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INVISIBLE HUMIDITY, REAL THREAT: MOLD AND ITS CONSEQUENCES FOR RESPIRATORY HEALTH AFTER FLOODING IN BELÉM-PA

UMIDADE INVISÍVEL, AMEAÇA REAL: MOFO E SUAS CONSEQUÊNCIAS PARA A SAÚDE RESPIRATÓRIA APÓS ALAGAMENTOS EM BELÉM-PA

HUMEDAD INVISIBLE, AMENAZA REAL: EL MOHO Y SUS CONSECUENCIAS PARA LA SALUD RESPIRATORIA TRAS LAS INUNDACIONES EN BELÉM-PA

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Ana Shirley Freire Ramos Chaves[1], Marcia Cristina Ribeiro Gonçalves Nunes[2], Francisco Denis Pereira Chaves[3], Marco Valério de Albuquerque Vinagre[4]

ABSTRACT
This article analyzes the relationship between recurring flooding in Belém, Pará, excessive humidity in residential environments, and mold proliferation as a risk factor for respiratory diseases. A qualitative and quantitative approach is adopted, combining an integrative literature review (2019–2024), secondary data analysis (DATASUS, INMET, SNIS), and direct observation in vulnerable areas. The results indicate a correlation between rainfall peaks, increased hospitalizations for severe acute respiratory syndrome (SARS), and the presence of opportunistic fungi in domestic environments, with an emphasis on the most vulnerable populations. The study highlights the importance of intersectoral measures, including adequate ventilation, building waterproofing, health education, and investment in urban infrastructure. It concludes that mitigating respiratory risks associated with humidity requires coordinated public policies that promote socio-environmental justice and urban resilience in Amazonian territories.

Keywords: Mold. Humidity. Flooding. Respiratory Health. Sanitation.

RESUMO
Este artigo analisa a relação entre os alagamentos recorrentes em Belém-PA, a umidade excessiva em ambientes residenciais e a proliferação de mofo como fator de risco para doenças respiratórias. Adota-se uma abordagem quali-quantitativa, combinando revisão integrativa da literatura (2019–2024), análise de dados secundários (DATASUS, INMET, SNIS) e observação direta em áreas vulneráveis. Os resultados apontam correlação entre picos de pluviosidade, aumento de internações por síndromes respiratórias agudas graves (SRAG) e presença de fungos oportunistas em ambientes domésticos, com ênfase nas populações mais vulneráveis. O estudo destaca a importância de medidas intersetoriais, envolvendo ventilação adequada, impermeabilização de edificações, educação em saúde e investimentos em infraestrutura urbana. Conclui-se que a mitigação dos riscos respiratórios

[1] Doctorate student in Development and Urban Environment (PPDMU). Universidade da Amazônia (UNAMA). E-mail: anashirleyfrchaves@gmail.com
[2] Dr. in History. Universidade da Amazônia (UNAMA). E-mail: marcianunes2011@gmail.com
[3] Doctorate student in Development and Urban Environment (PPDMU). Universidade da Amazônia (UNAMA). E-mail: franciscodpchaves@gmail.com
[4] Dr. in Natural Resources Engineering of the Amazon. Universidade da Amazônia (UNAMA). E-mail: valeriovinagre@gmail.com

associados à umidade requer políticas públicas articuladas que promovam justiça socioambiental e resiliência urbana em territórios amazônicos.

Palavras-chave: Mofo. Umidade. Alagamentos. Saúde Respiratória. Saneamento.

RESUMEN

Este artículo analiza la relación entre las inundaciones recurrentes en Belém, Pará, la humedad excesiva en entornos residenciales y la proliferación de moho como factor de riesgo para enfermedades respiratorias. Se adopta un enfoque cualitativo y cuantitativo, combinando una revisión bibliográfica integradora (2019-2024), análisis de datos secundarios (DATASUS, INMET, SNIS) y observación directa en zonas vulnerables. Los resultados indican una correlación entre los picos de precipitación, el aumento de las hospitalizaciones por síndrome respiratorio agudo severo (SARS) y la presencia de hongos oportunistas en entornos domésticos, con énfasis en las poblaciones más vulnerables. El estudio destaca la importancia de las medidas intersectoriales, como la ventilación adecuada, la impermeabilización de edificios, la educación sanitaria y la inversión en infraestructura urbana. Concluye que la mitigación de los riesgos respiratorios asociados a la humedad requiere políticas públicas coordinadas que promuevan la justicia socioambiental y la resiliencia urbana en los territorios amazónicos.

Palabras clave: Moho. Humedad. Inundaciones. Salud Respiratoria. Saneamiento.

1 INTRODUCTION

Belém, the capital of the state of Pará, is characterized by high humidity throughout the year, with high rainfall, typical of the Amazon region, which varies between 2,000 and 3,000 mm per year (Belém, 2020 p.20). As indicated in the Municipal Plan for Basic Sanitation, the city has two defined climatic seasons: a hot one (May to December), with an average of 27°C, and a cool one (January to April), with an average of 26°C. The climatic context, combined with the process of dense urbanization, the insufficiency of infrastructure and public equipment, and the high occurrence of precarious occupations, is evidenced, above all, by the deficiencies in the urban drainage system, often resulting in flooding in different areas of the municipality (Belém, 2020 p.248).

For Caldeira (2024, p 15), the peripheral regions of the city, due to the lack of infrastructure, are the most affected by climatic events. In this context, these populations are more exposed to humidity. This prolonged exposure after flooding events favors the development of opportunistic fungi, whose proliferation poses a real threat to respiratory health, especially among children, the elderly, and individuals with chronic diseases (Suehara and Silva, 2023).

Despite the relevance of the topic and the recurrence of extreme events in the urban Amazon, specific studies on the relationship between the proliferation of fungi after flooding and their direct impacts on respiratory health are still scarce for the reality of Belém. This study aims to analyze this relationship, identifying epidemiological and socio-environmental patterns that can help in understanding the phenomenon, in addition to proposing preventive and corrective measures essential to mitigate risks to public health.

In this way, it is intended to provide solid subsidies for the formulation of integrated and effective public policies, which articulate urban planning, basic sanitation and environmental health, aiming to reduce social and environmental vulnerabilities in the specific context of the Amazon region.

2 METHODOLOGY

This study adopted a mixed approach, which consists of the combination of qualitative and quantitative methods, allowing both the interpretation of the phenomena and the quantification of the results (Günther, 2006). This method was chosen for its ability to deepen the understanding of the social and environmental phenomena involved in the proliferation of fungi and, simultaneously, to establish quantitative relationships between climatic, sanitary and epidemiological variables, thus ensuring a more comprehensive and robust view of the factors studied.

2.1 INTEGRATIVE LITERATURE REVIEW

An integrative literature review was carried out, a method that allows the critical and broad synthesis of existing scientific evidence, providing a comprehensive understanding of a given phenomenon or specific problem (Souza; Silva and Carvalho, 2010). The choice of this type of review stems from the need to integrate available knowledge on the relationship between mold, flooding, and respiratory diseases, especially in the Amazonian context.

In this stage, the SciELO, Google Scholar, Capes Periódicos, and PubMed databases were consulted, using the Boolean operators AND and OR to search for the following descriptors: "mold" or "fungi", "respiratory health" or "respiratory disease", and "humidity", in Portuguese and English, prioritizing publications between 2019 and 2024. Next, the inclusion and exclusion criteria were applied, resulting in the analysis of 15 articles considered directly relevant to the research objectives.

2.2 QUANTITATIVE ANALYSIS OF LOCAL DATA

To complement the integrative review, a secondary quantitative analysis of publicly available epidemiological and rainfall data about the city was performed. The data were obtained from official reports from the Ministry of Health, such as the Department of Informatics of the Unified Health System (DATASUS) and the National Institute of Meteorology (INMET), in order to identify statistical correlations between episodes of high humidity/precipitation and the increase in cases of respiratory diseases.

The use of these secondary data is justifiable by the possibility of drawing a precise quantitative overview of the environmental and health impacts in Belém, in addition to validating the qualitative relationships previously discussed in the literature.

2.3 DIRECT OBSERVATION IN RISK AREAS AND PROPOSAL OF PREVENTIVE MEASURES

During the month of March, some neighborhoods were visited, but the Maracangalha neighborhood was chosen as the object of the study due to flooding even without the presence of precipitation (suffering tidal action). From then on, a photoFigureic record was made of a main access street and the external area of one of the properties in this region.

Subsequently, proposals for detailed preventive and corrective measures were gathered, both individual and community-based, in line with the best practices identified in the researched literature.

3 RESULTS

3.1 LITERATURE REVIEW

3.1.1 Major Moisture-Associated Fungi and Respiratory Health Impacts

The presence of anemophilous fungi in indoor environments with high relative humidity is a critical factor for the microbiological quality of the air and represents a relevant risk to public health, especially in urban contexts with inadequate infrastructure.

According to Suehara and Silva (2023), the genera *Aspergillus*, *Penicillium*, *Cladosporium*, *Curvularia*, *Fusarium* and *Alternaria* stand out as the main fungal contaminants of indoor air, being present in hospitals, educational institutions and libraries in Brazil.

These organisms act as aeroallergens and pathogens, being capable of triggering various impacts on respiratory health, such as bronchopulmonary aspergillosis, as well as respiratory allergic manifestations (asthma, rhinitis, sinusitis), toxic reactions by mycotoxins, and opportunistic infections in immunocompromised individuals (Suehara and Silva, 2023).

Table 1 summarizes the main genera identified, their conditions conducive to proliferation and the adverse effects on human health.

Table 1

Main genera of anemophilous fungi in humid indoor environments and their clinical implications

Fungal genus	Favorable conditions	Effects on human health
Aspergillus	High humidity, organic substrates	Pulmonary aspergillosis, mycotoxicosis, respiratory allergies
Penicillium	Humid enclosed environments	Peniciliosis, brain abscesses, rhinitis, sinusitis
Cladosporium	High humidity and plant matter	Seasonal allergies, brain abscesses
Fusarium	Humid hospital environments	Skin, ocular and systemic infections in immunosuppressed patients
Curvularia	Heat and humidity	Allergic rhinitis, sinusitis, opportunistic infections in frail patients
Alternaria	Rainy seasons	Asthma, allergic rhinitis, respiratory hypersensitivity

Source: Adapted from Suehara and Silva (2023)

These findings highlight the need for systematic environmental control strategies, with emphasis on humidity monitoring, cleaning of air conditioning systems, and installation of physical barriers, such as HEPA filters

3.1.2 Socio-environmental vulnerability in Belém-PA

Belém-PA, characterized by a humid tropical climate with annual rainfall between 2,000 and 3,000 mm concentrated mainly between December and May, presents environmental conditions naturally conducive to the occurrence of extreme flooding events. This environmental situation is significantly aggravated by disorderly urban expansion and inadequate basic sanitation infrastructure, especially in peripheral neighborhoods (Belém, 2020).

The socio-environmental vulnerability of Belém is confirmed by the recent mapping of the areas most susceptible to flooding, showing 35 critical points with a high frequency of events that directly compromise quality of life and increase possible respiratory problems in the resident population (Belém, 2020; p.283).

Data from the National Sanitation Information System (SNIS) indicate alarming conditions in the city, where the total population residing in the municipality with sanitary sewage has been decreasing. In 2020, there were 1,499,641, rising to 1,303,403 in 2022. This scenario, aggravated by the precariousness of water treatment and inadequate collection of wastewater and rainwater, directly favors contamination by pathogenic agents, such as fungi, intensifying the health risks of the local population.

The seriousness of this situation is reinforced by recent epidemiological data from the state of Pará, which recorded more than 1,500 notifications for Severe Acute Respiratory Syndrome (SARS) in the first months of 2025 alone, emphasizing the need for urgent measures to mitigate environmental impacts on the population's respiratory health (DATASUS, 2025).

These factors make explicit the need for effective public policies that prioritize structural, social, and environmental interventions in the most vulnerable areas, with the aim of reducing the population's exposure to the risks arising from the precarious conditions of urban and sanitary infrastructure.

3.1.3 Integrated Socio-Environmental Preventive Measures

To mitigate the risks arising from humidity and mold proliferation after flooding, the literature highlights an interdisciplinary field. This study focused on measures involving the fields of health, architecture, sanitation, and urban security.

Next, three main fronts are presented: construction techniques, urban infrastructure and health education, demonstrating their complementarity.

3.1.3.1 Constructive or corrective techniques (focused on the property)

- Natural ventilation: Mechanical or natural ventilation must be adequate to control humidity (Kumar, 2022).
- Waterproofing: It is a preventive barrier against rising humidity by capillarity, preventing the proliferation of biological agents harmful to health (Oliveira and Nunes, 2020).
- Treatment of masonry with moisture-resistant materials: such as antifungal and washable paints (Rosa, 2024).

3.1.3.2 Techniques applicable to the surroundings (urban infrastructure).

- Installation of efficient storm drainage systems, with adequate drainage (Liang and Guan, 2024).
- Nature-based solutions like increasing the number of trees, rain gardens, green roofs, vegetated filter strip (Qin, 2020).

3.1.3.3 Health education techniques (focused on the action of individuals and collectivities).

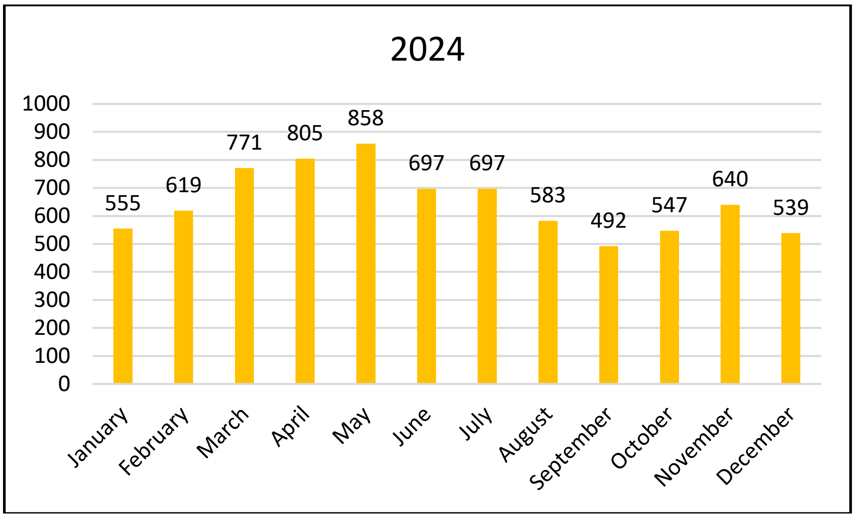
- Training of community agents for guidance on post-flood cleaning (EPA, 2018).
- Avoid drying clothes indoors, in order not to raise the relative humidity of the air, if necessary, do so in areas close to the air exhaust system (Thevenet et al., 2025).
- Use of personal protective equipment (PPE) to clean properties after flooding: such as PFF2 masks, gloves, boots and goggles (EPA, 2018).
- Educational campaigns on environmental public health risks (Szykula-Piec et al., 2020), can be associated with the theme of mold, prevention methods and adequate cleaning.

3.2 TRENDS IN RESPIRATORY HOSPITALIZATIONS

The analysis of data on hospitalizations for respiratory diseases in Belém in 2024 revealed a significant increase in periods of high rainfall, as shown in Figure 1 below.

Figure 1

Number of hospitalizations due to respiratory diseases in the city of Belém do Pará in 2024



Source: created by the authors, adapted from DATASUS (2024).

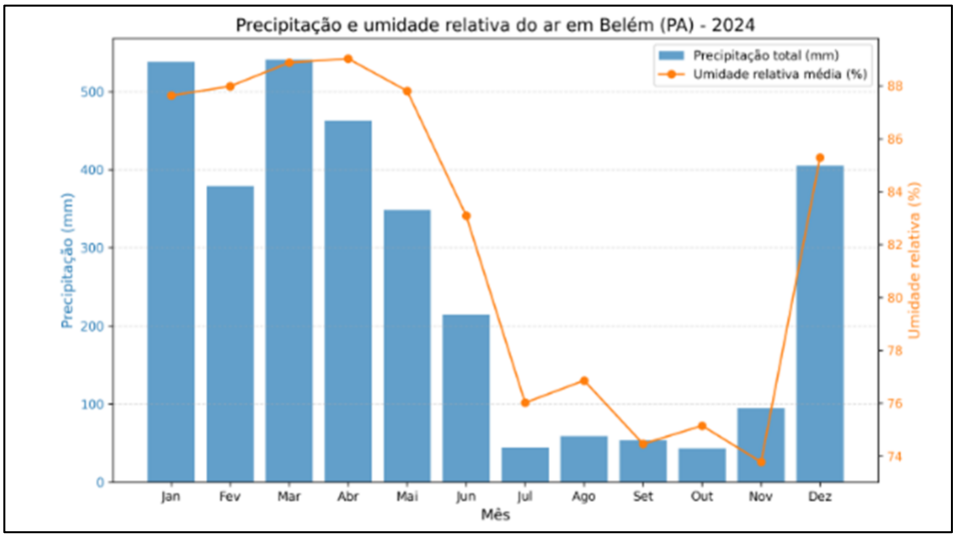
The analysis reinforces the hypothesis that there is a direct correlation between climatic conditions and the respiratory health of the population.

3.3 PRECIPITATION AND HUMIDITY PATTERN

Figure 2 represents the analysis of data on precipitation and humidity for the year 2024 available by the National Institute of Meteorology (INMET).

Figure 2

Precipitation and relative humidity in the city of Belém do Pará in 2024



Source: created by the authors, adapted from INMET (2024).

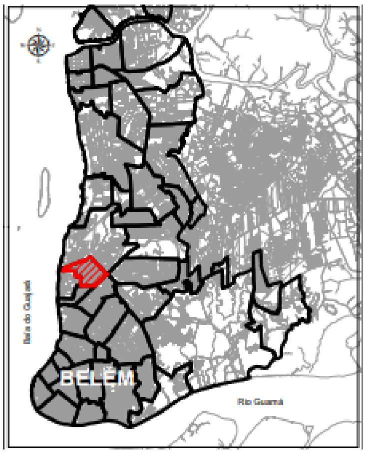
The data show that precipitation was higher in the months of January and May, and the season with the lowest rainfall was from July to November. Regarding the relative humidity of the air, it followed the precipitation period, but remained relatively high throughout the year. Typical condition of the humid equatorial climate, which favors the persistence of microambiences conducive to fungal growth.

3.4 CRITICAL AREAS IDENTIFIED

In direct observation, some points were visited. Among these are the Jurunas, Pedreira, Guamá and Maracangalha neighborhoods. As an illustration, the Maracangalha neighborhood was chosen for photoFigureic record because it was flooded even without precipitation.

Figure 3

Location of the Maracangalha Neighborhood in the municipality of Belém do Pará



Source: Codem, 2014

This neighborhood suffers constant influence of tides as shown in Figure 3.

Figure 4

Flooding Point in the Maracangalha neighborhood

Source: the authors

Figure 4 shows the presence of mold on the ceiling and walls of a surrounding residence, revealing the direct consequence of the humidity accumulated after flooding. Fungal proliferation significantly increases the risk of developing respiratory diseases, especially among the most vulnerable.

Figure 5

Pathology of infiltration in the slab with the presence of molds on the ceiling and wall

Source: the authors

Meanwhile, in figure 5 it is possible to see the advanced deterioration of the wall near the floor, revealing intense mold proliferation associated with persistent humidity due to flooding in this residence.

Figure 6

Pathology on the wall near the floor, caused by humidity and the presence of mold

Source: the authors

It is also noted that the paint peels off, evidencing the precarious conditions of the housing infrastructure and highlighting the socio-environmental vulnerability of the communities affected by the floods in the city of Belém-PA.

Constant exposure to these fungi significantly increases the risk of respiratory illness among residents, especially children, the elderly, and immunocompromised individuals.

4 DISCUSSION

The findings corroborate studies that link humid environments to respiratory morbidities (Suehara and Silva, 2023). The correlation between rainfall and hospitalizations suggests a direct influence of tropical seasonality on the burden of disease. In Belém, socio-environmental vulnerability further aggravates this exposure (Belém, 2020; SNIS, 2024). For Caldeira (2024, p 15), the peripheral regions of the city are the most affected, due to the lack of infrastructure.

For Suehara and Silva (2023), the most susceptible populations are children, the elderly, and individuals with comorbidities such as asthma and Chronic Obstructive Pulmonary Disease (COPD). Thus, the need for health surveillance and interdisciplinary actions on the subject is relevant.

5 CONCLUSION

This study evidenced the close relationship between recurrent flooding in Belém-PA, excessive humidity in residential environments and the consequent proliferation of mold, configuring a concrete risk to the respiratory health of the population. The triangulated analysis between literature review, epidemiological data, and direct observation revealed that respiratory impacts (notably those associated with acute respiratory syndromes and allergic diseases) are strongly correlated with poor structural conditions and the continuous presence of opportunistic fungi in humid microenvironments.

The high relative humidity of the air, typical of the Amazonian equatorial climate, added to the chronic deficiency of urban infrastructure and basic sanitation, especially exposes socially vulnerable populations, such as children, the elderly and people with comorbidities, to avoidable respiratory problems. The Maracangalha neighborhood, studied in this work, emblematically illustrates this situation, by presenting flooding even without direct precipitation, due to the action of the tides, revealing the complexity of the interaction between natural and urban factors in the Amazonian context.

In view of this scenario, the urgency of formulating and implementing intersectoral public policies that articulate urban planning, collective health and environmental management is highlighted. The mitigation of the identified risks requires structural interventions such as investments in rainwater drainage and social housing with waterproofing technologies, in addition to educational actions, aimed at community awareness about preventive practices in environmental health. The promotion of cross ventilation, the use of antifungal materials and the distribution of technical guidelines for post-flood hygiene, combined with the strengthening of epidemiological surveillance, are indispensable measures.

In addition, the integration of meteorological, sanitary, and epidemiological databases, as well as the use of geospatial technologies for mapping critical areas, can support more effective strategies for preventing and responding to climate emergencies. The incorporation of approaches based on environmental justice and the right to the city becomes equally essential to address the territorial inequalities that amplify the impacts of humidity and fungi in urban peripheries.

Therefore, "invisible humidity" and its health consequences should not be underestimated. It is a real and systemic threat, which requires structuring and sustainable responses, based on science, equity and the valorization of the Amazon territory as a legitimate and complex urban space. Future research could advance risk modeling, monitoring fungal bioindicators, and evaluating urban interventions that combine health and climate resilience

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