic biota, affecting organisms from microalgae to fish. Such findings confirm the first objective of this work: documenting the occurrence and diversity of contaminants in urban rivers. Many of these pollutants, including PCBs, PBDEs, PAHs, and PTEs, also pose potential risks to human health. The presence of pathogenic microorganisms, particularly antibiotic-resistant strains, further exacerbates these risks, emphasizing the second objective of the study: assessing potential ecological and human health hazards. Together, these findings highlight that urban rivers are under continuous chemical and biological stress, with implications for both ecosystem integrity and public health. Therefore, ensuring the quality of effluents discharged into receiving water bodies is crucial, regardless of the treatment methods applied.

Ecotoxicological assessments are essential to understand the effects of contaminants on organisms and to evaluate adverse outcomes at individual, population, community, and ecosystem levels. Implementing sustainable management policies, improving wastewater treatment, and developing restoration strategies for urban rivers are fundamental steps to mitigate pollution, protect biodiversity, and safeguard human health. This final synthesis addresses the overarching objective of the work: providing a basis for informed water management and policy decisions aimed at improving urban river quality and resilience. Finally, aligning these mitigation efforts with the United Nations Sustainable Development Goals (SDGs) strengthens their societal impact. Reducing urban water contamination directly supports SDG 6 (Clean Water and Sanitation) by safeguarding freshwater ecosystems and improving water quality. It also contributes to SDG 14 (Life Below Water) and SDG 15 (Life on Land) by conserving aquatic and terrestrial biodiversity affected by chemical pollution. Integrating rigorous ecotoxicological monitoring, effective wastewater management, and community engagement is therefore essential for promoting sustainable urban water management, protecting ecosystem services, and advancing global environmental sustainability.

AUTHOR CONTRIBUTIONS

JSA: Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Roles/Writing - original draft. **AMSS:** Data curation; Formal analysis; Investigation; Validation. **VSR**: Formal analysis; Investigation; Validation; Roles/Writing - original draft.

range of chemical contaminants into these aquatic systems. These pollutants generate various adverse

KFL: Conceptualization; Investigation; Visualization; Writing – original draft; Writing – review & editing; Resources; Supervision. **KSSA:** Project administration; Validation; Conceptualization; Formal analysis; Investigation; Roles/Writing - original draft; Writing - review & editing. **BMA:** Investigation; Methodology. **JACM:** Investigation; Methodology. **TMS.:** Visualization; Roles/Writing - original draft; Writing - review & editing. **ICNS:** Resources; Supervision.

FUNDING

The authors did not receive support from any organization for the submitted work.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Acioly, T. M. D. S., da Silva, M. F., Barbosa, L. A., Iannacone, J., & Viana, D. C. (2024). Levels of Potentially Toxic and Essential Elements in Water and Estimation of Human Health Risks in a River Located at the Interface of Brazilian Savanna and Amazon Biomes (Tocantins River). Toxics, 12(7), 444. https://doi.org/10.3390/toxics12070444

Agência Brasil. (2025). País tem desafio de eliminar equipamentos com substância tóxica PCB. Empresa Brasil de Comunicação. Available in: https://agenciabrasil.ebc.com.br/meio-ambiente/noticia/2025-08/brasil-tem-desafio-de-eliminar-equipamentos-com-substancia-toxica-pcb.

Aladl, M. S., Younis, A. M., Nossier, E. S., & El-Sayed, W. A. (2025). Chemistry of Persistent Organic Pollutants (POPs): Distribution, Environmental Impact and Mitigation Approaches. Egyptian Journal of Chemistry, 68(9), 663-677. https://doi.org/10.1007/978-3-031-53341-9_6

Alves, R. N., Mariz, C. F., Jr, de Melo Alves, M. K., Cavalcanti, M. G. N., de Melo, T. J. B., de Arruda-Santos, R. H., Zanardi-Lamardo, E., & Carvalho, P. S. M. (2021). Contamination and toxicity of surface waters along rural and urban regions of the Capibaribe River in tropical northeastern Brazil. Environmental Toxicology and Chemistry, 40(11), 3063-3077. https://doi.org/10.1002/etc.5180

An, L., Cui, T., Zhang, Y., & Liu, H. (2022). A case study on small-size microplastics in water and snails in an urban river. Science of the Total Environment, 847. https://doi.org/10.1016/j.scitotenv.2022.157461

Araújo, K. S. D. S., Acioly, T. M. D. S., Nascimento, I. O., Costa, F. N., Corrêa, F., Gagneten, A. M., & Viana, D. C. (2024). Biomonitoring of waters and tambacu (Colossoma macropomum × Piaractus mesopotamicus) from the Amazônia Legal, Brazil. Water, 16(18), 2588. https://doi.org/10.3390/w16182588

Arsand, J. B., Dallegrave, A., Jank, L., Feijo, T., Perin, M., Hoff, R. B., Arenzon, A., Gomes, A., & Pizzolato, T. M. (2023). Spatial-temporal occurrence of contaminants of emerging concern in urban rivers in southern Brazil. Chemosphere, 311. https://doi.org/10.1016/j.chemosphere.2022.136814

Bae, D. Y., Atique, U., Yoon, J. H., Lim, B. J., & An, K. G. (2020). Ecological Risk Assessment of Urban Streams Using Fish Biomarkers of DNA Damage and Physiological Responses. Polish Journal of Environmental Studies, 29(2). https://doi.org/https://doi.org/10.15244/pjoes/104660

Barreto, L. S., Souza, A. T. da C., Martins, C. C., Araujo, S. B. L., & Oliveira Ribeiro, C. A. de. (2020). Urban effluents affect the early development stages of Brazilian fish species with implications for their population dynamics. Ecotoxicology and Environmental Safety, 188, 109907. https://doi.org/https://doi.org/10.1016/j.ecoenv.2019.109907

Benson, N. U., Agboola, O. D., Fred-Ahmadu, O. H., De-la-Torre, G. E., Oluwalana, A., & Williams, A. B. (2022). Micro (nano) plastics prevalence, food web interactions, and toxicity assessment in aquatic organisms: a review. Frontiers in marine science, 9, 851281. https://doi.org/10.3389/fmars.2022.851281

Bereda, G. (2022). What the body does to a drug: pharmacokinetics. J Pharm Pharmacol, 10, 316-329.

Bhavani, G., & Subbulakshmi, P. (2025). Basics of Pharmacology: Drugs, Mechanisms, and Effects. Academic Guru Publishing House.

Biswas, P., Vellanki, B. P., & Kazmi, A. A. (2022). Investigating a broad range of emerging contaminants in a set of anthropogenically impacted environmental compartments. Science of The Total Environment, 824, 153757. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.153757

Boahen, E., Owusu, L., & Adjei-Anim, S. O. (2025). A comprehensive review of emerging environmental contaminants of global concern. Discover Environment, 3(1), 144. https://doi.org/10.1007/s44274-025-00259-x

Bottoni, P., Caroli, S., & Caracciolo, A. B. (2010). Pharmaceuticals as priority water contaminants. Toxicological & Environmental Chemistry, 92(3), 549-565. https://doi.org/10.1080/02772241003614320

Bunke, D., Moritz, S., Brack, W., Herráez, D. L., Posthuma, L., & Nuss, M. (2019). Developments in society and implications for emerging pollutants in the aquatic environment. Environmental Sciences Europe, 31(1), 32. https://doi.org/10.1186/s12302-019-0213-1.

Caixeta, E. S., Bravo, J. V. M., & Pereira, B. B. (2022). Ecotoxicological assessment of water and sediment river samples to evaluate the environmental risks of anthropogenic contamination. Chemosphere, 306, 135595. https://doi.org/10.1016/j.chemosphere.2022.135595

Carvalho, M. M., Lira, V. S., Watanabe, C. H., & Fracácio, R. (2017). Estudo da toxicidade de metais (zinco e cádmio) sobre Ceriodaphnia dubia, por multivias de exposição e recuperação biológica de descendentes. Engenharia Sanitaria e Ambiental, 22(05), 961-968. https://doi.org/10.1590/S1413-41522017158722

Cheng, Y., Ding, J., Arenas, C. E. D., Brinkmann, M., & Ji, X. (2024). A brief review on the assessment of potential joint effects of complex mixtures of contaminants in the environment. Environmental Science: Advances, 3(5), 661-675. https://doi.org/10.1039/D4VA00014E

de Morais, L. S., Chagas, I. C. G. D. C., da Silva, D. P., & Scalize, P. S. (2023). Surface water quality in rural communities in the state of Goiás during the dry season and its relationship with land use and occupation. Engenharia Sanitaria e Ambiental, 28(1). https://doi.org/10.1590/S1413-415220220215

de Morais, T. P., Barreto, L. S., de Souza, T. L., Pozzan, R., Vargas, D. Á. R., Yamamoto, F. Y., Prodocimo, M. M., Neto, F. F., Randi, M. A. F., & Ribeiro, C. A. O. (2024). Assessing the pollution and ecotoxicological status of the Iguaçu River, southern Brazil: A review. Integrated Environmental Assessment and

Management, 20(5), 1280-1305. https://doi.org/10.1002/ieam.4865

Domínguez-García, P., Aljabasini, O., Barata, C., & Gómez-Canela, C. (2024). Environmental risk assessment of pharmaceuticals in wastewaters and reclaimed water from catalan main river basins. Science of The Total Environment, 949, 175020. https://doi.org/10.1016/j.scitotenv.2024.175020

Etuk, I. F., & Inyang, U. E. (2024). Applications of various plasticizers in the plastic industry-review. International Journal of Engineering and Modern Technology (IJEMT), 10, 38-54. https://doi.org/10.56201/ijemt.v10.no1.2024.pg38.54

Fistarol, G. O., Coutinho, F. H., Moreira, A. P., Venas, T., Cánovas, A., de Paula, S. E., Jr, Coutinho, R., de Moura, R. L., Valentin, J. L., Tenenbaum, D. R., Paranhos, R., do Valle, R.deA., Vicente, A. C., Amado Filho, G. M., Pereira, R. C., Kruger, R., Rezende, C. E., Thompson, C. C., Salomon, P. S., & Thompson, F. L. (2015). Environmental and sanitary conditions of Guanabara Bay, Rio de Janeiro. Frontiers in microbiology, 6, 1232. https://doi.org/10.3389/fmicb.2015.01232

Gemusse, S. L., Turcatti Folle, N. M., Souza, A. T. da C., Azevedo-Linhares, M., Neto, F. F., Ortolani-Machado, C. F., Esquivel Garcia, J. R., Esquivel, L., da Silva, C. P., de Campos, S. X., Martins, C. de C., & de Oliveira Ribeiro, C. A. (2021). Micropollutants impair the survival of Oreochromis niloticus and threat local species from Iguaçu River, Southern of Brazil. Environmental Toxicology and Pharmacology, 83, 103596. https://doi.org/https://doi.org/10.1016/j.etap.2021.103596

Gillis, P. L., Higgins, S. K., & Jorge, M. B. (2014). Evidence of oxidative stress in wild freshwater mussels (Lasmigona costata) exposed to urban-derived contaminants. Ecotoxicology and Environmental Safety, 102, 62–69. https://doi.org/https://doi.org/10.1016/j.ecoenv.2013.12.026

Godwin, A. D. (2024). Plasticizers. In Applied plastics engineering handbook (pp. 595-618). William Andrew Publishing. https://doi.org/10.1016/B978-0-323-88667-3.00031-X

Guabloche, A., Alvariño, L., Acioly, T. M. D. S., Viana, D. C., & Iannacone, J. (2024). Assessment of Essential and Potentially Toxic Elements in Water and Sediment and the Tissues of Sciaena deliciosa (Tschudi, 1846) from the Coast of Callao Bay, Peru. Toxics, 12(1), 68. https://doi.org/10.3390/toxics12010068

Gurnell, A., Lee, M., & Souch, C. (2007). Urban rivers: Hydrology, geomorphology, ecology and opportunities for change. Geography Compass, 1(5), 1118–1137. https://doi.org/10.1111/j.1749-8198.2007.00058.x

Gwenzi, W., Selvasembian, R., Offiong, N. A. O., Mahmoud, A. E. D., Sanganyado, E., & Mal, J. (2022). COVID-19 drugs in aquatic systems: a review. Environmental chemistry letters, 20(2), 1275-1294. https://doi.org/10.1007/s10311-021-01356-y

Haarstrick, A., & Sharma, L. (2024). Chapter 8—Urban river pollution control. In V. R. Shinde, R. R. Mishra, U. Bhonde, & H. Vaidya (Orgs.), Managing Urban Rivers (p. 131–159). Elsevier. https://doi.org/10.1016/B978-0-323-85703-1.00013-4

Hou, J., Hu, C., Yang, L., & Wang, X. (2024). Aquatic ecological risk assessment of imidacloprid and thiacloprid in an urban river of Qingdao, China. Marine Pollution Bulletin, 199. https://doi.org/10.1016/j.marpolbul.2023.116013

Jomova, K., Alomar, S. Y., Nepovimova, E., Kuca, K., & Valko, M. (2025). Heavy metals: toxicity and human health effects. Archives of toxicology, 99(1), 153-209. https://doi.org/10.1007/s00204-024-03903-2

Kanzari, F., Syakti, A. D., Asia, L., Malleret, L., Piram, A., Mille, G., & Doumenq, P. (2014). Distributions and sources of persistent organic pollutants (aliphatic hydrocarbons, PAHs, PCBs and pesticides) in surface sediments of an industrialized urban river (Huveaune), France. Science of the Total Environment, 478, 141–151. https://doi.org/10.1016/j.scitotenv.2014.01.065

Khalid, M., & Abdollahi, M. (2021). Environmental distribution of personal care products and their effects on human health. Iranian journal of pharmaceutical research: IJPR, 20(1), 216. https://doi.org/10.22037/ijpr.2021.114891.15088

Kryston, A., Woods, C. G., & Manga, M. (2024). Social barriers to safe sanitation access among housed populations in the United States: A systematic review. International Journal of Hygiene and Environmental Health, 257, 114326. https://doi.org/10.1016/j.ijheh.2024.114326

Kumari, N., Yadav, D. K., Yasha, Khan, P. K., & Kumar, R. (2023). Occurrence of plastics and their characterization in wild caught fish species (Labeo rohita, Wallago attu and Mystus tengara) of River Ganga (India) compared to a commercially cultured species (L. rohita). Environmental Pollution, 334, 122141. D. A., Tretyakov, A. V., Kozeicheva, E. S., ... & Borunova, S. M. (2024). Pharmaceuticals and their transformation products in environment and plants. Asian Journal of Agriculture and Biology, 2024(04). https://doi.org/10.35495/

Machado da Silva Acioly, T., Francisco da Silva, M., Iannacone, J., & Viana, D. C. (2024b). Levels of potentially toxic and essential elements in Tocantins River sediment: Health risks at Brazil's Savanna-Amazon interface. Scientific Reports, 14(1), 18037. http://dx.doi.org/10.1038/s41598-024-66570-4

Magalhães, D. de P., & Ferrão-Filho, A. da S. (2008). A ecotoxicologia como ferramenta no biomonitoramento de ecossistemas aquáticos. Oecologia Brasiliensis, 12(3), 355–381

Marques, R. Z., Kochi, L. Y., Guzman-Tordecilla, M., Malage, L., Juneau, P., & Gomes, M. P. (2023). COVID-19 pharmaceuticals in aquatic matrices: The threatening effects over cyanobacteria and microalgae. Science of the Total Environment, 892. https://doi.org/10.1016/j.scitotenv.2023.164309

Martinez, A. S., Underwood, T., Christofoletti, R. A., Pardal, A., Fortuna, M. A., Marcelo-Silva, J., Morais, G. C., & Lana, P. C. (2022). Reviewing the effects of contamination on the biota of Brazilian coastal ecosystems: scientific challenges for a developing country in a changing world. Science of the Total Environment, 803, 150097. https://doi.org/10.1016/j.scitotenv.2021.150097

Mata, H. K., al Salah, D. M. M., Ngweme, G. N., Konde, J. N., Mulaji, C. K., Kiyombo, G. M., & Poté, J. W. (2020). Toxic metal concentration and ecotoxicity test of sediments from dense populated areas of Congo River, Kinshasa, Democratic Republic of the Congo. Environmental Chemistry and Ecotoxicology, 2, 83–90. https://doi.org/https://doi.org/10.1016/j.enceco.2020.07.001

Materon, E. M., Ibáñez-Redín, G., Joshi, N., Gonçalves, D., Oliveira, O. N., & Faria, R. C. (2020). Analytical detection of pesticides, pollutants, and pharmaceutical waste in the environment. Em S. Kumar Tuteja, D. Arora, N. Dilbaghi, & E. Lichtfouse (Orgs.), Nanosensors for Environmental Applications (p. 87–129). Springer International Publishing. https://doi.org/10.1007/978-3-030-38101-1_3

https://doi.org/https://doi.org/10.1016/j.envpol.2023.122141

Lavrukhina, O. I., Amelin, V. G., Kish, L. K., Makarov,

Miglioranza, K. S., Ondarza, P. M., Grondona, S. I., & Scenna, L. B. (2022). Persistent organic contaminants. In Marine Analytical Chemistry (pp. 275-306). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-14486-8_5

Mills, M., Mollenkopf, D., Wittum, T., Sullivan, M. P., & Lee, J. (2024). One Health threat of treated wastewater discharge in urban Ohio rivers: implications for surface water and fish gut microbiome and resistome. Environmental Science & Technology, 58(30), 13402-13414. https://doi.org/10.1021/acs.est.3c09070

Mishra, R. R., & Saxena, S. (2024). Cities and rivers: a symbiotic relationship. In Managing Urban Rivers (pp. 3-24). Elsevier. http://dx.doi.org/10.1038/s41598-024-66570-4

MMA. (2025). Ministério do Meio Ambiente e Mudança do Clima (MMA). Projeto PCB Responsável: Promovendo a destinação ambientalmente adequada de bifenilas policloradas (PCB) no Brasil. Governo Federal do Brasil. Available in: https://www.gov.br/mma/pt-br/assuntos/meio-ambiente-urbano-recursos-hidricos-qualidade-ambiental/seguranca-quimica/convencao-de-estocolmo/pcb/projeto_pcb-responsavel/home

Murrell, J. A. L., Alvarez, B. R., Petre, A., Gómez, A. S., Moya, D. L., Badía, M. M. R., & Boltes, K. (2024). Presence of pharmaceutical contaminants of emerging concerns in two rivers of western Cuba and their relationship with the extracellular enzymatic activity of microbial communities. Environmental Pollution, 346, 123589. https://doi.org/https://doi.org/10.1016/j.envpol.2024.123589

Mwanamoki, P. M., Devarajan, N., Thevenon, F., Birane, N., de Alencastro, L. F., Grandjean, D., Mpiana, P. T., Prabakar, K., Mubedi, J. I., Kabele, C. G. Wildi, W., & Poté, J. (2014). Trace metals and persistent organic pollutants in sediments from river-reservoir systems in Democratic Republic of Congo (DRC): Spatial distribution and potential ecotoxicological effects. Chemosphere, 111, 485–492. https://doi.org/10.1016/j.chemosphere.2014.04.083

Najam, L., & Alam, T. (2023). Occurrence, distribution, and fate of emerging persistent organic pollutants (POPs) in the environment. In Emerging contaminants and plants: interactions, adaptations and remediation technologies (pp. 135-161). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-22269-6_6

Danio rerio: ênfase para análise de biomarcadores histológicos e histoquímicos da espécie Danio rerio. Universidade Estadual Paulista (UNESP), Sorocaba, Brasil. Available in: https://repositorio.unesp.br/entities/publication/ace891a6-2c70-4898-a98c-15a0f1a0e22c

Olguín, E. J., González-Portela, R. E., Sánchez-Galván, G., Zamora-Castro, J. E., & Owen, T. (2010). Contaminación de ríos urbanos: El caso de la subcuenca del río Sordo en Xalapa, Veracruz, México. Revista Latinoamericana de Biotecnología Ambiental y Algal, 1(2), 178-190.

Othman, H. B., Pick, F. R., Hlaili, A. S., & Leboulanger, C. (2023). Effects of polycyclic aromatic hydrocarbons on marine and freshwater microalgae–A review. Journal of Hazardous Materials, 441, 129869. https://doi.org/10.1016/j.jhazmat.2022.129869

Patel, A. B., Shaikh, S., Jain, K. R., Desai, C., & Madamwar, D. (2020). Polycyclic aromatic hydrocarbons: sources, toxicity, and remediation approaches. Frontiers in microbiology, 11, 562813. https://doi.org/10.3389/fmicb.2020.562813

PNUD. (2022). Programa das Nações Unidas para o Desenvolvimento – Brazil (PNUD). PNUD participa de projeto de erradicação dos compostos tóxicos PCBs. UNDP Brazil. Available in: https://brasil.un.org/pt-br/180426-pnud-participa-de-projeto-de-erradica%C3%A7%C3%A3o-dos-compostos-t%C3%B3xicos-pcbs

Pereira, R., Sousa, J. P., Niemeyer, J., Markwiese, J., Andersen, C. P., & Cachada, A. (2026). Ecotoxicological effects and risk assessment of pollutants. In Soil pollution (pp. 241-270). Academic Press. https://doi.org/10.1016/B978-0-443-33329-3.00005-2

Prasad, D. K., Shukla, R., & Ahammad, S. Z. (2024). Pharmaceuticals and personal care products and heavy metals in the Ganga River, India: Distribution, ecological and human health risk assessment. Environmental Research, 263, 119993. https://doi.org/10.1016/j.envres.2024.119993

Qiao, M., Fu, L., Li, Z., Liu, D., Bai, Y., & Zhao, X. (2020). Distribution and ecological risk of substituted and parent polycyclic aromatic hydrocarbons in surface waters of the Bai, Chao,

Novaes, G. H. C. F. de, & Francisco, R. F. (2019). Atuação dos metais cobre e níquel em tecidos de

and Chaobai rivers in northern China. Environmental Pollution, 257, 113600. https://doi.org/10.1016/j.envpol.2019.113600

Rapp-Wright, H., Regan, F., White, B., & Barron, L. P. (2023). A year-long study of the occurrence and risk of over 140 contaminants of emerging concern in wastewater influent, effluent and receiving waters in the Republic of Ireland. Science of The Total Environment, 860, 160379. https://doi.org/10.1016/j.scitotenv.2022.160379

Santana, M. S., Yamamoto, F. Y., Sandrini-Neto, L., Filipak Neto, F., Ortolani-Machado, C. F., Oliveira Ribeiro, C. A., & Prodocimo, M. M. (2018). Diffuse sources of contamination in freshwater fish: Detecting effects through active biomonitoring and multi-biomarker approaches. Ecotoxicology and Environmental Safety, 149, 173–181. https://doi.org/10.1016/j.ecoenv.2017.11.036

Sharma, J., Pant, G., Hossain, K., Ahmad, A., Bakht, Md. A., Alka, Tripathi, R., & Setapar, S. H. M. (2022). Chromium toxicity in the Yamuna River ecosystem at Brij Region – Uttar Pradesh, India. Desalination and Water Treatment, 267, 13–25. https://doi.org/10.5004/dwt.2022.28632

Sharma, A., Grewal, A. S., Sharma, D., & Srivastav, A. L. (2023). Heavy metal contamination in water: consequences on human health and environment. In Metals in water (pp. 39-52). Elsevier. https://doi.org/10.1016/B978-0-323-95919-3.00015-X

Sharma, I., & Birman, S. (2024). Biodiversity Loss, Ecosystem Services, and Their Role in Promoting Sustainable Health. In The Climate-Health-Sustainability Nexus: Understanding the Interconnected Impact on Populations and the Environment (pp. 163-188). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-56564-9_7

Singh, P. K., Kumar, U., Kumar, I., Dwivedi, A., Singh, P., Mishra, S., Seth, C. S., & Sharma, R. K. (2024). Critical review on toxic contaminants in surface water ecosystem: sources, monitoring, and its impact on human health. Environmental Science and Pollution Research, 31(45), 56428-56462. https://doi.org/10.1007/s11356-024-34932-0

Singh, U., Gosu, V., & Subbaramaiah, V. (2025). Review on Phthalates: Exposure Pathways, Health Risks, Regulatory Imperatives and Mitigation Strategies. Water, Air, & Soil

Pollution, 236(10), 676. https://doi.org/10.1007/s11270-025-08263-w

Skelly, P. W., Li, L., & Braslau, R. (2022). Internal

Sousa, M. C., Martins, R., Simões, N. E., & Feio, M. J. (2025). Ecosystem services of urban rivers: a systematic review. Aquatic Sciences, 87(1), 10. https://doi.org/10.1007/s00027-024-01138-y

Srinivasulu, M., Chandra, M. S., Gooty, J. M., & Madhavi, A. (2022). Personal care products—fragrances, cosmetics, and sunscreens—in the environment. In Environmental micropollutants (pp. 131-149). Elsevier. https://doi.org/10.1016/B978-0-323-90555-8.00015-5

Tamura, I., Yasuda, Y., Kagota, K., Yoneda, S., Nakada, N., Kumar, V., Kameda, Y., Kimura, K., Tatarazako, N., & Yamamoto, H. (2017). Contribution of pharmaceuticals and personal care products (PPCPs) to whole toxicity of water samples collected in effluent-dominated urban streams. Ecotoxicology and Environmental Safety, 144, 338–350. https://doi.org/https://doi.org/10.1016/j.ecoenv.2017.06.032

Tang, Y., Liu, Y., He, Y., Zhang, J., Guo, H., & Liu, W. (2024). Quantifying the impact of anthropogenic emissions and aquatic environmental impacts on sedimentary mercury variations in a typical urban river. Environmental Pollution, 355, 124185. https://doi.org/https://doi.org/10.1016/j.envpol.2024.124185

Thakur, S., Chandra, A., Kumar, V., & Bharti, S. (2025). Environmental pollutants: endocrine disruptors/pesticides/reactive dyes and inorganic toxic compounds metals, radionuclides, and metalloids and their impact on the ecosystem. In Biotechnology for environmental sustainability (pp. 55-100). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-97-7221-6_3

Truong, D. A., Trinh, H. T., Le, G. T., Phan, T. Q., Duong, H. T., Tran, T. T. L., Nguyen, T. Q., Hoang, M. T. T., & Nguyen, T. V. (2023). Occurrence and ecological risk assessment of organophosphate esters in surface water from rivers and lakes in urban Hanoi, Vietnam. Chemosphere, 331, 138805. https://doi.org/10.1016/j.chemosphere.2023.138805

Tu, Y. T., Ou, J. H., Tsang, D. C. W., Dong, C. D., Chen, C. W., & Kao, C. M. (2018). Source identification and ecological impact evaluation plasticization of PVC. Polymer Reviews, 62(3), 485-528. https://doi.org/10.1080/15583724.2021.1986066 of PAHs in urban river sediments: A case study in Taiwan. Chemosphere, 194, 666–674. https://doi.org/10.1016/j.chemosphere.2017.12.008

Ugwu, K., Herrera, A., & Gómez, M. (2021). Microplastics in marine biota: A review. Marine pollution bulletin, 169, 112540. https://doi.org/10.1016/j.marpolbul.2021.112540

United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. United Nations. Available in: https://sdgs.un.org/2030agenda (Accessed 24 oct, 2025).

Urmi, M. A., Akbor, Md. A., Sarker, S., Nahar, A., Shaikh, Md. A. A., Siddique, Md. A. B., Ahmed, S., Meghna, A. J., Malafaia, G., & Rahman, Md. M. (2023). A pioneering study on endocrine disruptors (phthalates esters) in urban rivers of Bangladesh: An appraisal of possible risk assessment to ecology and human health. Journal of Hazardous Materials Advances, 12, 100369. https://doi.org/https://doi.org/10.1016/j.hazadv.2023.100369

Wang, B., Dong, F., Chen, S., Chen, M., Bai, Y., Tan, J., Li, F., & Wang, Q. (2016). Phenolic endocrine disrupting chemicals in an urban receiving river (Panlong river) of Yunnan–Guizhou plateau: Occurrence, bioaccumulation and sources. Ecotoxicology and Environmental Safety, 128, 133–142. https://doi.org/https://doi.org/10.1016/j.ecoenv.2016.02.018

Wang, R., Tang, H., Yang, R., & Zhang, J. (2024). Emerging contaminants in water environments: progress, evolution, and prospects. Water Science & Technology, 89(10), 2763-2782. https://doi.org/10.2166/wst.2024.151

Wang, S., Li, C., Zhang, L., Chen, Q., & Wang, S. (2024). Assessing the ecological impacts of polycyclic aromatic hydrocarbons petroleum pollutants using a network toxicity model. Environmental Research, 245, 117901. https://doi.org/10.1016/j.envres.2023.117901

Wang, W., Bai, J., Zhang, G., Jia, J., Wang, X., Liu, X., & Cui, B. (2019). Occurrence, sources and ecotoxicological risks of polychlorinated biphenyls (PCBs) in sediment cores from urban, rural and reclamation-affected rivers of the Pearl River Delta, China. Chemosphere, 218, 359–367. https://doi.org/10.1016/j.chemosphere.2018.11.046

World Bank. (2025). Urban Development. The World Bank. Available in: https://www.worldbank.org/en/topic/urbandevelopment/overview

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics onmarine organisms: a review. Environmental pollution, 178, 483-492. https://doi.org/10.1016/j.envpol.2013.02.031

Wu, D., Zheng, L., Wang, Y., Gong, J., Li, J., & Chen, Q. (2024). Characteristics of urban expansion in megacities and its impact on water-related ecosystem services: A comparative study of Chengdu and Wuhan, China. Ecological Indicators, 158, 111322. https://doi.org/10.1016/j.ecolind.2023.111322

Xiong, P., Zhu, J., He, R., & Li, H. (2024). Synergy Assessment of River Health Values from a Symbiotic Perspective: A Case Study of the Yellow River Basin in China. Water, 16(1), 91. https://doi.org/10.3390/w16010091

Zhang, Y., Chen, H., Jing, L., & Teng, Y. (2020). Ecotoxicological risk assessment and source apportionment of antibiotics in the waters and sediments of a peri-urban river. Science of the Total Environment, 731. https://doi.org/10.1016/j.scitotenv.2020.139128

Zhu, Q., Chen, B., Zhang, F., Zhang, B., Guo, Y., Pang, M., Huang, L., & Wang, T. (2024). Toxic and essential metals: metabolic interactions with the gut microbiota and health implications. Frontiers in Nutrition, 11, 1448388. https://doi.org/10.3389/fnut.2024.1448388

Zingraff-Hamed, A., Bonnefond, M., Bonthoux, S., Legay, N., Greulich, S., Robert, A., Rotgé, V., Serrano, J., Cao, Y., Bala, R., Vazha, A., Tharme, R. E., & Wantzen, K. M. (2021). Human–river encounter sites: Looking for harmony between humans and nature in cities. Sustainability, 13(5), 2864. https://doi.org/10.3390/su13052864