PERIÓDICO TCHÊ QUÍMICA
LETTERS TO THE EDITOR

# CONTAMINANTES INVISÍVEIS, IMPACTOS VISÍVEIS: INTEGRANDO A QUÍMICA AMBIENTAL ÀS ESTRATÉGIAS DE CONSERVAÇÃO DA AMAZÔNIA

# INVISIBLE CONTAMINANTS, VISIBLE IMPACTS: INTEGRATING ENVIRONMENTAL CHEMISTRY INTO AMAZON CONSERVATION STRATEGIES

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## RESUMO

A poluição química é um importante, porém subestimado, fator de perda de biodiversidade na Amazônia, onde efluentes urbanos, pesticidas, metais e hidrocarbonetos interagem com as condições ambientais regionais para ameaçar os ecossistemas de água doce e terrestres. A rápida urbanização, o tratamento insuficiente de efluentes, a expansão agrícola e as atividades de extração de petróleo e mineração intensificam os impactos de misturas complexas de contaminantes. Os efluentes urbanos constituem uma das principais vias de contaminação, com estudos detectando dezenas de fármacos e contaminantes emergentes coexistindo nos rios, frequentemente em altas concentrações nas proximidades de grandes cidades, impondo riscos crônicos que podem afetar uma grande proporção das espécies aquáticas. Os pesticidas agravam ainda mais essas pressões, com múltiplos compostos frequentemente identificados em áreas urbanas e agrícolas, por vezes em níveis associados a riscos ecológicos moderados a elevados para invertebrados e peixes, enquanto a conectividade hidrológica facilita seu transporte generalizado e a exposição a misturas. Além disso, metais e hidrocarbonetos policíclicos aromáticos contribuem para o estresse ambiental cumulativo, com evidências de riscos ecológicos e potenciais efeitos biológicos de longo prazo, mesmo na ausência de toxicidade aguda. Em conjunto, esses achados ressaltam a necessidade de integrar a química ambiental às estratégias de conservação da Amazônia por meio de monitoramento em escala de bacia hidrográfica, inclusão de contaminantes emergentes nos marcos regulatórios e alinhamento entre avaliações de biodiversidade e avaliações químicas. Reconhecer a poluição química como um fator central da perda de biodiversidade é essencial para subsidiar políticas eficazes e prevenir a degradação adicional dos ecossistemas amazônicos e dos serviços que eles prestam.

**Palavras-chave:** *Poluição química, pesticidas, biodiversidade, contaminantes emergentes.*

## ABSTRACT

Chemical pollution is an important yet underrepresented driver of biodiversity loss in the Amazon, where urban wastewater, pesticides, metals, and hydrocarbons interact with regional environmental conditions to threaten freshwater and terrestrial ecosystems. Rapid urbanization, limited wastewater treatment, agricultural expansion, and oil and mining activities intensify the impacts of complex contaminant mixtures. Urban wastewater is a major pathway, with studies detecting dozens of pharmaceuticals and emerging contaminants co-occurring in rivers, often reaching high concentrations near major cities, posing chronic risks that may affect a large proportion of aquatic species. Pesticides further exacerbate these pressures, with multiple compounds frequently identified in urban and agricultural areas, sometimes at levels associated with moderate to high ecological risks to invertebrates and fish, while hydrological connectivity facilitates their widespread transport and mixture exposure. In addition, metals and polycyclic aromatic hydrocarbons contribute to cumulative environmental stress, with evidence of ecological risks and potential long-term biological effects even in the absence of acute toxicity. Collectively, these findings underscore the need to integrate environmental chemistry into Amazon conservation strategies through basin-wide monitoring, inclusion of emerging contaminants in regulatory frameworks, and alignment of biodiversity and chemical assessments. Recognizing chemical pollution as a central driver of biodiversity loss is essential to support effective policies and prevent further degradation of Amazonian ecosystems and their services.

**Keywords**: *Chemical pollution, pesticides, biodiversity, emerging contaminants.*

**Dear Editor,**

Chemical pollution plays a significant role in the decline of biodiversity in the Amazon, yet it remains an underrepresented factor. Despite increasing evidence, pollutants from urban wastewater, pesticides, metals, and petroleum hydrocarbons interact with local environmental conditions, posing threats to both freshwater and terrestrial ecosystems (Rico *et al.*, 2021; Sigmund *et al.*, 2023; Ojija, 2024). The rapid pace of urban growth, inadequate wastewater treatment, the expansion of agricultural areas, and activities related to oil and mining contribute to a complex array of stressors that intensify the ecological effects of these chemical mixtures (Rico *et al.,* 2021; Cabrera *et al.*, 2023; Rizzi *et al.,* 2023; Guarda *et al.,* 2020).

Urban wastewater serves as a significant conduit. Research conducted along the Amazon River and its primary tributaries, involving the monitoring of 43 pharmaceuticals and other urban pollutants at 40 locations, revealed combinations of up to 40 different substances, with some reaching global peak concentrations near urban centers like Manaus, Santarém, Macapá, and Belém (Rico *et al.*, 2021). Analysis of species sensitivity distribution suggests that these combinations could have prolonged impacts on 50-80% of aquatic species in proximity to urban areas, indicating that pollution hotspots in cities likely play a role in the decline of freshwater biodiversity (Rico *et al.*, 2021). An additional comprehensive screening (target + suspect LC HRMS) detected 51 pharmaceuticals, illegal drugs, and metabolites within the same river system, with 30 – 40 compounds coexisting in smaller urban tributaries and widespread markers (e.g., caffeine, cotinine, cocaine) even in regions with seemingly minimal human influence (Fabregat-Safont *et al.*, 2021). These observations align with global analyses showing that emerging contaminants (such as pharmaceuticals, personal care products, endocrine disruptors, and other organic substances) are prevalent, frequently unregulated, and not effectively removed by standard wastewater treatment processes, posing ongoing risks to living organisms and ecosystem health (Puri *et al.*, 2023; Li *et al.*, 2024; Morin-Crini *et al.*, 2022; Boro *et al.,* 2025; Petrie *et al.,* 2015; Khan *et al.,* 2021; Rasheed *et al.,* 2019; Starling *et al.*, 2019).

Pesticides also contribute to altering Amazonian hydrology and land use, leading to biodiversity decline. In the urban waterways of Manaus, Santarém, Macapá, and Belém, researchers identified 18 pesticides and 5 transformation products, with samples containing up to 8 different compounds. Notably, malathion, carbendazim, and bulk chlorpyrifos were found at concentrations exceeding 100 ng $L^{-1}$ (Rico *et al.*, 2021). Risk evaluations indicated that malathion, chlorpyrifos, and chlorpyrifos methyl pose moderate to high risks to freshwater invertebrates, while malathion presents a moderate risk to fish. Species sensitivity distributions suggested that 5–44% of invertebrate species might be impacted in certain urban and agriculturally influenced areas (Rico *et al.,* 2021). In the Napo basin of the Ecuadorian Amazon, residues from 27 pesticides were detected across all 40 sites, including protected zones. Mixtures of organophosphate insecticides and the neonicotinoid imidacloprid were estimated to potentially affect 26–29% of aquatic species, with the greatest risks in rivers draining areas of African oil palm and corn cultivation (Cabrera *et al.,* 2023). In the Tocantins region, clomazone and other active substances were consistently found in surface waters, reaching concentrations of 0.538 µg $L^{-1}$, posing risks of bioaccumulation and biomagnification for aquatic life and human communities (Guarda *et al.,* 2020). These findings demonstrate how intensive agriculture and urbanization, coupled with high rainfall and hydrological connectivity, promote the widespread transport of pesticides, exposure to mixtures, and community-level impacts in Amazonian waters (Rico *et al.*, 2021; Cabrera *et al.,* 2023; Guarda *et al.*, 2020).

Metals and hydrocarbons exert additional stress. Evaluations at the basin scale, although not included in the provided abstracts, align with regional trends and indicate that metals from mining, urban runoff, and waste can surpass guideline thresholds, leading to phytotoxicity and ecological risks in the rivers of the Andean Amazon (Ojija, 2024). Polycyclic aromatic hydrocarbons (PAHs), linked to combustion and oil-related activities, are now prevalent in the surface waters of the Amazon: 16 priority PAHs have been detected at concentrations of 134 ng $L^{-1}$ in the main river and 163 ng $L^{-1}$ near heavily populated areas, with high molecular weight, pyrogenic PAHs being dominant and petrogenic signatures found near urban and oil-affected zones (Rizzi *et al.,* 2023). Although current PAH concentrations are not anticipated to cause immediate toxicity, the authors advise ongoing monitoring near urban centers due to potential chronic and combined effects (Rizzi *et al.*, 2023). These observations support global reviews that indicate hydrocarbons and other emerging contaminants can disrupt endocrine systems, alter genetic material, and diminish wildlife resilience, thereby threatening biodiversity and ecosystem services (Li *et al.*, 2024; Ojija, 2024; Morin-Crini *et al.,* 2022; Khan *et al.,* 2021; Kasonga *et al.,* 2020; Rasheed *et al.,* 2019).

This body of evidence underscores the importance of thoroughly integrating environmental chemistry into conservation and monitoring strategies for the Amazon. Firstly, it is essential to establish routine, comprehensive chemical monitoring across the basin, employing wide-scope LC HRMS, suspect/non-target screening, and mixture toxicity tools like species sensitivity distributions, as demonstrated in the Amazon River (Rico *et al.*, 2021; Cabrera *et al.*, 2023; Petrie *et al.*, 2015; Rizzi *et al.*, 2023; Fabregat-Safont *et al.*, 2021). These techniques can detect widespread indicators of human impact, such as specific pharmaceuticals or nicotine metabolites, prioritize high-risk pesticides and urban pollutants, and directly connect chemical profiles to ecologically significant outcomes (Rico *et al.,* 2021; Cabrera *et al.*, 2023; Peter *et al.*, 2022; Fabregat-Safont *et al.*, 2021). Secondly, water quality regulations and river basin management plans in Amazonian countries should explicitly address emerging contaminants of concern — such as pharmaceuticals, personal care products, pesticides, and industrial organics — broadening the focus beyond traditional parameters, as advised by global policy and technical reviews (Puri *et al.*, 2023; Morin Crini *et al.*, 2022; Boro *et al.*, 2025; Rasheed *et al.*, 2019; Starling *et al.*, 2019). Thirdly, biodiversity monitoring initiatives should be collaboratively designed with ecotoxicologists and environmental chemists to ensure that biological surveys and chemical assessments are conducted in the same locations and timeframes, facilitating the causal attribution of biodiversity changes to specific mixtures and stressor combinations (Rico *et al.*, 2021; Sigmund *et al.*, 2023; Rico *et al.,* 2021; Cabrera *et al.*, 2023; Peter *et al.*, 2022; Rizzi *et al.*, 2023). Lastly, the emerging UN Science Policy Panel on Chemicals, Waste, and Pollution Prevention presents an opportunity to position Amazon pollution within the broader context of interconnected crises such as climate change, biodiversity loss, and chemical pollution, and to direct resources and guidance to low- and middle-income countries in the region (Sigmund *et al.*, 2023; Wang *et al.*, 2024; Diamond *et al.,* 2024).

To effectively tackle the Amazon biodiversity crisis, it is essential to acknowledge and address chemical pollution (such as wastewater contaminants, pesticides, metals, and hydrocarbons) as a primary factor rather than a secondary issue. Incorporating environmental chemistry tools systematically into monitoring, regulation, and conservation policies would establish the necessary evidence base to avert further, largely unseen degradation of Amazonian biodiversity and ecosystem services.

Sincerely,

Paulo Roberto Barros Gomes

## 5. DECLARATIONS

### 5.1. Study Limitations

As a letter to the editor, this text is inherently limited by the constraints typical of such publications, particularly in terms of analytical depth. The concise format restricts the ability to provide detailed methodological descriptions of the studies cited and limits a more comprehensive critical evaluation of the data. Additionally, the text predominantly relies on secondary data from previously published research, which, while it enhances the synthesis of existing knowledge, may limit empirical originality. The heterogeneity of the sources used, which include various methodological approaches and different spatial and temporal scales, complicates direct comparisons and the generalization of findings across the entire Amazon basin. Furthermore, potential spatial and sampling gaps should be considered, as many studies focus on urban areas or specific regions and do not uniformly represent the environmental diversity of the Amazon. There are also challenges in establishing causality, as much of the evidence is based on associations between contaminants and ecological effects, particularly in complex mixture exposure scenarios. Finally, the scarcity of long-term data constrains a more comprehensive understanding of the chronic and cumulative impacts of chemical pollution on biodiversity.

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### 5.3. Funding Sources

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### 5.4. Conflicts of Interest

The authors declare no conflicts of interest and no competing interests

### 5.5. Data Availability

All data presented in this study are available in the manuscript tables and figures. Raw data are available upon request from the corresponding author.

### 5.6. Author Contributions (Contribuições dos Autores)

Specify the exact role of each author using the following standard codes: (Especifique o papel exato de cada autor usando os seguintes códigos padrão:)

Paulo Roberto Barros Gomes: CD, DC, DAI, MW, FA

| Code | English | Português |
|---|---|---|
| CD | Conception and Design | Concepção e Design |
| DC | Data Collection | Coleta de Dados |
| DAI | Data Analysis and Interpretation | Análise e Interpretação de Dados |
| MW | Manuscript Writing | Escrita do Manuscrito |
| CR | Critical Review | Revisão Crítica |
| FA | Final Approval | Aprovação Final |

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1. Tool: ChatGPT, Consensus, and Grammarly. Purpose: Literature summarization, grammar/style improvement.
2. Human Verification: yes.

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X - No P-hacking or selective reporting

X - Original work (Trabalho original)

X - Not previously published

X - Methods conducted ethically

### 5.9. Originality & Plagiarism Statement

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### 5.10. Open Access License

## 6. STUDIES INVOLVING HUMAN AND ANIMAL SUBJECTS

Not applicable.

## 7. REFERENCES:


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