

## Opinion

# Pathogen Pollution: Viral Diseases Associated with Poor Sanitation in Brazil

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**Abstract:** Brazil faces many types of pollution, including atmospheric CO<sub>2</sub> pollution due to Amazon deforestation, pollution by heavy metals, microplastics, pesticides, pathogens, and other classes of environmental contaminants. Pathogen pollution refers to (I) the introduction of a pathogen to a new host species or population and (II) a concept used in the study of pathogenic organisms in water or terrestrial ecosystems. Anthropogenic activities are the leading forces of pathogen pollution in both contexts previously cited. In this Opinion article, we discuss the impacts of pathogen pollution on public health, infectious diseases emergence, and ecosystems using mosquito- and water-borne viral diseases in Brazil as case studies. Finally, we advocate improvements and expansion in sanitation systems, considering sewage treatment and soil waste management, as an umbrella factor to minimize risks and spreading of pathogen pollution in Brazil.

**Keywords:** Brazil; environmental health; pathogens; pollution; sanitation; virus



**Citation:** Ellwanger, J.H.; Chies, J.A.B. Pathogen Pollution: Viral Diseases Associated with Poor Sanitation in Brazil. *Hygiene* **2023**, *3*, 441–449. <https://doi.org/10.3390/hygiene3040033>

Academic Editor: Günter Kampf

Received: 23 October 2023

Accepted: 2 November 2023

Published: 6 November 2023



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## 1. Introduction: Pathogen Pollution in Brazil

Brazil is known worldwide for its rich biodiversity, popular culture, and the beauty of its natural landscapes. In the public health area, the Brazilian Unified Health System (Sistema Único de Saúde—SUS) is an example of success for several countries, especially concerning prevention and treatment of infectious diseases and universal access to basic healthcare [1]. However, Brazil has been facing multiple challenges both in environmental and public health areas. The country is at the center of the international ecological and political debate due to deforestation of the Amazon Forest, which has reached 17% of the total forest area, putting the Amazon at the limit of its healthy ecological functioning [2]. Disruption of ecosystem services performed by this biome put the global ecological stability at risk. The degradation of the Amazon Forest causes biodiversity loss, facilitates the emergence of infectious diseases, disrupts water cycles, and releases enormous amounts of CO<sub>2</sub> into the atmosphere, triggering climate change [3]. In addition to the removal and degradation of vegetation for the cultivation of monocultures, road and settlement development, timber extraction, and cattle ranching in the Amazon Forest [3,4], the fires and consequent smoke plumes observed in the Amazon and other Brazilian biomes may transport bioaerosols containing pathogens over long distances [5] and, most significantly, fuel atmospheric pollution [4].

The release of greenhouse gases into the atmosphere places Brazil at the top of the ranking of the most polluting countries in the world. According to the Carbon Brief ranking [6], Brazil shows the fourth largest cumulative CO<sub>2</sub> emissions considering the 1850–2021 period, with United States, China, and Russia leading the ranking. Brazil's emissions are mostly linked to land-use changes, such as deforestation [6]. Beyond atmospheric pollution-related issues, the combination of infrastructure problems, low investment in waste management, social challenges, insufficient environmental education, political issues, flaws in the environmental legislation, and pressure from specific groups in society (e.g.,

agribusiness, mining sector) put the Brazilian population and ecosystems under the effects from many other types of pollution, with emphasis on pollution from pesticides [7,8], solid waste [9], microplastics [10,11], heavy metals [12], industrial waste [13], and domestic sewage [14,15]. These various types of pollution negatively impact the health of the Brazilian population, creating important economic costs for Brazil's health system.

Data from 2021 indicated that only 55.8% of the Brazilian population is served by sewage collection [16]. Financial losses to the Brazilian Unified Health System from diseases related to poor sanitation are estimated at ~BRL 100 million (in Brazilian real) per year in Brazil [17]. In addition, Brazilian cities are commonly affected by inefficiencies in the solid waste collection and recycling services [18], and Brazil has several open-air dumpsites and non-sanitary landfills due to failures in its waste management systems [18,19]. These places represent a significant threat to the aquatic and terrestrial Brazilian ecosystems [19]. These pollution-related environmental problems add to the Amazon Forest's deforestation issues and should receive greater attention from decision makers, the general population, researchers, and the international community. In this context, we would like to call the attention to "pathogen pollution", a type of pollution that, despite leading to multiple deleterious effects on human, animal, and environmental health in Brazil, has been rather neglected.

The concept of "pathogen pollution" emerged in the infectious disease field in the early 2000s and is classically defined as the introduction of a pathogen to a new host species or population, usually triggered by anthropogenic forces [20–22]. In this context, pathogen pollution may be closely related to zoonotic spillover events and the emergence of infectious diseases in animal and plant populations, posing threats to public health and biodiversity [20–26]. The expression "pathogen pollution" also applies to the study of pathogenic organisms found in water and terrestrial ecosystems as a result of the presence of fecal material or improper disposal of sewage in the environment [27–30].

Aiming to expand discussions regarding pollution issues in Brazil, in this Opinion article we address how pathogen pollution impacts public health, infectious diseases emergence, and ecosystems, with a focus on the Brazilian context. To discuss these aspects, we use mosquito- and water-borne viral diseases as case studies. Finally, we advocate improvements and expansion in sanitation systems as an umbrella factor to control pathogen pollution in Brazil. This is a fundamental action to preserve Brazilian biodiversity and the health of the human population in an integrated manner.

## 2. Viral Diseases Associated with Poor Environmental Sanitation in Brazil: Two Case Studies

### 2.1. Mosquito-Borne Diseases

Viral mosquito-borne diseases are among the main public health problems in Brazil. In 2022, 1,450,270 cases of Dengue, 174,517 cases of Chikungunya, and 9204 cases of Zika were reported in the country [31]. In addition to these worrying and "well-known" pathogens, emerging mosquito-transmitted viruses (e.g., Mayaro, Ilhéus, Bussuquara, Oropouche, Saint Louis encephalitis, West Nile, and Rocio) are of concern to public health authorities in Brazil since they have the potential to cause new outbreaks or epidemics [32–34]. *Aedes aegypti* is the most concerning mosquito species in Brazil due to its ability to transmit different species of viruses combined with its high adaptation to various ecological niches in urban environments. However, other mosquito taxa also have public health importance in Brazil, such as *Aedes albopictus*, *Wyeomyia* spp., *Haemagogus* spp., and *Culex* spp. [35,36]. In other words, the country harbors a wide diversity of vectors, and has multiple favorable conditions for the spread of classic and emerging mosquito-borne diseases.

Climate change, at least partially caused by Amazon deforestation-related CO<sub>2</sub> pollution [4], may contribute to the spread of mosquito-borne diseases by creating and maintaining climatic conditions favorable to mosquito proliferation [37]. Although it is true that presently the Amazon deforestation and related environmental issues are being better approached by the Brazilian government as compared to previous years [38], other

Brazilian biomes should not be neglected. This is especially worrying considering the recent increase in deforestation rates in the Cerrado [39], and issues concerning the Pampa biome [40]. These environmental disturbances observed in different Brazilian biomes facilitate the spread of zoonotic pathogens, including arboviruses [41]. However, the pollution associated with poor sanitation has more direct and evident impacts on mosquito-borne diseases, fueling the deleterious effects of climate change on public health in Brazil. The disposal of domestic sewage in the environment creates open streams and water puddles, thus favoring the proliferation of mosquito larvae. The accumulation of solid waste both in urban environments and in open-air dumps also favors the accumulation of rainwater and, consequently, the proliferation of mosquitoes [42,43]. A robust body of evidence indicates that, together with mosquito-related biological factors, insufficient management of solid waste and sewage is strongly associated with the spread of mosquito-borne diseases in Brazil, as well as being factors strongly connected with social inequality and urbanization issues observed in the country [42,44–47].

Environmental pollution contributes substantially to biodiversity loss [48–50]. Fecal contamination of terrestrial and aquatic ecosystems has adverse effects on multiple organisms [51]. The decay of animal species that feed on mosquitoes (larvae and adult insects) favors the proliferation of these insects and the spread of vector-borne diseases [52].

Furthermore, a greater number of mosquitoes circulating between urban and wild environments creates opportunities for spillover and spillback events, characterized as the transmission of pathogens from animals to humans (spillover) and from humans to animals (spillback), thus favoring the emergence of new zoonotic diseases [52,53]. This problem is particularly worrying in Brazil, where many large cities (e.g., Manaus, Rio de Janeiro, Porto Alegre) have highly urbanized areas connected to natural environments where wild species, including non-human primates, live [54]. Some viral outbreaks may put both humans and wild animals at risk, such as in the case of the Yellow Fever virus. Past outbreaks and epizootics caused by this virus have had major impacts on humans and non-human primates in Brazil [55]. In brief, the body of evidence cited above supports that poor sanitation favors pathogen pollution by mosquito-borne viruses in Brazil through direct and indirect mechanisms, threatening the public health and ecosystems.

## 2.2. Water-Borne Diseases

Hepatitis A virus, rotavirus, norovirus, adenovirus, and enterovirus are some of the most important water-borne pathogens for public health in Brazil [56]. People are usually infected by water-borne viruses by drinking water contaminated with domestic sewage, lack of access to potable water to sanitize food, or direct contact with contaminated fecal material or sewage. These water-borne viruses may cause, among other conditions, hepatitis and gastroenteritis, with major consequences especially in children [56].

A robust body of evidence shows that transmission of these viruses is strongly associated with poor environmental sanitation [56–60]. Examples can be found distributed throughout the Brazilian territory. For instance, a study performed with children from an urban area of the Brazilian Amazon showed that risk factors for hepatitis A transmission are related to social inequalities and sanitation issues [61]. Kluge et al. [62] detected genetic material of human adenovirus (23.3% detection rate), human enteroviruses (27.4% detection rate), and genogroup A rotavirus (16.4% detection rate) in 73 tap water samples collected in public schools from six municipalities of Rio Grande do Sul State, southern Brazil. These results suggest deficiencies in sanitation and water treatment in the regions evaluated. Furthermore, Teixeira et al. [63] showed that norovirus was disseminated in water samples of Belém city (Amazon region, northern Brazil) due to a lack of sanitation and the associated discharge of contaminated effluents in the environment. Also, in a study performed in Rio de Janeiro State, high positivity rates and concentrations of noroviruses were detected in bivalve samples, probably due to ocean contamination by sewage, representing a disease risk for shellfish consumers [64]. In Brazil, noroviruses and adenoviruses are also commonly found in recreational water environments, which indicates that the

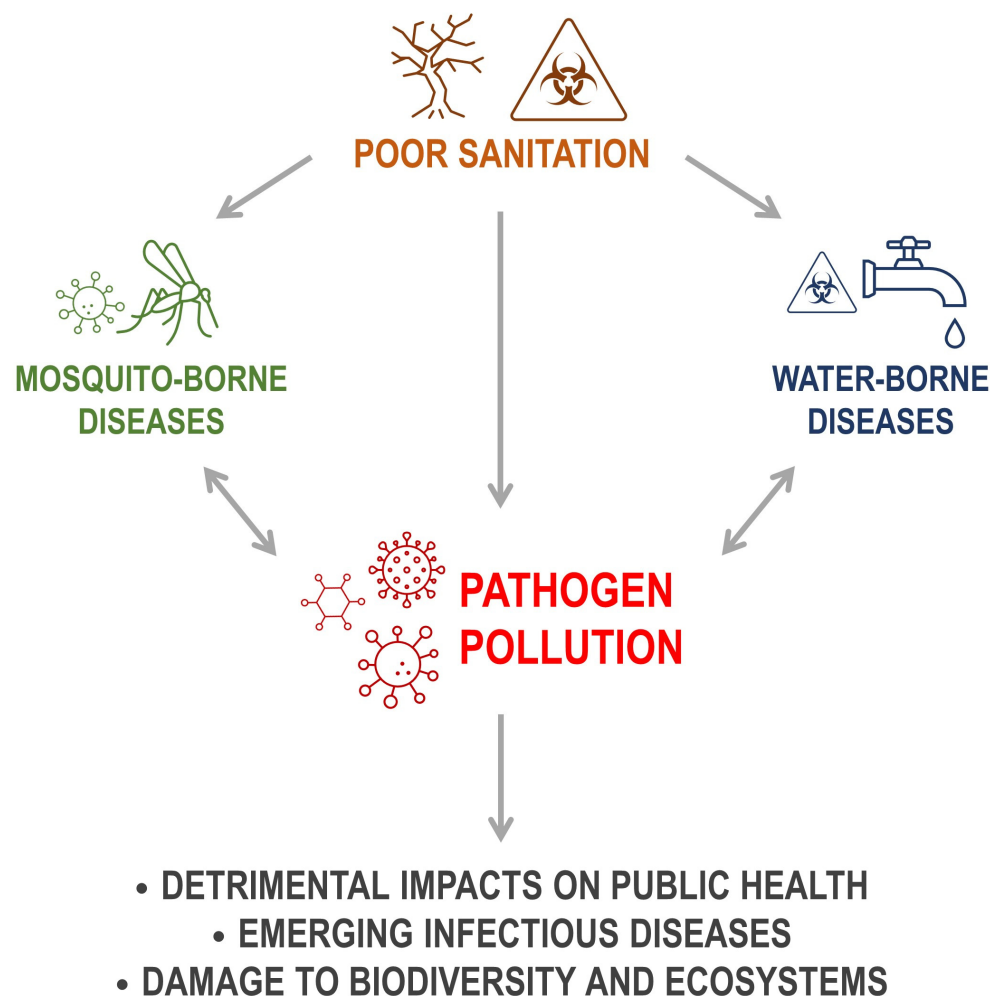
spread of water-borne viruses is quite wide and can reach the population through varied routes [65].

Inappropriate management of solid waste also facilitates the occurrence of water-borne disease in indirect ways. In Brazil, waste pickers suffer from hepatitis A, episodic diarrhea, and other non-viral water-borne diseases, conditions associated with inadequate housing, sanitation, and the occupational circumstances that these workers are exposed to [66].

These varied examples indicate that poor sanitation contributes significantly to the spread of water-borne viruses in Brazil, reinforcing that important actions to improve sanitation need to be implemented in the country.

### 3. Back to Basics: Sanitation as an Umbrella Factor to Control Pathogen Pollution in Brazil

This article described some examples of how insufficient sewage treatment and solid waste management affect the circulation of viral pathogens in Brazilian ecosystems. In brief, poor sanitation is closely related to pathogen pollution, affecting public health, harming biodiversity, and facilitating spillover events and the emergence of infectious diseases (Figure 1).



**Figure 1.** Connections between poor sanitation and pathogen pollution, showing consequences for ecosystems and public health.

In Brazil, sanitation is recognized as a basic human right according to the 1988 Federal Constitution [67]. Since then, some improvements have been made in sanitation and distribution of treated water in Brazil, with a reduction in disease burden linked to poor sanitation [57]. Also, the National Solid Waste Policy (Política Nacional de Resíduos

Sólidos—PNRS; Law No. 12,305 of 2 August 2010) brought some advances in the management of solid waste to the country [68]. However, sanitation is still a neglected (underused) strategy in the control of mosquito- and water-borne diseases in Brazil, even though its effectiveness for this purpose is widely recognized [69,70].

Ferreira et al. [71] demonstrated that an efficient investment in sanitation and treated water services would massively reduce the cases of water-borne diseases in Brazil, being a relatively inexpensive strategy for the country considering the costs of hospital admissions and productivity losses that would be avoided. Investment in solid waste management would also have a positive impact on disease prevention. In this sense, Mol et al. [72] showed that proper solid waste management was associated with protection against Dengue in Minas Gerais State.

Sanitation is a structural and long-term measure to control mosquito populations, unlike palliative or emergency measures, such as the use of insecticides for vector control (an action that has limited impacts on disease control and puts the population and ecosystems under pesticide-related risks) [73]. Sanitation may also help avoid the emergence (or re-emergence) of diseases in urban areas as well as the urbanization of sylvatic diseases [74,75].

Beyond the sphere of public health, improvement in sanitation is also critical for Brazil to achieve the Sustainable Development Goals of United Nations 2030 Agenda [67], and a healthy environment is directly linked with sustainability issues. The stimulus to an economy model focused on reducing overconsumption and overproduction of non-essential and low-quality products (“degrowth”) [76] and biodiversity-based economic activities [77] may contribute to reduce solid waste in our societies and protect biodiversity. Reducing social inequalities and urbanization issues are key factors for addressing sanitation-related problems in Brazil. Of note, the quality of sanitation services is as important as its coverage rate. For example, although Brazil has a ~90% distribution rate of treated water, this service is still precarious in many places [16,46].

Investing in sanitation and better solid waste management are measures to control several diseases that affect the Brazilian population in an integrated, broad, and consistent way, also bringing positive impacts to Brazilian biodiversity and ecosystems. However, this strategy remains overlooked in Brazil for many reasons. For example, (I) Brazil’s successes in some economic areas and even in the field of public health (e.g., a robust vaccination system) often overshadow still unresolved problems in the country, such as sanitation; (II) investments in sanitation infrastructure are often considered unattractive by politicians in Brazil because they are, in large part, improvements in underground infrastructure with little visibility after they are completed, and consequently with less potential to generate political support in municipal or state elections; (III) the scientific funding system and economic interests encourages researchers to seek innovative solutions (e.g., genetically modified mosquitoes) to deal with poor sanitation-related diseases instead of promoting “ready to use” (and effective) strategies for controlling these diseases, such as improvements in the cities’ sanitation infrastructure and a better environmental management.

Finally, we advocate that more financial resources and efforts should be directed to put into practice classic solutions with proven effectiveness in protecting human, animal, and environmental health in a broad way: namely, sanitation and better waste management. New technologies for controlling diseases related to poor sanitation are welcome, but should be considered as complementary strategies. Brazil’s pathogen pollution directly affects Brazilians and indirectly affects the other populations since pathogens do not respect borders. Therefore, sanitation issues should receive greater attention by Brazilians and the international community. Shedding more light on this problem is a fundamental step for decision makers to focus their efforts on solving Brazil’s pathogen pollution.

**Author Contributions:** Conceptualization: J.H.E.; investigation: J.H.E.; writing—original draft preparation: J.H.E.; writing—review and editing: J.A.B.C. and J.H.E.; visualization: J.H.E.; supervision: J.A.B.C. All authors have read and agreed to the published version of the manuscript.



**Funding:** J.H.E. receives a postdoctoral fellowship from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, Programa Nacional de Pós-Doutorado—PNPD, Brazil—Finance Code 001). J.A.B.C. is supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Bolsa de Produtividade em Pesquisa—Nível 1A, Brazil) and has research funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES AUXPE 686/2020; Brazil).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** Graphical abstract and Figure 1 were created with the aid of Microsoft 365. Brazil's map shown in the graphical abstract was obtained from Map Chart [78].

**Conflicts of Interest:** The authors declare no conflict of interest.

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