50 adults in South India, where comprehensive ambient and personal monitoring was carried out (Milà et al., 2018). This study exemplifies advanced data integration techniques in resource-limited settings by combining personal and ambient air pollution concentrations with questionnaires, GPS, and wearable camera data, which allowed identification not only of activities associated with increased exposure but also of the times of day and the locations where these exposures occurred.

To further exposome research in the Global South and enhance global collaboration in the field, various initiatives have been taken. Most notably, the International Human Exposome Network (IHEN) Project, funded by the European Commission, seeks to unite stakeholders from various sectors at the global scale. Such a collaborative approach is crucial for maximising the impact of future exposome research, particularly in the many Global South countries where research has historically been limited or undervalued.

7.3. Exposome and planetary health

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The exposome concept has evolved to encompass not only the chemical exposures but also the broader environmental factors affecting human health (Price et al., 2022). This holistic view of the exposome, especially as regards the external exposome, assesses the links between human health and the intricate web of interactions within ecosystems, including the impacts of lifestyle, social determinants, and natural environments. In considering the interconnectivity between an individual's exposures and these broader ecological and environmental factors, the exposome framework can be aligned with that of *One Health*, which advocates for a unified health perspective across humans, animals, and their shared environments. Furthermore, study of the exposome could also contribute to considerations of the importance of safeguarding *planetary health* as a means of preventing disease and of promoting well-being, insofar as it highlights the exposure-related challenges and opportunities for mitigating global environmental changes derived from environmental degradation.

Although the three concepts highlighted converge, they can be distinguished from each other in certain respects:

— Exposome and studies conducted in this field are concerned with mapping individual environmental exposures and their health effects.

— One Health framework emphasises the interconnected health of humans, animals, and the environment, particularly the links between zoonotic diseases and ecosystem health (Erkyihun & Alemayehu, 2022; Wilcox & Steele, 2021).

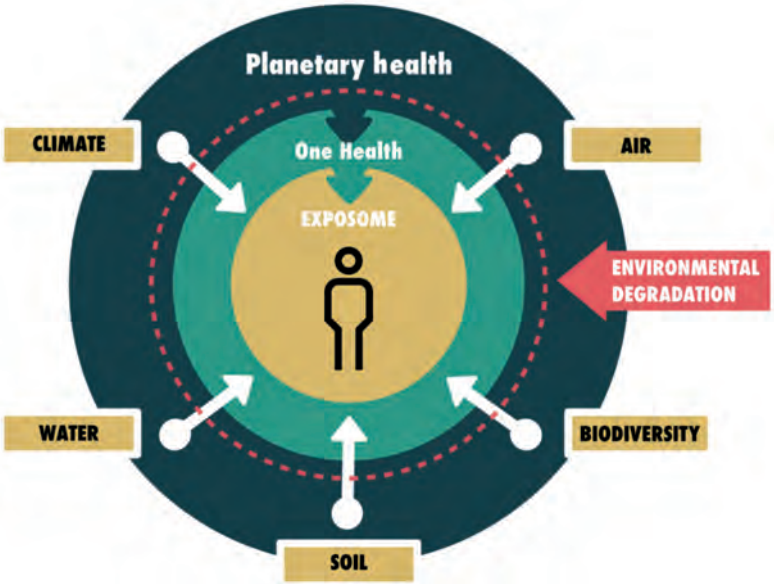

FIGURE 16. Diagram illustrating the interconnections between planetary health, One Health, and the exposome in the context of environmental degradation.
SOURCE: Created by Albert Bach.

— Planetary health takes a broader view by examining the human health impacts of human-caused disruptions of Earth's natural systems (Martens, 2024).

Each approach, associated with its own focus and methodology, underscores, however, the critical need for integrated health strategies that consider the complex interconnections between human activities, health, and the environment.

The concept of the exposome highlights the critical role played by environmental health in either enhancing or impairing human well-being. Broadly speaking, environmental influences on human health originate from one of the Earth's five key domains: namely, water, soil, climate, air, and biodiversity (Figure 16). However, the Earth functions as an intricately connected system, underscoring the complex interplay between human development and the environment (Ragnarsdottir, 2022). This perspective encourages a shift from examining isolated impacts within specific areas to exploring their interconnected consequences. In this regard, environmental degradation, largely driven by human activity, constrains or reverses the benefits and services provided by the environment, potentially leading to adverse effects and ultimately pushing ecosystems and human survival to the limit.

At the forefront of environmental transformation, climate change acts as a catalyst for a series of interconnected environmental disturbances. Driven by increasing greenhouse gas emissions, between 2011 and 2020, the global surface temperature rose 1.1 °C above pre-industrial levels. This warming has disrupted the balance of precipitation and accelerated the retreat of glaciers at unprecedented rates, contributing to a sea level rise of 3.4 mm per year since 1993 (Nerem et al., 2018). These alterations in water resources challenge their availability and quality and impact the fabric of biodiversity. Species are compelled to migrate or face extinction, disrupting ecosystems that have provided essential environmental services, from pollination to climate regulation, for millennia.

The effects of degradation extend to air quality. Air pollution from urban and industrial regions exacerbates planetary warming, promoting a cycle that jeopardises the development of all living organisms and the integrity of ecosystems. These sources of pollution have a number of environmental consequences including acid rain, forest decline, ground-level ozone fluctuation, and eutrophication. More than 90% of the global population is exposed to air quality that exceeds World Health Organization (WHO) guidelines because of significant pollutant concentrations (WHO, 2022). The burden is particularly severe in low- and middle-income nations, where the highest levels of exposure are recorded (Rentschler & Leonova, 2023), leading to an estimated 7 million premature deaths each year.

Against this backdrop, biodiversity is faced with an array of unprecedented threats. The Anthropocene, characterised by significant changes in atmospheric and oceanic chemistry, urbanisation, habitat fragmentation, land use alterations, and globalisation, has significantly degraded the biosphere. This degradation is contributing to the global biodiversity loss crisis, with estimates indicating that between 150,000 and 260,000 species have become extinct since 1500, marking the onset of the planet's sixth mass extinction (Ceballos & Ehrlich, 2018; Cowie et al., 2022). Biodiversity loss not only jeopardises the functioning of the biosphere but also impairs the role it plays in climate regulation and water quality maintenance, among others.

Alongside this loss of biodiversity, the threat of chemical pollution, heavy metal contamination and erosion posed by conventional farming and infrastructure development critically undermines the vital functions and services of the soil. Healthy soils in temperate climates should maintain at least 2% soil organic carbon, yet European farmlands are depleting carbon at a rate of 0.5% annually (Bruni et al., 2022; Lal, 2020). As soil organic carbon is depleted, soils lose their capacity to act as effective carbon sinks, contributing to increased atmospheric carbon dioxide levels (Nazir et al., 2024). This process not only potentially exacerbates the risk of water aquifer contamination due to diminished

soil filtration capacities but can also influence nitrous oxide (N_2O) emissions (Guenet et al., 2021).

Direct human health impacts of climate change-induced exposures include the exacerbation of respiratory, cardiovascular, renal, and mental health issues due to increased temperatures and heatwaves, alongside injuries and diseases triggered by extreme weather events like torrential rains and floods. Indirect effects encompass a rise in infectious diseases through shifts in vector and host distributions, aggravated allergic reactions due to changes in allergen profiles, and health issues associated with the toxins produced by marine organisms affected by warming waters. Additionally, climate change is anticipated to indirectly affect human health through socioeconomic factors such as worsened air pollution, decreased availability of water and food, and the strain place on health systems by climate-induced migrations (Marrasé et al., 2020).

Impacts from biodiversity loss-induced exposures encompass all the derived effects of environmental degradation on the multiple pathways connecting biodiversity to human health. The crucial function of biodiversity in supplying medicinal resources and ensuring food security is at risk, increasing the likelihood of malnutrition and the loss of prospective pharmaceutical discoveries. Furthermore, the natural filtration systems that safeguard water quality are under threat, augmenting exposure to waterborne diseases. Urban biodiversity loss exacerbates air and noise pollution, elevates urban temperatures, and increases exposure to extreme heat, collectively heightening the risk of respiratory disorders, cardiovascular diseases, and heat-related illnesses. Additionally, changes in wildlife populations and habitats can accelerate the spread of zoonotic diseases, altering the dynamics of disease hosts and vectors and increasing human exposure to infectious diseases. The alteration of plant and animal species compositions can also lead to increased exposure to airborne allergens (Marselle et al., 2021).

As this report has shown, the exposome research field has developed a variety of tools and methodologies to quantify and analyse the complex array of environmental exposures individuals face. The potential integration of these technological advances to the field of planetary health should help shed light on particular climate change-induced or environmental degradation-driven exposures and their potential health implications (Abdelzaher et al., 2022; Cui et al., 2016).

This scientific inquiry not only maps the myriad of exposures affecting individuals and communities but also lays the groundwork for developing strategic interventions aimed at mitigating these environmental challenges. Thus, exposome knowledge and tools are key to the development of science-based policies that can preserve public health and restore planetary health in this critical moment in our history. The narrative of interlinked impacts across life forms, continents, and populations highlights a critical truth that has yet to be fully integrated

into policy agendas: the urgency of addressing environmental degradation. Given the extensive damage already evident, we must continue to question the motives for such degradation and whether the perceived benefits can ever truly outweigh the enormous costs.