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Editorial

Bioaerosols in Urban Settings: Roles of Climate Change, Ecosystem Services and Human Health

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Urban environments constitute of spaces in which the majority of humankind reside, work and recreate. While many study designs have focused on outdoor environments, the inter-relationship between indoor and outdoor conditions is not well characterized. Within the current context of a changing climate, reduced biodiversity and a lack of (sustainable) urban green spaces can have a significant impact on human and environmental health, and therefore relevant information is needed more than ever. In parallel, comparatively little is known in relation to indoor environments, despite the fact that humans spend almost 80% of their time in these spaces.

Bioaerosols, both outdoors and indoors, comprise an air quality component that is often neglected compared to other forms of chemical and particulate air pollution. They originate from biological sources and include pollen, fungi, bacteria, viruses, etc. Their relevance for environmental and human health is increasing as they are considered bio-indicators of climate change [1]; hence, it is imperative to understand the ecological processes involving the production, transfer, and deposition of bioaerosols.

There is therefore an urgent need to understand the atmospheric microbiome, especially in highly populated regions such as urban environments, and assess how environmental exposure may positively or negatively influence human health and wellbeing in these areas. This relationship should be investigated with regard to its high complexity, its bi-directionality between humans and the environment, and for a variety of bioaerosol types and their interactions, including those that are less often considered, like viruses, bacteria, fungi, and pollen. We suggest that specific focus should be placed on the following areas:

- *Bioaerosol studies under different meteorological/ecosystem conditions (urban vs. rural/natural environments):*

The air is the primary means of transportation and dispersal for many types of bioaerosol. Dispersal is key for the survival of many organisms over time and crucial for ecosystem health. A healthy ecosystem relies on diversity balanced through evolution and the enrichment of its genetic resources through the atmospheric transfer of the genetic pool. Climate change has already affected the environmental conditions required for growth and reproduction directly and indirectly, with natural ecosystems being impacted by fires, pollution, loss of biodiversity, etc. Furthermore, current urban settings, especially very large ones, alter the dispersal processes and modify the aerobiological pathway of bioaerosols in the atmosphere due to their complex topography, different types of spaces, and use of infrastructure materials that can act as pollution sources, reservoirs, obstacles, or a combination thereof. It is therefore necessary to investigate whether this phenomenon also

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holds true in urban environments where plants, animals, and people are more susceptible to such disturbances and the heat island effect could magnify the impacts of climate change. Through continuous biomonitoring and regular assessment, urban planning and urban management agencies should take into consideration the challenges of bioaerosol pollution and adopt recommendations to implement more environment-friendly and nature-based practices that will promote biodiversity and support the sustainable development of the ever-changing urban environment.

- *Indoor vs. outdoor biodiversity:*

Considering that the modern and expanding urban environment itself exerts pressure on microbes and local vegetation, its atmospheric content is a dynamic result of local sources and long-distance transportation. Taking into consideration the connectivity of indoor and outdoor environments, microbial air quality of constructed environments is particularly important. Different building types, ventilation systems and automation systems in relation to the climate zone can either reduce exposure or lead to buildings acting as fungal reservoirs or pollen and dust deposits, with both situations having various effects on occupants' health [2].

- *Evaluation of health outcomes and risks of co- and multi-exposure (e.g., pollen and viruses, pollen and fungi, fungi, viruses and bacteria, etc.):*

While the health impacts of single bioaerosol exposure may be well studied, such as for some pollen types or certain viruses, studies on co- and multi-bioexposure are scarce. Even the co-circulation of different respiratory pathogens [3], aeroallergens [4], or their combinations [5] is often neglected, with much fewer studies having been completed with respect to the above effects.

- *Direct and indirect effects of climatic changes on non-communicable and infectious diseases (including emerging diseases, new diseases, more severe diseases, or occasions of co-disease):*

The Intergovernmental Panel on Climate Change (IPCC) has provided strong to very strong evidence of the rising global burden of respiratory illnesses, including allergies and asthma [6]. In the face of climate change and increasing urban agglomeration and urbanization, new zoonotic diseases, the spread of new allergens, extreme events, crop failure, and epidemic livestock diseases will become increasingly frequent, with significant direct and indirect consequences for human health [7–10].

- *Inclusion of policies on bioaerosol monitoring in European Union Directives, relevant to air quality or urban green spaces:*

Bioaerosols have never been incorporated in any official centrally and permanently administered and funded large-scale project, despite their acknowledged importance. Policy and decision makers should be involved in creating the infrastructure for an inter-continental biomonitoring network of exposure to multiple pollutants, particularly bioaerosols. Within the framework of livable and sustainable cities and increasing public awareness, policy and decision makers are expected to create such networks worldwide, so as to reduce future human health risks and to more efficiently manage diseases and pollution [11].

Conflicts of Interest: The authors declare no conflicts of interest.

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