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Urban Environments and Human Health

Edited by Hanuman Singh Jatav, Ummed Singh, Vishnu D. Rajput and Satish Kumar Singh



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Contributors
Aakash Kumar Sain, Abdelmoneim Suleiman, Adriana Arango Castiblanco, An Goldbauer, Avinash Pilla, Constantin Kappas, Eetela Sathyanarayana, Fotini Kosma, Hanuman Singh Jatav, Hernando Alonso Martín Forero, Joan Camilo Piedrahita Mejía, Joseph Eloge Tiekwe, Josep M. Ramon-Torrell, Kiki Theodorou, L. T. Longkumer, Loic Kojom, Martin Leonardo Battaglia, Olanrewaju Olamide Popoola, Phélix Bruno Telefo, Prem Kumar Bharteey, Rathod Sridhar, Samson Oboche Agbo, Satish Kumar Singh, Sebastián Gaviria Londoño, Solange Dabou, Tamam Nissren, Vasiliki Softa

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IntechOpen Book Series

Public Health

Volume 15

Aims and Scope of the Series

Public health is what we as a society do collectively to contribute to and ensure the health and social conditions for the enjoyment of health as a resource for life. It can also be defined as science and research that promotes health, prevents disease, and improves populations' well-being and quality of life. Its objective is to know the risk factors that determine and condition the populations' health levels at present. At the end of the 20th century and the beginning of the 21st century, it is unjustifiable and regrettable that morbimortality according to age plays a leading role when the causes are mostly well known and therefore preventable, such as obesity, AIDS, cirrhosis, diabetes mellitus, addictions and cancer associated with the consumption of tobacco and alcohol, etc. In short, public health is science based on epidemiology and biostatistics, and currently, new technologies and artificial intelligence must be incorporated to identify patterns and trends in what we do collectively as a society to ensure living conditions and prevent risk factors that affect individual and population health. For all these reasons, it is essential to scientifically investigate and act on the determinants that impede the well-being and quality of life related to the health of people, patients, and populations in general, given that to control the determinants of diseases, it is important to control the environment and genetics. Consequently, the current fight for public health must prioritize the control of the environment, such as atmospheric and biological pollution and environmental and social biodiversity, promoting the sensitivity and training of society and its individuals by empowering them to make free and appropriate decisions about these aspects to lead healthy lifestyles based on motivation and responsibility in the face of the challenges they cope with from an individual point of view, such as dealing with the addictions that exist in today's complex world. Public health also requires an ethical vision and incorporates strategies to reduce social inequality.

Meet the Series Editor



José Antonio Mirón Canelo is a physician, doctor, and professor of Preventive Medicine and Public Health at the Faculty of Medicine and Dentistry of the University of Salamanca with over 30 years of experience. He is the director of the USAL's Expert Degree in Health Management, currently in its 13th edition. Prof. Mirón Canelo directs a research group at the Research Institute of Biomedical Sciences (IBSAL) of the University of Salamanca focused on addressing the challenges and care needs of vulnerable people and patients such as the elderly with multiple pathologies and people with disabilities and dependence. As a teacher, he has been recognized for excellence in teaching three times in a period of five years.

Meet the Volume Editors



Dr. Hanuman Singh Jatav is a Senior Assistant Professor in the Department of Soil Science and Agricultural Chemistry at Sri Karan Narendra Agriculture University, Jobner, Rajasthan. With over 8 years of experience in teaching and research, he has expertise in soil fertility management, biochar technology, micronutrient dynamics, sewage sludge reuse, and heavy metal pollution, with a focus on climate-resilient and sustainable agriculture. He earned his B. Sc. (Hons.) Agriculture from MPUAT, Udaipur, and M. Sc. and Ph.D. in Soil Science and Agricultural Chemistry from Banaras Hindu University, Varanasi. Dr. Jatav has published over 120 scientific works, including research papers, book chapters, and edited books with reputed international publishers. He actively serves as editor and reviewer for leading journals and has delivered invited lectures internationally. His contributions to agricultural research and education have earned him several prestigious awards.



Prof. Satish Kumar Singh is a distinguished soil scientist and academician specializing in Soil Science and Agricultural Chemistry. He obtained his B. Sc. (Ag.), M. Sc. (Ag.), and Ph.D. from Banaras Hindu University, Varanasi. He began his professional career as a Lecturer of Agricultural Chemistry at Amar Singh (PG) College, Bulandshahr. He later served as an Associate Professor at G. B. Pant University of Agriculture and Technology, Pantnagar. He subsequently joined Banaras Hindu University as a Professor in 2006. Prof. Singh is a Fellow of the Indian Society of Soil Science and the Indian Society of Agricultural Chemists. With an impressive academic record, he has guided 31 postgraduate and 10 Ph.D. students and published more than 250 scientific works, including research papers, books, book chapters, laboratory manuals, and technical bulletins.



Prof. Vishnu D. Rajput is a Leading Researcher and Head of the Soil Health Laboratory at Southern Federal University, Rostov-on-Don, Russia. His research focuses on environmental toxicology, particularly the impact of heavy metals and nanoparticles on soil–plant systems. His work investigates the bioaccumulation, uptake, translocation, and physiological effects of metal contaminants on plants, as well as nanotechnology-based remediation approaches, such as biochar and nano-biochar sorbents. Prof. Rajput has an outstanding publication record with more than 350 scientific publications, including over 200 peer-reviewed articles. He serves on the editorial boards of several international journals and leads major research grants, including BRICS and Mega-Grant projects. Recognized for his scientific contributions, he has received multiple academic honors and has been listed among the top 2% of Russian scientists.



Prof. Ummed Singh is a distinguished agronomist and currently serves as Dean of the College of Agriculture at Fatehpur-Shekhawati, Sikar, Rajasthan. He completed his B. Sc. (Hons.) Agriculture and M. Sc. (Ag.) Agronomy from Rajasthan Agricultural University, Bikaner, Ph.D. from the Indian Agricultural Research Institute, New Delhi, and postdoctoral research at Nanjing Agricultural University, China. His professional career includes positions at SKUAST-K and the ICAR–Indian Institute of Pulses Research, as well as various leadership roles at agricultural universities in Rajasthan. His research focuses on biofortification, cropping systems, and plant nutrition. Prof. Singh has handled numerous research projects and delivered over 130 invited lectures. With an extensive publication record including research papers, books, book chapters, and extension materials, he has received several prestigious awards for his contributions to agricultural research and education.

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Preface

Rapid urbanization has become one of the most defining global transformations of the 21st century. Cities are expanding at an unprecedented rate, bringing opportunities for economic growth, technological innovation, and improved living standards. At the same time, urban environments present complex challenges that directly and indirectly affect human health. Increasing population density, environmental pollution, changing lifestyles, climate-related stressors, and widening social inequalities have created multifaceted risks for the health and well-being of urban populations.

The relationship between urban environments and human health is dynamic and multifactorial. Environmental exposures such as air pollution, ultrafine particles, noise, heat stress, and inadequate sanitation are increasingly recognized as major contributors to both communicable and non-communicable diseases. Urban lifestyles characterized by sedentary behavior, processed food consumption, tobacco use, and high stress levels further compound these health risks. Additionally, vulnerable populations living in informal settlements often face disproportionate health burdens due to limited access to healthcare, safe housing, and essential services.

In recent decades, scientific research has increasingly emphasized the need to understand the intricate interactions between environmental, social, economic, and behavioral determinants of health within urban settings. Urban health is no longer viewed solely as a medical concern but as a multidisciplinary field that integrates environmental science, public health, urban planning, sociology and policy development. Effective strategies to address urban health challenges, therefore, require evidence-based, interdisciplinary approaches that bridge these diverse domains.

This book, Urban Environments and Human Health, explores the complex relationships among urbanization, environmental exposures, social determinants, and human health outcomes. The chapters in this volume examine key themes, including the influence of urban infrastructure and lifestyle patterns, the impact of environmental pollutants, including ultrafine particles, the health implications of tobacco and other urban risk factors, and the broader effects of climate change on public health. The book also highlights the critical issues of health inequities in informal settlements and the importance of community resilience and social support systems.

A distinctive feature of this volume is its emphasis on both challenges and solutions. Alongside discussions of emerging health risks, the book presents evidence-based strategies to improve urban environments, strengthen public health systems, and promote sustainable, resilient communities. By integrating scientific insights with practical perspectives, the chapters aim to provide policymakers, researchers, urban planners, and public health professionals with a comprehensive understanding of the pathways linking urban environments and health.

Ultimately, improving urban health requires coordinated action at multiple levels from local communities and city administrations to national governments and global institutions. Sustainable urban development, environmental protection, equitable access to healthcare, and inclusive social policies are essential components of healthier cities.

We hope this book will contribute to a deeper understanding of the complex interactions between urban environments and human health, while also inspiring innovative research, informed policymaking, and collaborative action to build healthier, more resilient urban societies.

Hanuman Singh Jatav
Department of Soil science and Agricultural Chemistry,
Sri Karan Narendra Agriculture University,
Jobner, India

Satish Kumar Singh
Department of Soil science and Agricultural Chemistry,
Institute of Agricultural Sciences,
Banaras Hindu University,
Varanasi, India

Vishnu D. Rajput
Southern Federal University,
Rostov-on-Don, Russia

Ummed Singh
Distinguished University Professor of Agronomy and Director Research,
Sri Karan Narendra Agriculture University,
Jobner, India

Chapter 1

High-Rise Buildings, Crowded Cities, Urban Diets: How Urbanization Shapes Public Health Globally

Olanrewaju Olamide Popoola

Abstract

More than half of the world's population (55%) lives in urban areas, a proportion projected to increase to 68% by 2050. Understanding how urbanization influences global health outcomes directly and indirectly, including climate change acceleration, is increasingly urgent. High-rise buildings contribute to the urban heat island effect, facilitating heat-related morbidity and mortality. These structures often lack communal spaces, contributing to psychological distress. Poor ventilation and shared indoor spaces also promote infectious disease transmission. Urban crowding results in traffic congestion, poor ventilation, and overcrowded housing, promoting infectious disease transmission, as witnessed during the COVID-19 pandemic. Increased fossil fuel combustion through transportation, heating and cooling systems, and industrialization increases emissions of particulate matter, hydrocarbons, and nitrogen oxides. These pollutants predispose populations to adverse respiratory outcomes, metabolic-disorders, cardiovascular-diseases, and cancer. Urban dietary patterns are shaped by demand-side factors (education, income, time constraints) and supply-side factors (convenient availability and low cost of ultra-processed foods, aggressive advertising). High salt, sugar, and fat consumption contribute to overweight and obesity, major risk factors for diabetes, heart disease, and cancer. Interventions including targeted nutrition education, marketing restrictions, traffic-light labeling, and sugar taxes have demonstrated effectiveness in improving urban dietary patterns. Although interactions between urban features and health outcomes are complex and nonlinear, multisectoral considerations are essential as urbanization expands. High-rise buildings should incorporate biodegradable materials; residential buildings should be located at least 500 m from major roads; regulations reducing fossil fuel consumption should be strengthened; and urban planning should support physical activity through dedicated pedestrian and bicycle pathways.

Keywords: high-rise buildings, urban diets, crowded cities, urbanization, public health

1. Introduction

1.1 Urbanization and global public health in the twenty-first century

Since 2007, humanity has crossed a historic threshold: for the first time in history, more than half of the world's population (55%) lives in urban areas rather than rural settlements [1]. This demographic shift represents one of the most profound transformations of the modern era, fundamentally reshaping how billions of people live, work, and interact with their environment. By 2050, it is projected that over two-thirds – approximately 68% – of the global population will reside in cities, with over 95% of this urban growth occurring in low- and middle-income countries (LMICs) across Africa, Asia, and Latin America [1–3].

Urbanization encompasses far more than simple population concentration in cities. It represents a complex socioeconomic process characterized by the expansion of built, well-developed environments, the transformation of land use, shifts from agricultural to industrial and service-based economies, and the creation of physically dense, socially diverse, and economically interconnected communities [4, 5]. This process brings together populations of varied ethnic, racial, and economic backgrounds. This diversity often results in disparities in income, wealth, and well-being among people living in proximity to one another [2].

The health implications of this unprecedented urban transformation present what the WHO describes as a "triple threat" to urban populations: the rising burden of noncommunicable diseases, the persistent threat of infectious disease outbreaks, and increased risks of violence and injuries [1]. Moreover, when adequately planned and managed, cities offer remarkable opportunities for improving population health through better access to healthcare services, clean water, sanitation systems, education, and nutrition [2]. The concentration of resources and expertise in cities has historically driven medical innovation and enabled more efficient delivery of preventive and curative health services. This gives rise to an "urban health advantage," with urban populations now experiencing better health outcomes than their rural counterparts [4]. However, the socioeconomic inequalities between residents of urban areas often limit the access of vulnerable groups to health services. Additionally, the reality of contemporary urbanization, particularly in rapidly developing regions with urban slums, often falls short in providing access to standardized health services.

The physical density and complexity of urban life create unique health challenges that differ substantially from those in rural settings. High population density facilitates the rapid transmission of infectious diseases such as tuberculosis and COVID-19 [1, 3, 5]. On the contrary, overcrowded housing and inadequate sanitation contribute to both communicable and noncommunicable disease burdens. Noncommunicable diseases like heart disease, diabetes, asthma, and cancer are exacerbated by unhealthy living, inadequate green space, and various forms of pollution [1]. An estimated 91% of people in urban areas breathe polluted air, while almost 40% of urban dwellers lack access to safely managed sanitation services [1]. Urban air pollution, urban heat island (UHI) effects, and urban diets add additional layers of health risk that disproportionately affect the most vulnerable populations: the elderly, children, and those of lower socioeconomic status.

Globally, over one billion people, approximately one-third of the urban population, currently live in slums characterized by inadequate housing, poor

ventilation, limited access to clean water and sanitation, and vulnerability to natural hazards such as flooding and landslides [2]. If current trends continue, the number of slum dwellers will double by 2030, with two in every five urban residents living under these precarious conditions. These urban slums are often associated with high rates of communicable diseases, a rising prevalence of noncommunicable diseases, and inadequate healthcare infrastructure to address either category effectively [2]. Health inequities are perhaps most stark in urban areas, sometimes varying from street to street, with migrants, ethnic minorities, and other disadvantaged groups clustered in the most deprived and degraded neighborhoods with the poorest access to health services [1].

The relationship between urbanization and health is further complicated by climate change, which disproportionately affects urban areas. Urbanization accelerates climate change through increased emissions from industrialization. Cities offer access to employment, education, healthcare, and social services that are often limited in rural areas, reinforcing economic growth, innovation, and industrialization. Industrialization, which drives the establishment of factories, manufacturing hubs, and service industries within cities, also contributes to the massive emission, use, and production of particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2), heavy metals, as well as benzene (C_6H_6) and benzopyrene (BaP), accelerating climate change. A rise in the production of fine PM, 2.5 micrometers or smaller in diameter ($PM_{2.5}$), has been linked to significant health challenges. $PM_{2.5}$ has been identified as the largest driver of air pollution's burden of disease worldwide and has been linked to deaths in cities in East, South, and Central Asia, as well as those in Central and Eastern Europe [6].

Furthermore, urban cities consume over two-thirds of the world's energy and are responsible for over 60% of greenhouse gas emissions [1]. Inland cities may experience temperatures 3°C–5°C higher than surrounding rural areas due to the UHI effect [1, 2]. On the contrary, the fluid movement of populations between rural and urban areas, and across international borders, makes traditional health policy frameworks and service delivery increasingly obsolete in catering to the urban population and monitoring infectious disease trends [2].

As cities continue to expand and evolve, understanding how contemporary urban features, including high-rise buildings, population density, and dietary patterns, shape public health outcomes becomes increasingly urgent. Recent research has demonstrated complex and sometimes contradictory relationships between urbanization and health outcomes, with effects varying significantly across different economic contexts and stages of urban development [3–5]. This chapter examines these complex relationships across diverse global contexts, providing evidence-based insights into both the health challenges posed by modern urbanization and the opportunities for designing healthier, more sustainable cities for the billions who will call them home in the decades ahead.

2. High-rise buildings

With rising global populations, economic development, and technological advancements, high-rise buildings have become an increasingly common

solution to address housing shortages. The prestige of skyscrapers as symbols of wealthy economies, their appeal as architectural achievements, and their demonstration of technological progress contribute to the growing construction and use of these structures. High-rise buildings lack a fixed definition; some define them as structures exceeding 100 m in height, while others classify them as buildings that are significantly taller than surrounding structures [7]. These towering edifices have a substantial impact on human health and the environment.

Figure 1 illustrates the key pathways through which high-rise buildings affect human health and the surrounding environment. These pathways, as well as the risks associated with emergencies and construction accidents, are explored in detail in the next section.

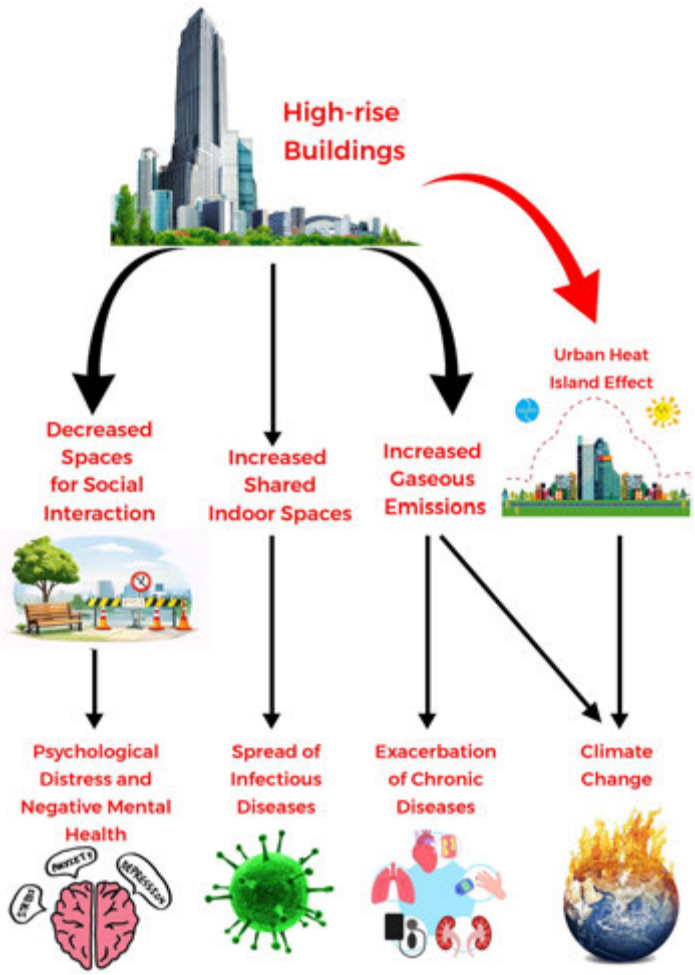


Figure 1.
Pathways through which high-rise buildings affect human health and the environment.

2.1 Environmental effects of high-rise buildings

The thermal and environmental effects of high-rise buildings have been well-documented. High-rise buildings have been found to influence the temperature of their surrounding environments. The UHI effect in high-rise buildings occurs when concrete, steel, glass, and asphalt used in the construction of high-rise buildings absorb substantial solar energy and heat radiation during the day and release their stored thermal energy at night and during cooler periods. This warms the areas around high-rise structures more than the surrounding regions.

High-rise buildings also trap hot air in the corridors and spaces between structures within the building, preventing natural ventilation and heat dissipation. This creates localized pockets of elevated temperatures that persist long after sunset. Additionally, the intensive energy consumption within these buildings significantly intensifies their warming effects. Air conditioning systems, heating units, electrical elevators, lighting, and other building operations generate waste heat that is expelled directly into the surrounding environment. Together, these factors create self-reinforcing heat accumulation, resulting in the temperatures of the surroundings around high-rise buildings being higher than in other areas by several degrees [8]. A study in Indonesia found that high-rise buildings change airflow patterns, air humidity, and the temperature of the surrounding environment, exacerbating climate change [8]. Increased temperatures around these buildings may contribute to the risk of heat exhaustion and stroke. Additionally, these increased temperatures strain the kidneys as the body tries to cool itself [9].

To limit the negative environmental impacts of high-rise buildings on climate change and health, the United Nations Environment Programme (UNEP) recommends increasing the use of renewable energy sources to power operations in these buildings. It also advocates for the design and enforcement of building codes that regulate the use of climate-friendly construction materials. These building codes should strengthen and enforce improved energy efficiency in both new and existing buildings. In addition, they encourage innovation through the adoption of low-carbon building materials, including biodegradable plant- and animal-based building materials like bamboo, straw, and animal waste [10].

2.2 Effects on health

2.2.1 Mental health

The impact of high-rise buildings on mental health has been extensively studied. Studies have revealed that residents of high-rise buildings report higher levels of psychological distress, depression, and emotional strain [11]. This trend is particularly prevalent among lower-income populations, who often experience greater stress, social isolation, and a diminished sense of community [11]. High-rise structures typically lack communal spaces with natural scenery, such as parks and playgrounds, which limits opportunities for social interaction and weakens community cohesion [7]. This absence of communal spaces for social connectivity and community bonding has profound implications for mental health and psychological well-being among urban residents. On the contrary, strong community bonds offer emotional support and a sense of belonging that buffer against psychological distress [7].

The isolation fostered by high-rise living environments contributes to increased rates of depression, anxiety, and chronic stress, particularly among vulnerable populations, including children, the elderly, and individuals with pre-existing mental health conditions. Kearns [12] reported that occupants of high-rise buildings exhibited increased antisocial behaviors. These antisocial behaviors have been linked to violence, drug abuse, reckless driving, and low-levels of empathy [13]. Living on higher floors has also been associated with increased suicide rates, possibly due to chronic negative mental health impacts [14].

2.2.2 Emergencies and accidents

In cases of natural disasters, living in high-rise buildings may have a higher likelihood of resulting in death. These buildings often have numerous windows and may experience more swaying than low-rise buildings during storms and natural disasters. This could increase disorientation and confusion, making access to exit routes more difficult. Furthermore, many residents of high-rise buildings rely on elevators for access. During emergencies, these elevators become inoperative, necessitating more detailed evacuation plans. With limited access to exits during disasters, residents may need to stay in the building until exits are accessible. People living on upper floors face particularly elevated risks, as they require greater travel distances to evacuate, exposing them to prolonged danger.

Construction of high-rise buildings requires the use of heavy machinery, excavators, pump trucks, and tower cranes, which may present a risk of injury to construction workers if not properly utilized. Additionally, the risk of construction workers falling during the construction or maintenance of high-rise buildings presents an avoidable but considerable risk to public health [15]. This calls for a multidisciplinary approach to regulating the construction and maintenance of high-rise buildings, involving engineers, architects, building regulatory authorities, and public health experts to ensure safety and security. Faulty design and/or faulty construction work, as well as the use of substandard materials in the construction or maintenance of high-rise buildings, could predispose them to fire or collapse, which could create a considerable death toll amounting to hundreds or even thousands of preventable deaths annually [16].

Implementing comprehensive fall protection systems, including guardrails, safety nets, and personal fall arrest systems, may significantly reduce worker injuries [17]. Additionally, enforcing strict quality control measures that ensure compliance with building codes and material specifications may also make the construction of these high-rise structures safer. Real-time monitoring systems that track structural loads and environmental conditions during construction may prevent catastrophic total collapse in the future [18].

2.2.3 Infectious diseases

High-rise buildings can facilitate the spread of infectious diseases by increasing shared indoor spaces and reliance on centralized ventilation systems. During the COVID-19 pandemic, living in high-rise buildings increased the risks of transmission through elevators, corridors, doorknobs, and inadequate ventilation, as close contact and poor cross-ventilation enabled the airborne spread of SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) [19]. Studies have shown that COVID-19

aerosolized viral particles can accumulate in enclosed spaces and remain suspended in the air for extended periods, increasing exposure among occupants [19]. This highlights the importance of improved ventilation design, infection control measures, and building management strategies to mitigate future risks of high-rise buildings becoming sites of rapid infectious disease transmission.

2.2.4 Air pollution and chronic diseases

Regarding air quality, pollutants from industrial areas, road emissions, landfills, and other sources rise upward and may contribute to increased air pollution. The UHI effect caused by high-rise buildings also limits the dispersion of pollutants because they restrict the upward flow of air, concentrating pollution at lower altitudes. A study by Jung et al. [20] reported that exhaust from motor vehicles, cooking emissions, and downward dispersion from chimneys reached peak levels on the third to fifth floors, exposing residents on these floors to increased concentrations of pollutants. A four-year study of the high-rise district of La Défense in Paris, France, measured the impact of these buildings on climatic factors and air pollution patterns [21]. The research revealed that upper-floor quarters (floor 30 and above) benefit from natural air conditioning and lower concentrations of pollution compared to lower floors [21]. This suggests that residents of lower floors of high-rise buildings are exposed to increased air pollutants like PM, nitrous oxide, carbon dioxide, dust, and sulfur oxide, contributing to significant health risks like stroke, cancers, and inflammatory diseases [22].

The high number of people living in high-rise buildings contributes to increased CO_2 emissions from burning fossil fuels, kitchen exhausts, and effluents. Furthermore, the increased energy demands required for the operational functionality of high-rise buildings, such as increased electricity consumption for elevators, mechanical ventilators, heating and cooling systems, and water pumps, lead to higher emissions of $PM_{2.5}$, nitrous oxide, and sulfur oxide. Increased exposure to these pollutants can contribute to cardiovascular disorders, asthma, emergency hospital visits, and cancers [6, 22–24].

Increased daily activities like cooking, showering, or drying laundry indoors, as well as water leaks in high-rise buildings, introduce moisture into the atmosphere, contributing to increased humidity. Increased indoor humidity can support the growth of molds, bacteria, and the deterioration of building materials, which could release spores, PM, and more allergens into the environment. Cumulatively, this can result in a buildup of dust and allergens that could predispose occupants to allergic reactions, asthma, and inflammatory diseases [25].

3. Crowded cities

Crowded cities represent urban environments characterized by high population density, limited living space, and intensive resource utilization. The migration of people to urban areas for job or business opportunities, as well as improved quality of life, contributes to diverse demographics in these regions. These demographic and infrastructural features create unique public health challenges that disproportionately affect vulnerable populations and contribute to significant morbidity and mortality worldwide.

3.1 Effects on health

3.1.1 Infectious diseases

The high population density characteristic of urban areas facilitates the transmission of communicable diseases, including waterborne, airborne, and vector-borne infections. In addition, urban centers are highly connected to other regions through air, rail, road, and water transport networks, creating pathways for the rapid cross-border spread of infectious diseases and potentially undermining the effectiveness of disease surveillance and containment systems.

Sanitation, housing infrastructure, and infectious diseases. Due to congestion and overcrowding, housing infrastructure in crowded urban cities may lack adequate sanitation, appropriate waste disposal infrastructure, water, and ventilation [26]. Research from Addis Ababa demonstrates that households lacking basic sanitation and experiencing overcrowding face an increased risk of infectious disease transmission [27]. The close proximity of waste and fecal disposal systems to sources of drinking water has been associated with increased diarrheal infections in urban slums in India, Nairobi, Ethiopia, and Southeast Asia [28, 29].

Globally, one billion people living in urban slums are potentially exposed to poor housing infrastructures and inadequate environmental health conditions that facilitate the transmission of communicable diseases [30]. With this figure expected to double over the next 30 years, there is an urgent need for robust public health considerations in the planning, design, and regulation of housing infrastructure in urban slums and densely populated cities.

Airborne disease transmission. Poor ventilation in residential areas, slums, and crowded transportation systems in densely populated urban cities allows droplets of airborne transmissible diseases, such as tuberculosis, to remain suspended in the air for longer periods, thereby increasing transmission risks [26]. A meta-analysis of studies conducted across India, Brazil, South Africa, Pakistan, Haiti, Uganda, Bangladesh, Cambodia, Iran, Nepal, Nigeria, Peru, and the Philippines revealed that people living in urban slums had threefold higher odds of smear-positive tuberculosis compared to the general population [31]. Research from Brazil also indicated that household crowding may directly favor tuberculosis transmission by increasing contact rates between *Mycobacterium tuberculosis* and susceptible individuals [32].

Conversely, analysis of the association between large population densities and airborne disease transmission has been mixed. Analyzing the relationship between urbanization and the spread of tuberculosis, Wang et al. [3] identified that a positive relationship between urbanization and tuberculosis was more noticeable in upper-middle-income countries, while a negative relationship was more common in high-income countries. This could also signify that as countries develop with urbanization, attention should be given to significant factors that influence the spread of infectious diseases and adapt integrated approaches that promote economic growth and address region-specific factors that contribute to the spread of infectious diseases.

Regarding the COVID-19 pandemic, findings from China and Italy revealed that cities with higher crowding had longer epidemics and higher attack rates after the first epidemic wave [33]. Although 90% of all COVID-19 cases occurred in urban areas, there were mixed correlations between urban crowded cities and disease

transmission [34]. Positive correlations between population density and COVID-19 infections were reported in Poland, the United States, Japan, Italy, and India [35]. Crowding in these settings before the outbreak of the COVID-19 virus negatively impacted the ability of residents to self-isolate and stay safe, potentially contributing to increased deaths in these regions [35]. Additionally, factors including the walkability of neighborhoods, adherence to mask-wearing measures, and interactions between people and places make such associations unclear [35]. This indicates that the impact of urbanization on the spread of infectious diseases is influenced by factors beyond population density. Other factors, including smoking habits, housing infrastructure, income, education, socioeconomic discrepancies, and inequalities, could significantly influence the prevalence and spread of infectious diseases in crowded urban cities [3, 36].

Vector-borne diseases. Turning to vector-borne diseases, in a bid to expand settlement areas and expand land for economic activities, encroachment into forests and fields often occurs. This potentially disperses insects, bats, and other animals living within these forest regions, forcing them to encroach into human habitats, exposing humans to vector-borne diseases. A comprehensive 13-year study examining 795 municipalities across the Brazilian Amazon demonstrated this relationship quantitatively, identifying that a 10% increase in deforestation resulted in a 3.3% increase in malaria incidence [37]. While population concentration alone does not drive infectious disease transmission, other factors like nutrition, sanitation and hygiene practices, and socioeconomic inequity also play crucial roles.

3.1.2 Air pollution and respiratory health

Urban cities attract a high number of people due to economic opportunities, better infrastructure, and a perceived higher quality of life. The increased number of people contributes to the burning of more fossil fuels through transportation and energy production, the burning of fossil fuels for cooling or heating in buildings, and the burning of waste, resulting in increased emissions, including carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs) or hydrocarbons (HCs), nitrogen oxides (NOx), and PM.

Vehicles are major contributors to urban air pollution through the combustion of fossil fuels, emitting several harmful pollutants that significantly impact air quality and public health. The primary pollutants from vehicles are nitrogen dioxide (NO_2), a gaseous pollutant that serves as a key marker of traffic-related air pollution, and fine PM ($PM_{2.5}$) [6]. Rising incomes and improved standards of living in urban areas substantially contribute to increased car ownership, leading to higher traffic volumes in urban areas [38]. Inadequate public transportation systems also force residents to rely on personal vehicles, further exacerbating congestion problems [39]. The concentration of employment, commercial activities, and service providers in city centers and central business districts creates peak-hour demand surges and traffic congestion as many commuters travel to and from work simultaneously. This traffic congestion substantially contributes to vehicular emissions and the deterioration of ambient air quality.

Poor ventilation in crowded cities, the presence of high-rise buildings, and warm air caused by the UHI effect trap cooler air near the ground, preventing the dispersion of vehicular emissions. In urban areas, residents living closer to busy roads with dense traffic are often exposed to vehicular emissions, including nitrogen

oxides and PM, which have significant health consequences. A study by Beckwith et al. [40] identified that areas where vehicles were accelerating or queuing in traffic had significantly higher levels of nitrogen dioxide, putting residents around those areas at increased risk of cardiovascular and chronic diseases [6]. A cohort study conducted in California reported that women residing within 500 m of major roadways experienced significantly higher breast cancer risk, attributed to elevated exposure to NOx [41]. Additional evidence indicates elevated morbidity and mortality among drivers, commuters, and populations residing in close proximity to major roadways. A study by Zhang and Batterman [38] demonstrated that, along arterial roads, incremental increases in traffic volume were associated with marked rises in hospital admissions, emergency department visits, and mortality rates among both roadside and near-road populations. This association is likely mediated by heightened exposure to NOx. Further evidence indicates a strong association between traffic-related air pollution and adverse respiratory outcomes, including increased lung cancer mortality, asthma incidence in both children and adults, and acute lower respiratory infections in children [6].

PM ($PM_{2.5}$) generated from vehicular emissions is small enough to pass into the bloodstream, generate reactive oxygen species, and activate inflammatory mechanisms. This inflammation could exacerbate respiratory conditions such as asthma and chronic obstructive pulmonary disease. $PM_{2.5}$ has been found to accelerate atherosclerotic plaque formation, increasing the risk of cardiovascular disease and stroke [42]. The oxidative stress, inflammation, dysfunction, and vascular damage arising from exposure to $PM_{2.5}$ have been strongly associated with a wide range of adverse health outcomes and premature mortality [43]. Emerging evidence links long-term $PM_{2.5}$ exposure to metabolic disorders and cancers [44]. Evidence indicates that long-term (10-year) cumulative exposure to $PM_{2.5}$ and nitrogen dioxide (NO_2) has been shown to increase risks of primary cancer incidence among older adults in the United States. This emphasizes the significant long-term health risks associated with sustained air pollution exposure from vehicular emissions [24].

Long-term roadside exposure to fine PM ($PM_{2.5)}$ and NOx has also been positively correlated with the progression of coronary artery calcification, a key marker of cardiovascular disease risk [45]. Moreover, sustained exposure to traffic-related pollution, particularly black carbon, has been associated with reduced high-density lipoprotein cholesterol levels, which are independently linked to carotid atherosclerosis and coronary heart disease in multi-ethnic populations [46].

With 81 out of 103 of the most populous cities reporting NO_2 exposures higher than the global average, there is an urgent need for interventions to reduce vehicular emissions [6]. The establishment of low-emission zones – zones that restrict the movement of vehicles emitting high levels of pollutants or charge fees for their entry – has proven to be an effective strategy to reduce vehicular emissions. London's Ultra Low Emission Zone initiative delivered a 36% reduction in NO_2 emissions within the first six months after its launch in 2019 [6]. Furthermore, promoting the transition from internal combustion engine vehicles to electric and hydrogen-powered vehicles has been shown to substantially reduce carbon dioxide and PM emissions over their life cycle [47]. Providing incentives for using electric vehicles and reducing taxes for the production, importation, and supply of these low-emission vehicles could facilitate this transition [6]. While some debates have arisen regarding the source of electricity used to power electric vehicles, the

increasing use of renewable sources – such as solar, wind, and hydro-powered plants – to generate electricity for these vehicles makes them progressively cleaner and more sustainable alternatives to conventional combustion engine vehicles. Lastly, effective air quality monitoring forms the foundation of successful pollution reduction efforts. According to the 2022 State of Global Air Report [6], 40% of countries lack ground-level PM monitors. Without adequate air pollutant monitoring, progress or regression in urban pollution cannot be assessed, nor can pollution patterns be fully understood. Robust monitoring systems enable the tracking of intervention effectiveness and support data-driven policies that promote clean air, reduce population exposure, and improve health outcomes [6].

3.1.3 Decreased physical activity

Crowded urban environments can either facilitate or hinder physical activity depending on design quality. Crowded cities that are poorly planned, with an unregulated density of pedestrians at road intersections, may contribute to pedestrian accidents, which may discourage physical activity in those regions. Conversely, well-planned urban cities with bicycle and running tracks, green spaces, accessible parks, and gyms could promote physical activity. Studies across the United States and Canada found associations between neighborhood walkability and walking [48, 49] Intrinsic factors such as inner satisfaction and enjoyment, and social relatedness can also influence the degree of physical activity [48]. Declining physical activity in crowded areas has been linked to obesity. However, the relationship between city crowding and obesity is not linear but complex, with both protective and harmful effects depending on urban design and population characteristics.

Strategies to increase physical activity in urban areas should focus on creating supportive environments, including the development of safe, well-connected sidewalks, protected bicycle lanes, parks and open green spaces, and traffic measures that encourage walking and cycling as part of daily routines. A longitudinal study using data from Canada's National Population Health Survey that assessed over 2,900 Canadians revealed that exposure to walkable neighborhoods increased physical activity significantly, highlighting how environmental planning can improve physical activity [49]. Economic estimates reveal that every US$1 invested in physical activity results in an estimated net saving in healthcare costs of between US$32 and US$42 per person [50]. The bicycle hiring system, also called the bike-share system, is a public transport service that provides short-term access to bicycles for urban travel. Users can rent bicycles from designated docking stations or via app-based dockless systems and return them at the same or different locations. The bike-share system was found to improve physical fitness and mobility, as well as enhance environmental sustainability in Poland [51]. In the United States, bike-share systems resulted in an annual reduction of 4.7 preventable deaths and US$36 million in health economic impacts [52]. Turning to traffic measures, closing or restricting traffic and vehicular access to a large network of streets on weekends and public holidays may promote physical activity. The Ciclovía Recreativa initiative in Bogotá, Colombia, closed about 100 km of streets to traffic on Sundays and public holidays, resulting in increased physical activity among over 1,000,000 residents [50]. Workplace and school-based initiatives, including active breaks, promoting the use of stairs, and structured physical activity programs, could support regular physical activity in urban regions. Examples of school-based initiatives include British Gas-sponsored

Pools 4 Schools and Swim:ED, which involved the temporary deployment of swimming pools in schools to teach children to swim. These initiatives promoted physical activity among children, potentially contributing to decreased obesity in the future [53, 54]. Promoting community-based programs that provide social support for exercise should also be encouraged.

4. Urban diets

Urban food and nutrition systems are similar in many ways, often characterized by an increase in dietary diversity as populations diversify, promoting diets rich in fat, salt, refined carbohydrates, and reduced fruit and vegetable intakes. This shift results in a massive increase in the number of people who are overweight and obese, which are risk factors for numerous chronic noncommunicable diseases. Although 70% of food produced globally is consumed in urban areas [55], urban settings experience unequal access to safe, nutritious, and affordable food. This results in a dual burden of malnutrition, characterized by the coexistence of undernutrition alongside increasing rates of obesity [30].

The WHO estimates that, in 2022, one in eight people globally were living with obesity, and 2.5 billion people were overweight [56]. The rise in obesity is also witnessed in children, with about 8% of children and adolescents aged 5–19 years in 2022 being obese [56]. Economically, the cost of obesity and overweight is predicted to reach US$3 trillion by 2030 and over US$18 trillion by 2060 [56].

Urban diets are shaped by interacting demand- and supply-side factors. Demand factors refer to characteristics of urban dwellers, including income, educational levels, time constraints, among others, that influence their food choices. On the contrary, supply-side factors refer to food systems and market environments that determine what foods are available, accessible, and promoted to urban dwellers, including marketing and advertising, delivery infrastructure, and pricing, which shape urban diets and customer choices.

As illustrated in **Figure 2**, urban diets are shaped by the interplay of demand-side factors, including income, education, time constraints, housing, and generational preferences, and supply-side factors such as food availability, cost, advertising, and delivery infrastructure. Each of these drivers is explored in detail in the next section.

4.1 Drivers of urban diets

4.1.1 Demand-side factors

Socioeconomic factors. The relationship between income, education, and dietary patterns in urban settings is complex, nonlinear, and multifaceted. While higher incomes and higher levels of education characterize many urban populations, they do not automatically translate into healthy dietary choices. Studies have revealed that rising income is associated with increased consumption of ultra-processed food [57]. Processed food accounts for at least 65% of total food expenditure across low, lower-middle, upper-middle, and upper-income countries [57]. In other settings, such as in Australia, higher incomes are linked with increased consumption of fruits and vegetables [58]. This indicates that other factors besides income, like social and



Figure 2.
Supply- and demand-side factors that influence urban diets.

cultural norms, taste preferences, and nutritional knowledge, could be significant factors influencing food choices in urban regions and not income alone.

Educational attainment plays a crucial role in shaping nutritional knowledge and dietary behaviors in urban populations. Higher educational levels have been consistently associated with improved nutrition literacy, enabling individuals to better understand food labels, interpret nutritional information, and make informed dietary decisions [59]. Individuals with higher educational status demonstrate a better ability to navigate complex urban food environments and resist marketing. They have also been found to be more aware of the health consequences of poor dietary choices, increasing their likelihood of selecting nutrient-dense foods over energy-dense, nutrient-poor alternatives [60].

Housing. Due to a dense population, housing costs in urban areas consume an increasing amount of household budgets, with reports from New York indicating that housing typically takes more than one-third of household income, either toward rental or mortgage payments [30]. This could increase to as much as 75% in cities like London, 62% in Dublin, and reduce to 29% in Geneva [61], potentially reducing available funds for food purchases. This creates a fundamental financial constraint, causing urban dwellers to purchase already processed foods and fast-foods, which are often cheaper than purchasing fresh ingredients for freshly prepared meals. Additionally, smaller living spaces associated with affordable urban housing often result in smaller kitchen sizes, making home food preparation difficult and discouraging [30]. These constraints

create a dual challenge of affordability and feasibility for home cooking, reinforcing the pressure on urban dwellers to consume convenient and ultra-processed foods.

Time constraint. Limited time and motivation to prepare meals are fundamental drivers of urban dietary patterns. Urban life is often characterized by time scarcity, long working hours, and sedentary jobs, resulting in what researchers have described as "time poverty." Studies across urban regions in Africa have found positive associations between reduced time availability and increased consumption of unhealthy street foods, with about one-quarter of urban dwellers in Africa consuming daily meals outside the home, often including ultra-processed foods [57]. Globally, there is a growing reliance on street foods, often high in salt and sugar, as they serve as a daily source of food for an estimated 2.5 billion people [30].

In many urban settings, women often still carry the primary responsibility within households for food preparation. Time spent out of the home through employment and commuting reduces the time available for home-made cooking. However, the relationship between women's employment and household nutrition is complex. While some research has found that as women's economic empowerment advances, there can be a decline in household nutrition quality, other studies have shown positive associations between women's empowerment and household dietary diversity [57].

Generational difference. Generational differences in food preferences and consumption patterns reflect broader processes of social change. This change is driven through multiple channels, including social media, peer networks, educational institutions, and food environment systems. Globalization and the international exposure of urban dwellers often shift their preferences toward dietary diversity and experimentation with new foods, particularly those perceived as modern and international. Younger generations view international fast-food as convenient, modern, and associated with a sense of higher status, often due to marketing and advertising [57]. These factors collectively drive increased consumption of highly processed foods among younger generations, as such dietary choices provide a sense of social belonging and peer acceptance.

The systematic review by Dicken et al. [58] found that age consistently demonstrated an inverse association with ultra-processed food intake, with the younger population consuming more of these products. A study in Australia found that people aged 19–30 years consumed significantly more cakes, pies, and ultra-processed foods than people aged 51–70 years [58]. Similar findings were reported in France, with 18–39-year-olds consuming double the amount of ultra-processed foods compared with adults aged 60 and over [58].

4.1.2 Supply side factors

Distribution of urban food supply. Technological advances in agriculture and food processing in urban areas, alongside the growing ease of global food trade, have resulted in higher volumes and lower prices of processed food [30]. Some urban areas can be characterized as "food deserts," with no or only a few stores that sell healthy food. Others can be described as "food swamps," with many stores of high density that sell cheap, highly processed foods, often high in salt, sugar, and fats [30]. In food swamp urban environments, the high density of fast-food outlets,

aggressive marketing, and convenient access create conditions particularly conducive to the overconsumption of highly processed, nutrient-poor foods.

The vast spread and dominance of supermarkets in urban areas have caused a decline in the use of conventional food markets. While supermarkets may increase the availability and supply of fresh and nutritious foods and reduce food prices, they have been linked to an increasing supply of unhealthy, ultra-processed foods [30]. This massive expansion of national and multinational supermarket chains is often supported by government policies that promote privatization, public infrastructure development, and globalized food distribution [30]. The transformation from traditional markets to modern supermarket chains has mixed implications. These supermarkets make ultra-processed food available in convenient and attractive forms. Several studies find that shopping in supermarkets increases the intake of processed foods, significantly raising the likelihood of overweight and obesity in adults. A national study across over 55,000 households in Brazil found that the purchase of ultra-processed food in supermarkets was 25% higher than at other food stores [62]. Other studies across urban regions in Kenya and Zambia have associated shopping in supermarkets with increased consumption of highly processed foods [57].

The geographic relocation of agricultural businesses to the outskirts of cities can distance fresh food supplies from urban areas. This contributes to longer supply chains and increased transportation costs. Urban planning has historically contributed to this displacement through zoning regulations that segregate land for agricultural use from land for residential and commercial use. Developmental pressures also make urban and peri-urban land increasingly valuable for residential or industrial purposes. This displacement of agricultural land contributes to urban areas becoming increasingly dependent on processed foods that can withstand extended transportation and storage [30].

Cost. Prices of processed unhealthy foods are lower relative to nutritious staple foods. In many urban settings, energy-dense processed foods offer more calories per currency unit than fresh fruits, vegetables, and other nutrient-rich foods. The seasonal supply of fruits and vegetables also affects market prices and access. A study in Belgium found that ultra-processed foods cost less than half of healthy alternatives on a caloric basis [63]. In Brazil, a Household Budget Survey indicated that lower prices of ultra-processed foods (per kg) were associated with higher rates of overweight and obesity, with this relationship being more prominent among populations of lower socioeconomic status [62]. Financial constraints and high food prices have been identified as key barriers to consuming more diverse and healthy diets across urban regions in Africa and other low- and middle-income regions [57].

Strategies such as subsidies for healthy foods and imposing taxes on ultraprocessed food can alter the pricing of food items and may encourage healthier consumption of food. Development in agricultural systems that promote long-term storage of staple foods, fruits, and vegetables ensures their availability across all seasons, potentially improving food options for urban populations.

Advertisement. Extensive marketing represents a powerful factor shaping urban food environments and consumption. Food advertising has evolved, becoming increasingly sophisticated, ubiquitous, and difficult to ignore. Marketing materials that promote the consumption of highly processed food flood traditional media channels alongside digital and social media platforms, driving a growing shift toward unhealthy diets. Adolescents report that their food choices are significantly

influenced by the desire for social acceptance among peers [57]. Social media platforms play a central role in shaping these decisions through advertising exposure, brand familiarity, and product appeal [57]. Social media has also become a key source of nutritional information for mothers, influencing dietary choices for their children [64]. While social media provides easy and convenient access to a wide range of information, the proliferation of unverified and misleading health content on these platforms poses significant public health risks. A systematic review and meta-analysis of randomized trials reported that children aged 2–18 exposed to unhealthy food and beverage marketing had a 10% higher likelihood of choosing the promoted foods or drinks [65].

Marketing strategies attribute fast-food with social status, modernity, convenience, a sense of belonging, a sense of higher status, and trendiness. These aggressive marketing strategies have been adopted worldwide, spreading faster than public health policies and programs can keep up with [30, 57]. The widespread advertisement, appeal, and promotion of sugary foods, fast-foods, and unhealthy diets raise a significant public health threat as they normalize the consumption of unhealthy foods.

Delivery infrastructure. Easy accessibility to fast-food, driven by the rising use of delivery channels, has fundamentally transformed urban food environments. This change was particularly accelerated by digitalization and the COVID-19 pandemic [30]. The growing use of e-commerce food retail channels and online shopping for groceries has transformed how consumers select and buy food, promoting convenient access to ultra-processed food. The widespread access to and use of GPS-enabled mobile phones and navigation systems have increased the convenience of home-delivered food. An international cross-sectional online survey, including over 19,000 people across Australia, Canada, Mexico, and the United Kingdom, revealed that over 58% of respondents utilize online retail and delivery platforms, mostly to purchase food from restaurants, which are often high in sugar, salt, and fat [66].

The interplay between demand-side and supply-side factors creates urban food environments that fundamentally shape dietary patterns and, consequently, population health outcomes. Understanding how urban diets translate into specific health impacts is essential for developing effective policy interventions to promote healthier urban diets and improve public health globally.

4.2 Influence of urban diets on health

4.2.1 Chronic disease

Urban dietary patterns contribute to the prevalence of overweight and obesity. Overweight and obesity are important risk factors for several noncommunicable diseases, including diabetes, heart disease, and cancers. In the United States, the prevalence of obesity has risen dramatically from 15% in the 1980s to over 40% currently [67]. Obesity contributes to chronic disease through different pathophysiological mechanisms. Excess adipose tissue triggers the secretion of pro-inflammatory cytokines, which disrupt metabolic processes and contribute to chronic inflammatory conditions [68]. They also contribute to insulin resistance (a key driver of type 2 diabetes) and accelerate atherosclerosis, increasing cardiovascular disease risk [68]. In the United States, the analysis of the Medical

Expenditure Panel Survey found that obesity increased the probability of hypertension by 35%, hyperlipidemia by 28%, and diabetes by 11% compared to non-obese individuals [67]. A global large-scale retrospective cohort study involving over 120 million electronic health records demonstrated that obesity increases the risk for 24 of 46 investigated chronic inflammatory diseases [69]. Economically, in the United States, over $100 billion annually is allocated to obesity-related healthcare costs, with 61% of type 2 diabetes costs attributable to obesity [67]. These figures underscore the critical importance of obesity prevention and treatment strategies for reducing both chronic disease burden and healthcare expenditures.

4.2.2 Pediatric health

Levels of undernutrition (stunting and wasting) remain high in urban areas in Africa and Asia, affecting about 25% of children in these regions [30]. Overweight children remain more prevalent in urban areas than in rural areas, ranging from around 5% in Africa and Asia to up to 9% in Latin America and the Caribbean [30]. Globally, children's obesity levels continue to rise, with 1 in 10 school-aged children and adolescents being obese, while levels of undernutrition remain stagnant [70]. The increasing coexistence of undernutrition and obesity among children in urban regions has significant health implications on death rates, psychological development, and predisposes them to chronic diseases. WHO has identified that childhood and adolescent obesity is linked with adverse psychosocial consequences and mental health issues. It has also been associated with bullying, stigma, and discrimination, negatively affecting school performance and quality of life [56]. Although there are mixed reports of an association between increased body mass index and mental health across countries, studies conducted in China, South Korea, Asia, and France found a relevant association between obesity and negative body satisfaction, body dissatisfaction, low self-esteem, and anxiety [71]. Childhood obesity has also been linked to chronic diseases, including diabetes, cardiovascular diseases, cancer, and musculoskeletal disorders [72].

4.2.3 Unsafe food and food poisoning

Frequent consumption of already processed, prepared, and packaged food predisposes consumers to food safety issues. The growing consumption of street food, which provides daily meals for an estimated 2.5 billion people globally, emphasizes concerns related to food hygiene and safety [30]. Weak regulation of street and fast-food vendors could promote the consumption of contaminated food, contributing to food-borne diseases. Multiple factors predispose urban populations to food-borne diseases from street food, including unsafe water, poor sanitation and hygiene practices, improper food handling processes, inadequate cooking, and insufficient storage infrastructure [30]. Food-borne diseases like diarrheal diseases and typhoid fever present significant global health risks. WHO estimates that annually, 600,000 million people fall ill and 420,000 die from consuming contaminated food globally, and 30% of all deaths from food-borne diseases occur in children under 5 [73].

Street foods and prepared packaged foods worldwide have been found to contain strains of harmful bacteria, including *Escherichia coli, Listeria monocytogenes*, Salmonella, and Campylobacter species [74, 75]. In 2024, an outbreak of *E. coli* infection affecting over 100 individuals across 14 states in the United States was

linked to freshly served onions used in McDonald's menu items [76]. Similarly, 36 confirmed cases of *E. coli* infection in Wales, United Kingdom, were associated with imported cucumbers used in a fast-food product [77]. Furthermore, the European Union attributed the record-high incidence of Shiga toxin–producing *E. coli* and Listeria infections reported across 30 EU countries in 2023 to increased consumption of ready-to-eat foods [78]. These reports demonstrate the substantial public health burden of foodborne diseases associated with contaminated fast and ready-to-eat foods.

4.3 Strategies to improve urban diets

4.3.1 Targeted school-based education

Evidence from multiple regions demonstrates that comprehensive, multisectoral approaches targeting school children can effectively promote healthier dietary behaviors among children and families. The ACTIVITAL program in urban Ecuador exemplifies a comprehensive school-based approach that combines environmental and educational strategies [79]. Implemented in Cuenca, Ecuador, over three years (2009–2012), this participatory program engaged 10 intervention schools with both classroom-based education and environmental interventions. Classroom interventions focused on using interactive toolkits to teach students about healthy eating and the benefits of physical activity, ensuring age-appropriate engagement with health concepts. Simultaneously, the program employed environmental strategies, including a participatory workshop where parents engaged in discussions with food shop staff about diet and healthy eating. Another environmental strategy was the establishment of walking trails for selected schools. The program led to decreased sugar and processed food intake, as well as reduced waist circumference and blood pressure across all socioeconomic groups [79]. These outcomes underscore the importance of addressing both knowledge gaps and environmental barriers simultaneously. By engaging multiple stakeholders – students, parents, educators, and food vendors – school-based programs can catalyze community-wide shifts toward healthier dietary patterns and more active lifestyles in urban environments.

4.3.2 Marketing restrictions for ultra-processed foods

Restricting the commercialization and marketing of ultra-processed foods in and around schools, television programs, and the public transport system (including buses, subways, and trains) is an effective strategy proven to reduce the exposure to and consumption of unhealthy foods. Restrictions on the marketing of ultra-processed foods and beverages during children's television programming in Chile and the United Kingdom reportedly reduced children's exposure to such advertisements by 35% and 52%, respectively, during the periods covered by the restrictions. Although advertisement restrictions may reduce internal revenue generation for advertising agencies, they significantly reduce healthcare expenditure. Economic models in Australia and the United Kingdom estimate that eliminating all unhealthy food and beverage television advertising during daytime hours could result in a reduction in healthcare expenditure of AUD 78.3 million (approximately US$ 56.5 million) and £7.4 billion (approximately US$ 10 billion), respectively [65].

4.3.3 Improving access to fresh foods

Enhancing access to fresh food markets through improved market infrastructure, optimized mobile distribution, and extended opening hours can increase the consumption of healthy foods and vegetables. In Medellín, Colombia, "Huertas de Abastecimiento" (Supply Gardens) were established, promoting business relationships between fresh food vendors and area farmers to improve the distribution of nutritious food [65]. This approach ensured community access to fresh and nutritious foods. Buenos Aires implemented the "Ferias de Abastecimiento Barrial" (Neighborhood Supply Markets) program, deploying mobile farmers' markets to reach peripheral neighborhoods and remote communities [65]. This initiative provided residents access to fresh, high-quality, natural, and nutritious foods at affordable prices [65]. These Latin American initiatives demonstrate that strengthening direct linkages between urban consumers and local food producers through innovative market infrastructure may effectively improve access to and consumption of nutritious food, all while supporting local agricultural economies.

4.3.4 Disclosure of nutritional content on food products

Regulatory interventions that increase public access to nutritional information, including the disclosure of fat, sugar, and salt content, as well as the use of traffic-light labeling systems, can improve urban dietary behaviors. The 2012 mandatory regulation for fast-food restaurants in New York, USA, requiring them to publish calorie information on food options increased consumer awareness of the energy content of food options and contributed to healthier purchasing decisions [50]. Traffic-light labeling is a front-of-package nutritional labeling system that uses color-coded indicators to communicate the sugar, fat, and/or salt content of processed foods. The system employs three colors: red (indicating high levels of sugar, fat, or salt); yellow (representing medium levels); and green, signifying low levels of these nutrients [80]. This labeling process aims to provide consumers with an accessible and quick method for assessing the healthiness of food products at the point of purchase, thereby facilitating healthier dietary choices. However, research findings regarding the effectiveness of traffic-light labeling have been mixed [81].

Studies from Ecuador and Austria have demonstrated several important effects of traffic-light labeling on consumer behavior and perceptions. In Ecuador, where mandatory traffic-light labeling was implemented in 2014, studies revealed that the system significantly improved consumers' understanding of packaged foods' nutritional profiles. An Ecuadorian study involving over a 1,000 Ecuadorian adults showed strong consumer preferences for healthier products, with consumers willing to pay more for food items with yellow and green labels for fat and sugar content relative to products with the red label [80]. However, many participants in this study reportedly used traffic-light labeling infrequently to make decisions, calling for more educational campaigns on the labeling [80]. Another study in Ecuador identified a downward trend in the purchase of high-sugar carbonated soft drinks and an upward trend in the purchase of low and non-sugar carbonated soft drinks after the introduction of traffic-light labeling for sugar content on these products [82].

Similarly, research conducted in Austria examined the impact of traffic-light labels on consumer expectations and purchase intentions. This research identified that traffic-light labels helped participants more accurately differentiate between the healthiness of products with varying sugar levels [81]. The study revealed that participants reported higher purchase intentions for products low in sugar when traffic-light labels were present. However, participants did not show decreased purchase intentions for products high in sugar [81].

4.3.5 Sugar taxes

Sugar taxes, also known as sugar-sweetened beverage (SSB) taxes, are fiscal policies applied to non-alcoholic beverages containing added sugars. These SSB beverages include carbonated soft drinks, fruit juices and drinks, energy and sports drinks, ready-to-drink tea and coffee, and flavored milk drinks. These taxes are often administered based on the sugar amount per volume, as implemented in the United Kingdom, or as a percentage of a product's volume. Sugar taxes have been found to increase the prices of these beverages, making them less affordable and decreasing consumption. On the other hand, they have served as an additional source of revenue for governments. In the United States, average sugar taxes across seven cities have been reported to generate up to US$133.9 million per city, while similar taxes in Tonga generated up to T$8.4 million in 2017/2018 [70].

Comprehensive evidence across countries globally demonstrates the effectiveness of sugar taxes in reducing consumption and improving dietary outcomes. A systematic review and meta-analysis of the impact of taxes on SSBs across 17 studies found that a 10% average SSB tax resulted in an average 10% decline in the consumption of SSBs across Berkeley, Catalonia, Chile, France, and other settings [83].

Multi-faceted implementations provide compelling real-world evidence. In Mexico, the combination of a social mobilization campaign highlighting the effect of soda on health, linking it to obesity and chronic diseases, and a 10% tax on SSBs resulted in a 10% increase in the price of these beverages and an average 7.6% decrease in their consumption over the first year. Beyond its health impacts, the Mexican sugar tax generated approximately US$1.2 billion in government revenue in its first year of implementation, with no significant negative changes in employment within the beverage industry [83].

In 2018, the United Kingdom implemented a "Soft Drinks Levy" of 18p per liter on soft drinks with 5–8 g of sugar per 100 mL, and 24p per liter for soft drinks with more than 8 g of sugar. This resulted in a decreased average sugar consumption of 5 g per day for children and almost 11 g per day for adults just one year after implementation [84]. An economic-epidemiologic mathematical model, developed using data from the National Bureau of Agricultural Commodity and Food Standards, Thailand, demonstrated that a 20% tax on SSBs can reduce the prevalence of overweight by 1%–3% and obesity by 1%–4% [85]. Children are among the greatest beneficiaries of SSB taxes, with SSB consumption declines in Mexico and Thailand being more pronounced for children [83]. The World Health Organization, drawing on extensive evidence, recommends implementing taxes of at least 20% to effectively change consumer behavior and achieve meaningful health impacts [83].

5. Conclusion

This chapter reveals how urbanization and its features impact health directly and indirectly through climate change. Although the interactions between urban features and health outcomes are often mixed, nonlinear, complex, and sometimes contradictory, several multisectoral factors must be considered as urbanization expands globally. There needs to be increased awareness and public health considerations regarding how urban features continue to shape public health outcomes globally.

Regarding high-rise buildings, their impact on temperature through the UHI effect may increase heat-related health challenges, including heat strokes. Gaseous emissions from daily operations and human activities in these vertical structural edifices contribute to and accelerate climate change. These directly or indirectly affect health by exacerbating chronic diseases, chronic respiratory diseases, and putting residents at increased risk of cardiovascular disorders. The mental health effects of these structures cannot be ignored, as they often lack communal spaces, with residents reporting feelings of isolation. The construction of high-rise buildings demands a more emergency-friendly design that provides alternative routes of escape in emergencies and the use of more eco-friendly, biodegradable materials for climate sustainability.

Both high-rise buildings and crowding in urban cities facilitate the transmission of infectious diseases, as witnessed during the COVID-19 pandemic. It is important that epidemiological considerations are given to the zoning and planning of urban cities to limit the spread of infectious diseases. Additionally, traffic congestion in urban cities contributes significantly to vehicular nitrous oxide and PM emissions. Findings on pollution call for policy interventions and recommendations for siting residential buildings at least 500 m away from roads due to increased exposure to vehicular nitrous oxide emissions. Furthermore, urban cities should be designed to accommodate large numbers of pedestrians, with dedicated pedestrian and bicycle lanes to support safe physical activity.

Urban dietary patterns and food systems are the outcomes of carefully orchestrated and complexly interacting demand and supply factors. While it is no news that urban diets are rich in fat, salt, and sugar, these observations are not a coincidence. Intrinsic demand-side factors like income and education, high housing costs and limited living spaces, time constraints, and a growing younger population influenced by social media and peer pressure play important roles. Supply-side factors like limited distribution of healthy food supply and the almost omnipresent availability of ultra-processed foods, low cost for highly processed foods, aggressive marketing, and ease of access to ultra-processed food contribute to their increased consumption in urban settings. Urban diets high in fat, sugar, and salt contribute to rising burdens of obesity and overweight, chronic diseases, depression in children, and food poisoning from unsafe or unhygienically prepared street food. Improving access to nutritious fresh food, restrictive marketing, targeted educational programs, traffic-light labeling systems, and sugar taxes are proven initiatives that may shift the trajectory of urban diets to more nutritious foods.

These interactions and impacts of urbanization and urban structures are often unpopular. However, to ensure the health and safety of our generation and future generations, even as urbanization continues to expand and global economies prosper, it is important for public health professionals to raise awareness of the

impact of these urban features on health and participate in practicable, evidence-based solutions that address them.

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Conflict of Interest

Author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author details

Olanrewaju Olamide Popoola
Obafemi Awolowo University, Ile-Ife, Nigeria

*Address all correspondence to: popoolalanre8@gmail.com

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Chapter 2

Climate Change and Human Health: A Real Emergency?

Josep M. Ramon-Torrell

Abstract

Chapter objective is to rigorously analyze how climate change affects human health, distinguishing between direct, indirect, and systemic impacts, with an emphasis on vulnerable populations and strategies for mitigation and adaptation. Although there is no clear consensus on the issue, climate change may represent a potential threat to human health in the twenty-first century. This chapter examines, from a technical and multidisciplinary perspective, the mechanisms through which global warming affects health, distinguishing between direct, indirect, and systemic impacts. Among the direct effects, heatwaves stand out, increasing cardiovascular and respiratory mortality, as well as extreme weather events – floods, wildfires, and storms – that cause injuries, infectious diseases, and the deterioration of healthcare infrastructure. Indirect impacts include the geographic expansion of disease-carrying; Air pollution, worsened by climatic phenomena, contributes to chronic respiratory diseases, while forced displacement and loss of livelihoods have significant effects on mental health. The chapter also analyzes how these impacts affect vulnerable populations: children, the elderly, people with chronic illnesses, Indigenous communities, and low-income countries. Epidemiological and climate models are presented, projecting a significant increase in disease burden and mortality associated with climate change between 2030 and 2050. The chapter explores mitigation strategies with co-benefits for health and adaptation measures within the healthcare system, including early warning systems, resilient infrastructure, and professional training. Finally, it addresses governance frameworks and public policies that integrate health and climate, emphasizing the need for urgent and equitable cross-sectoral action.

Keywords: climate change, health impact, direct impact, indirect impact, mitigation strategies

1. Introduction

Despite the controversies it provokes, climate change has become consolidated as one of the principal challenges of the twenty-first century. It represents one of the most significant transformations of the period defined by human influence on the planet's biophysical systems. For decades, it was primarily regarded as an

environmental issue. However, there is now a growing consensus, supported by robust evidence, that its effects extend beyond the ecological domain, constituting a real threat to human health by disrupting, among other aspects, ecological balance [1, 2].

The term "climate change" has been incorporated – albeit sometimes incorrectly – into contemporary discourse, with increasing emphasis on its scientific conceptualization, as well as on the understanding of its causes and consequences. Frequently, the concepts of "climate change" and "global warming" are employed synonymously and interchangeably, even though they do not convey identical meanings (see **Table 1**).

Climate change is defined as a series of statistically demonstrable, long-term, and wide-ranging alterations in the average patterns of the Earth's climate. These include variations in precipitation, sea level, the frequency of extreme events, and other factors beyond the mere increase in temperature [3]. By contrast, global warming refers specifically to the sustained rise in the average temperature of the Earth's surface and oceans [4]. From an academic perspective, the term "climate change" is more accurate in describing the phenomenon, as it encompasses all manifestations of the climate system and more adequately reflects its multidimensional and complex nature.

Scientific knowledge regarding climate change is not recent; rather, it has developed gradually, driven by advances in science and technology that have allowed for a more comprehensive understanding and conceptualization of the phenomenon. As early as 1824, Fourier proposed that the atmosphere functions as a heat trap, a precursor concept to what is now known as the greenhouse effect [5]. In 1859, Tyndall [6] demonstrated that certain gases, including carbon dioxide (CO_2) and water vapor, absorb infrared radiation. Subsequently, the Swedish chemist Svante Arrhenius was the first to calculate that a doubling of atmospheric CO_2 concentrations could increase global temperatures by several degrees [7].

During the first half of the twentieth century, scientific interest in climate remained limited. However, it experienced a strong resurgence after World War II.

Aspect	Climate change	Global warming
Scope	Broad (temperature, precipitation, extreme events, sea level)	Specific (global average surface temperature)
Causes	Natural and anthropogenic (human-driven)	Primarily anthropogenic
Timeframe	Long-term (decades to millennia)	Since the industrial era (approximately 1850)
Geographic dimension	Global and regional	Global (surface temperature average)
Use in media	More recent; used by the IPCC, UNFCCC, and scientific institutions	Older; popularized in the 1980s
Public perception	More neutral or technical	More alarmist or focused on warming

Table 1.
Comparison between climate change and global warming.

In 1958, Charles David Keeling initiated the systematic measurement of atmospheric CO_2 concentrations at the Mauna Loa Observatory (Hawaii), resulting in the renowned "Keeling Curve," which demonstrated a steady increase in this gas. Concurrently, Gilbert Plass and other scientists developed more sophisticated models that confirmed the role of CO_2. In 1972, the Club of Rome report *The Limits to Growth* warned of the environmental consequences of uncontrolled economic expansion, including climate change [8].

During the 1980s, climate change emerged as both a scientific and political concern at the global level. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established with the mandate to systematically assess available scientific information on climate change and its potential impacts. The IPCC's First Assessment Report, published in 1990, concluded that anthropogenic greenhouse gas (GHG) emissions were rising and were likely to exert a significant influence on the global climate. This report played a pivotal role in the adoption of the United Nations Framework Convention on Climate Change in 1992. Throughout that decade, climate models became increasingly sophisticated, incorporating components such as oceans, cloud dynamics, and feedback mechanisms. Moreover, more detailed emissions scenarios were developed, and the capacity to attribute climate phenomena to anthropogenic causes was considerably enhanced.

Starting in the year 2000, scientific knowledge on climate change became consolidated, accompanied by a strengthening of international actions to address it. The successive IPCC reports have contributed to reinforcing the scientific consensus on the causes and consequences of climate change. The IPCC Fourth Assessment Report, published in 2007, stated with 90% certainty that most of the warming observed since the mid-twentieth century was attributable to human activities. In parallel, key international agreements were signed, such as the Kyoto Protocol (1997) and the Paris Agreement (2015), both of which explicitly recognize the scientific basis of climate change and establish concrete commitments for emission reduction. Advances in satellite observation, paleoclimatology, and climate modeling have enabled the reconstruction of climate over the past millennia and the projection of future scenarios with greater accuracy. Furthermore, the integration of disciplines such as economics, public health, and ecology has given rise to innovative approaches such as "planetary health" and "climate justice," which address climate change from alternative perspectives [9].

This chapter will explore the different strands of scientific evidence regarding how climate change affects human health, with particular emphasis on vulnerable groups and potential mitigation strategies. Although the chapter does not aim to provide a systematic review, the literature was examined concerning the existence of associations between climate change and the risk of various diseases. The search strategy was based on identifying relevant articles on the subject through Google Scholar and PubMed databases. The studies included were prioritized based on their impact and publication in peer-reviewed journals in English.

2. Scientific hypotheses on the causes of climate change

As new knowledge has accumulated, several hypotheses have emerged with the aim of explaining, from a scientific perspective, the phenomenon of climate change.

These hypotheses can be broadly categorized into two groups: natural-origin hypotheses and anthropogenic-origin hypotheses.

Natural hypotheses include factors such as variability in solar activity [10], Milankovitch astronomical cycles [11], volcanic activity [12], and oceanic phenomena such as El Niño [13]. These theories have significantly contributed to the understanding of the dynamics of the global climate system. However, empirical evidence accumulated since the mid-twentieth century indicates that none of these mechanisms – whether individually or in combination – are sufficient to account for the observed rise in global temperatures without considering the impact of anthropogenic GHG emissions.

For this reason, scientific attention has focused on anthropogenic hypotheses, which attribute climate change to human activities, particularly the massive emission of GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases originate mainly from fossil fuel combustion, intensive agriculture, and industrial processes. Unlike natural factors, this phenomenon is a direct consequence of human action and has led to a marked increase in the concentration of GHGs in the atmosphere.

The greenhouse effect is a fundamental physical-climatic process that makes habitable conditions on Earth possible. It is based on the ability of certain atmospheric gases to absorb and reemit infrared radiation emitted by the Earth's surface, thereby contributing to the regulation of the planet's energy balance. Nevertheless, this balance has been disrupted by the intensification of anthropogenic emissions.

2.1 Fundamentals of the greenhouse effect

The Earth's climate system is governed by the laws of thermodynamics, electromagnetic radiation, and energy balance. The Earth receives solar energy primarily in the form of shortwave radiation (0.3–2.5 μm), which passes relatively easily through the atmosphere and heats the Earth's surface. The surface, in turn, reemits energy in the infrared range (4–100 μm) and interacts with certain atmospheric gases.

Gases composed of three or more atoms (such as CO_2, CH_4, N_2O, and water vapor) possess the capacity to absorb infrared energy. This phenomenon was described spectroscopically by Tyndall in the nineteenth century and later quantified through absorption spectra. The omnidirectional reemission of this energy by these gases generates an additional warming effect on the Earth's surface, raising the global mean temperature from –18°C (in the absence of an atmosphere) to approximately 15°C [14].

As noted above, the principal GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3), and water vapor (H_2O). Although the latter is not directly regulated by human emissions, it acts as an amplifier of the greenhouse effect due to positive feedback mechanisms. **Table 2** presents the origin and main characteristics of the gases involved in the greenhouse effect:

- **CO_2**: Responsible for approximately 76% of global GHG emissions. Its atmospheric lifetime exceeds 100 years, and its absorption capacity is concentrated in the 13–17 μm bands [15].

Mechanism type	Specific pathways	Health outcomes
Direct mechanisms	Extreme heat Natural disasters (floods, storms, wildfires) Sea-level rise	Heatstroke, dehydration;Trauma, drowning, burns; injuries, mental health disorders Global mortality Cardiovascular disease
Indirect mechanisms	Altered vector/pathogen ecology Water and food insecurity Air quality degradation	Malaria, dengue, Zika Diarrheal diseases, undernutrition Asthma, cardiovascular disease
Systemic mechanisms	Economic disruption Displacement and migration Health system overload Social instability	Mental illness, PTSD Increased poverty and inequity Reduced health service access Violence

Table 2.
Climate change and human health: Mechanisms of impact.

- **CH_4**: Possesses a global warming potential (GWP) 84–86 times greater than CO_2 over a 20-year period. It originates primarily from livestock farming, rice cultivation, and organic waste [16].

- **N_2O**: A potent gas in the 7.8 μm range, with a GWP roughly 265 times greater than CO_2 and an atmospheric lifetime of about 114 years [17].

Since the Industrial Revolution, atmospheric CO_2 concentrations have risen from approximately 280 ppm to more than 420 ppm [18]. This increase has been confirmed through isotopic analysis of carbon (reduction of isotope ^{13}C) and by the decrease in atmospheric O_2, consistent with fossil carbon combustion [19]. The intensification of the greenhouse effect has triggered multiple climatic impacts, including sea-level rise, glacier loss, ocean acidification, extreme weather events, and alterations in the biogeographic distribution of species [20]. Understanding the greenhouse effect is crucial for establishing CO_2 thresholds and defining mitigation policies. The Paris Agreement is based on limiting warming to 1.5°C or 2°C through the reduction of GHG emissions. Integrated assessment models (IAMs) build on the principles of the greenhouse effect to project future climate scenarios as well as inform decisions regarding energy, transportation, and land use [17].

The greenhouse effect is a proven physical phenomenon, measured and quantified through multiple independent methods. Its intensification due to human activities constitutes the foundation of modern climate change. The spectroscopic properties of GHGs, historical records, and simulation models converge to validate this mechanism. A thorough understanding of it is fundamental to designing scientific, technological, and policy responses to the climate crisis of the twenty-first century.

3. Climate change and human health

As discussed in previous sections, climate change is a real phenomenon, supported by a robust scientific basis, whose implications profoundly affect both ecosystems and human health. The sustained increase in global mean temperature,

the intensification of extreme weather events, and the alteration of precipitation patterns are reshaping the environmental and social determinants of health on an unprecedented scale [2].

The mechanisms through which climate change affects populations can be classified into direct and indirect health impacts (see **Table 2**).

Among the most evident direct effects are heat waves, which increase cardiovascular and respiratory mortality, particularly in vulnerable populations [21]. Likewise, extreme climatic events – such as floods, droughts, and wildfires – cause physical injuries, outbreaks of infectious diseases, and deterioration of health infrastructure [21].

At an indirect level, climate change promotes the geographic expansion of disease-transmitting vectors such as dengue, malaria, and other pathogens [22]. It also compromises food security [23] and exacerbates air pollution, with consequences for respiratory and mental health [24].

It is also important to consider systemic impacts, such as the collapse of health systems during extreme events, as well as the inequalities in impacts among different vulnerable populations.

This environmental shift, which affects population health through diverse mechanisms, raises several key questions: What health effects are already occurring? Have they all been identified? What are the mechanisms through which health is affected? When will these effects manifest (latency)?

The body of scientific evidence accumulated in recent years has enabled the modeling and projection of the impacts of climate change on health and healthcare systems, estimating a significant increase in disease burden and mortality. In light of these projections, public health faces the dual challenge of mitigating the effects of climate change and adapting health systems to adequately respond to its consequences.

3.1 Direct impacts

Direct impacts include physiological effects arising from exposure to extreme temperatures and severe climatic events. The latter encompasses a wide range of natural disasters, such as floods, wildfires, droughts, and others. However, despite not being as visibly destructive as other extreme events, heat waves exert a profound impact on population health.

The rise in temperature and the occurrence of extreme heat waves are the most extensively studied phenomena in relation to their impact on human health [25, 26]. Instrumental measurement of temperature began in the seventeenth century, but homogeneous and comparable series did not appear until the mid-nineteenth century. Records reveal a clear pattern: the global mean temperature has risen by approximately 1.1°C from the pre-industrial era (1850–1900) to the present [3] (see **Figure 1**), with a marked upward trend since the mid-twentieth century. Taking the period 1951–1980 as a reference (see **Figure 1**), from 1975 onward, a sustained and accelerated increase in temperatures can be observed, with anomalies since 2000 being notably positive.

Over time, populations adapt to the local climate through both cultural and technological responses; however, when extreme events occur, these adaptive mechanisms may be overwhelmed. To understand how these phenomena affect the human body, it is necessary to analyze the mechanisms of thermal regulation. The

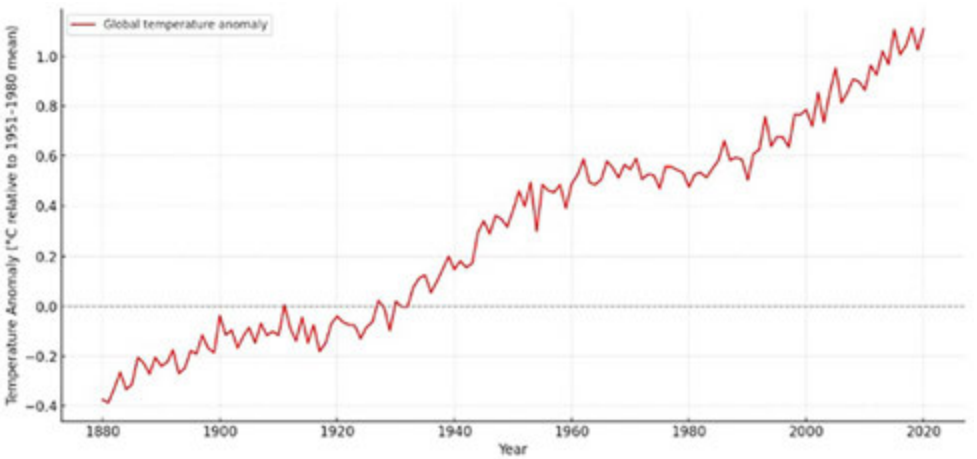


Figure 1.
Historical evolution of global temperature (1880–2020).

human organism maintains a relatively constant internal temperature (~36.5°C–37.5° C) through a complex thermoregulatory system that involves conductive mechanisms (conduction, convection, radiation, evaporation) as well as central control through the hypothalamus [27]. When ambient temperatures exceed certain thresholds, these mechanisms become overloaded. Heat stress occurs when heat gain (internal + environmental) surpasses the body's ability to dissipate it [27]. Under conditions of high humidity, evaporation – the primary avenue of heat loss – is significantly reduced, thereby increasing the risk of hyperthermia.

Chronic heat stress is defined as prolonged and repeated exposure to hot (or, less frequently, cold) environmental conditions that exceed the body's capacity to maintain thermal homeostasis without adverse consequences. Unlike heatstroke or heat exhaustion, which are acute episodes, chronic heat stress develops over days, weeks, or even years, generating incomplete and ineffective adaptations that have a significant impact on health.

Data analyses showed that mortality associated with heat was higher in urban areas affected by the heat island effect, with high population density and reduced access to healthcare services [28]. In addition to mortality, morbidity attributable to heat also includes increases in hospital admissions for asthma exacerbations, chronic obstructive pulmonary disease (COPD), and cardiovascular disease, among others.

The dose–response curves between temperature and mortality generally display a "U" or "J" shape (see **Figure 2**), indicating that both very low and very high temperatures increase risk. The threshold varies depending on latitude and population acclimatization, but in many European cities, the inflection point lies between 25°C and 30°C. As noted, this threshold also depends on the socioeconomic characteristics of the area [29]. **Table 3** presents the effects of heat waves and extreme cold events on different physiological systems.

A number of studies have quantified the impact of heat waves. For instance, it is estimated that more than 70,000 deaths were attributable to the European heat wave of August 2003, according to data from 12 countries. The majority of these deaths were due to cerebrovascular accidents, cardiac failure, renal failure, and overall mortality in vulnerable populations. Subsequent analyses indicated that mortality

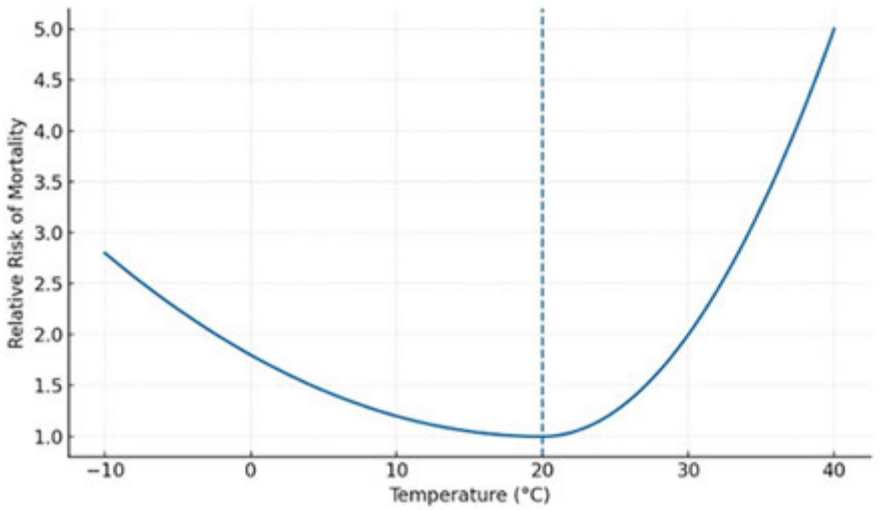


Figure 2.
J-shaped temperature–mortality dose–response.

Clinical category	Extreme cold (direct effects)	Heat waves (direct effects)
Thermoregulation	Hypothermia (mild, moderate, severe); shivering; altered consciousness	Classic or exertional heat stroke; malignant hyperthermia; failure of heat dissipation
Cardiovascular	Peripheral vasoconstriction; risk of hypothermia-induced arrhythmias	Peripheral vasodilation;hypotension, tachycardia, syncope; arrhythmias associated with hyperthermia
Neurological/CNS	Confusion, drowsiness, lethargy, and coma due to hypothermia	Altered mental status (delirium, seizures, coma in heat stroke)
Musculoskeletal	Cold-induced contractures; muscle rigidity; rhabdomyolysis in severe hypothermia	Heat cramps; physical exhaustion; rhabdomyolysis associated with heat stroke
Renal	Reduced renal perfusion in prolonged hypothermia	Severe dehydration → acute kidney injury (AKI)
Metabolic	Hypoglycemia (↑ energy expenditure in hypothermia); metabolic acidosis in severe cases	Dehydration, electrolyte imbalance (hyponatremia, hypokalemia), and lactic acidosis
Other systemic effects	Coagulation disorders in severe hypothermia	Multi-organ failure in heat stroke

Gasparrini et al. [23].

Table 3.
Comparative direct health effects of extreme cold versus heat wave.

was highest in urban areas with heat island effects, high population density, and limited access to healthcare services [22]. Beyond mortality, heat waves also cause increased morbidity, with higher rates of hospitalization for asthma exacerbations, COPD, and cardiovascular conditions, among others [28].

Dose–response curves between temperature and mortality typically take a "U" or "J" shape, indicating elevated risk at both very low and very high temperatures (see **Figure 2**). The risk threshold varies with latitude and the degree of population acclimatization, but in many European cities, the inflection point lies between 25°C and 30°C. This threshold also depends on the socioeconomic characteristics of the area [29].

Table 4 provides a summary of the major European heat waves between 2000 and 2024, highlighting considerable variability in attributable mortality across countries. Since 2003, other heat waves have had a substantial impact, although mortality figures have generally been lower due to improvements in healthcare preparedness, early warning systems, and public awareness campaigns.

For example, in 2019, a series of late June and July heat waves resulted in excess mortality in France (1,435 deaths), Belgium (716), the Netherlands (400), and England (~900), demonstrating that populations in northern and central Europe are also vulnerable [30, 32].

The years 2022 and 2023 registered two of the hottest summers in Europe, with unprecedented temperature anomalies. According to published estimates, heat-related deaths in 2022 were particularly high: Italy (18,010), Spain (11,324), Germany (8,173), and France (4,807) [33, 34]. In 2023, mortality remained elevated, with Italy (12,743), Spain (8,352), Germany (6,376), and the United Kingdom (1,851) experiencing a significant burden of deaths attributable to this heat wave.

Year	Heatwave period	Country	Attributed deaths
2003	Summer 2003	France	14,802
2003	Summer 2003	Italy	~20,000
2003	Summer 2003	Spain	6,595–8,648
2003	Summer 2003	Germany	~9,500
2003	Summer 2003	Portugal	1,953
2003	Summer 2003	Netherlands	1,400–2,200
2019	Late June & July 2019	Belgium	716
2019	Late June & July 2019	France	1,435
2019	Late June & July 2019	Netherlands	400
2019	Late June & July 2019	United Kingdom (England)	900
2022	May–Sept 2022	Italy	18,010
2022	May–Sept 2022	Spain	11,324
2022	May–Sept 2022	Germany	8,173
2022	May–Sept 2022	France	4,807
2023	May–Oct 2023	Italy	12,743
2023	May–Oct 2023	Spain	8,352
2023	May–Oct 2023	Germany	6,376
2023	May–Oct 2023	United Kingdom	1,851

Table 4.
Heatwave events and attributed mortality in Europe (2000–2024).

Overall, the data reveal a growing public health burden associated with recurrent heat waves in Europe. This phenomenon reflects both the intensification of extreme heat events due to climate change and the persistent vulnerability of populations, particularly older adults and individuals with chronic illnesses. Differences between countries can be explained by variability in climatic exposure, demographic profiles, the resilience of healthcare systems, and the effectiveness of adaptation measures.

Extreme cold waves constitute a meteorological phenomenon with significant repercussions for human health, which has historically received less attention than heat waves. Mortality attributable to episodes of extreme cold generally extends over longer periods than heat-related mortality, as the effects can accumulate during weeks of persistently low temperatures [35]. Multicenter studies in Europe have demonstrated that cold-related mortality exceeds that of heat in many contexts, with particularly notable impacts in southern and eastern regions of Europe, where population adaptation to low temperatures is considerably lower [23, 25].

Most of the morbidity and mortality burden associated with extreme cold is due to the decompensation of pre-existing cardiovascular and respiratory diseases, with significant increases in hospitalizations for pneumonia, influenza, and other upper respiratory tract infections. This generates substantial strain on healthcare systems.

The impact is not limited to the clinical sphere but also entails social and economic consequences. Vulnerable populations, such as those experiencing energy poverty, elderly individuals living alone, and homeless persons, face a disproportionately high risk. Inadequate heating, poorly insulated housing, and limited access to medical services exacerbate the burden of extreme cold. In this regard, the literature emphasizes that winter mortality not only depends on climatic severity but also on social determinants and housing conditions.

In the context of climate change, although global warming has reduced the frequency of severe cold episodes in many regions, climatic variability and phenomena such as polar vortex instability continue to trigger extreme cold waves with devastating effects [36]. Such events have been recently documented in Europe and North America, demonstrating that health risks persist despite the overall rise in mean global temperatures.

The impact of extreme cold events is summarized in **Table 5**. Despite widespread perceptions to the contrary, at the global level, exposure to extreme cold is estimated to cause more deaths than heat. A multicenter study analyzing more than 74 million deaths across 13 countries attributed 7.3% of all-cause mortality to cold, compared to 0.4% caused by heat waves [23, 25]. Furthermore, these extreme temperatures increase the risk of hospitalization for cardiovascular diseases. A study conducted in Sweden found that a 10°C decrease in daily mean temperature was associated with a 7% increase in acute myocardial infarction among older adults [37]. Similarly, in the United Kingdom, during the winter of 2017–2018, there was an excess of approximately 50 daily deaths over several weeks, accompanied by an increase in hospitalizations for pneumonia and seasonal influenza [38].

In the European context, analyses from the PHEWE project (15 cities, 1990–2000) demonstrated that each 1°C decrease below the optimal temperature was associated with a 1.35% increase in all-cause mortality [40]. Historical examples also highlight this risk, such as the cold wave that struck Eastern and Central Europe in January 2012, when

Year	Country/Region	Event description	Estimated attributable mortality	Reference
2001	Eastern Europe (Poland, Russia)	Severe cold spell with temperatures below −30°C	Over 300 deaths, mainly among the homeless and elderly	[35]
2005–2006	Central and Eastern Europe	Prolonged winter cold with snowstorms	~200 deaths across Eastern Europe	[37]
2010	Northern and Western Europe (United Kingdom, France, Germany)	"Big Freeze": prolonged snow and temperatures down to −20°C	~25,000 excess winter deaths in the United Kingdom	[38]
2012	Central and Eastern Europe (Ukraine, Poland, Romania, Balkans)	Arctic outbreak, temperatures down to −35°C	>650 deaths across the region	[39]
2017–2018	Western Europe (United Kingdom, Ireland, France)	"Beast from the East": heavy snow and subzero temperatures	~3,000 excess deaths in the United Kingdom	[40]
2021	Central & Eastern Europe	Severe cold linked to polar vortex instability	Dozens of deaths, mainly in Poland and the Czech Republic	[39]

Table 5.
Major extreme cold events in Europe (2000–2024) and associated mortality.

temperatures reached as low as −35 °C and nearly 700 deaths were reported in countries such as Poland, Ukraine, and Romania. Most of these deaths were due to hypothermia and cardiovascular complications [37].

In conclusion, extreme cold waves represent a significant challenge for public health. Their impact goes beyond increases in cardiovascular and respiratory mortality, extending into the social sphere, particularly in contexts of energy poverty and socioeconomic vulnerability. Although the frequency of such events may decrease in future climate change scenarios, the health risk will persist. This underscores the need to implement specific strategies for prevention, adaptation, and protection targeting the most vulnerable populations.

3.2 Indirect impacts

Climate change will not only affect health through its direct effects – such as heat waves and extreme weather events – but also through indirect effects that operate via complex environmental, social, and ecological interactions. These indirect mechanisms create conditions that foster the emergence or exacerbation of diseases by altering social and environmental determinants of health [41, 42]. They amplify the burden of disease and exacerbate preexisting health inequities.

The main indirect mechanisms include:

(1) **Food insecurity and malnutrition:** Prolonged droughts, shifts in precipitation patterns, and extreme events affect agricultural productivity and food availability. This increases undernutrition, particularly in vulnerable populations, and may lead to nutritional deficiencies.

(2) **Deterioration of water quality and the spread of waterborne diseases:** Increased heavy rainfall, flooding, and the salinization of coastal aquifers compromise potable water sources, facilitating the transmission of cholera, diarrhea, and other enteric infections.

(3) **Population displacement and social conflicts:** Ecosystem degradation, loss of livelihoods, and the increasing frequency of natural disasters generate forced migration. These situations heighten exposure to overcrowded conditions, psychological stress, violence, and limited access to healthcare services.

(4) **Changes in vector distribution:** Shifts in temperature, humidity, and rainfall patterns influence the ecology of mosquitoes, ticks, and other vectors, expanding the geographic range of vector-borne diseases (VBDs).

These mechanisms do not operate in isolation but rather in synergy, creating a web of complex risks that deepen social and health inequities.

One of the most studied mechanisms with potentially significant impacts on population health is the geographic and seasonal expansion of vectors transmitting infectious diseases. Regions historically free of diseases such as dengue, West Nile virus, and malaria are now reporting locally acquired cases [43]. Factors such as rising temperatures, variability in humidity, and changes in rainfall patterns directly influence the biology, distribution, and transmission capacity of mosquitoes, ticks, and other vectors.

Climate has a direct impact on the dynamics of a subset of infectious diseases, including VBDs, some waterborne diseases such as cholera, and other pathogens transmitted through soil and food. Infectious VBDs are primarily transmitted by arthropod vectors, which are particularly sensitive to climate change for several reasons. Arthropods are ectothermic, with their internal temperature regulated by external environmental conditions [44]. Their larval development stage generally requires the presence of water bodies and/or specific humidity levels. Vector biting rates tend to increase with temperature up to an upper threshold, beyond which they decline. The development and replication of vector-transmitted pathogens (the extrinsic incubation period, EIP) or in the environment also occur more rapidly at higher temperatures. Additionally, the development and survival of vectors are significantly influenced by seasonal conditions.

Many transmission-related traits in the mosquito life cycle (biting rate, adult lifespan, population size, and distribution) and pathogen life cycle (extrinsic incubation rate) are temperature-sensitive, while oviposition patterns depend on water availability. Consequently, the geographic range of dengue, malaria, and other VBDs is shaped by the local climate, and there is substantial research dedicated to understanding how these ranges may evolve under climate change [45–47]. For certain VBDs, such as Zika virus disease, climate change may lead to range expansion. For others, such as malaria, it may shift infection zones toward higher latitudes. **Table 6** highlights the ways in which different dimensions of climate change shape the ecology and epidemiology of infectious diseases. Rising temperatures accelerate parasite and virus development in vectors, shortening transmission cycles and facilitating spread into previously unaffected regions. Altered precipitation and droughts create favorable breeding habitats for mosquitoes, intensifying arboviral diseases in both rural and urban settings.

Climate change factor	Mechanism of impact on disease ecology	Infectious diseases most affected	Geographic trends observed
Rising temperatures	Faster pathogen replication in vectors; extended breeding season	Malaria, dengue, chikungunya, Zika	Expansion to higher altitudes (East Africa, Andes) and temperate zones
Altered precipitation patterns	Standing water increases mosquito habitats	Dengue, West Nile virus	Urban outbreaks in Asia and Latin America
Extreme weather events	Flooding disrupts sanitation and facilitates water-vector contact	Leptospirosis, cholera, malaria	Increased incidence after cyclones and monsoons in South Asia
Warmer winters	Higher tick survival and extended activity period	Lyme disease, tick-borne encephalitis	Northward expansion in Europe and North America
Droughts	Reduced water access leads to unsafe storage practices	Dengue, chikungunya (via Aedes breeding)	Intensified risk in arid and peri-urban areas

Table 6.
Climate change drivers and associated vector-borne or infectious diseases.

Meanwhile, warmer winters enhance tick survival, shifting Lyme disease risk toward northern latitudes. Extreme weather events, by damaging sanitation systems, further elevate the risk of water-related infections.

Another significant indirect impact is the deterioration of air quality, which increases exacerbations of respiratory and cardiovascular diseases. Wildfires and other climate-related factors raise the concentration of airborne particulate matter, with profound consequences for respiratory and cardiovascular health.

3.3 Systemic impact

The impact of climate change is not a linear phenomenon but rather one that arises from a web of interdependent risks simultaneously affecting human health, food security, the global economy, geopolitics, and natural ecosystems. It does not generate isolated environmental impacts alone but produces systemic, interconnected, and cumulative effects that influence society as a whole, ecosystems, and the global economy. It is important to explicitly distinguish between physiological risks (direct impacts, as discussed earlier), environmentally mediated exposures (indirect impacts), and broader systemic effects, which are more complex to assess.

Among these systemic effects, one may include, first, the impacts on natural systems, such as alterations in the hydrological cycle: intensification of droughts, torrential rainfall, and flooding; sea-level rise due to glacial melt and thermal expansion of seawater; and biodiversity and ecosystem loss, including habitat shifts, species extinction, and coral reef degradation.

Additionally, socio-economic and security-related impacts must be considered, such as:

- Destruction of infrastructure: damages caused by floods, storms, and hurricanes.

- Climate-related migration: forced displacement due to desertification, water scarcity, or coastal flooding.
- Decline in labor productivity: particularly in agricultural and industrial sectors exposed to extreme heat.
- Increase in poverty and inequalities: vulnerable communities are more severely affected and possess lower adaptive capacity.
- Social and geopolitical conflicts: competition over resources such as water and food may exacerbate international tensions.
- Higher healthcare costs: increased pressure on health systems due to climate-related morbidity.
- Disruptions to trade and supply chains: interruptions caused by extreme weather events and reduced resource availability.
- Risks to energy security: reduced water availability for cooling nuclear or hydroelectric plants and impacts on power grids due to extreme heat.
- Large-scale wildfires: destruction of forests, carbon release, and aggravation of global warming.

Finally, at the psychosocial level, climate change is associated with a rise in mental health disorders such as anxiety, depression, and post-traumatic stress, particularly in populations affected by natural disasters, forced migration, or loss of livelihoods. The concept of "eco-anxiety" has gained prominence in recent literature, describing chronic emotional distress linked to the perception of an unsolvable global environmental crisis. Eco-anxiety is defined as a chronic fear of environmental doom and distress related to climate change and ecological crises. It is not classified as a mental disorder but rather as an adaptive emotional response to perceived environmental threats and uncertainty about the future [48]. Eco-anxiety manifests as persistent worry, sadness, guilt, or helplessness regarding climate change and its consequences. It may involve intrusive thoughts, sleep disturbances, and impaired concentration, particularly among younger populations, and is shaped by social context. Media exposure to environmental disasters, governmental inaction, and intergenerational debates over responsibility amplify feelings of despair and lack of control.

4. Vulnerable populations

According to the IPCC, climate vulnerability is defined as the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extreme events [2]. This vulnerability depends on three components: exposure, sensitivity, and adaptive capacity. Vulnerable populations are those characterized by high levels of exposure and sensitivity, combined with low adaptive capacity.

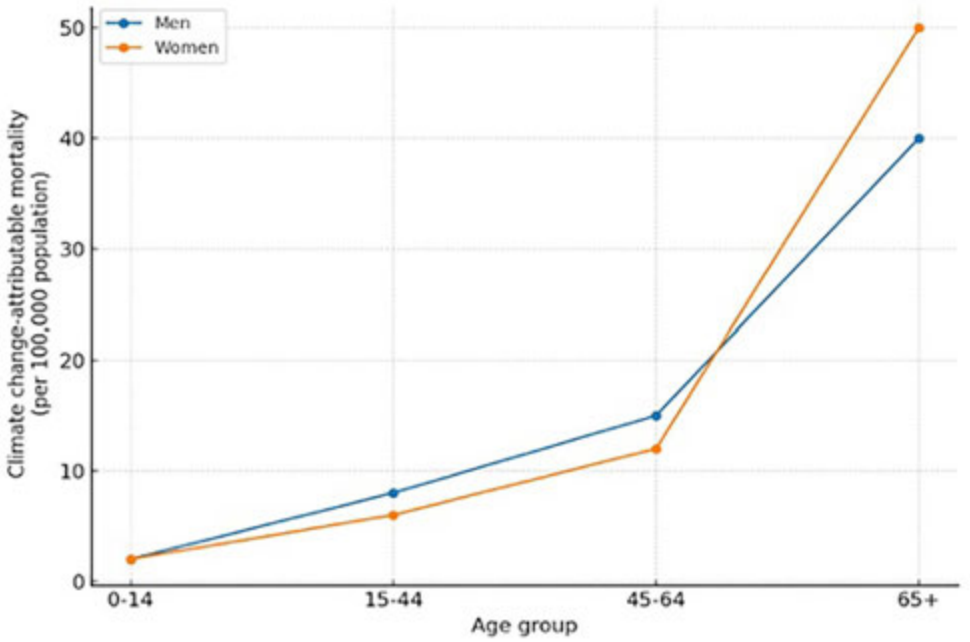


Figure 3.
Climate change-attributable mortality by gender and age.

The health impacts of climate change are not distributed equitably across populations. Significant inequalities exist in terms of exposure, sensitivity to a given exposure, adaptive capacity, and access to healthcare services. Vulnerability does not depend solely on exposure to extreme weather events but is also shaped by social, economic, cultural, and political factors that condition adaptive capacity.

Several groups have been identified as particularly vulnerable:

- **Older adults:** They are more susceptible to heat-related illnesses, such as heatstroke and dehydration, and have reduced mobility to escape extreme events. **Figure 3** illustrates age-specific mortality rates, showing higher mortality among older adults – particularly women – while men tend to experience higher mortality linked to occupational exposures [1].

- **Children:** Their developing immune systems make them more prone to waterborne diseases and VBDs, and they suffer deeper psychological impacts from natural disasters. Infants and young children also have limited thermoregulation capacity and face higher risks of dehydration compared to adults. However, time-series analyses have not shown excess infant mortality during heat waves, with the exception of the 1981 and 1991 heat waves in Portugal [49, 50].

- **Women:** Women are among the groups most vulnerable to the effects of climate change due to biological, social, and economic factors that increase their exposure and reduce their adaptive capacity. In many regions, they play a central role in water management, food production, and family care. When droughts, floods, or heat waves impact natural resources, the burden of work

and food insecurity falls disproportionately on women, especially in rural and low-income communities. Pregnant and breastfeeding women also face greater physiological vulnerability to extreme heat, pollution, and malnutrition.

- **Indigenous peoples and low-income countries:** The loss of territories and natural resources directly affects their livelihoods, culture, and health. Indigenous, rural, and coastal communities, along with low-income countries, face heightened risks due to insufficient health infrastructure and limited institutional capacity to implement adaptation measures. These inequalities have given rise to the concept of "climate injustice." Climate injustice refers to the unequal distribution of the impacts, responsibilities, and benefits associated with climate change across social groups, regions, and generations. This concept recognizes that those who contribute least to GHG emissions are often the most affected by their consequences, while those historically responsible for higher emissions tend to possess greater capacities for adaptation and mitigation [51, 52].

- **Persons with disabilities and chronic diseases:** Physical and social barriers restrict their access to shelters, healthcare, and early warning systems. Chronic diseases – including cardiovascular, chronic respiratory, metabolic, and renal conditions – represent the leading burden of morbidity and mortality associated with climate change, which exacerbates this burden through direct and indirect mechanisms that increase vulnerability. Among the most studied phenomena are heat waves, which, as discussed previously, are linked to significant increases in morbidity and mortality among individuals with cardiovascular and respiratory diseases. However, the vulnerability of patients with chronic conditions extends beyond temperature, encompassing other factors such as air pollution, changes in food and water quality and availability, shifts in vector distribution, and psychosocial impacts related to displacement and economic insecurity [23]. Particularly high-risk groups include older adults in hospitals or nursing homes, individuals living in poverty or social isolation, and those with mental illnesses. Patients with dementia, psychotic disorders, depression, and substance use disorders are also vulnerable to both the direct and indirect consequences of climate change.

- **Migrants and displaced populations:** They often lack legal protection, access to basic services, and support networks, which exacerbates their exposure to climate risks. In developing regions, climate-related disasters may trigger large-scale displacements, frequently toward areas ill-prepared to receive refugees, who are then confronted with undernutrition and psychological stress. Displaced populations commonly face violence, sexual abuse, and mental illness. Increasing – though still inconclusive – evidence links climate change with violence, ranging from self-inflicted and interpersonal harm to armed conflict. A 2013 meta-analysis found that each standard deviation increase in rainfall or temperature rise was associated with an average 14% increase in the likelihood of intergroup conflict [28].

5. Mitigation and adaptation strategies

The growing body of evidence on the processes driving climate change has, in recent years, led to increasing interest in its impact on population health and the mechanisms through which it exerts this impact (see **Figure 4**) [53]. These effects are modulated by various factors, including socioeconomic status and the extent to which adaptation measures are implemented. Most epidemiological studies have evaluated the impact of individual factors in isolation, although these effects interact with demographic changes, urbanization, land-use changes, and other processes [53].

Current policies for managing climate-sensitive health impacts do not sufficiently account for the dimensions of climate change. As a result, these policies must be modified to remain effective in the coming years [42]. In the context of climate change and its relationship with population health, mitigation strategies refer to the set of policies, interventions, and actions aimed at reducing or preventing GHG emissions, promoting energy efficiency, and expanding the use of renewable energy sources. In other words, mitigation strategies encompass comprehensive actions that address the root causes of climate change while simultaneously producing direct benefits in disease prevention and improved quality of life for communities. These strategies also include interventions that, while not directly reducing GHGs, mitigate other environmental drivers of climate change and its health effects, such as ecosystem conservation, sustainable production and consumption, and resilient infrastructure and urban planning.

By contrast, adaptation mechanisms and strategies comprise measures designed to adjust social, health, and environmental systems to reduce population vulnerability to the current and inevitable impacts of climate change. Unlike mitigation, which targets the causes of the problem, adaptation focuses on minimizing damage and seizing opportunities in a changing environment [54]. Examples of such strategies include:

(1) Strengthening health systems:

- Developing early warning systems for heat waves, floods, and epidemics.

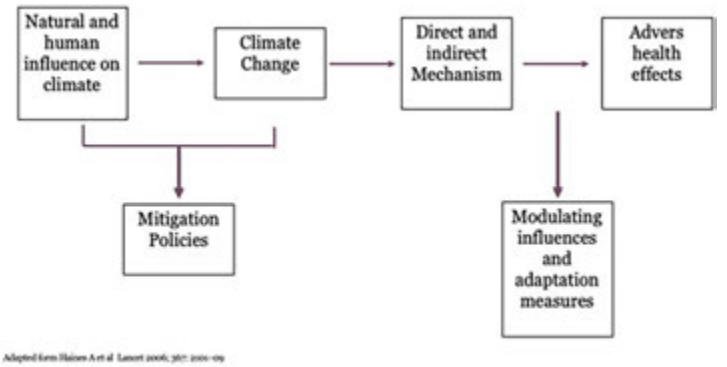


Figure 4.
Climate change and interventions and health effect.

- Improving hospital infrastructure to withstand climate-related disasters.
- Training healthcare personnel in emerging climate-related risks.

(2) Targeted interventions for vulnerable groups.

(3) Climate-sensitive epidemiological surveillance:

- Monitoring climate-sensitive vector-, water-, and food-borne diseases.
- Integrating climate and health data to predict and control outbreaks.

(4) Risk management and community resilience:

- Local preparedness and disaster response plans.
- Community education on protective measures (hydration, cooling shelters, safe water use).
- Social support networks for vulnerable groups (older adults, children, patients with chronic illnesses).

(5) Climate-adapted infrastructure and urban planning:

- Designing cities with effective stormwater drainage, green spaces, and climate shelters.
- Developing housing resistant to floods, extreme heat, and storms.

(6) Food and water security:

- Agricultural diversification and promotion of climate-resilient crops.
- Water storage and treatment technologies in drought-prone regions.

(7) Mental health and psychosocial support:

- Early intervention programs following natural disasters.
- Integration of mental health into climate emergency planning.

Health adaptation strategies constitute a set of planned and dynamic responses aimed at reducing populations' exposure, sensitivity, and vulnerability to the unavoidable impacts of climate change. Their effectiveness depends on multisectoral integration (health, urban planning, agriculture, water management) and an equity-focused approach, since the most vulnerable communities are often the most affected. Health professionals play a leadership role in supporting health systems to adopt effective measures that reduce climate risks, promote health behaviors and policies with low environmental impact, support intersectoral

actions to lower the ecological footprint of society in general – and of healthcare systems in particular – and conduct research and education on climate change and health [55].

In recent years, certain adaptation strategies have gained prominence in vulnerable regions of Africa and South Asia, including the implementation of early warning systems for extreme weather events, climate-resilient infrastructure (e.g., levees, green urban drainage), which have already mitigated the health impacts of flooding in some European cities [15], and the development of national climate and health action plans. Nevertheless, these measures encounter substantial barriers to implementation, as many countries lack the financial and technological capacity required for large-scale deployment. Furthermore, evidence increasingly indicates that some adaptation efforts may result in "maladaptation" – that is, interventions that inadvertently heighten long-term vulnerability. A salient example is the widespread reliance on air conditioning, which may provide short-term relief during heat waves but simultaneously exacerbates GHG emissions and contributes to the perpetuation of climate-related health risks.

6. Conclusions

Climate change constitutes one of the greatest global challenges of the twenty-first century, not only from an environmental perspective but also as a fundamental determinant of public health. This phenomenon is not mere natural variability but the direct consequence of human activities such as fossil fuel combustion, deforestation, and intensive agriculture. Recognizing the existence and severity of climate change is essential for understanding the magnitude of its repercussions on population health and the urgency of implementing coordinated responses.

Substantial controversy persists regarding climate change, with denialist perspectives often positioned in opposition to the robust body of scientific evidence affirming its reality. It must also be acknowledged that certain adverse events are sometimes directly attributed to climate change when their proximate causes may be more complex. Mediterranean wildfires provide an illustrative example: while the absence of comprehensive prevention policies in most countries undoubtedly exacerbates fire risk, the majority of such events are of anthropogenic origin, both in their initiation and propagation. For instance, in the wildfires that struck western Spain in the summer, approximately 80% were traced to human causes, with many being deliberate in nature. These observations, however, do not diminish the critical role of inadequate and ineffective forest risk management in amplifying their public health consequences.

Mitigation and adaptation strategies intended to address climate change encounter persistent barriers that frequently intersect with health systems and exacerbate inequities in health outcomes. Mitigation efforts – such as transitions to renewable energy, energy efficiency measures, and land-use changes – are impeded by entrenched global dependence on fossil fuels, which fosters economic and political resistance. Additionally, the rising demand for critical minerals needed for clean technologies (e.g., batteries and solar panels) risks generating new environmental and geopolitical conflicts. From a health equity perspective, mitigation policies implemented in high-income countries often fail to account for

the disproportionate exposure of marginalized and low-income communities to environmental hazards, thereby perpetuating structural vulnerabilities. A further challenge lies in the limited resources and institutional capacity of public health agencies, constraining their ability to integrate climate considerations into surveillance, preparedness, and service delivery.

Adaptation strategies – encompassing infrastructural improvements, behavioral change, and regulatory frameworks – are likewise obstructed by organizational, procedural, and legal barriers, including bureaucratic complexity and the absence of coherent governance mechanisms. In Europe, for example, adaptation within the health sector is constrained by insufficient intersectoral coordination and budgetary limitations [56]. In urban settings, population vulnerability is magnified by environmental stressors such as extreme heat events and chronic air pollution, both of which are strongly associated with excess morbidity and mortality. The imperative to scale up adaptation represents an unprecedented challenge for health systems, where professionals are increasingly called upon to respond to novel and intensifying climate-related threats without the resources or structural support necessary to ensure resilience and equity in health outcomes.

The health effects of climate change are likely to be predominantly negative and disproportionately severe in low-income countries, where adaptive capacity is weakest, as well as in vulnerable groups within high-income countries. While the implementation of adaptation strategies can mitigate some adverse impacts, low-income countries face considerable challenges in adopting such measures. Therefore, it is necessary to assess vulnerabilities and identify cost-effective interventions and adaptation options in the health sector and in other sectors linked to human health. Early planning can help reduce future adverse health impacts. Mitigation strategies, such as the adoption of renewable energy sources, can improve health by reducing air pollution while simultaneously addressing climate change.

Barriers in governance, insufficient financial resources, and sociopolitical determinants – including cultural resistance and the dissemination of misinformation – hinder the effective implementation of ambitious climate policies. These constraints contribute to an expanding discrepancy between the formal commitments articulated by the international community and their practical execution, a gap that is evidenced by the persistent rise in GHG emissions and the associated climatic impacts.

Climate change is an undeniable reality that directly affects population health through multiple pathways, including heat waves, VBDs, food insecurity, and mental health disorders. Its impact is uneven, falling most heavily on the most vulnerable populations. In this context, the response must be both integral and simultaneous: mitigating emissions to slow future warming while adapting societies to the changes already underway. Mitigation and adaptation strategies should not be considered merely as economic burdens but as investments that yield co-benefits for health, well-being, and social equity. Protecting health against climate change requires evidence-based policies, international cooperation, and intergenerational commitment. The success or failure of these actions will determine not only the future of the planet but also the health and survival of millions of people in the coming decades.

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Author details

Josep M. Ramon-Torrell
Full Professor of Preventive Medicine and Public Health. Clinical Science Department, School of Medicine and Health Sciences, University of Barcelona, Catalonia, Spain

*Address all correspondence to: jmramon@ateneu.ub.edu

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Chapter 3

Urban Environments and Human Health: Multifactorial Influences and Evidence-Based Solutions

Rathod Sridhar, Hanuman Singh Jatav, L. T. Longkumer, Avinash Pilla, Satish Kumar Singh, Prem Kumar Bharteey, Eetela Sathyanarayana, Martin Leonardo Battaglia and Aakash Kumar Saini

Abstract

The urban environments impose effects on human health by presenting a complex combination of environmental, social, infrastructural, and behavioral determinants. The quickening of urbanization, specifically in low- and middle-income countries, has exacerbated unpleasant conditions such as air contamination, water and sanitation shortages, noise disturbances, overheating, and chemical exposures. These determinants interact with variables related to housing quality, mobility systems, food environments, and access to green spaces, thereby creating a burden of both infectious and chronic diseases in urban areas. In cities, health inequities remain highly visible, with slum populations, migrants, women, and low-income groups experiencing unequal exposure to environmental risks and limited access to healthcare services. The large population density increases the spread of disease, while insufficient waste disposal and environmental degradation heighten the risk of vector-borne and zoonotic diseases. The increased susceptibility of congested cities to the COVID-19 outbreak and the urgent need for strong health systems have been highlighted. However, based on the urban environment, alongside challenges, there are opportunities for innovations in climate-resilient planning, green infrastructure, well-being-focused housing, intelligent transportation, and digital health initiatives. This chapter summarizes the evidence related to the role of urban environments in health, examines how disparities contribute to vulnerabilities, and discusses integrated solutions and examples that illustrate how we can create healthier, more inclusive, and sustainable urban futures.

Keywords: urbanization, environmental factors, built environment, health inequities, contagious diseases, climate resilience, sustainable urban planning

1. Introduction

An urban environment can be defined as a dense population, highly urbanized food systems, specialized economic activity, and the loss of natural land use. These are usually cities, urban centers, peri-urban regions, industrial belts, and growing urban townships. These places are significantly differentiated with regard to land use, transport, housing structures, waste generation, energy use, and the social structure of rural places [1]. City spaces are dynamic socio-ecological spaces where human activities constantly transform the physical and social environment. They are characterized by high-rise buildings, complex transport systems, tarmac cover, industrial effluents, commercial areas, and a lack of green areas. The gross interaction of people, infrastructure, and environmental factors forms the basis of the effects of urban environments on health outcomes.

Urban ecosystems are not only physical spaces but also involve the flows of people, goods, energy, information, pollutants, and cultural interactions. These features make them a site of innovation and economic development, while at the same time a "hot spot" of environmental stressors such as air pollution, heat islands, water scarcity, noise, and waste accumulation [2]. As cities continue to grow and expand, gaining greater insight into their structure and function is critical to solving emerging challenges to urban health.

1.1 Trends of rapid urbanization in the world and in developing countries

The twenty-first century is often described as the "urban century," when, for the first time in human history, the majority of people live in urban areas rather than in rural regions. According to the United Nations, the global urban population grew from 751 million in 1950 to more than 4.4 billion in 2023 and is expected to reach 6.7 billion in 2050 [3]. This rapid transition is most significant in the case of Asia and Africa, where cities are also expanding at unprecedented rates.

The general urbanization trend in most countries is reinforced by the fact that over four billion people now live in cities and slums worldwide. Population growth in future years is expected to be concentrated in developing countries, with more and more urban poor, whose needs are not adequately met by governments in terms of service provision and infrastructure [4].

1.1.1 Patterns of urbanization across the world

High-income countries experienced urban expansion in the nineteenth and twentieth centuries, which was driven by industrialization, economic development, and technological advancement [5].

In contrast, modern urbanization in low- and middle-income countries (LMICs) is rapid and often takes place in the absence of commensurate infrastructure, governance capacity, or environmental safeguards.

1.1.2 Urbanization of developing countries

Developing countries like India, China, Brazil, Nigeria, and Indonesia record some of the fastest rates of urban growth, which is mostly due to rural–urban migration, a growing population, as well as the reclassification of rural areas into

urban jurisdictions. Rapid and, at times, unplanned urbanization puts enormous pressure on housing, transportation, waste management, water supply, energy systems, and health services. In many LMIC cities, informal settlements or slums house 30%–60% of the population and thus subject residents to low living standards, overcrowding, poor sanitation, and increasing chances of catching diseases [1].

1.2 Urbanization and environmental stresses

As cities grow, they cause environmental modifications that have direct consequences for health:

- Increased air pollution, mainly from vehicles and industries.
- Increased urban heat island effect due to a decreased amount of vegetation.
- Pollution of water by untreated sewage.
- Increased production of solid waste.
- Disappearance of biodiversity and natural ecosystems.

Thus, although urbanization is linked with economic growth and access to better services, it is simultaneously associated with several health risks that are particular to urban life.

1.2.1 Importance of investigating the association between urban living and human health

Urban environments have significant impacts on human health through a range of physical, biological, social, and behavioral pathways. A deep study essential for understanding these links is critical to public health planning, urban policy, sustainable development, and disease prevention.

1.2.2 Exposure to environmental hazards

Cities are hubs of pollution – air pollution, water pollution, noise pollution, and chemical pollution. Air pollution on its own is responsible for millions of premature deaths every year, with those living in cities being disproportionately affected [6]. Traffic emissions, industrial pollutants, construction dust, and smoke from people's homes all contribute to high rates of respiratory diseases, cardiovascular conditions, and cancers.

1.2.3 Social factors that affect health

Urban areas have sharp socioeconomic disparities. Inequalities in income, quality of housing, availability of clean water, jobs, and healthcare services have a strong impact on health. People who live in marginalized neighborhoods often suffer from disproportionate levels of infectious diseases, malnutrition, chronic diseases, and mental health problems [7]. Social determinants of health (SDOH) are the conditions in which people are born, grow, live, work, and age, and they affect health outcomes

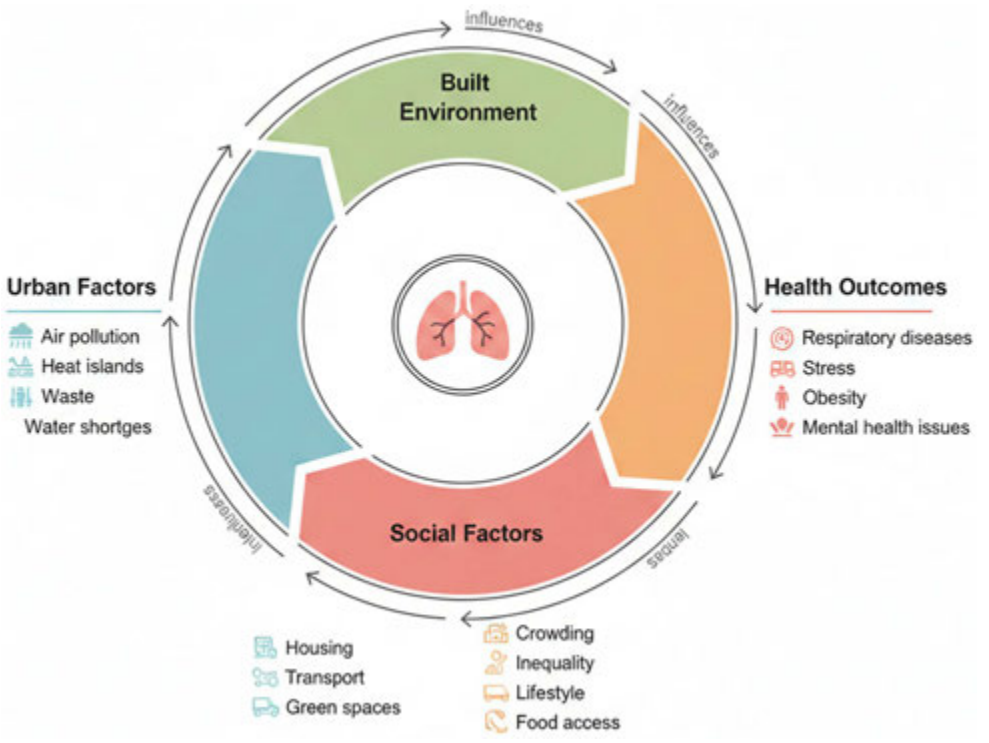


Figure 1.
Linkages between urban environment and human health.

to a greater extent than healthcare practices and lifestyle choices. These determinants represent a broad array of social, economic, and environmental factors that contribute to health disparities and inequities. Addressing them is essential to improving health outcomes and achieving health equity. The effect of urbanization on health is depicted in **Figure 1**.

2. Urban growth in low-, middle-, and high-income countries

Urbanization is a complex process affected by various drivers and patterns that differ between low-, middle-, and high-income countries. Economic, social, and environmental factors determine the dynamics of urban growth and are quite different depending on the income level of the country. This section examines the drivers and patterns of urbanization within separate income groups and highlights the unique challenges and opportunities they encounter.

2.1 Urbanization in the LMICs

- Economic and infrastructure development: This is often driven by urbanization in LMICs. The Belt and Road Initiative (BRI) has had a great influence on urbanization in poor countries by stimulating local urbanization through external investments and infrastructure [8]. Industrial support, employment

opportunities, and infrastructure accessibility also contribute to urbanization in these regions [9].

- Environmental challenges: Unplanned and rapid urbanization occurs mostly in flooded areas. Between 1985 and 2015, 82% of new settlements in high-risk flood zones were in LMICs ("Global evidence of rapid urban growth in," 2022), a development that highlights the need for better urban planning to reduce risks to the environment.

Demographic changes: Migration is an important factor in urbanization (52% of new urban residents in the world are accounted for by in-migration), with a total of zero net out-migration. This trend is particularly evident in LMICs, where urban areas are rapidly expanding to meet the increasing population [10].

2.1.1 Urbanization in high-income countries

Controlled and safe growth: High-income countries tend to experience slower and more controlled urban growth. Urban growth in these areas focuses on minimizing exposure to environmental hazards [11].

Economic and environmental balance: Urbanization, in the case of high-income countries, is strongly associated with economic growth and environmental sustainability. These countries often have the means to invest in green technologies and sustainable urban planning to offset economic development with the protection of the environment [12].

Demographic stability: High-income countries tend to have more stable demographic structures with lower dependency ratios and less dramatic changes in population dynamics than LMICs [10].

2.1.2 Global urbanization trends

Technological and economic drivers: At all levels of income, urbanization is based on technological developments and economic improvements. The Industrial Revolution and later technological developments were historically the cause of accelerating urbanization, turning cities into epicenters of economic and social activity [13].

Environmental and social impacts: The process of urbanization is linked to serious environmental and social consequences, such as the production of more carbon and the change in demographic structures. Such consequences depend on the degree of national income, where high-income countries have more ability to deal with environmental problems by implementing sustainable practices [14].

Urbanization has brought both challenges and prospects to a country in the sense that it has provided the opportunity to grow and develop economically, but at the same time, it has come with its challenges of environmental sustainability and equity in society. The sharp urbanization of the population is often associated, in LMICs, with increased vulnerability to environmental hazards and a lack of infrastructure.

On the other hand, in high-income nations, the problem is to promote economic growth and reduce the impact on the environment. These disparate trends, as well as the drivers behind them, need to be clearly understood in order to develop firm urban policies that will encourage sustainable and inclusive development among different income groups.

2.2 Concept of megacities and peri-urban expansion

Urbanization is a complex process that is affected by a number of factors, and it has specific characteristics, especially in megacities and peri-urbanization. The urban agglomeration, which is described as the clustering of over 10 million people in urban centers, is characterized by faster growth rates, particularly in the Global South, due to improved economic potential and agglomeration economies of scale. Peri-urban areas also experience a fast growth rate as they are absorbed into the urban fabric, often driven by the actions of the private sector and frequently without the necessary government planning.

2.2.1 Environmental determinants of urban health

Urban air quality is a critical factor predetermining the state of human health, and various sources of pollutant emissions can be observed in urban areas. The major sources of emissions are vehicles, industrial activities, and construction, and each of them has a significant impact on the worsening of air quality and the resulting effect on health. These sources should be explained in detail to develop effective mitigation measures that would contribute to the improvement of air quality in urban areas and protect human health. Air pollution or quality is altered by different sources mentioned in **Figure 2**.



Figure 2.
Sources of urban pollution.

2.2.2 Vehicular emissions

Vehicular pollution and traffic are contributing causes of major air pollution in most cities, releasing pollutants like nitrogen oxides (NOx), sulfur oxides (SOx), volatile organic compounds (VOCs), and particulate matter (PM) into the atmosphere. These emissions are mainly a result of burning fossil fuels from cars, trucks, and buses [15, 16].

- The expansion in urbanization has led to a corresponding rise in vehicular movement, thus increasing the level of air pollution. Cities like Los Angeles, where transport depends to a great degree on automobiles, face huge challenges in how to deal with transportation-related emissions [16].

Innovative solutions, such as the promotion of electric vehicles, improvement of public transportation, and the implementation of smart traffic management systems, are being explored in order to mitigate vehicular emissions [17, 18].

2.2.3 Industrial activities

Air pollution caused by industrial emissions is a major contributor to air pollution, mainly in the form of PM, VOCs, and dangerous chemicals [19, 20]. These contaminants result from manufacturing processes, power generation, and other associated industrial activities.

Industrial emissions have a significant effect, contributing to respiratory and cardiovascular morbidity among urban citizens. Strong mitigation measures include enforcing high levels of emission standards and utilizing cleaner technology [15].

2.2.4 Construction activities

Construction works cause air pollution in the city through the emission of dust and PM. Air emissions of pollutants (NOx and VOCs) can also result from the use of heavy machinery and construction materials [17].

Clean construction (i.e., low-emission working machines, dust control) is essential in order to minimize the effect of the construction operation on air quality in the city [17].

2.2.5 Health impacts

Air pollution in urban settings, which is characterized by particulate matter 2.5 μm in diameter (PM 2.5), NO_2, and ozone (O_3), has been invariably associated with a continuum of health conditions, including respiratory diseases, cardiovascular diseases, and high death rates. Children, the elderly, and people with underlying conditions are some of the vulnerable groups that are disproportionately impacted [21].

Chronic disease conditions may develop as a result of long-lasting exposure to air pollutants, which explains why effective environmental laws and the

implementation of broad-scale interventions targeting the entire population are essential [22].

Though much effort has been devoted to the cause of urban air pollution, more should be focused on the overall context of urban planning and policy actions. The design of cities with sustainable structures, including the establishment of green areas and the optimization of mass transportation systems, promises to significantly decrease the level of pollutants and, consequently, increase the quality of air in the atmosphere. Community involvement and participation through educational campaigns are invaluable in terms of developing group dedication toward air quality improvement. Through a systematic approach to considering the complex interconnection between the sources of pollution and implementing proactive ways of reducing pollution, city centers can transform into healthier and more sustainable places that can accommodate everyone [15].

3. Water, sanitation, and hygiene

In cities, the environmental determinants of health, especially those related to the quality of air and water, sanitation, and hygiene (WASH), are significant aspects that determine the health outcomes of the population. Urban locales are faced with unique challenges from high population density, high rates of urbanization, and often poor infrastructure, which exacerbate air and water quality concerns. These challenges are compounded by socioeconomic disparities, driving the importance of adequate WASH service management to improve health status and reduce risks of diseases. The subsections that follow outline the specific problems and implications of urban water supply, wastewater management, and the risks of disease originating in poor sanitation (see **Table 1**).

3.1 Challenges in urban water supply

Urban Enviro – "Urban environments often face problems in providing a consistent water supply that is safe for the public, and the proper environment defines 'safe' at the end of the day – a problem that is a result of rapid urbanization

Urban stressor	Health effects	Evidence/ citation
Air pollution [$PM_{2.5}$, NO_2, O_3)	Asthma, COPD, cardiovascular disease	13, 14
Noise pollution	Stress, sleep disturbances, anxiety	15
Urban heat island	Heat stress, dehydration, heat-related mortality	16, 17
Poor sanitation and water contamination	Diarrheal diseases, cholera, typhoid	18
Overcrowding	Infectious disease spread [TB, influenza], mental stress	19
Limited green spaces	Depression, poor mental health, and low physical activity	20, 36

Table 1.
Urban stressors and associated health effects.

and lack of infrastructure." This can especially be seen in the LMICs, where urban planning has failed to keep up with demographic growth [23, 24].

For example, in Bangladesh, reliance on tube wells as a significant water source has been linked to increased risks of communicable diseases, thus showing the need for better water supply systems [25].

The following are some reasons why climate change is exacerbating water supply challenges: Climate change is making water supply challenges worse by increasing the frequency of extreme weather events, which can disrupt water infrastructure and make it harder to access [24].

3.1.1 Wastewater management

Introduction: – Urban areas in many developing countries lack wastewater disposal and treatment plants, which are responsible for urban health [26]. There is an increase in waterborne diseases due to insufficient wastewater management, which contributes to environmental pollution.

"Urban planning that is integrated with investment in wastewater infrastructure is an indispensable required approach to tackle the problem and protect public health" [24, 26].

3.1.2 Disease risks due to poor sanitation

Insufficient sanitation facilities play an important role in spreading communicable diseases in an urban environment. For instance, poor sanitation has been associated with high incidences of diarrheal diseases in Bangladesh (Nabi et al., 2025). The suggested study should take into consideration the fact that the lack of proper sanitation systems in city slums and informal areas is a great health risk, especially affecting vulnerable groups, particularly children and women [27, 28].

It has been seen that community-based interventions, which include hygiene education programs and the establishment of better sanitation facilities, are effective in preventing the spread of diseases and improving health conditions [29].

Despite the fact that the obstacles to WASH management in urban environments are significant, they can be overcome. The management of these issues requires a complex approach that includes the improvement of infrastructure, the development of hygiene education, and the equal distribution of resources. In addition, the political aspects of the WASH problems themselves prove the necessity of policy actions and stakeholder involvement in finding sustainable solutions (Corburn, 2022). The prospective role of schools as focal points of WASH interventions adds further emphasis to the potential of educational institutions to catalyze change and improve health outcomes within urban environments [30].

3.2 Noise pollution

Noise pollution in the urban environment, mainly from traffic and construction, has significant effects on human health, especially on sleep, stress levels, and cognitive performance. Traffic and construction activities are the main causes of

urban noise and thus contribute to an array of health problems, such as sleep ailments, increased stress, and lack of cognitive function. The following sections examine in detail the effects of noise pollution and assess possible mitigation methods.

3.3 Major sources of noise: Traffic and construction

Traffic noise is found to be a major contributor to urban noise pollution, with vehicle horns – mostly from buses, as well as trucks and motorcycles – contributing significantly to increased noise levels [31].

Further, construction activities, including operations involving heavy machinery, contribute to further exacerbating the urban noise landscape, especially in fast-growing urban areas [32].

3.3.1 Aviation noise and its mitigation

In the majority of developing countries, aviation contributes significantly to public and environmental health concerns, especially for communities near airports, due to the expansion of air travel and urbanization. The noise created by aircraft operations can cause a variety of health problems, ranging from stress, high blood pressure, and sleep disturbances, and disproportionately affects low-income and minority communities. Chronic exposure to aircraft noise is associated with a number of health issues, including noise stress, hypertension, headaches, and sleep disturbances. These effects are stronger in communities closer to airports, as evidenced by studies carried out around Abu Dhabi International Airport and other locations [33]. The World Health Organization (WHO) considers noise levels above 85 dB(A) as dangerous, and this is often exceeded within the vicinity of airports, causing a decrease in the quality of life for residents [34]. Taking noise-reduction measures during take-off and landing can also help reduce exposure [10]. Regulatory measures, such as land use planning and compliance with the standards of the International Civil Aviation Organization (ICAO), are fundamental to effectively managing noise levels. These measures should be accompanied by community engagement programs, such as window insulation initiatives and transparent reporting of noise levels [10, 34]. Urban landscape solutions, like expanding tree forests, will combat noise and facilitate environmental equity, as Istanbul needs to implement [35].

3.3.2 Noise in community and residential areas

Noise pollution in cities is a multidimensional problem and is greatly affected by music playing, partying, sidewalk cafes, and even the presence of dogs. These elements make up the complex soundscape of cities, with impacts on the quality of life and health of residents. While music and social gatherings are an integral part of urban culture, at the same time, they also present a challenge of noise management and regulation.

3.3.3 Music shows and parties

Music concerts and outdoor events are major sources of urban noise pollution. Studies, for example, in Makassar City, Indonesia, confirm that noise levels during concerts frequently exceed regulatory norms and bring the need for an effective noise management strategy to the forefront [36]. In the context of construction, it can be understood as follows: "The challenge is to balance the entertainment needs with the well-being of residents." For example, the Sydney Opera House has employed certain noise criteria for outdoor events to control noise pollution while providing a good experience for the people in the audience [37]. What was found was that, particularly, low-frequency noise (LFN) from contemporary music is especially problematic, as it is very hard to measure and can cause severe health issues, including trauma and even death [38]. Sidewalk cafes: Cafes add to the noise pollution of an urban area, mainly through conversations and background music. Surveys have shown that noise in cafes can interfere with conversation and impair experiences, requiring an improvement in acoustic design to increase voice privacy and intelligibility. As examples, "In New York City, noise levels in restaurants and bars are often too loud to allow people to have comfortable conversations, particularly for people with hearing impairments, which demonstrates that noise control measures should be taken in these venues" [39]. Dogs and other sources of urban noise: There is no doubt that urban environments are characterized by a range of noise sources, including traffic, construction, and social activities. Dogs are a source of noise pollution, but the papers provided do not specifically address them as a significant contributor. The presence of dogs, especially in high- density areas, can be part of the sound level, impacting the comfort and peace of residents.

3.3.4 Noise management strategies

The need to balance noise control and the improvement of the auditory environment is addressed by the following: urban design interventions, such as the inclusion of natural elements and the creation of quiet zones. For instance, the following have been tested or their applications suggested: Structural barriers, such as concrete barriers, have been proven to effectively reduce the intensity of noise [36], suggesting that such barriers may be used in the urban planning of music events to reduce noise. Given the negative impacts that noise pollution from outdoor music events can have on the community, the author highlights that noise mapping and prediction tools can be used to help assess the impact of noise pollution from outdoor music events and aid in decision-making processes for event planning and regulation (ten Kate, 2017). While there are significant challenges in the issue of noise pollution from music shows, parties, and cafes, it is critical to understand the cultural and social value of these activities. Urban planners and policymakers must attempt to create environments that can accommodate the need for vibrant social interactions and the need for maintaining public health and well-being. By embracing new approaches to noise management and by encouraging cooperation between different stakeholders, cities can become places that provide better acoustic experiences with minimal noise disturbances.

3.3.5 Impacts on sleep

"Environmental Noise and Health" (2022) further agrees that "Noise pollution shows a strong correlation with sleep problems, which can trigger a cascade of health problems, including fatigue, reduced cognitive function, and higher anxiety."

In the specific study discussed above, "Empirical studies show that persistent exposure to urban noise affects the quality of people's sleep, particularly for younger cohorts such as Generation Z, which, in turn, causes stress and mental health concerns."

3.3.6 Effects on stress and cognitive performance

"Exposure to high levels of noise is associated with an increase in stress, anxiety, and depression," which negatively affects cognitive functions such as attention, problem-solving, and memory. Given how noise pollution has been shown to reduce cognitive function, particularly among children, it affects their ability to read and problem-solve [40].

3.3.7 Mitigation strategies

Canopy tree planting and canopy tree green-belt creation can serve as natural sound barriers and thus can lower the sound level and improve the urban acoustic environment [32] Reduction technologies, including sound-proofing and noise barriers, may be used in urban planning and building design to reduce the negative impact [41].

Public awareness campaigns and regulatory actions are key to encouraging the public to participate in addressing the harmful effects of noise pollution and enforcing noise standards [41, 42].

Although noise pollution is a major problem in the city surroundings, it is often considered recessive to more visible environmental problems like air and water pollution. However, noise pollution has a tremendous effect on human health and well-being and hence requires comprehensive mitigation measures. Through adequate noise control procedures and by creating awareness among the populace, it could be viable to make urban environments healthier and livelier.

Solid waste and exposure to chemicals, especially through municipal and electronic waste accumulation, significantly determine the environmental determinants of health in urban settings. These pollutants pose great danger to humanity and the environment, making it very necessary to develop strong management approaches. The presence of municipal and e-waste is a pressing issue that leads to environmental pollution and health hazards, which mostly arise in the urban environment. The following sections provide a detailed analysis of these aspects.

3.4 Accumulation of municipal waste

3.4.1 Volume/impact of municipal solid waste

This is estimated to be about 3.5 billion tons of municipal solid waste (MSW) in 2050, and not properly utilizing the MSW in a way that minimizes it leads to more

health and environmental complications. Urban waste collections often cause esthetic pollution as well as health hazards due to poor disposal in most cases [43].

3.4.2 Health risks

A large number of poor waste management behaviors, which include open dumping and incineration, are the causes of air, water, and soil pollution, which further increase respiratory diseases and other health-related complications. Such practices are especially common in developing nations, whose resources cannot be used to promote efficient waste management systems [44, 45].

3.4.3 Environmental consequences

Waste degradation in landfills emits gases with greenhouse effects and toxic leachates, thus polluting soil and water bodies. This contamination threatens agricultural yields and food security [46, 47].

3.5 E-waste and chemical hazards

3.5.1 Composition and risks

E-waste is composed of hazardous chemicals like heavy metals and organic pollutants, which may cause endocrine interference and neurological impairment when improperly disposed of. The informal recycling industry in third-world countries also adds to the menace, as it releases toxic chemicals into the environment [48, 49].

3.5.2 Excessively large amounts of lead in the blood may cause the following

Health implications: The exposure to chemicals contained in e-waste can result in severe health effects (respiratory diseases and congenital anomalies). This issue is exacerbated by the lack of sophisticated recycling processes and strict regulatory systems [48, 49].

In addition to these risks, the other challenges of e-waste recycling include management strategies. To address the health and environmental risks, proper recycling technologies, strict regulations, and environmentally friendly design principles must be used [48] as shown in **Figure 3**.

3.6 Integrated waste management strategies

3.6.1 Holistic strategies

This approach to waste management requires the consideration of both environmental preservation and the health of the people at the same time. In this strategy, there is an integration of community involvement, recovery of resources, and the embracing of sustainable measures to reduce health hazards and enhance environmental sustainability [45].

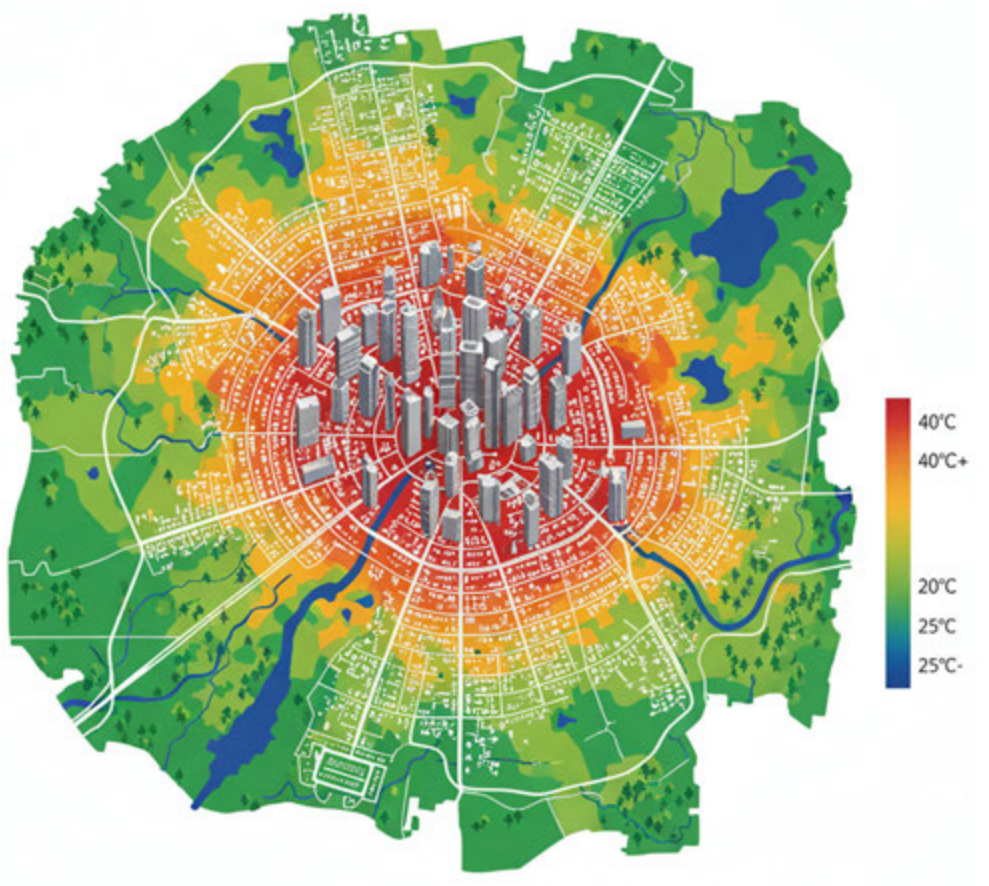


Figure 3.
Urban heat island effect map of a typical city.

3.6.2 Policy and education

The policymakers and the planners need to work together in coming up with holistic waste management strategies that involve community involvement and education. These programs can reduce the negative impact of waste on the health of the population and the environment [46, 47].

Although the focus on solid waste and e-waste highlights the significant threats to health and the environment, it is necessary to put such concerns in context as part of the scope of environmental determinants in urban environments. The quality of air and water, noise pollution, and access to green spaces are also consistently important factors that contribute to the determination of health outcomes in metropolitan areas. All these issues require a complex approach that integrates various environmental exposures and their overall effect on health [50].

4. Built environment and health outcomes related to lifestyle

4.1 Housing conditions

Overcrowding increases the frequency of proximate interpersonal contact and hence the rate of transmission of respiratory pathogens such as tuberculosis, influenza, and pneumonia [60]. Inadequate ventilation compounds the problem of indoor air pollution from the buildup of PM, combustion by-products of cooking fuels, and VOCs. These contaminants contribute to asthma, chronic obstructive pulmonary disease (COPD), as well as allergic manifestations, especially in children and the elderly [61]. Healthy and unhealthy urban cities depend on pollution, population, and anthropogenic activities. The design of both has been depicted in **Figure 4**. Low-income households and informal settlements are disproportionately affected because such dwellings often depend on biomass fuels or kerosene stoves and do not have access to improved building materials.

4.1.1 Impacts on infectious and chronic diseases

Substandard housing materially increases the risk of infectious illnesses as well as chronic illnesses. Moisture infiltration, mold growth, structural deterioration, and poor sanitation result in environmental conditions favorable to respiratory infections, gastrointestinal disorders, and vector-borne diseases [62]. Prolonged exposure to negative indoor conditions can also worsen the risk of chronic diseases such as cardiovascular disease and hypertension. Persistent

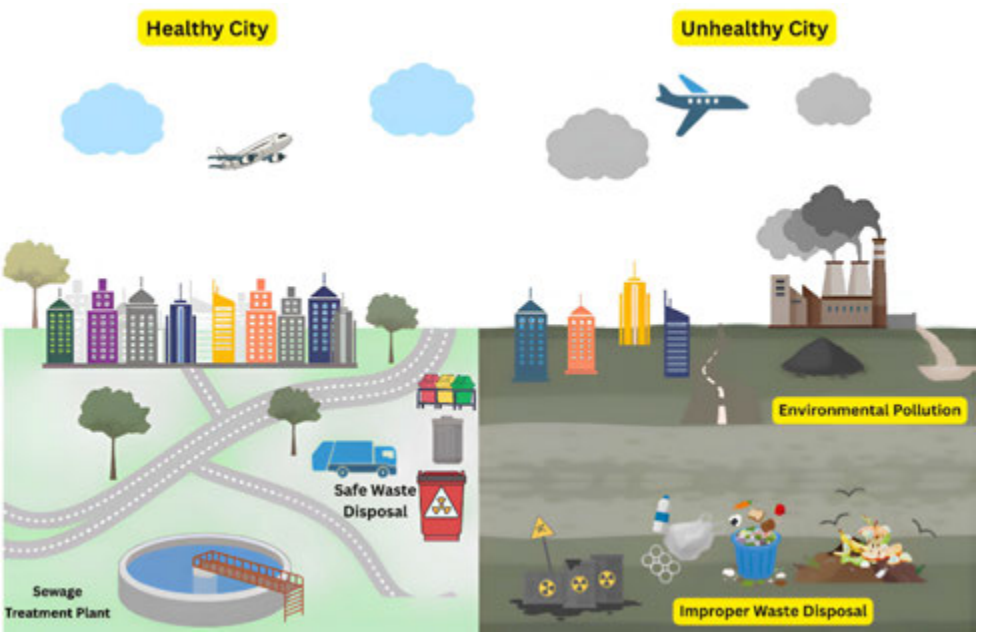


Figure 4.
Design of healthy vs. unhealthy urban cities.

stress due to noise, insecurity, and overcrowding is further eroding health. Empirical evidence obtained from urban global health studies shows that an increase in the quality of housing ventilation, the improvement of the quality of materials, and the reduction of pollution inside the home can have a huge impact in curbing the burden of illnesses and their healthcare costs [63]. Consequently, housing interventions are a strong tool to promote health equity at the metropolitan scale.

4.2 Urban mobility and transportation

4.2.1 Sedentary behavior compared to active transport

Urban mobility infrastructures have a significant impact on the daily level of physical activity. Cities dominated by car-centric infrastructures promote sedentary lifestyles and contribute to a rise in the prevalence of obesity, diabetes, and cardiovascular disease [64]. On the other hand, environments that encourage active transport modalities, such as pedestrian activity and bicycle riding, foster healthier routines by incorporating physical activity into daily transportation. Studies undertaken in European and Asian city centers suggest that the more accessible pedestrian and cycling lanes are to a population, the higher the levels of activity reported, the better the fitness, and lower the risk of chronic diseases [65]. Utilization of public transit also correlates with more walking because commuters usually walk significant distances to and from transit stops.

4.2.2 Traffic accidents and safety

Traffic injuries are one of the greatest health burdens in rapidly urbanizing regions. High-speed traffic, poorly designed road networks, lack of pedestrian crossings, and lack of enforcement of safety regulations are some of the causes for the high rate of urban road accidents [66]. Vulnerable cohorts, such as cyclists, pedestrians, children, and older people, face disproportionately greater risks. In many LMICs, motorbikes are a primary source of accidents due to congestion, economic imperatives, and lack of transport alternatives. Infrastructure improvements like protected bike lanes, well-lit sidewalks, and traffic-calming measures greatly help to decrease the level of accidents and contribute to public safety [67]. Therefore, safe mobility is a key factor in equitable urban development that cannot be disregarded.

4.3 Access to green spaces

4.3.1 Parks and urban forests

Green spaces, including parks, urban forests, community gardens, and green corridors, are necessary parts of a healthy urban landscape. These environments mitigate urban heat, support biodiversity, and improve air quality by acting as a filter against pollutants [68]. Access to green spaces plays an important role in promoting social cohesion and further encourages recreational activities while facilitating the provision of facilities that promote relaxation. A key component of sustainable cities is equitably-distributed, high-quality green infrastructure that ensures all

socioeconomic groups – including those living in dense urban neighborhoods – receive the benefits of nature – as health advantages.

4.3.2 Benefits: mental health, physical activity, decreased stress

Extensive research has been carried out and has found that green spaces make a significant contribution to mental well-being. Exposure to nature reduces psychosomatic stress, decreases the production of cortisol in the blood, improves mood, and enhances cognitive functioning [69]. Parks encourage walking, jogging, and playing and help support physical activity while reducing risks of obesity and chronic diseases [70]. During the current COVID-19 pandemic, access to green areas was associated with lower anxiety and greater psychological resilience in urban residents. Importantly, green spaces also provide environmental benefits, such as reducing heat islands, which lead to further improvements in health. Cities that enjoy equal access to green spaces tend to have lower levels of mortality and healthier communities [71].

4.4 Food environment

4.4.1 Access to fresh food

Urban food environments determine dietary behavior and nutritional outcomes. Numerous low-income neighborhoods face "food deserts," where fresh produce is limited or unaffordable, forcing people to rely on processed foods or foods high in calories [72]. Limited access to healthy food increases the risks of malnutrition, obesity, diabetes, and cardiovascular diseases. On the other hand, cities that possess robust food systems, such as local markets, urban agriculture, mobile vendors, and community gardens, reveal an increased level of dietary diversity and better health outcomes for the population [73]. Consequently, the provision of affordable and quality food is critical toward fostering healthy cities.

4.4.2 Fast-food density and obesity trends

Fast-food density has repeatedly been linked to increased obesity rates and adverse food behaviors. Comparative studies in North America, Europe, and Asia show that neighborhoods with a high concentration of fast-food outlets have a high rate of overweight and obesity, particularly among children and adolescents [74]. Fast-food environments are likely to be concentrated in low-income urban neighborhoods and thus contribute to health inequities. Aggressive marketing, convenience, and low price points make fast food more accessible than healthier alternatives. Urban planning interventions such as zoning restrictions, nutrition labeling, or incentives for nutritious food retailers can attenuate these trends and foster healthier dietary patterns.

5. Urban health inequities

5.1 Socioeconomic inequalities in health outcomes

Socioeconomic status is a very strong predictor of health in an urban environment. Low-income people are more likely to live in polluted neighborhoods, experience

overcrowding, and face financial difficulties accessing healthcare. For this reason, they bear a disproportionate burden of diseases of the respiratory system, infectious diseases, malnutrition, and chronic non-communicable conditions [7]. Research has shown that neighborhoods with concentrated poverty have fewer health facilities, lower-quality schools, fewer green spaces, and fewer opportunities for physical activity [75]. Urban children from poor households show a higher prevalence of stunting, incomplete vaccination, and preventable infections compared to their wealthier counterparts [76]. These disparities illustrate the extent of structural inequities, such as labor segregation, unequal distribution of services, and political influence, that determine health across the urban social gradient.

5.2 Slums, informal settlements, and vulnerable populations

Globally, about one billion people live in slums or informal settlements, which are generally defined by insecure tenure, poor housing materials, poor sanitation, and overcrowded living conditions [1]. These environments place residents at elevated risks for water and vector transmission of diseases and environmental contamination. Empirical research in cities such as Nairobi, Mumbai, Port-au-Prince, and Dhaka has highlighted high burdens of diarrheal disease, respiratory infections, and undernutrition in children that stem from unsafe housing and the absence of basic services [77]. Vulnerable cohorts (migrants, daily wage laborers, elderly, and persons with disabilities) bear the brunt of these challenges as they disproportionately represent the most vulnerable sections of the informal settlements. Informal dwellers also face intensified exposure to climate-related hazards such as heat waves, landslides, and flooding, thus contributing to current health inequities [78]. The lack of formal infrastructure and political representation often means that these populations are invisible in urban policy and planning processes.

5.3 Gender dimensions to urban health

Gender is an appropriate parameter that defines the risk profile and opportunities that can be enjoyed by urban inhabitants. Women and girls are always vulnerable to the issues surrounding insecure public spaces, gender-based violence, mobility, and inability to access income-generating activities. These conditions come with serious physical and psychological aftereffects on health [79]. Studies of urban areas in South Asia and sub-Saharan Africa suggest that, in low-income settlements, women are disadvantaged in terms of access to healthcare because of their financial dependency, care giving roles, and mobility constraints imposed by cultural norms [80]. Urban infrastructure – including public transport systems and sanitation infrastructure – is often designed without considering the safety or needs of women, making them much more vulnerable to violence and limiting their participation in education, employment, and public life [81]. Gender inequalities intersect with class, age, disability, and migratory status to compound disadvantage and create disparate health outcomes across cities.

5.4 Case studies demonstrating the health burdens of inequality

Case studies from around the world highlight how cities face direct health burdens due to inequities within them. In Rio de Janeiro's favelas, for

instance, children and adolescents experience high rates of exposure to violence, poor sanitation, and limited access to primary care, resulting in elevated rates of trauma, infectious diseases, and malnutrition [82]. In Delhi, India, low-income areas near industrial zones suffer from alarmingly high rates of asthma and cardiovascular disease because of disproportionate exposure to air pollution [83]. Research in Cape Town, South Africa, points to the perpetuation of apartheid-era spatial planning, which continues to foster the unavailability of healthcare, green spaces, and safe housing, leading to drastic differences in life expectancy between racial and socioeconomic groups [84]. During the global outbreak of the novel coronavirus, some informal settlements in Mumbai, Nairobi, and Manila experienced higher rates of transmission, coupled with greater socioeconomic loss due to overcrowding, water shortages, and limited healthcare access [85]. These cases demonstrate that health inequities are deeply rooted within the structures of cities and require targeted, equity-focused interventions.

6. Infectious diseases in US urban areas

6.1 High-density living and disease transmission

High-density urban living provides ideal conditions for the fast spread of infectious diseases: Crowded housing, congested public transport, and frequent interpersonal contact facilitate the spread of respiratory infections such as influenza, tuberculosis, and measles [86]. Poorly ventilated indoor spaces and cramped living spaces increase rates of household transmission, especially in low-income neighborhoods. Informal settlements, where several families are often sharing one room or sanitation facility, face even greater exposure risks. Studies from rapidly expanding cities in Africa and Asia show that there is a strong correlation between population density and increased rates of tuberculosis and other airborne diseases [87]. These patterns highlight the importance of improving the infrastructure and services needed to reduce infectious disease burdens and better meet the needs of urbanizing populations.

6.2 Vector-borne diseases: dengue, malaria, and peri-urban expansion

Urban and peri-urban growth has led to an increase in the prevalence of vector-borne diseases, especially dengue, chikungunya, Zika, and malaria. The Aedes aegypti mosquito, which breeds in standing water at construction sites, uncovered containers, and areas with disorderly waste management, has become increasingly dominant in rapidly urbanizing cities [88]. Dengue transmission is particularly high in tropical megacities like Delhi, Rio de Janeiro, Dhaka, and Manila, where dense populations and poor drainage create a plethora of breeding sites. While malaria is a disease traditionally linked with rural areas, the development of peri-urban areas and environmental modifications have increased malaria transmission in the outskirts of cities in Africa and Asia [89]. These changes highlight the extent to which poor urban planning, inadequate sanitation, and unregulated settlement growth reinforce vector-related risks.

6.3 Zoonoses and risks of waste-driven disease

Urban localities are increasingly faced with the risks posed by zoonotic diseases due to close contact between humans, animals, and waste (usually uncontrolled) in cities. Unregulated meat markets, the presence of stray animals, rodents, and waste accumulation favor the spillover of pathogens from animals to humans [90]. Rodents, abundant in informal settlements and areas with inadequate waste disposal, produce diseases such as leptospirosis, plague, and hantavirus infections. Poor sanitation and the congestion of drainage systems increase the exposure of individuals to contaminated water, precipitating outbreaks of leptospirosis and other waterborne zoonoses [91]. As cities grow, the disruption of ecological systems and the conversion of peri-urban habitats promote human contact with wildlife hosts and reservoirs of disease. The trends mentioned above depict that garbage, lack of proper infrastructure in society, and ecological disruption are also major predeterminants in the spread of urban zoonotic diseases.

6.4 Urban pandemics: lessons from the COVID-19 pandemic

The vulnerability of cities to the increased spread of infectious disease agents was demonstrated by the current coronavirus pandemic (2019-nCoV, which is also called COVID-19). Metropolitan regions acted as centers of transmission, caused by the increase in mobility levels, overpopulation, and the formation of a highly connected contact network [92]. The populations of informal settlements were disproportionately exposed to these risks, which can be explained by the inability to access potable water, sanitation facilities, and the inability to physically distance oneself due to limited access to these facilities. At the same time, the pandemic highlighted disparities in equality of access to healthcare facilities, diagnostic testing, and the capacity of local health systems to organize a successful response. There is empirical data showing that marginalized communities had a higher rate of infection, hospitalization, and mortality, which could be explained by socioeconomic vulnerability, underlying comorbidities, and occupational exposure [93]. Key lessons learned during the coronavirus experience include the need for better surveillance systems, public health infrastructure, early warning mechanisms, sanitation, and targeted interventions in poor urban populations. The pandemic highlighted that epidemic preparedness should be part of urban planning, governance, and community engagement.

7. Mental health in the urban environment

Anxiety and depression are among the most common factors impacting life and performance.

7.1 Stress, anxiety, and depression

Urban environments expose residents to the intersection of environmental, social, and economic strain, which significantly increases the risk of stress, anxiety, and depression. The high cost of living, overcrowding, competitive work environments, and constant sensory stimulation may increase cortisol secretion and

affect the ability to regulate emotions. Empirical studies have demonstrated the existence of more mood disorders among people living in urban areas compared to those living in rural areas [57]. Chronic exposure to traffic congestion, long commuting times, and insecurity in the workplace also contribute to psychological stress. According to the WHO [6], depression is more prevalent in urban settings due to ongoing psychosocial pressures and decreased opportunities for recuperative rest. These findings highlight the need for urban planning to consider mental health.

7.2 Social isolation despite high population density

Although metropolitan areas are densely populated, many inhabitants suffer from tremendous social isolation. Urban lifestyles often put limits on intimate social interactions, with busy schedules, long work hours, and fragmented community structures. High-rise housing, neighborhoods induced by migration, and a lack of enduring bonds in communities can undermine the sense of belonging, resulting in feelings of emotional loneliness despite having millions of inhabitants living within them [94]. Research has shown that migrants and young adults living in cities are especially vulnerable to isolation since they usually lack social support structures and face a cultural or linguistic barrier [95]. Social isolation is a powerful prognostic sign for depression, anxiety, and low life satisfaction, suggesting a paradox of the city: Proximity does not mean connection.

7.3 Noise, speed of life, and psychological stressors

The noise pollution from daily traffic, building work, commercial activity, and crowded public spaces contributes to psychological fatigue and emotional stress. Continuous exposure to urban noise has been linked to sleep disturbances, poor concentration, and an increased risk of anxiety disorders [53]. Additionally, the fast-paced nature of urban living, with its associated stress from constant deadlines, rapid technological development, and high occupational demands, can lead to chronic mental overload. Urban residents are frequently under "hustle pressure," where expectations of performance and competition are associated with an increase in psychological stress [96]. These factors are further compounded by overstimulation from advertisements, crowds, and electronic devices, thus diminishing mental capacity for recovery and increasing the risk of burnout.

7.4 Role of green spaces and community interactions

Access to green spaces is one of the strongest protective factors for mental health in the city. Parks, recreational gardens, tree-lined streetscapes, and water bodies offer sensory respite, promote relaxation, and diffuse the stress hormone [69]. Exposure to natural environments improves mood, increases cognitive function, and enhances emotional resiliency. Green spaces also create incentives for physical activity and social interactions, both linked to better mental well-being [58]. Community interactions – neighborhood gatherings, local clubs, and public spaces – are associated with social cohesion and help counteract loneliness. Consistent research shows that urban areas well-designed with public spaces have an observed decrease in rates of depression and anxiety due to higher social support and community engagement [71].

8. Climate change and urban health

8.1 Heat waves, flooding, and excessive weather risks

Climate change has intensified the frequency and intensity of extreme weather events in the urban environment, and heat waves have become one of the most pressing threats to human health. Urban heat islands, caused by high levels of construction, low vegetation cover, and heat-absorbing surfaces, heighten temperature extremes, increasing the incidence of heat stroke, dehydration, cardiovascular stress, and mortality [54]. Vulnerable demographics, such as the elderly, outdoor laborers, and low-income communities, suffer disproportionately high health risks. Beyond heat waves, urban flooding precipitated by intense rainfall overburdens stormwater systems, pollutes drinking water supplies, and increases the spread of waterborne diseases [56]. Extreme events such as cyclones, storms, and droughts add to these poor health outcomes as they disrupt essential services.

8.2 Effects on infrastructure and health services

Climate-induced disruptions seriously affect the functioning of urban infrastructure, reducing the ability of cities to maintain essential services in times of crisis. Decreased or increased elevated temperatures can disrupt transportation networks, electricity grids, and water systems, causing power outages and limited access to clean water, which negatively affect public health [97]. Flooding can cripple roads and hospitals, disrupt supply chains, and hamper emergency response operations. Health facilities in many developing countries are not climate-resilient, and hence, they can be easily damaged to the point of failure (structural damage or service interruption) when exposed to extreme weather conditions. WHO [6] states that climatic events hinder normal healthcare provision, reduce surveillance capacity, and result in an increase in hospital admissions associated with injuries, infections, and heat-related illnesses. As the impacts of climate risks become more severe, urban health systems will have to adapt as quickly as possible to prevent long-term consequences.

8.3 Climate-resilient urban planning technological potential

Climate-resilient urban planning outlines long-term approaches to reduce vulnerability and ensure public health. Key approaches include the expansion of green infrastructure, including urban forests, green roofs, and permeable surfaces, to mitigate heat islands and control stormwater runoff [98]. The integration of nature-based solutions enables city cooling, creates better air quality, and promotes mental well-being. Climate-resilient building designs, high infrastructure, and flood-resilience designs and configurations minimize damage during extreme events. Cities are increasingly implementing early warning systems, climate-responsive zoning, and risk-sensitive land use planning as a means to limit exposure and ensure swift processing of emergency responses [5]. Strengthening public health surveillance, better water management, and investment in renewable energy systems increase urban resilience even further. Effective planning with a focus on equity ensures proper protection and adaptation support for low-income and marginalized communities.

9. Strategies for enhancing urban health

9.1 Urban planning and green infrastructure

9.1.1 Smart city concepts

Smart city approaches combine digital technologies, data-driven monitoring, and sustainable infrastructure in order to improve health, mobility, and environmental quality. Smart transportation systems, real-time air quality sensors, and energy-efficient urban services reduce pollution and congestion and directly boost public health [99]. In **Table 2**, smart cities also promote intelligent waste management, disaster early warning systems, as well as efficient public services that make urban environments safer and more responsive to the needs of their citizens [100].

9.1.2 Nature-based solutions

Examples of nature-based solutions (NBS) include green roofs, urban forests, bioswales, and wetland restoration because they help to reduce urban heat islands, improve air quality, and enhance mental health. Such ecological interventions offer towns and cities, in addition to providing adaptive means to deal with climate change, while also delivering co-benefits including conservation of biodiversity and

Strategy	Description	Health benefits	Evidence/ citation
Smart city systems	Sensors, digital monitoring, efficient services	Reduced pollution, better mobility	[99, 100]
Nature-based solutions	Green roofs, parks, wetlands	Cooler temperatures, mental well-being	101, 112]
Air quality regulation	Emission limits, clean fuel, low-emission zones	Reduced respiratory diseases	[52]
Integrated waste management	Recycling, segregation, sanitary landfills	Lower vector-borne diseases	[102, 103]
Healthy housing design	Ventilation, insulation, natural light	Better indoor air quality	[104]
Strong primary health care	Urban clinics and preventive care	Reduced disease burden	[106]
Mobile health clinics	Health care for underserved communities	Higher access and early diagnosis	[107]
Digital health solutions	Telemedicine, apps, EMRs	Improved access and monitoring	[108]
Community participation	Citizen-led decision-making	More inclusive and healthy environments	[58, 110]

Table 2.
Urban health strategies and evidence.

better management of stormwater [101]. Empirical studies show that people who live near a green space report lower stress levels, better physical health, and stronger socialization [59].

9.2 Pollution control and risk control

9.2.1 Air quality regulations

Stringent air quality standards and emission control policies are important measures in lowering respiratory and cardiovascular-related morbidity in the urban environment. Regulatory frameworks, through emission limitations of vehicles and industrial pollution, as well as the promotion of clean-energy technologies, reduce ambient concentrations of PM 2.5, NO_2, and O_3, as reported by the 14 urban centers that have introduced aggressive air pollution control strategies. Urban centers that have implemented measures such as low-emission vehicle zones and the expansion of public transportation regularly show improvements in the respiratory health outcomes of their residents [51].

9.2.2 Waste management systems

Effective waste management reduces environmental contamination and health risks from open dumping, vector breeding, and water pollution. Modern practices – such as source-segregated waste, recycling programs and sanitary landfills – contribute to safer living environments [102]. Integrated waste management systems, including composting and controlled disposal of hazardous waste, reduce the spread of disease and conserve urban water resources [103].

9.3 Healthy housing and smart architecture

9.3.1 Ventilation and energy-efficient design

Healthy housing is characterized by adequate ventilation, natural illumination, and thermo-comfort, which are of paramount importance for the control of respiratory diseases and general well-being. Energy-efficient building designs – passive cooling, insulation, and renewable use of materials – reduce pollution levels indoors while lowering the demand for energy [104]. Buildings with better air circulation and low-emission building materials offer healthier building environments, which is especially important in high-density cities.

9.3.2 Inexpensive housing policies

The provision of affordable and secure housing is fundamental to ensuring that low-income, migrant, and vulnerable populations are able to reside in safe environments. Policies to promote subsidized housing, slum regeneration, and inclusive zoning are effective in reducing overcrowding and exposure to environmental risks [1]. Empirical studies have shown that access to stable housing is strongly linked with better mental health outcomes, a lower risk of infectious diseases, and favorable long-term socioeconomic trajectories [105].

9.4 Increasing healthcare access in cities

9.4.1 Strengthening primary health services

Robust urban primary healthcare systems are considered indispensable for the management of chronic and infectious diseases, maternal and child health, and emergency care. Integrated primary care networks have a role to play in eliminating health inequalities through the provision of timely diagnosis, preventive care, and community-based interventions [106]. Improved urban health center enable early detection of diseases, thereby reducing the burden faced by tertiary hospitals.

9.4.2 Mobile health clinics

Mobile clinics provide healthcare services directly to marginalized segments of the population, such as people living in slums, migrants, or people with mobility constraints. They help provide immunization, basic diagnostics, maternal care, and chronic disease care and help to reduce barriers to travel [107]. Mobile health initiatives have been shown to be effective in increasing outreach and bridging the inequalities in health care in rapidly growing cities.

9.4.3 Digital health solutions

Digital solutions, such as telemedicine, mobile apps for health, electronic medical records, or artificial intelligence (AI)-based surveillance systems, improve accessibility and efficiency. These technologies allow remote consultations, disease tracking, and personalized care, particularly during pandemics and/or mobility restrictions [108]. Digital health helps to mitigate inequities by connecting marginalized populations to quality information and services linked to health.

9.5 Community engagement and police integration

9.5.1 Role of governments and nongovernmental organizations

Governments, nongovernmental organizations (NGOs), and community organizations have key roles in the implementation of health-oriented policies in cities. Cooperative governance frameworks facilitate evidence-based planning, equitable distribution of resources, and targeted interventions for vulnerable populations [109]. NGOs often play a role in building grassroots health campaigns, sanitation programs, and environmental awareness programs, thereby increasing the resilience and involvement of the community.

9.5.2 Public involvement in urban design

Public participation is essential in ensuring that urban development is pursued in line with the needs and values of the communities it serves. The involvement of residents and neighborhood committees in locally based and participatory planning processes, including mapping and urban interventions, is a way to promote social cohesion and increased acceptance [110]. Empirical studies show that cities that

integrate communities into the planning process foster more inclusive, secure, and healthy environments [111].

10. Case studies

10.1 Examples of developed countries

Developed nations have applied innovative urban health strategies that showcase the positive impact of long-term planning and investment. Copenhagen, Denmark, is world-famous for being a city with an urban design that combines cycling, and almost 60 percent of people commute by bike every day. This shift has meant that traffic emissions have decreased, cardiovascular fitness has improved, and air quality has also improved [113]. The city of Tokyo, Japan, has made outstanding gains in urban sanitation and air quality thanks to stringent pollution control laws, state-of-the-art waste management systems, and compact transit-oriented development [114]. New York City has increased green spaces (particularly through the High Line urban park), which has led to increased physical activity, improved mental health, and revitalized neighborhoods [115]. These are all cases that illustrate how integrated planning, mobility reforms, and environmental controls can directly improve the health of populations.

10.2 Examples from developing countries

Developing countries are exposed to fast urbanization, informal settlements, and resource constraints, but a number of cities have implemented effective solutions. Curitiba, Brazil, is well known for its low-cost, high-efficiency Bus Rapid Transit (BRT) system that helped sharply reduce congestion, air pollution, and accidents while providing low-cost mobility to low-income residents [116]. Bogota, Colombia, transformed public spaces through the TransMilenio BRT, bike lanes, and weekly Ciclovias, which encourage physical activity and positive community cohesion [117]. In India's Delhi, aggressive diesel vehicle regulations, metro construction, and odd-even road rationing led to short-term improvements in air quality and a decrease in the risk of respiratory illnesses [83]. Meanwhile, in Cape Town, South Africa, community health outreach programs and mobile clinics were launched to overcome the issue of inequality and increase access to primary care [118]. These examples highlight how the use of strategic planning and innovation can produce health benefits even in resource-constrained settings.

10.3 Success in urban health programs

Effective interventions of this kind often incorporate green infrastructure, transportation reform, and community involvement. The Healthy Cities Initiative, issued by the WHO, provides empirical data on the improvement of urban environments like Toronto, Singapore, and Accra, which can be attributed to improved sanitation, integrated health planning, and cross-governmental cooperation [109]. Green infrastructure programs, typified by

City and country	Type	Intervention	Health impact	Citation
Copenhagen, Denmark	Developed	Cycling-first mobility system	Reduced air pollution, higher physical activity	[113]
Tokyo, Japan	Developed	Strict air quality laws and efficient public transit	Lower respiratory illness, clean air	[114]
New York, USA	Developed	Urban green space expansion (High Line)	Improved mental health and walkability	[115]
Curitiba, Brazil	Developing	Low-cost BRT system	Reduced congestion and air pollution	[116]
Bogotá, Colombia	Developing	TransMilenio BRT, Ciclovía events	Better physical activity and public fitness	[117]
Delhi, India	Developing	Vehicle regulation + metro expansion	Short-term decline in PM levels	[65]

Table 3.
Case study comparison of urban health interventions.

Singapore's "Garden City" model, have helped to mitigate heat stress, boost mental well-being, and support biodiversity through high levels of urban parks, green roofs, and nature corridors [112]. In the city of Melbourne, Australia, urban greening integrated with heat action plans significantly lowered heatwave-related mortality [55]. Community-led waste management in cities such as Pune in India, where the refuse is collected and segregated by waste picker cooperatives, has led to improved sanitation with a reduction in vector-borne diseases [119]. In **Table 3**, these interventions are evidence of health outcomes improving where the intersection of environmental design, governance, and public engagement exists.

10.4 Global comparison of global cities

Comparative studies of cities around the world show great variation in the impact of infrastructure and governance on health outcomes, as well as public investment. European cities like Amsterdam, Stockholm, and Zurich, which focus on cycling, compact cities, and tough air quality standards, result in higher rates of cycling, lower obesity rates, and lower rates of respiratory disease [120]. In contrast, many Asian megacities, such as Manila, Jakarta, and Dhaka, face challenges such as overcrowding, air pollution, and informal settlements, though progress has been made by expanding mass-transit and investing in flood control infrastructure [121]. North American cities have spent considerable money revamping green spaces and smart technology with mixed success based on socioeconomic inequality. Meanwhile, African cities like Kigali have achieved massive sanitation and cleanliness gains through strong governance and community-led environmental programs [122]. This comparative perspective underlines the fact that cities that have proactive planning, with good public participation and integrated transport–environment policies, tend to always show better health indicators.

11. Conclusion

11.1 Summary of key points

The city environment has a significant impact on human health through interrelational environmental, social, and infrastructural interactions. In this chapter, the effects of air quality, noise, heat islands, congestion, poor sanitation, and the lack of green space on physical and psychological health are reviewed. Other factors that characterize urban lifestyles, such as sedentary behavior, the nutritional environment, and social isolation, are additional determinants that contribute to the burden of diseases. The results of empirical investigations of metropolitan regions in any country of the world show that proactive policies, including green infrastructure, sustainable mobility systems, climate-resilient design, and improved access to healthcare, play a significant role in mitigating these threats. The evidence, therefore, highlights the fact that urban health issues are multidimensional in nature and should be addressed through integrated and long-term approaches.

11.2 Quantifying the relevance of health management in urban planning

Health considerations should be integrated into the urban planning process to create resilient, equitable, and sustainable cities. By integrating these three aspects – environmental perils, socioeconomic inequalities, and infrastructural shortfalls – into the initial design phases, rather than as an after-thought, municipalities stand a better chance of addressing these aspects concurrently. Planning with a focus on health leads to the growth of green areas, the promotion of active transportation, the improvement of housing conditions, and the reduction of urban pollution. Interprofessional cooperation between architects, planners, government officials in health, environmental agencies, and the community ensures that the interventions are accommodative, contextual, and sensitive to community needs. The inclusion of health in urban policy reduces the burden of disease and increases well-being, productivity, and the general quality of life for urban dwellers.

11.3 Future research directions

The development of research in the field of urban health requires the creation of scalable, context-sensitive solutions that are attuned to the emerging forces of urbanization and climate change. There is an urgent need for interdisciplinary analysis, which includes public health, environmental science, data analytics, and urban design, in order to clarify the complex nature of urban risk profiles. Modern studies on the long-term effects of heat islands, composite exposures to air pollution, micro-mobility systems, and digital health technologies are likely to achieve a new level of importance. It is necessary to conduct more empirical research to determine the effectiveness of nature-based interventions and smart city technologies in improving health outcomes. In addition, future studies must focus on vulnerable groups within the population living in informal settlements so that urban health strategies can enhance equity and social justice. The fortification of data infrastructures, promotion of community involvement, and implementation of real-time surveillance systems will form the foundation of evidence-based policy responses in fast-changing urban settings.

Author details

Rathod Sridhar[1], Hanuman Singh Jatav[2*], L. T. Longkumer[1], Avinash Pilla[3], Satish Kumar Singh[4], Prem Kumar Bharteey[5], Eetela Sathyanarayana[6], Martin Leonardo Battaglia[7,8] and Aakash Kumar Saini[9]

1 Department of Agronomy, School of Agricultural Sciences, Nagaland University, Medziphema, India

2 Department of Soil Science and Agricultural Chemistry, Sri Karan Narendra Agriculture University, Jobner, India

3 Department of Agriculture, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India

4 Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India

5 Department of Agricultural Chemistry and soil science, C.C.R. (P.G.) College, Muzaffarnagar, India

6 Department of Soil Science and Agril. Chemsitry, Agricultural College, Palem, PJTAU, Hyderabad, India

7 Regenify Ag, Ithaca, US

8 Lomas de Zamora University, Buenos Aires, Argentina

9 ICAR-Indian Institute of Soil Science (IISS), Bhopal, India

*Address all correspondence to: hanumaniasbhu@gmail.com; hsjatav.soils@sknau.ac.in

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Chapter 4

Chronic Respiratory and Neurological Disorders Associated with Chronic Ultrafine Particle (UFP) Exposure in Urban Areas

Joseph Eloge Tiekwe, Solange Dabou, Loic Kojom and Phélix Bruno Telefo

Abstract

Ultrafine particles (UFP), with their aerosol diameter smaller than 100 nm, are of increasing relevance to public health. Their small size, high surface area, and capacity to aggregate with other pollutants, metals, and some microorganisms can allow UFP to chronically disturb lung function, translocate across biological barriers, accumulate in the brain, and initiate molecular processes linked to neurological diseases such as Alzheimer's, dementia, Parkinson's disease, and multiple sclerosis. Due to their highly reactive properties, UFP, according to recent studies, can induce neuroinflammatory reactions, oxidative stress-associated-reactions, and apoptosis, leading to the development of several neurodegenerative disorders. The main objective of this review is to highlight the pathophysiological evidence of the chronic respiratory and neurological disorders associated with chronic UFP exposure, with a regional focus on urban populations. A narrative synthesis of recent epidemiological cohort data, in vivo and in vitro toxicological studies, and urban exposure assessments was conducted to provide a more comprehensive understanding of the translocation pathways of UFP through the blood-brain barrier or olfactory nerve, as well as cellular mechanisms (neuroinflammation, oxidative stress, protein aggregation) in the nervous system. Evidence suggests that chronic UFP exposure contributes to an increased risk not only for lung function disturbances but also for neurodegenerative diseases, including Alzheimer's, Parkinson's disease, multiple sclerosis, and cognitive deficits. The most affected individuals are often children and the elderly. According to findings presented in some studies, aggregated-UFP were detected in postmortem human brain tissue, supporting a causal pathway. Urban monitoring data indicate considerable regional and socioeconomic disparities in exposure across some cities.

Keywords: ultrafine particles (UFP), respiratory disorders, neurodegeneration, Alzheimer's disease, Parkinson's disease, multiple sclerosis

1. Introduction

Some harmful air pollutants have been under the monitoring of the World Health Organization (WHO) for several years, and among the known particulate matter that has been specifically monitored due to substantial evidence linking it to premature deaths worldwide, ultrafine particles (UFPs) have been revealed to have more toxic effects on human health [1]. Due to their ultrafine aerosol diameter (<100 nm), UFPs are considered, according to recent studies, a significant health risk. In 2021, the WHO updated its global air quality guidelines, emphasizing the adverse health outcomes caused by UFPs and highlighting the importance of monitoring them [1]. The different compounds of UFPs include various elements and molecules, such as elemental carbon (EC), organic carbon (OC), and other water-soluble ions like $NH4^+$, Na^+, K^+, and SO_4^{2-}. Their sources in ambient air are diverse and are categorized into primary and secondary sources. Primary sources emit UFPs directly and have been identified as anthropogenic, including traffic emissions (often resulting from incomplete fuel combustion), industrial emissions, construction dust, biomass combustion, domestic fuel burning, engineered nanoparticles [2, 3] and natural sources such as volcanic activity, forest fires, marine aerosols, and mineral deposition [2, 3]. Sources, on the other hand, arise from dynamic photochemical processes, which involve reactions between existing low-volatility gaseous air precursors (SOx, NOx) and hydroxyl groups (OH^-) to form sulfuric acid vapors [2].

The residence time of UFP in the atmosphere, their transport distance, their capacity to aggregate with organic compounds, metals (Cd, Pb, Hg, Ni, Cr, Zn, and Mn), and trace elements, their surface area, and their electromagnetic charge give them the ability to greatly impact organisms' health [2], particularly susceptible groups such as the elderly and children [3]. UFP, with their smaller aerodynamic diameter combined with the morphological factors of the human lung, are inhaled deeply into the respiratory system, penetrate further to the level of pulmonary alveoli, and translocate into the circulatory system [1, 2]. They could, therefore, affect other organs such as the cardiovascular system, liver, kidneys, and brain. The penetration of UFP into the body causes the mobility and activation of inflammatory factors and cells, particularly macrophages, which proceed to eliminate the UFP through phagocytosis in the vascular system. The mobilized macrophages are assisted by inflammatory factors such as tumor necrosis factor-α (TNF- α), interleukin-8 (IL-8), interleukin-6 (IL-6), and interleukin-1β (IL-1β) [3, 4], which are implicated in the neutralization of unidentified agents via inflammatory mechanisms. Furthermore, the metals or other elements in UFP can create increased reactive oxygen species (ROS) or free radicals. These ROS, in increased quantities, could cause damage to cells, tissues, and organs [2, 3]. UFP combined with absorbed constituents can also directly access the nervous system via the olfactory and trigeminal nerves by circumventing the blood-brain barrier (BBB) [1, 5, 6]. However, there are only a small number of studies revealing the biological mechanisms through which UFP lead to neurological disorders. A few recent studies have revealed that neuroinflammatory reactions, oxidative-associated reactions, and excitotoxicity, leading to cellular disorders such as mitochondrial damage, apoptosis, synapse dysfunction, and neurodegeneration, are implicated in most neurological diseases such as Alzheimer's, Parkinson's disease, and multiple sclerosis [1, 3, 7].

The main objective of this review paper is to provide the implications of UFP through diverse molecular and epigenetic mechanisms in the development of neurodegenerative disorders in populations living in urban areas. Therefore, we will first discuss the different urban sources of UFP, their characteristics, and exposure modes, followed by the importance of the physicochemical properties and biological mechanisms in the translocation of UFP through the pulmonary alveoli and the development of neurological diseases. Moreover, it is also very important, according to recent findings, to present future perspectives and outlooks to develop UFP regulation not only in Europe but also worldwide.

2. Definition and physicochemical properties of ultrafine particles (UFPs)

UFPs, also called "nanoparticles," have an aerodynamic equivalent diameter of less than 100 nm or 0.1 μm (**Figure 1**) [2] and exist in the environment in various forms, notably artificially synthesized or naturally occurring [3]. Their physicochemical characteristics are due to their different morphological properties, surface area, compositions, and functional groups. Factors such as climate, season, environment, and emission sources influence these physicochemical properties, presenting a significant challenge in analyze their toxic components. Some proxy units, such as surface area per particle, mass, particle number (PN), or the concentration of any of these per volume, are used to describe UFPs [2, 8, 9]. The quantities of ambient UFPs can be evaluated using particle number concentration (PNC) and particle number size distribution (PNSD). However, their smaller aerodynamic diameter allows them to remain suspended in the air for a more extended period compared to larger particles [2].

The time in ambient air, area diffusion, and flow processes of atmospheric UFP are significantly affected by environmental conditions [2, 9], which include the direction and speed of wind, temperature variations, moisture, height of mixing, orography (land relief, geomorphology, topography, and vegetation), rainfall, solar radiation, and other physicochemical events (chemical, physical, or biological transformations) that differ according to the location [2, 9].

Sometimes, UFP appears variable and enhances larger forms through coagulation and condensation. These formed particles are essentially made up of accumulated water ions (sulfates, nitrates), trace metals, EC and OC, and absorbed volatile and semi-volatile organic compounds [9]. Compared to other larger particles, the

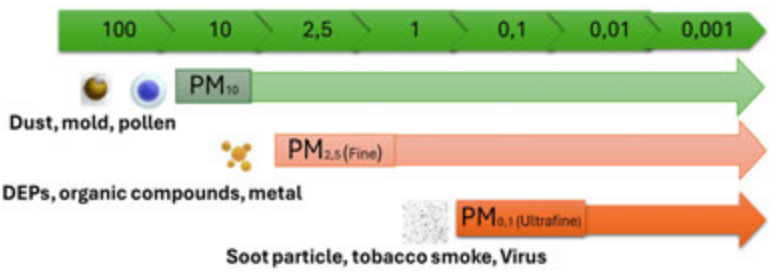


Figure 1.
Ambient particles categorized by aerodynamic diameter.

number of UFPs per unit volume is significant. This increases the surface area and absorption of other polluting elements, such as organic gases and potentially toxic elements, forming larger coated or agglomerated particles with higher toxicity. The physicochemical properties of UFPs can be determined by the type of chemicals that build their nucleus and surfaces [2, 9]. This means that the precursor pollutants from the combustion process of certain compounds, such as polycyclic aromatic hydrocarbons (PAHs), OC, water ions (NH_4^+, Na^+, K^+, and SO_4^{2-}), hazardous substances, and oxidizing agents, have the capacity to dictate the composition of UFPs [2]. The radiation of UV (UV–A, UV–B) can modify the chemical properties of UFPs, and the ambient UFPs might be enriched with transition metals and highly oxygenated organic molecules, which not only possess harmful features but also exhibit high oxidant capability [9].

Regarding the chemical composition of UFPs, very few studies have been observed that focus on this aspect. Recent studies have utilized the segregation of UFPs' PNSD according to the chemical composition of the source and the type of conditions to characterize this aspect. Most studies use this approach due to the prevalent challenge of profiling PNSD during UFP nucleation and growth processes, which has become the focal point for developing mechanisms of new UFPs [2]. When studying the chemical composition of ambient-formed UFPs, it can be observed organic compounds, EC (black carbon [BC], OC), trace metal oxides (Al^{3+} Fe^{3+}, Cu^{2+} etc.), water-soluble ions (NH_4^+, SO_4^{2-}, NO_3^-), and PAHs (naphthalene, biphenyl, dibenzofuran etc.). BC, OC, and EC generally form the total mass of carbon in UFPs, and their relatively high carbon content is most often derived from the smoldering of organic biomass and the combustion of fuel [2]. Sulfate particles appear to be associated with toxic components such as transition metals or organic carbon [9].

3. Different sources of ambient air UFPs

Among the various identified sources of UFP, some are primary, while others are secondary. Most of the UFP in ambient air vary in composition and size depending on the emission source profile [2]. Primary sources involve the direct emission of UFP into the ambient air, whereas secondary sources contribute to UFP formation through the transformation of existing gaseous precursors. Primary sources are categorized into anthropogenic and natural sources (**Figure 2**). Anthropogenic sources include vehicle emissions (exhaust or non-exhaust), seaports, marine transportation, industrial emissions, domestic wood stoves, biomass burning, cigarette smoke, photochemical generation, and dust (from demolition, construction, roads, and agriculture). Natural sources encompass volcanic activity, forest fires, marine aerosols, drainage, runoff, biological particles, and mineral deposition [3, 9].

3.1 Anthropogenic sources of ambient UFP

According to several studies, ambient air UFPs in urban or suburban environments mostly originate from vehicle exhaust emissions. The combustion gases produced by vehicle emissions contain particles with characteristics that depend on various factors, such as the fuel composition, lubricants, thermodynamic

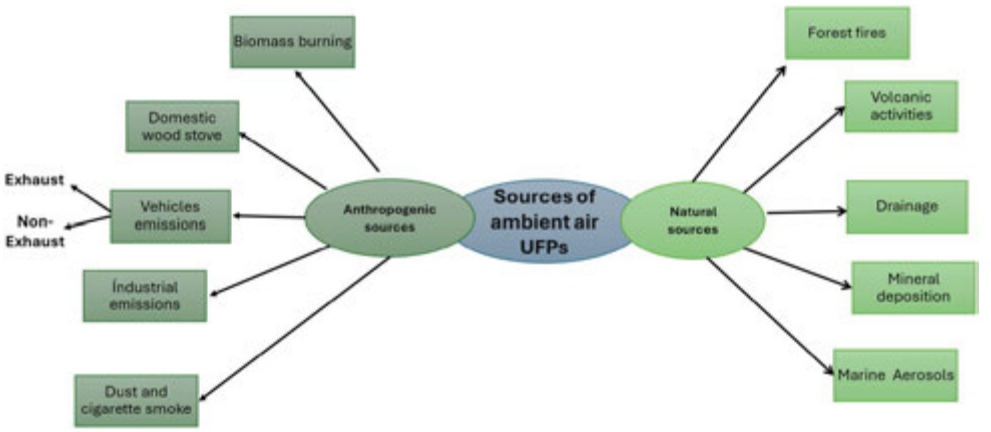


Figure 2.
Different sources of ambient air UFPs.

conditions, ignition technology, and the number of vehicles in operation [9]. However, UFPs in diesel and gasoline vehicle exhaust often contain calcium, sulfur, phosphorus, zinc, and iron compounds.

It is observed that most of the UFP emitted by diesel engine vehicles are in the range of 20–130 nm, whereas those emitted by gasoline vehicles are in the range of 40–80 nm [3, 9]. The engines of vehicles, such as light- and heavy-duty vehicles from large modes of transportation (buses, trains, trucks), are the main contributors to UFP concentrations in ambient air. However, some studies reveal that parameters such as the geometric mean diameter (GMD) of UFPs during the nucleation mode for diesel engine vehicles are in the range of 5–15 nm, while in the accumulation mode, they are in the range of 35–77 nm [2].

The vehicle's exhaust emissions are sometimes the source of BC, which is an aerosol resulting from the incomplete combustion of fossil fuels [9]. BC is often taken as an indicator of the type of fuel and the type of combustion because its physical characteristics and concentration levels change with fuel type [9]. Regarding the chemical composition of UFPs from vehicle emissions, they contain high carbon content and a significant number of surface oxygen-containing functional groups, which can lead to increased toxicity [3]. The interaction between specific parts of vehicles and the road or other surfaces can also be the origin of emissions of UFPs. This type of emission, called non-exhaust vehicle UFP emissions, is significantly implicated in ambient UFPs PNC.

The fuel combustion process may release emissions from sea vehicles used for various purposes, such as passenger transport, shipping, and exploration, in the form of considerable amounts of UFP. The type of engine and fuel significantly influence the quantity of UFPs emitted through their plumes [2]. It is important to note that the fate of these UFP emissions remains relatively unknown, as the ambient UFP concentration above the sea is extensively vast. These particles could either sink into the ocean or be carried by monsoon winds to the nearest land [2]. Emissions from aerial vehicles are closely related to aircraft and aviation activities and are also considered a major source of ambient UFPs. Evidence that aircraft activities influence UFP emissions can be demonstrated by defining elevated PNC

levels near certain airports [2]. Recent studies have revealed that aviation activities can affect UFP levels in ambient air near residential areas, which may result in elevated indoor UFP PNC levels [2].

The industrial emissions, along with the related-transport emissions of UFPs, are also implicated in the release of a considerable amount of airborne UFPs, which can vary depending on the scale of the industry, the processes involved, and the fuel sources used. Only a few studies discuss the composition of ambient UFPs originating from industrial emission sources [2]. According to recent studies and based on principal component analysis (PCA), it was revealed that certain industrial plants (e.g., Cu-smelter plants, oil refineries, and petrochemical plants) could contribute to increased ambient UFPs PNC events near residential areas in several cities. The GMD size of UFPs, primarily attributable to industrial emissions, may vary depending on the specific emissions processes [2]. Among industrial emissions, heavy industries are considered one of the largest anthropogenic sources of airborne trace metals, which are essential components of ambient UFPs [9].

The combustion of biomass is mainly implicated in ambient UFP emissions in the accumulation mode and is largely composed of organic matter with about 10–20% of BC, as well as inorganic species such as sodium, potassium, calcium, titanium, manganese, iron, cobalt, nickel, chromium, antimony, arsenic, selenium, sulfur and chlorine. The composition of emitted UFPs from this type of source fluctuates according to several parameters, such as the combustion appliance, fuel type, combustion phase, and measurement methods. Their contribution to ambient air UFPs in urban and suburban areas is significant, and recent studies have revealed that the concentration of air UFPs from burning biomass at suburban sites is 1.7 times larger than in urban areas due to the nature and conditions of the surroundings [2]. Biomass burning could also be a significant contributor to UFPs PNC at sites near residential and urban industrial areas. Concerning other anthropogenic sources, cooking activities are implicated in indoor UFP emissions and are sometimes a contributing factor to ambient UFP PNC. The type of emitted UFPs from cooking activities depends on the ingredients used, the type of fuel used for cooking, and the cooking style [2, 10].

3.2 The natural sources of ambient UFPs

Among the natural sources of ambient UFPs, volcanic eruption events are the main source of ambient air UFPs. Some studies revealed that UFPs from volcanic events have a relatively high number of mean PNC, and the size of UFPs can be within the range of 40–400 nm [2]. Concerning marine aerosols, they consist of primary-sea-salt aerosols, which are emitted from the physical disturbance of the ocean surface, and secondary aerosols, which are mostly made of non-sea-salt sulfate and organic species resulting from gas-to-particle conversion processes. Depending on the latitude region of the marine area, the overall PNC varies between 200 and 800 cm^3 [2].

However, the other natural source of emitted ambient UFP is forest fires (pyrogenic processes), which are sometimes associated with OC and EC [2, 9]. These UFPs from forest fires possess comparable features to those from the combustion of biomass [2].

3.3 The secondary source of ambient air UFPs

The UFPs from secondary sources are mainly generated through mechanisms of nucleation and growth from gaseous precursors. This phenomenon is referred to as new particle formation (NPF) (**Figure 3**) and occurs in both polluted and clean residential areas. Recent studies reveal that one of the crucial precursors of nucleation is sulfuric acid. The nucleation process also involves the presence of highly oxygenated molecules and organic compounds [2]. Different stages can occur during this process: It is primarily observed that reactions between gaseous compounds such as SOx, NOx, and OH^- form sulfuric acid vapors, which self-combine to form critical nuclei with a base size of about 1 nm, assisted by H_2O. Then, the nucleated particles collide with each other or coagulate with other existing particles resulting from newly formed nuclei. Furthermore, the growth of nuclei could continue into nucleation-mode particles through a homogeneous process that includes the condensation of low-pressure particles, or through a heterogeneous pathway, which can be described as the scavenging process of low-pressure nuclei on the surface of other particles [2].

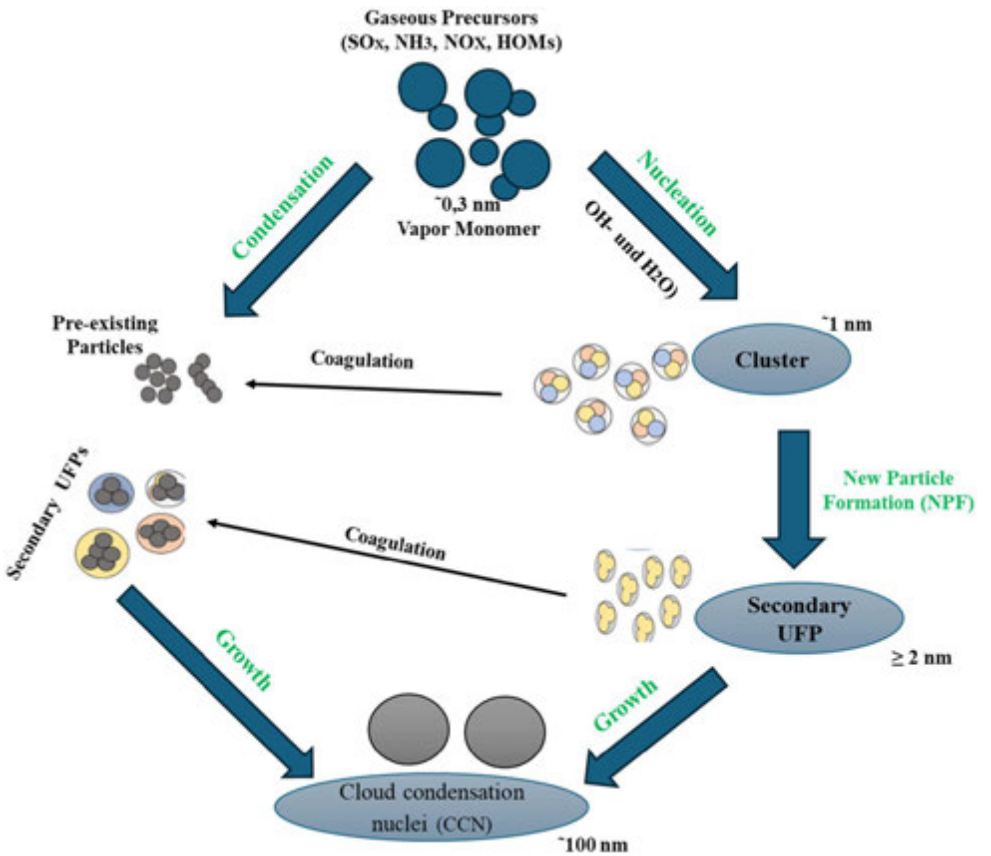


Figure 3.
Process of new particles from UFPs through secondary sources [2].

According to the results of some studies, new particle formation processes might be categorized by the rapid increase in the PN concentration in nucleation-mode particles, which results in a larger diameter [11]. Compared to polluted urban sites, clean rural background sites exhibit a higher NPF frequency. The growth and formation rate of particles are often higher at roadsides [2].

4. Uptake pathways of ambient air UFPs through respiratory system and molecular mechanisms in lung cells

The inhalation pathway is the main uptake pathway of exposure to ambient air UFPs, which can lead to greater effects on human health than other pathways. The high risk of UFP exposure and their inhalation is observed near roadsides and industrial areas and can be influenced by factors such as increased rates of source emissions, UFPs concentrations, and inhalation parameters. Furthermore, pre-existing respiratory diseases can increase the susceptibility of exposed individuals to UFP exposure [2].

In the respiratory system, the coat of mucus is generally used as the first line of defense against the transport of larger particles in the membrane of the respiratory system [12]. The cilia and mucus in the nasal mucosa help the nose filter out the dust and dirt that we breathe in. Particles with an aerodynamic diameter of less than 2.5 μm, or UFPs, cannot be filtered and can pass through to access the lower airway, alveoli, and the final part of the bronchioles [2, 13]. Inhaled UFPs penetrate first into the nasal cavity, then move further into deeper regions through the trachea, bronchi, and alveoli (**Figure 4**). The UFPs are influenced by random and erratic movements during their deposition in the acinar region of the lungs. These movements result in collisions with some gas molecules [13]. The diameter of human cells, particularly those of the pulmonary alveoli, plays a crucial role in the deep penetration of UFPs, as they are significantly larger than UFPs.

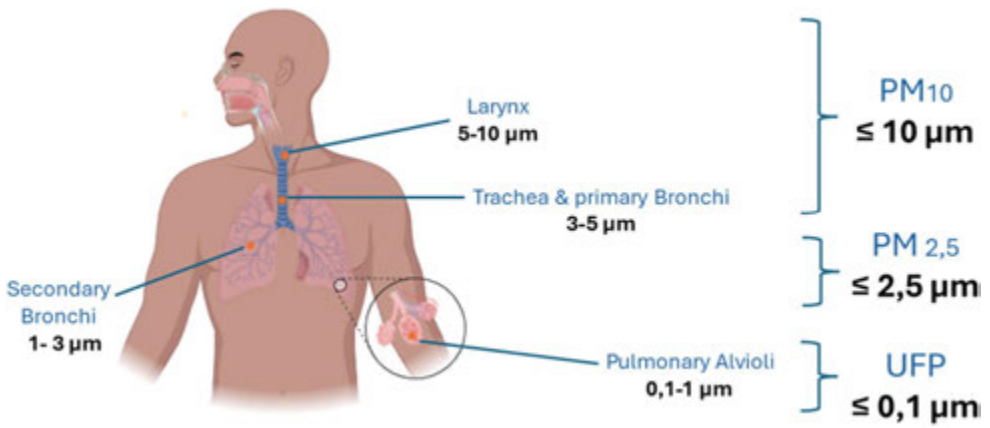


Figure 4.
Penetration of ambient air UFPs in the respiratory system.

However, in addition to their properties such as shape, size, surface area, electromagnetic charge, and chemical content, combined with the morphological and physiological factors of human lungs, the deposition of UFPs in the respiratory tract also depends on age, physical activity, health condition, and inhalation capacity [2].

The prevention of the deeper penetration of UFPs is accomplished by immune cells in the lungs, notably macrophages and non-ciliated bronchiolar epithelial cells. The process that removes inhaled UFPs from the lungs is primarily carried out by alveolar macrophages. The infiltrated macrophages increase the pro-inflammatory response triggered by the action of UFPs (**Figure 5**) [3]. The activated macrophages in the respiratory system proceed to eliminate the UFPs via phagocytosis and mucociliary clearance [9]. The release of cytokines (TNFα, IL-1β, IL-6, IL-8, and IL-18) and chemotoxins facilitates the neutralization of unidentified agents through the inflammatory response in the system.

The heterogeneity of UFPs, with a mosaic of compounds such as metals (Fe, Co, Cr, Cd, Hg, Ni, and Pb), BC, and PAHs, could impact various biological activities and respiratory alterations. Over a prolonged period of action in the airways, UFPs can lead to the recruitment of inflammatory cells and the production of associated-oxidative species from redox reactions in the mitochondria, which can damage cell membranes (lipid peroxidation), proteins, and DNA (epigenetic changes and disruption of DNA strand breaks) (**Figure 6**) [2, 3, 9]. The mutagenic, genotoxic, and carcinogenic properties are attributed to substances such as PAHs and N-PAHs present on the surface of UFPs. Genomic instability gives cells the ability to develop carcinogenic processes. The rate of alterations is related to the loss of fidelity in mechanisms such as DNA replication, chromosomal segregation, DNA repair, and cell cycle progression [9]. Furthermore, UFPs can induce programmed cell death through apoptosis.

This process contributes to impaired lung function and is associated with an amplified risk of pulmonary disorders (lung dysfunction, inflammation, asthma, COPD, lung cancer), particularly in the case of chronic exposure [14]. Several studies reveal an association between exposure to particulate matter, particularly UFP, and an increased risk of lung cancer. It consists of different steps during chronic UFP exposures. They are:

Small cell lung cancer (SCLC), with small cell carcinoma accounting for approximately 10–15% of all lung cancers, is often associated with early, widespread metastasis.

Non-small cell lung cancer (NSCLC), which consists of adenocarcinoma (40% of total cases), squamous cell carcinoma (25–30% of total cases), and large cell undifferentiated carcinoma (10–15% of total cases), often includes minimally invasive adenocarcinoma (MIA) and adenocarcinoma in situ (AIS). The time interval between the first exposure and the development of carcinoma is generally more than 20 years [12, 15].

However, the inhaled but not eliminated UFPs in the respiratory tract translocate into the human bloodstream via alveolar cells and can affect other extrapulmonary tissues [2, 13]. The compounds present in UFPs can accumulate selectively in adipose tissue and interact with other substances, increasing their toxicity. The chemical characteristics, reactivity, and affinity of the chemical substances influence this toxicity [2].

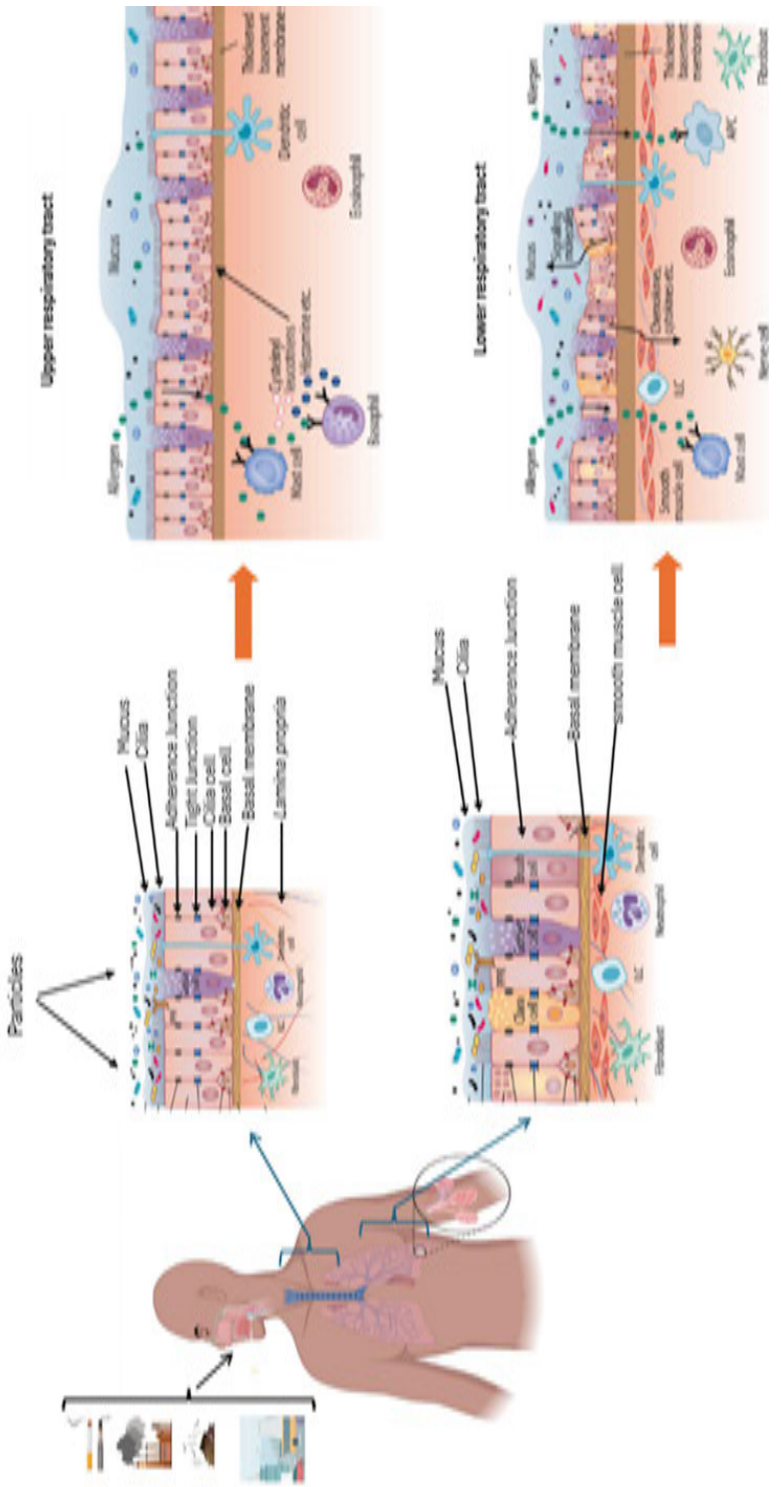


Figure 5.
Mobilization of cells and factors of defense in the lungs after penetration of UFPs.

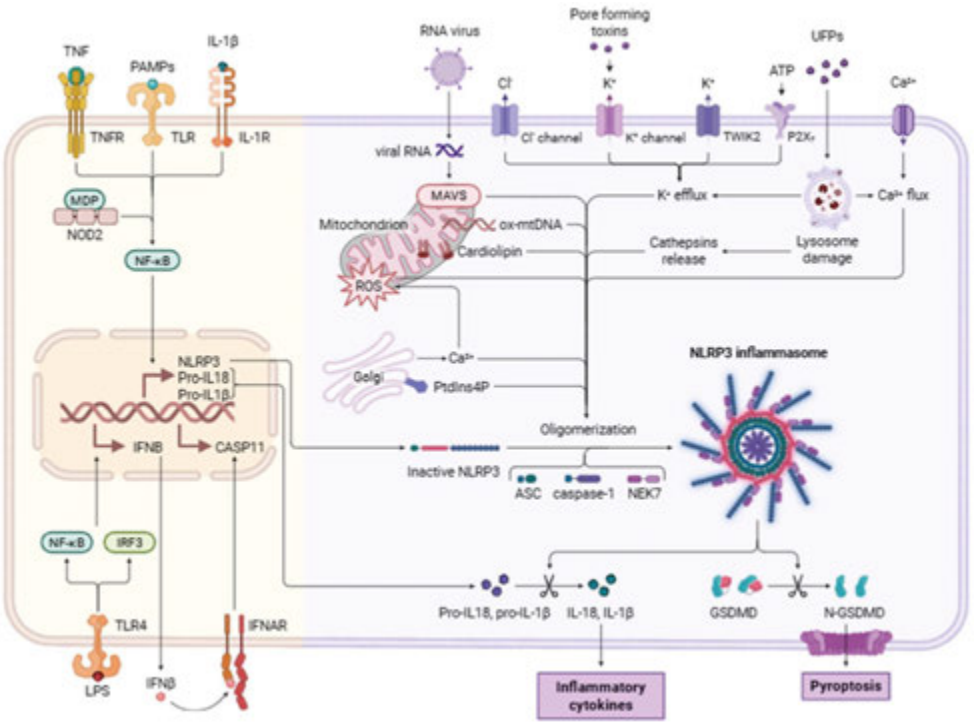


Figure 6.
Molecular mechanisms of interactions of compounds from UFPs in pulmonary cells (created with BioRender).

5. Penetration of UFP in the central nervous system and development of neurological disorders

Recent evidence from the results of several studies reveals that elevated concentrations of UFPs are associated with neuronal deficiencies and neurological diseases, including Alzheimer's, Parkinson's disease, autism, and multiple sclerosis [9]. Indeed, translocated UFPs in the bloodstream can penetrate the brain parenchyma through the BBB (**Figure 7**). The infiltration via the BBB occurs either through passive crossing by simple diffusion (passive lipophilic materials) or through protein-mediated, energy-dependent active transport carriers or receptors [16]. It has been revealed that the BBB is progressively damaged by the long-term penetration of UFPs. The abnormal proliferation of astrocytes and the decrease in their cell viability are also observed [3].

However, the UFPs can penetrate the central nervous system directly via the olfactory nerve (along the olfactory neurons retrograde) into the olfactory bulb (**Figure 8**). Furthermore, some results from recent studies show the growth of lesions on the amygdala and histopathological damage in the striatum of the brain.

There is also a two-way interaction between the amygdala and striatum, the decrease in the production of dopamine, changes in the density of D2 receptors (D2R), and the activation of astrocytes associated with UFP penetration [3].

However, according to several studies on animals' central nervous system, the different observed mechanisms implicated in the development of neuronal

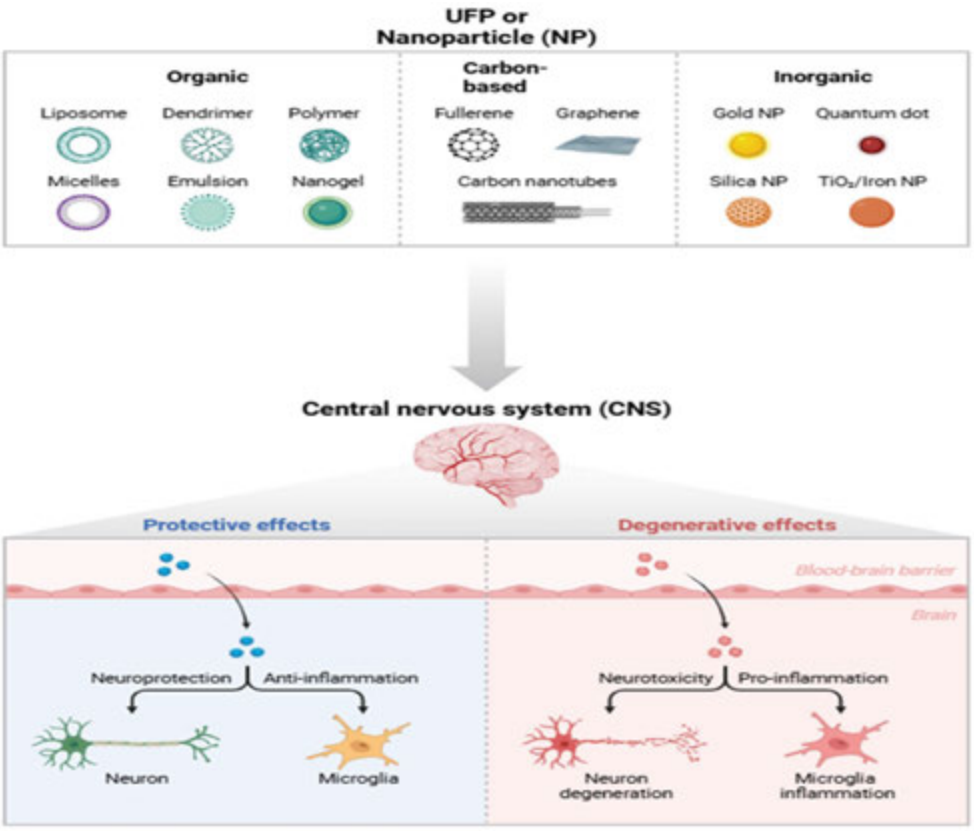


Figure 7.
Penetration of UFPs in CNS through BBB (created in BioRender).

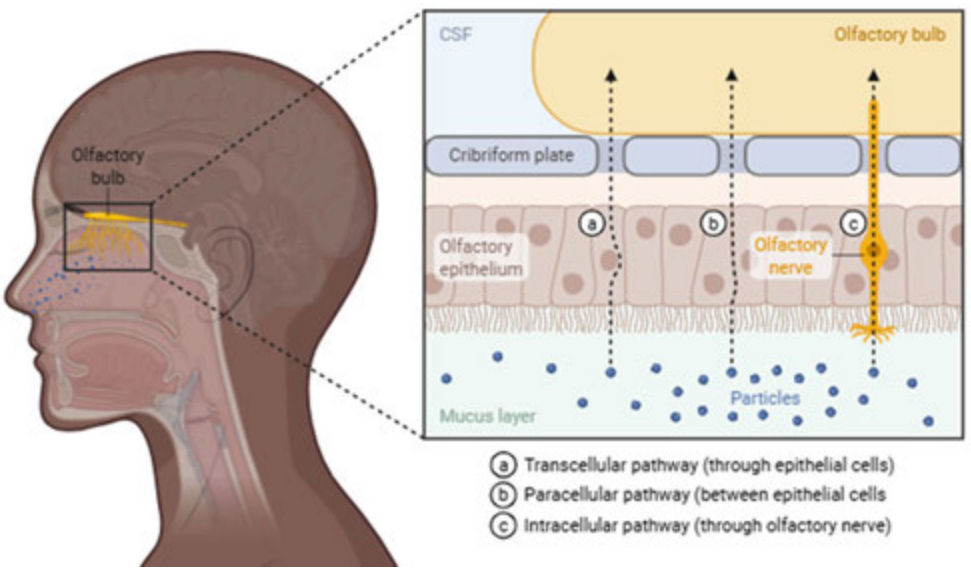


Figure 8.
Penetration of UFPs in CNS through olfactory bulb (created in BioRender).

deficiencies and neurological diseases associated with the penetration of UFPs and their compounds, notably diesel exhaust particles (DEPs), are neuroinflammation, enhanced oxidative stress, and aggregation of neuronal protein [9, 13], along with dopaminergic neuron mitochondrial function damage, cell phase block, excitotoxicity, apoptosis, and synapse dysfunction [13]. Altered inflammation-related gene expression and increased markers of neuroinflammation are also observed [6]. The nervous system impairment can be caused by the destruction of neuronal architecture through the affectation of cytoskeletal proteins [3].

In the hippocampus, altered neuronal morphology and reduced neurogenesis due to the penetration of UFPs and their compounds are associated with neuroinflammation in microglia, astrocytes, and neurons, and may be linked to dementia, aging, epilepsy, and other neurodegenerative disorders such as depression, anxiety, emotional and memory impairment, and cognitive disorders [6, 13, 17].

In the results of some studies, inflammatory cytokine responses in adult male mice and altered morphology of certain regions, such as CA_1 and CA_3 regions of the hippocampus, were observed [6]. Moreover, increased activation of microglia and glia releases pro-inflammatory factors and increases the expression of the genes Gfap and Iba-1 [13]. It is also observed not only that the release of inflammatory chemicals in the corpus callosum leads to an intensification of inflammatory factors such as IL-1β, IL-6, and TNFα, but also that there are variations in the expression of DNA methyltransferase 1 and transcripts related to the JAK2/STAT3 pathway [13].

The protein aggregation can promote UFP misfolding of proteins (tau, β-amyloid, α-synuclein), leading to aggregate formation and neuronal degeneration [18], a key feature in neurodegenerative diseases such as Alzheimer's and Parkinson's disease. In Alzheimer's animal models, the overactivation of the immune system in the CNS activates the Aβ oligomers' clearance and the release of inflammatory chemicals in the *corpus callosum,* with a consequent increase in IL-1β, IL-6, and TNFα [13].

In Parkinson's disease, the crucial point is the *substantia nigra*, where dopaminergic neurons are particularly sensitive to oxidative stress [19]. UFPs, especially those containing transition metals (Mn or Fe), minerals, metals, carbonaceous, and organic components, can intensify neurotoxic processes through Fenton reactions [20]. Not only are damage and loss of melanized dopaminergic neurons observed, but also an accumulation of Lewy bodies. Different dopamine pathways are affected at different stages (**Figure 9**) [9, 13, 18]. The *nigrostriatal* pathway is affected in the early and middle phases, consequently impacting the production of voluntary movements. Other pathways, such as the mesocortical, mesolimbic, and tuberoinfundibular systems, are affected later and influence cognition, memory, and learning, as well as motivation (mesocortical system), emotion, perception, reward (mesolimbic system), sensory processing, hormonal regulation, and maternal care (tuberoinfundibular system) [21].

The development of multiple sclerosis is due to the damage to fibrinogen from the blood vessels of the BBB and its entrance into the central nervous system (**Figure 10**). In this case, an activation of autoreactive T-cells and the partial or total damage to the BBB is observed. Demyelination and axonal degeneration are also observed [22].

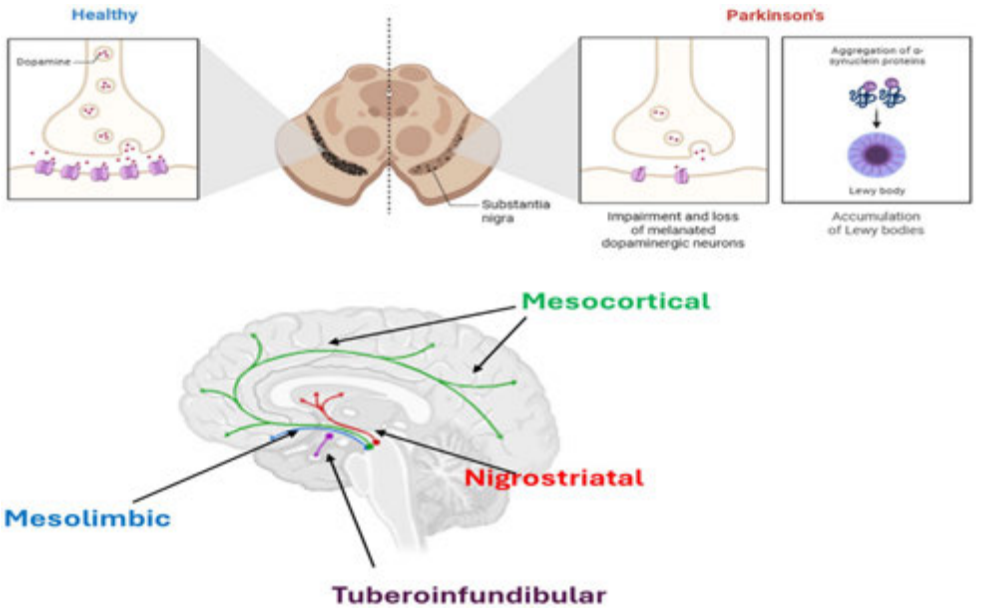


Figure 9.
Affected dopamine pathways due to UFP penetration in Parkinson's disease (created in BioRender).

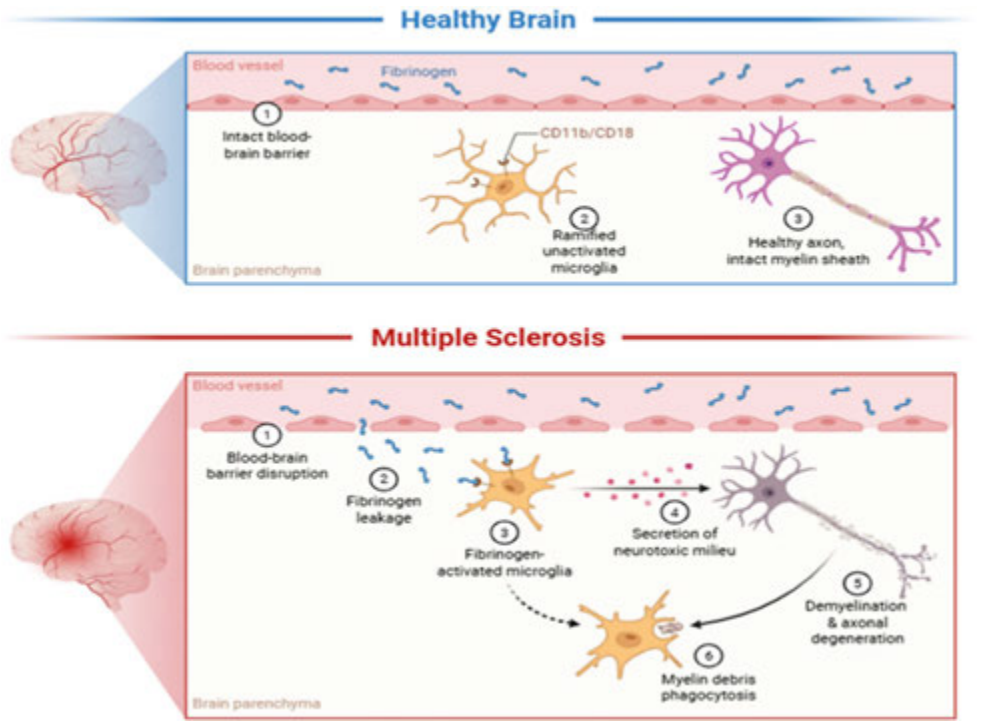


Figure 10.
Mechanism of development of multiple sclerosis (created with BioRender).

6. Neurological disorders associated with UFP exposure in vulnerable populations

Children are particularly susceptible to environmental pollutants as their nervous systems are still developing. UFP exposure can lead to cognitive deficits in childhood [23, 24], lower IQ scores, delayed language development, impaired attention and memory [25, 26], lower mental development index, lower non-verbal reasoning ability, and delayed psychomotor development [27, 28]. Recent studies have revealed that, in polluted cities, developmental delays have been associated with UFP exposure. Animal models support these findings and show neuronal changes in the hippocampus and prefrontal cortex when exposed to UFPs [1, 27].

A part the effects of ambient UFPs on children, older people also show an increased vulnerability to these particles. Studies indicate that long-term exposure increases the rate of cognitive decline and raises the risk of mild cognitive impairment (MCI) and dementia [29, 30]. Chronic exposure can reduce neuroplasticity, impair cerebral perfusion, and disrupt neuronal network integration. People with existing risk factors such as asthma, diabetes, hypertension, psychiatric disorders, or genetic predisposition (APOE-ε4) are particularly affected [1] and more prone to systemic inflammation, which enhances UFP-induced neurotoxicity. Exacerbation of mood disorders (depression, anxiety), sleep disorders, and stroke risk due to cerebrovascular impairment can also be observed [13, 18].

7. Influence of socio-economic aspects on the effects of UFP exposure in vulnerable groups

The health burden from UFPs is not evenly distributed across the population. Particularly vulnerable groups, such as children, the elderly, and socio-economically disadvantaged sections of the population, are disproportionately affected.

Children breathe in more air relative to their body weight and have an immature immune system. In addition, they are often active outdoors and, therefore, more directly exposed to air pollution. Studies from Germany, Spain, and Italy show a correlation between UFP exposure and developmental disorders such as attention deficits, hyperactivity, and delayed language development. Schools in areas with heavy traffic exhibit significantly higher levels of exposure, which has a direct impact on learning performance and behavior [5, 31]. In older people, the health effects of UFP are exacerbated by age-related pre-existing conditions, such as vascular diseases or neurodegenerative processes [32, 33]. This is particularly evident in care facilities located in urban areas.

In many cities, people on low incomes are more likely to live in areas with high traffic density, industrial emissions, or poor air circulation. They also often have limited access to healthcare or health education. These groups are both more exposed and more sensitive to health hazards, a phenomenon known as “environmental inequality” [34]. Data also show that social inequality is associated with higher rates of lung cancer, COPD, diabetes, and neurodegenerative diseases, some of which are caused or exacerbated by UFP exposure [35].

8. Discussion

The results of toxicological studies, epidemiological surveys, and experimental models consistently show that UFPs pose a particularly critical health risk due to their small size, high reactivity, and ability to translocate into organs [2, 36]. In the lungs, mechanisms such as oxidative stress, chronic inflammation, and DNA damage have been identified as key factors in the development of asthma, COPD, reduced lung function, and lung cancer. Different respiratory disorders can be influenced in various ways by the mass, physical state, number, or size distribution of particles [14, 36]. However, individuals with pre-existing chronic airway diseases are more intensively affected by inhaled UFPs, though the pathophysiological mechanisms remain unclear. Some studies have indicated that the number of hospitalizations and emergency visits due to respiratory disorders associated with UFP exposure increases in major metropolitan areas. The production of ROS, oxidative stress, and innate and adaptive immunity at the cellular level contribute to these adverse disorders [2, 14]. It has been observed that the physical characteristics of UFPs play a vital role in ROS generation both in vitro and in vivo, causing oxidative damage to biological macromolecules such as nucleic acids (DNA, RNA), lipids, and proteins. This leads to apoptotic cell death and an increase in respiratory diseases. According to some recent studies, the downregulation of antioxidant pathways has been associated with acute exacerbation of asthma and COPD [14, 36]. Other respiratory disorders, such as lung fibrosis, acute lung injury, and acute respiratory distress syndrome, are linked to the disruption of the oxidant/antioxidant balance and the mobility of cytokines and growth factors. The stimulation of epithelial cells and macrophages, along with the production of inflammatory cytokines due to UFP exposure, leads to acute and chronic inflammation, particularly in the alveolar space. The progression of this inflammatory process could cause goblet cell hyperplasia, which may eventually lead to chronic lung cancer. The different steps in this progression can take many years, with the time interval between initial exposure and carcinoma development generally exceeding 20 years [12, 15]. Several recent studies have revealed that prolonged exposure to ambient air particles is implicated in the progressive development of lung cancer. These particles have been classified by the IARC as carcinogenic (Group 1) to humans [37].

In the brain, UFPs favor neuroinflammation, protein aggregation, and neuronal dysfunction, which can lead to an elevated risk of neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, multiple sclerosis, and cognitive disorders. UFPs enter the CNS either through the BBB or olfactory neurons, consequently leading to neuroinflammation and oxidative stress. An increase in the abnormal proliferation of astrocytes can also be observed. Of particular concern is evidence of developmental neurological damage in children and cognitive decline in the elderly [2, 6, 22, 30]. Furthermore, a high rate of hospitalization due to stroke and dementia has been associated with long-term UFP exposure [3]. Epidemiological data from European cohort studies show that even low UFP exposures are associated with an increased risk of disease and death, particularly in urban centers with high traffic congestion. Vulnerable groups (children, elderly people, and socio-economically disadvantaged individuals) are disproportionately affected [34, 35]. The burden of UFP exposure on people' s lives and work has doubled due to the acceleration of population aging. The rate of UFPs could also be increased by indoor decoration and high traffic [3].

Reducing the health burden of UFP is a key challenge for public health in several urban areas. In view of demographic change, urbanization and increasing environmental pollution, research, politics, and society must act together. In the long term, stricter environmental standards, green technologies, and a sensitized population could help to significantly reduce the health risks posed by UFP. Nevertheless, dealing with UFP remains a dynamic task that requires regular scientific reassessment and adaptation of measures.

Based on the knowledge from these findings, some recommendations can be formulated. It appears very important to introduce specific limits for UFP in the EU, based on current and future scientific evidence, and to increase the monitoring network for UFP in cities and at transport hubs [38]. The promotion of research and development in the areas of filter technologies, sustainable mobility, and urban planning solutions, as well as the intensification of education and awareness campaigns on the risks of UFP and ways to reduce individual risk, are also necessary [39]. Furthermore, the stronger networking of environmental medicine, toxicology, urban planning, and social sciences to tackle complex environmental pollution holistically should also be considered important.

Future work should focus more on the systems biology of UFP interactions, the microbiome's influence, the long-term psychological consequences, and the effectiveness of prevention strategies to gain an even more holistic understanding.

9. Conclusion

In sum, this study examines the health risks posed by aggregates of UFPs in the lungs and brain and their possible role in the progression of pulmonary cancer, neurodegenerative diseases, and cognitive disorders. Based on current toxicological, epidemiological, and environmental medical findings, it becomes clear that UFPs represent a particularly critical group of pollutants, especially due to their small size, high reactivity, and ability to translocate.

The research results show that UFP not only cause local effects in the lungs but can also reach organs such as the brain via systemic pathways. Here, they influence neuroinflammatory processes, promote protein misfolding, and impair cognitive functions. Particularly alarming is the potential risk to children, the elderly, and socio-economically disadvantaged groups, who are subject to increased exposure and, at the same time, have lower protective factors. At the same time, this work makes it clear that scientific knowledge often lags behind political reality: While binding limit values exist for $PM_{2.5}$ and PM_{10}, regulatory frameworks for UFP have so far been lacking despite growing evidence of their harmful effects on health. Multimodal strategies are required to reduce the health risks posed by UFP: In addition to the introduction of specific limit values, innovative filter technologies, sustainable urban planning concepts, effective awareness campaigns, and increased research into aggregation mechanisms, translocation, and long-term effects are needed.

This work contributes to raising awareness of the complex health effects of UFP aggregates and emphasizes the need for an interdisciplinary approach that translates scientific findings into practical measures. The path to a healthier environment requires collective action from science, politics, business, and society. The findings underscore the urgent need for regulatory attention to UFP in populations. Effective mitigation will require standardized measurement protocols, targeted public health

interventions, and cross-sectoral policy integration to protect neurologically vulnerable populations. Only through this co-operation can we succeed in sustainably reducing the impact of UFP and safeguarding the quality of life for future generations. The clarification of the further mechanisms implicated in the development of diseases associated with UFP exposure is necessary through several studies.

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Conflict of interest

The authors declare no conflicts of interest.

Author details

Joseph Eloge Tiekwe[1,2*], Solange Dabou[2], Loic Kojom[3] and Phélix Bruno Telefo[2]

1 Faculty of Medicine, University of Leipzig, Leipzig, Germany

2 Department of Biochemistry, University of Dschang, Cameroon

3 International Centre for Genetic Engineering and Biotechnology, New Delhi, India

*Address all correspondence to: tiekweeloge@gmail.com

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Chapter 5

Perspective Chapter: Tobacco, Urban Living and Radiological Health Risks – A Public Health Perspective

Constantin Kappas, Vasiliki Softa, Fotini Kosma, Tamam Nissren, Abdelmoneim Suleiman and Kiki Theodorou

Abstract

Tobacco smoke contains numerous carcinogens, including benzo[a]pyrene, tobacco-specific nitrosamines, and radioactive substances – an often-overlooked but significant hazard. Since the 1960s, studies have identified radioactive isotopes such as polonium-210 (Po-210) in tobacco leaves and cigarette smoke. These radionuclides accumulate in smokers' lungs, particularly in bronchial bifurcations, where the radiation dose may reach levels 100 to 1,000 times higher than natural background radiation. A person smoking one pack daily for 25 years may absorb up to 2.5 sieverts at critical lung sites – equivalent to five daily chest X-rays. In urban environments, where smoking rates and secondhand smoke exposure are concentrated, this radiological burden represents a pressing public health issue. Effective responses must include comprehensive tobacco control policies, targeted health education, and access to early detection tools such as low-dose CT screening for high-risk individuals. Integrating radiological risk awareness into urban health strategies is essential for reducing smoking-related morbidity and creating healthier, more equitable cities.

Keywords: radiological risk, Po-210, tobacco radioactivity, lung cancer, urban public health

1. Introduction

International literature reports that almost all malignant neoplasms in humans (arising from external causes) are related to smoking, alcohol, and certain foods. Especially regarding the health implications of smoking, the scientific and medical communities, as well as public health authorities, have many times expressed their concern.

In line with these concerns, numerous large-scale studies have examined the risks of smoking, alcohol use, and smokeless tobacco (SLT) on cancer and cardiovascular disease (CVD). In Europe, the main types of cancer are laryngeal cancer and lung

cancer, with over 80% of these cancers attributed to smoking. There is also a high incidence of bladder cancer, which accounts for 50% of this type [1]. Additionally, the deaths attributed to smoking in 2019 were, in absolute numbers, 1.2 million for men and 0.42 million for women in Europe [2].

1.1 Harmful components of tobacco and synergies with other toxic substances

1.1.1 Chemical agents

The important role of smoking in carcinogenesis has been the subject of publications, discussions, and reports by scientific organizations such as the World Health Organization (WHO), the USA National Institute of Health (NIH), and others [3–5]. From these publications, it became apparent, in principle, that the most potent chemical carcinogen among the tobacco constituents is benzo-a-pyrene. Through the same mechanism, during smoking, a large range of carcinogenic polycyclic hydrocarbons is synthesized.

The constituents of tobacco and tobacco smoke can generally be divided into hydrocarbons (0.71%), oxygen-containing compounds (75.70%), nitrogen-containing compounds (12.98%), and various other substances (10.61%) [6]. Cigarette smoke specifically includes additional carcinogenic elements, such as aromatic amines, nickel, volatile nitrosamines, and, most notably, tobacco-specific N-nitrosamines [7]. N-nitrosamine components are created by the nitrogenization of nicotine and other alkaloids. It is characteristic that the concentration of nitrosamine in tobacco and its gaseous form is many hundreds of times higher than in other consumer products [8–10].

Nicotine affects the cardiovascular system and is associated with addiction, now classified as a Substance Use Disorder. While it may improve cognitive function in Alzheimer's patients, it also contributes to inflammation and cognitive decline. Nicotine triggers neurotransmitter release, particularly dopamine, creating pleasure and mood enhancement, but it also leads to tolerance and withdrawal symptoms [11].

1.1.2 Chewing tobacco and snuff (SLT)

Studies have examined the health risks associated with SLT. Nahhas et al. [12], analyzing data from the PATH Study (2013–2017) on 4,703 men, found no significant increase in CVD risk among exclusive SLT users, whereas exclusive cigarette smokers showed a much higher CVD risk, with the risk escalating based on smoking duration.

In another study, Wyss et al. [13] investigated 6,772 cases of head and neck cancer and 8,375 controls, revealing that snuff use in never-smokers notably increased head and neck cancer risk (odds ratio [OR] = 1.71), especially for oral cancers. The combined use of smokeless and smoking tobacco further amplified this risk.

Lead-210 and polonium-210

The tobacco leaves contain extremely small amounts of the isotopes Lead-210 (Pb-210) and Polonium-210 (Po-210; see **Figure 1**). These two elements are radioactive and carcinogenic and are also present in both the solid and gas phases of tobacco due to their combustion (cigars, cigarettes, etc.).

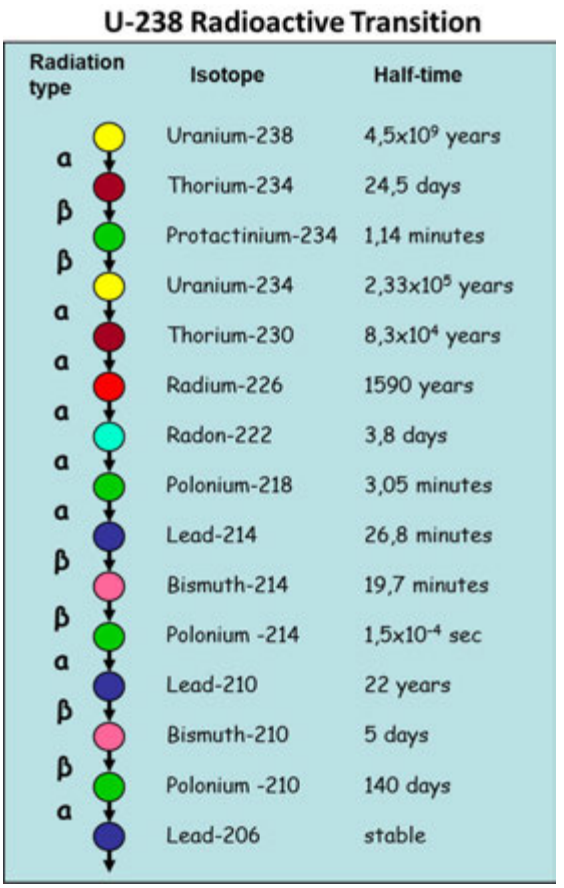


Figure 1.
U-238 radioactive transition to lead-206 and its half-lives.

The two radioisotopes are products of Radium-226 (Ra-226) and its daughter, Radon-222 (Ra-222):

- Pb-210 decays (emitting beta particles) to Bismuth-210 (Bi-210), which, in turn (via beta emission), decays to Po-210.
- Po-210, upon decay, has the ability to emit high-energy alpha particles (5.3 MeV) and gamma radiation (0.55 MeV), converted to stable Lead-206 (Pb-206).
- Deposition of Pb-210/Po-210 and the emission of alpha particles into the lungs of smokers (and passive smokers) create secondary sources of radiation that cause damage to sensitive tissues. This can cause cancer either solely due to the effect of the radioisotope or in combination with non-radioactive tobacco carcinogens.

1.1.3 Radioactivity in the induction of cancer

To the chemicals is added another smoking-related carcinogen, largely neglected to date: ionizing radiation. It has been known in the scientific community since the

1960s that the leaves of the plant and the gaseous form of tobacco contain radioactive substances, and those who inhale the tobacco retain radioisotopes in their lungs derived from it [7, 14, 15]. Indeed, the daughter isotopes of Radon-222 (mainly Polonium-210), which are present in the atmosphere and in the soil, are attached to the leaves of the tobacco plant.

Polonium is a rare, volatile metal found in small quantities within uranium ores. The most dangerous isotope, polonium-210 (Po-210), has a half-life of 138.4 days and emits highly potent alpha particles. Po-210 can be synthesized by neutron bombardment of bismuth-209 (Bi-209). Although scarce in nature, polonium is intensely radioactive, decaying into lead-206. It has a melting point of 254°C and a boiling point of 962°C [16].

Polonium is highly toxic and extremely radioactive, making it hazardous to handle even in tiny amounts. The maximum safe amount for ingestion is 1,100 Bq, which is equivalent to just 6.6×10^{-6} μg. Polonium emits alpha particles, which have limited penetrating ability but are highly ionizing, making them dangerous if inhaled or swallowed. Although they can be easily stopped by materials like paper and travel only a short distance, alpha particles can cause significant harm to tissues, leading to rapid cell damage and necrosis. Just 1 mg of Polonium can emit as many alpha particles as 5 g of radium [16].

Experts' reports [10, 17] conclude that the carcinogenic potential of tobacco lies in the synthesis of multiple cancer catalysts and specific carcinogens for organs and tissues, as well as inhaled radioisotopes. These co-carcinogens (chemical agents – in particular Benzo-a-pyrene – and radioactive Polonium-210) act in the following way:

- Chemical and possibly physical agents cause epithelial metaplastic lesions. Auerbach et al. [3] have shown that such lesions exist in 100% of heavy smokers and, to a lesser extent, in less-addicted individuals.

- Po-210, an alpha emitter derived from Pb-210, forms insoluble particles that penetrate non-ciliated epithelial cells in areas where mucus stagnates, exposing metaplastic cells to high doses. Continuous smoking maintains a steady supply of Po-210 to these areas.

1.1.4 Synergy of tobacco with alcohol

Tobacco and alcohol are major public health threats due to their strong carcinogenic effects. Tobacco causes about a quarter of global cancer deaths and increases lung cancer risk up to 22-fold. Alcohol also raises cancer risk, with no safe consumption level; in Europe alone, it was linked to 180,000 cancer cases and 92,000 deaths in 2018. Their combined use dramatically multiplies risk, with heavy users up to 30 times more likely to develop cancers of the mouth, throat, and esophagus. Secondhand smoke further elevates cancer risk in non-smokers [5, 18].

The Prostate, Lung, Colorectal, and Ovarian (PLCO) Cancer Screening Trial (1992–2001) Hashibe et al. [19] assessed head and neck cancer risk in a cohort of 101,182 participants, focusing on lifestyle factors like smoking and alcohol consumption. Current smokers exhibited a significantly elevated risk (risk ratio [RR] = 6.51) with a clear dose-response trend. Smoking alone contributed to 50.5% of cases, alcohol to 14.7%, and their combined influence to 0.9%, totaling a 66% attributable fraction.

Dal Maso et al. [20] analyzed data from hospital-based case-control studies in Italy and Switzerland (1982–2000), including 1,569 head and neck cancer cases and 3,147 controls. The study found that smoking significantly increased cancer risk, even at low levels, while alcohol had a weaker individual impact.

However, the combination of tobacco and alcohol use significantly raised cancer risk, with those consuming 89 g of ethanol and 10 cigarettes daily facing a 35-fold greater risk compared to non-users. The highest risks (OR = 172.25) were observed among heavy users of both substances. Similar risk patterns were noted across different cancer sites, with smoking having the most significant effect on laryngeal cancer, whereas alcohol's influence plateaued at 40 g per day among smokers.

The INHANCE Consortium [21], pooling 18 case–control studies (11,221 cases; 16,168 controls), showed that tobacco and alcohol each increase head and neck cancer risk, but their combined use has a strong multiplicative effect (ψ[1] = 2.15, 95% confidence interval [CI]: 1.53–3.04). The effect was strongest for oral and pharyngeal cancers, while laryngeal cancer showed an additive interaction, with a relative excess risk due to interaction (RERI; (RERI = 4.97; SI = 1.85). Overall, 72% of head and neck cancers were attributed to combined use (33% to tobacco, 4% to alcohol), with the highest burden among men and for laryngeal cancer.

1.2 Biological damage from tobacco consumption

1.2.1 Lung and respiratory system cancer risk

Lung cancer remains the leading cause of cancer deaths in both sexes [22]. The incidence of adenocarcinoma has risen, now surpassing squamous cell carcinoma [23]. Smoking not only increases the risk of a first primary cancer but also a second, particularly lung and head and neck cancers [22, 24, 25]. Richardson et al. [26] reported a 4.4-fold higher risk of second cancers in small-cell lung cancer survivors, while Aredo et al. [22] found that survivors of initial lung cancer face a 1%–2% annual risk of developing a second primary lung cancer after surgery.

Quitting smoking at diagnosis markedly lowers risk: the relative risk of second lung cancer was 11 for quitters versus 32 for continuing smokers [24]. Rice et al. [27] found that 15% of stage I non-small-cell lung cancer (NSCLC) patients developed second tumors, with none among never-smokers, and the incidence nearly doubled in current versus former smokers. A systematic review confirmed a fourfold higher risk in smokers compared with quitters [28].

Smoking not only causes lung cancer but also leads to respiratory conditions like chronic bronchitis, which accelerates lung decline, and chronic obstructive pulmonary disease (COPD), the primary cause of which is smoking. COPD causes long-term airflow obstruction, while emphysema breaks down lung tissue, reducing elasticity. Pulmonary hypertension, a severe COPD complication, raises lung artery pressure, worsening the condition and potentially affecting the heart [29].

[1] ψ = OR11 / (OR01 * OR10), where OR11 = OR for ever tobacco/ever alcohol use, OR01 = OR for never tobacco/ever alcohol use, OR10 = OR for ever tobacco/never alcohol use. A value of $\psi > 1$ suggests that the joint effect is greater than what would be expected under the multiplicative model. When a joint effect exceeding the multiplicative expectation was not observed, interactions on the additive scale were evaluated using relative excess risk due to interaction (RERI), attributable proportion (AP; the proportion of disease among individuals with both exposures that can be attributed to their interaction), and the synergy index. The null values for RERI and AP are 0, while the null value for SI is 1.

1.2.2 Head and neck cancer risk

Wyss et al. [30], using INHANCE data (13,935 cases; 18,691 controls), found that cigarette smoking strongly increased head and neck cancer risk (OR = 3.46) with a dose-response trend. Cigar (OR = 2.54) and pipe smoking (OR = 2.08) also raised risks in never-cigarette smokers, especially for laryngeal and hypopharyngeal cancers. Exclusive users of any tobacco type had similar risks, while combined use did not add further risk. Chronic conditions such as bronchitis, cirrhosis, and emphysema were additional contributors.

1.2.3 Bladder and other sites' cancer risk

In a population-based case–control study by Chiu et al. [31] (1986–1989), it was found that smoking significantly increased the risk of bladder, kidney, and pancreatic cancers, with a dose-response relationship for bladder cancer. The association was stronger for current smokers and higher cigarette consumption, particularly for kidney cancer in men and pancreatic cancer in both sexes. In contrast, smoking did not show consistent associations with colon and rectal cancer risks in either men or women [31].

Although smoking poses an equal risk for both men and women, men are still approximately four times more likely to be diagnosed with bladder cancer. Notably, the higher rates of bladder cancer among men persist even among those who have never smoked. This suggests that differences in smoking rates alone do not fully account for the higher incidence in American men, pointing instead to additional factors such as occupational exposures or physiological differences that may contribute to this gender disparity [32].

Carcinogenic chemicals in tobacco smoke are filtered through the kidneys and can remain in the urine for up to 18 hours, exposing bladder cells to harmful substances. This prolonged contact can lead to genetic mutations in the bladder cells, potentially initiating the development of bladder cancer [33, 34].

Freedman et al. [35] found a strong link between cigarette smoking and bladder cancer risk, with current smokers facing the highest risk, which increased with smoking intensity and duration. Former smokers had a lower risk but remained at higher risk than never-smokers, especially those who quit within 10 years. The study, based on the NIH-AARP Diet and Health Study [36], estimated that smoking contributes to about half of bladder cancer cases and emphasized the need for smoking prevention and cessation programs.

2. Radioactivity: From the environment to the lungs

2.1 Step 1: Radioactive elements (mainly radium-226 and radon-222) in the ground and in the air

There are three sources of enrichment of tobacco plantations with radioisotopes [4, 7, 14, 17, 24, 37–43].

(1) Subsoil: contains elements of the various radioactive series (e.g., Ra-226 and Rn-222).

(2) Atmosphere: Contains small amounts of Ra-226 and its daughter Rn-222, as well as small amounts of Ra-228. It also contains atmospheric radioactive fallout from nuclear tests, as well as natural radioisotopes that move due to changing weather conditions.

(3) Enhancement additives (phosphorus fertilizers): in raw material (mineral apatite), the inherent amount of Uranium-238 (U-238) ends up in phosphorus oxides and consequently in the fertilizer, while the product Radium-226 is mixed with the produced byproduct phosphogypsum. Martell [44] identified phosphorus fertilizers as the main source of Po-210 in tobacco cultivation. This exposure can be reduced by using alternative phosphorus treatment methods or organic fertilizers.

Since the 1960s, researchers have noted that tobacco contains concentrated radioactive elements, with levels varying across plantations and countries [45]. While natural soil radioactivity and pH play a role, modern farming practices are a major contributor. In developed countries, phosphate-based fertilizers are widely used to enhance tobacco flavor, as low-nitrogen soils produce a "more aromatic" product. These fertilizers, derived from apatite, introduce radium and its decay products, including lead-210 and polonium-210. Continuous use increases soil phosphate levels and raises Pb-210 and Po-210 concentrations in tobacco leaves. By contrast, farmers in poorer regions rarely use this technique, resulting in lower radioactivity levels in their tobacco.

2.2 Step 2: Daughter isotopes of Ra-226, Rn-222, Pb-210, and Po-210 in tobacco plant

The tobacco plant has been shown to be particularly capable of absorbing radioactive isotopes (in particular Pb-210 and Po-210) from phosphorus fertilizers, as well as from the radioactivity present in soil, atmosphere, and water. Pb-210 has the ability to bond electrostatically, with sufficient ease, to particles smaller than 0.3 microns in diameter. In this way, it becomes mixed with the gases of the atmosphere.

Greenhouse experiments with artificially radiolabeled soil and implanted specimens of tobacco plants show that the retention of particles on the leaves of the plant, especially during rainfall, is the main process of entry of Pb-210 and Po-210 into the tobacco plants [46].

With this procedure, even more Pb-210 and Po-210 are added to the surface, in addition to the concentration inside the leaves. It is noted that although radium and thorium atoms are present in inhaled smoke, 99% of the alpha particle activity is derived from Po-210.

2.3 Step 3: Tobacco and radioisotopes

The time that elapses between the harvest of the tobacco and its processing and conversion into a cigarette or a cigar determines the Po-210 content in the product. This concentration is a function of the initially deposited amount of Pb-210 and the decay-added amount of Po-210 [35]. It has also been experimentally found that, in addition to the amount of radioisotopes derived from the plant root, the accumulated

Pb-210/Po-210 in tobacco leaf fimbriae remains the same when the tobacco is dried and processed industrially [44].

2.3.1 Average tobacco activity

Numerous researchers have assessed tobacco radioactivity according to its origin, processing, and consumption habits. Khater and Al-Sewaidan [47] measured Po-210 in leading cigarette brands from Egypt and Saudi Arabia: in Egypt, the average activity was 16.6 mBq per cigarette (range 9.7–22.5 mBq), while in Riyadh, a daily intake of 302 mBq of Po-210 and Pb-210 was estimated for one pack of 20 cigarettes. Peres and Hiromoto [48] analyzed eight popular Brazilian brands, reporting 11.9–30.2 mBq/g of Pb-210 and 10.9–27.4 mBq/g of Po-210 in dried tobacco.

Tahir and Alaamer [49] measured Pb-210 in nine popular cigarette brands from Pakistan and Saudi Arabia, reporting a mean activity of 13 ± 4 mBq/g. Kilthau [50] found up to 15 mBq of Po-210 in Indian cigarettes, with mean levels of 3.3 mBq/g in Indian tobacco versus 19.1 mBq/g in US tobacco. Evans [51] reported an average of 11 mBq of Po-210 per cigarette. In Greece, Savidou et al. [52] measured mean concentrations of 13.1 mBq/g for Po-210 and 13.4 mBq/g for Pb-210 in dried tobacco.

Despite variations, studies agree that tobacco grown in developing countries shows lower radioactivity, mainly because phosphorus fertilizers are not widely used. In contrast, countries with strict ecological policies (e.g., Canada) reduce activity levels by using purified or organic fertilizers.

- The average cigarette has an average activity ranging from approximately 10 mBq to approximately 20 mBq.

Kubalek et al. [53] reported mean activities of 10 mBq of Pb-210 and 14 mBq of Po-210 per cigarette. Begy et al. [54] found that smokers inhaled approximately 63% of Po-210, corresponding to an annual dose of 8.36 μSv, while passive smokers in pubs received about 5.92 μSv.

2.4 Step 4: Tobacco burning, inhalation, and radiation exposure

Smoking is the most harmful way to ingest radioactive elements, with tobacco leaves containing high levels of radium and polonium, leading to radiation exposure. While smoking has been popular for centuries, lung cancer rates surged in the 1940s–1960s. Today, smoking remains the largest source of radiation in most countries, with radiation doses from tobacco often exceeding those from cesium-137 exposure after the Chernobyl accident and rivaling the radiation from the diet of Arctic inhabitants.

2.4.1 Alpha particles in smoke gas

When the sticky leaf fimbriae trap atmospheric gases, radioactive substances are also encapsulated. During combustion, the high heat of burning tobacco releases these particles, which are then inhaled. The alpha-emitting Po-210 becomes concentrated in insoluble smoke particles [55]. Cigarette tips reach 800°C–900°C during inhalation, up to 910°C overall, while cigars can exceed 1,200°C [55]; at these temperatures, Po-210 readily sublimates, while Pb-210 remains in smoke and ash.

Morgro-Campero and Fleischer [56] showed that radiation doses from polonium and radium in tobacco can exceed those from Chernobyl fallout in plants, and Watson [57] found smoking-related doses comparable to or higher than those of Arctic populations exposed through diet. Inhalation thus represents the most harmful route of exposure.

2.5 Step 5: Radioisotopes and tar

The study of the synergy of tobacco, tar, and radioactive isotopes on the one hand, and the biological response of the lung on the other, showed the magnitude of the interaction of these factors, but also the severity of the problem:

2.5.1 Irritated areas

When a smoker inhales smoke, the lungs respond instantly, showing irritated spots in the bronchi. Although often labeled as "precancerous lesions," these irritated areas are actually part of the body's natural defense mechanism and typically heal and disappear without lasting effects. However, insoluble tobacco tar can hinder this healing process by adhering to damaged areas and causing ongoing irritation [58]. Cigarette smoke causes a reflexive tightening of the bronchi for long periods of time, blocking the lungs and reducing their ability to remove cigarette debris on their own.

2.5.2 Concentration of Po-210 at bronchial bifurcation

With the inhalation of smoke, the fibrous movement of the cells leads the insoluble smoke particles, which are enriched with Pb-210 and Po-210, to accumulate mainly at the points of division of the peripheral bronchioles. Typically, the concentration of Po-210 on epithelial tissue in specific parts of the bronchial bifurcation is two orders of magnitude higher – for example, 100 times higher – than the concentration in the rest of the lung tissue. At the accumulation points, additional quantities of Po-210 are generated from the parent isotope Pb-210. If smoking continues for a long period of time, the radioactive deposition turns into radioactive, hot, localized small areas and remains in the bronchial branches for many years.

2.5.3 Tar and synergy

Although polonium is water-soluble and the movement of cilia cells would potentially clear the smokers' lungs, the radioisotope becomes trapped by cigarette tar, leading to local absorption of significant radiation. As polonium-210 has a half-life of 140 days but is continuously produced by its parent Pb-210 (half-life 22 years), it persists and radiates for many years, coinciding with areas of bronchogenic neoplasms.

2.6 Step 6: Tobacco radioactivity, absorbed dose, and biological damage

2.6.1 Carcinogenic effect of exposure to low-dose-rate radiation

Many researchers found that those individuals who inhaled the smoke directly were bombarded with alpha particles, accumulating large amounts of radiation over many

years of smoking. They concluded that the frequency and severity of the harmful effects of low-rate radiation dose absorption were directly proportional to the total dose that accumulated over time. Among others, Yuile et al. [59], although experimenting with all of the carcinogens, found that Po-210 is the only factor in cigarette tobacco that causes cancer in laboratory animals independently as a result of smoking.

2.6.2 Biological damage to the lungs

Martell [44, 60] found high Pb-210 concentrations in tobacco leaf fimbriae, which, when burned, release insoluble particles that accumulate in bronchial branches, particularly at sites of bronchogenic carcinoma. Later, he estimated that smokers who died from lung cancer had received a cumulative epithelial dose of 0.8 Sv – equivalent to 16 Sv when accounting for alpha particle weighting – sufficient to induce malignant mutations in basal cells.

Winters and Franza [10] showed that Po-210 in tobacco smoke is a potent carcinogen due to its alpha activity. Cohen et al. [61] found that it accumulates in the lower lungs, with localized doses of up to 200 mSv/year – equivalent to 10,000 chest X-rays. Radford and Hunt [62] reported that heavy smokers absorb seven times the natural radiation dose, reaching 10,000 mSv over 25 years in some areas. While beta or gamma radiation requires very high doses to induce cancer [63, 64], even low alpha doses caused tumors in animal studies [65]. Po-210 and Pb-210 are consistently found in excess in smokers' bronchial epithelium [48, 66, 67].

Kilthau [50] estimated that heavy smokers (>2 packs/day) absorb up to 0.80 mSv/day of Po-210 (≈300 mSv/year), with Indian tobacco yielding lower exposures. Evans [68] reported 80–90 mSv/year in epithelial sites, while Marmorstein [69] linked rising adenocarcinomas to deeper inhalation of Po-210/Pb-210 in modern cigarettes, noting a tripling of Po-210 in US tobacco from 1938 to 1960 due to fertilizers. Khater et al. [70] calculated annual doses of 193 μSv (Po-210) and 251 μSv (Pb-210) in Egypt, similar to values in Saudi Arabia [47], while Tahir and Alaamer [49] found lower levels (64 ± 20 μSv) in Pakistan. In Greece, Savidou et al. [52] reported 287 μSv/year for one pack/day, and Papastefanou et al. [71] measured comparable contributions from Ra-226, Ra-228, and Pb-210, whereas Cs-137 from Chernobyl fallout was negligible by comparison.

2.6.3 Biological damage to other organs and tissues of the body

Numerous researchers have studied the pathogenic effects of smoking-related diseases, with Po-210 and other mutagens playing a key role. Po-210 in the lungs is partly removed by cilia cells but is mostly absorbed into the bloodstream, spreading to various tissues. This leads to genetic mutations, altered cell characteristics, accelerated aging, and premature death, contributing to a range of diseases [62, 72].

The evidence that the mutagenic substances of tobacco circulate throughout the body is that Po-210 and other mutagens are detected and recovered not only by the tobacco and the mucous membrane of the bronchi but also by the blood and urine of smokers [8, 62]. From measurements, it has been found that for the majority of the organs of the human body (mainly bones, liver, spleen, and kidneys), the radiation burden from the consumption of tobacco products is greater than that borne by humans from the natural diet [7, 24].

Smokers have high levels of Po-210 in the urine, skeleton, liver, kidneys, spleen, pancreas, genitals, and bone hematopoietic cells [62, 65]. Po-210, a "bone hunter," is absorbed by bones, liver, and kidneys. Smokers have an average Po-210 blood activity of 64 mBq/kg, compared to 28 mBq/kg in non-smokers. Smokers' urine contains six times more Po-210, and bladder cancer risk increases with tobacco consumption. Non-radioactive tobacco carcinogens were not detected in smokers' urine, regardless of smoking intensity [50].

3. Passive and former smokers

3.1 Passive smokers and smoking indoors

Radon daughters in indoor air attach to tobacco smoke particles and are inhaled, adding to smokers' lung cancer risk [34]. Thus, bronchial branches receive alpha radiation from three sources: indoor radon isotopes, Po-210 in tobacco particles, and Po-210 from Pb-210 decay [44, 50]. Cigarette smoke also acts as a "magnet" for atmospheric particles, concentrating Pb and Po isotopes, which are then inhaled by smokers and bystanders [51, 60]. Studies of uranium miners highlight the heightened risk for smokers, who inhale more radon and thus face greater cancer risk [17]. Radford and Hunt [62] found that 75% of alpha activity from Po-210 in smoke diffuses into the air, exposing passive smokers. Evans [68], Harley and Pasternack [73], and Evans et al. [51] confirmed that indoor radon isotopes significantly contribute to lung cancer in non-smokers.

3.2 Former smokers

Po-210 emits high-energy, carcinogenic alpha radiation to localized small lung areas. Since Po-210 has a half-life of 22 years, it potentially burdens the former smoker for many years after quitting. This was found in studies of ex-smokers' lungs, where the concentration of Pb-210 and Po-210 in the costae and in the alveolar lung tissue was (even one year after smoking cessation) twice as high as in non-smokers [16, 23].

4. Protecting people from tobacco

Research highlights varying patterns of tobacco use and secondhand smoke exposure. Hashemi-Aghdam et al. [74] found that exposure among Iranian students rose from 35.6% in 2008 to 43.2% in 2015, linked to age, socioeconomic status, and family factors. In Florida, McClure et al. [75] reported that among young adults (18–24), 43% were non-smokers, 37% were former smokers, and 20% were current smokers. Globally, WHO's 2023 "Stop the Lies" campaign, supported by the Global Tobacco Industry Interference Index [76], seeks to protect youth from industry manipulation. Strong evidence confirms that secondhand smoke causes disease and premature death, prompting smoke-free laws; 28 US states and over 55 countries now protect 1.5 billion people [77].

In the European Union, a 2009 Council Recommendation expanded smoke-free policies, with strict measures in countries like Ireland, Greece, and Spain. By 2013,

most states had laws, and exposure in bars and restaurants dropped sharply, bringing health gains without economic harm; by 2017, rates were 20% in bars and 9% in restaurants [46, 78]. Europe's Beating Cancer Plan aims for a "Tobacco-Free Generation" by 2040 (<5% prevalence), stressing regulation of e-cigarettes and heated products. Tobacco remains the top preventable cause of cancer deaths in the EU, Iceland, and Norway (>25%) [79], with calls to extend smoke-free zones and curb deceptive marketing.

5. "Light" cigarettes and filters

In an important survey [27], the key question was:

If we compare two groups of smokers who consume approximately the same amounts of tar and nicotine – those who smoke "light" cigarettes (low in tar and nicotine) and "heavy" cigarettes (high in tar and nicotine) – in which group, will there be a higher incidence of fatal lung cancers?

Note: Obviously, the amount of light cigarettes needed will be greater than that of the "heavy" ones to obtain the same total tar and nicotine content.

Smokers of light cigarettes have higher death rates than those smoking regular cigarettes. This is because lighter cigarettes use porous paper and filters that reduce tar and nicotine but increase burning, leading to higher levels of toxic particles like Pb-210 and Po-210 per gram. Studies confirm that filters reduce tar and nicotine but do little to protect against these harmful substances. Moreover, individuals who switch to light cigarettes still inhale similar amounts of harmful chemicals, maintaining a high risk for smoking-related cancers and diseases [33].

In conclusion, if Po-210 and Pb-210 contribute to the growth of smoking-related cancers, then the number of cigarettes is a more important factor than the amount of tar and nicotine contained.

6. "Smokeless" tobacco

Polonium-210 (Po-210) is present in tobacco products consumed in "smokeless" forms, such as chewing tobacco. In a study by Meli et al. [80], Po-210 activity concentrations were measured in 16 different brands of SLT products across Europe using an alpha spectrometer. They also assessed the percent extraction of Po-210 into an artificial salivary solution during simulated sucking and chewing. Po-210 was detected in all samples, with concentrations ranging from 3.46 to 14.8 Bq/kg, the highest found in chewing tobacco. This method of tobacco consumption may contribute to the development of oral cavity tumors [33].

7. Discussion

7.1 Observations

Rising Po-210 levels in US tobacco – tripling between 1938 and 1960 due to phosphate fertilizers – led to higher lung concentrations in smokers, especially in lower regions. Modern cigarettes enhance inhalation of radioactive Pb and Po while

reducing benzo[a]pyrene. Experiments showed Po-210 induced lung tumors at doses far below lifetime exposure, with many smoking-related cancers being adenocarcinomas linked to alpha radiation [44]. In bronchial areas where insoluble Po-210 accumulates, alpha doses reach 100–1,000 times background levels, comparable to miners' exposure. For a pack-a-day smoker, this equals approximately 100 mSv/year, or about 2.5 Sv over 25 years – roughly the dose of five chest X-rays per pack.

7.2 How can the very large variations of the absorbed dose in the lung, as reported in international literature, be explained?

Some researchers average radiation doses across whole tissues, which can obscure localized high exposures. In the lung, Po-210 alpha particles travel only ~40 μm – about the size of a cell cluster – so a single particle crossing a cell nucleus (5–6 μm) can deliver up to 10 Sv. Thus, even when the average tissue dose appears low, cells near Po-210 deposits receive extremely high, carcinogenic doses, especially if multi-mutation mechanisms are triggered.

7.3 Suggestions

Although the obvious conclusion is smoking cessation, if the smoker insists on his or her habit, the alternative advice (primarily aimed at reducing the harmful effects of cigarette radioactivity) is: reduce the daily amount of tobacco consumed; avoid the possible use of paper-wrapped tobacco to avoid ingesting tar (e.g., smoking a cigar or pipe and, even more preferably, a hookah, which operates at a very low temperature [81]); smoke outdoors and not indoors; and participate in sports activities that help remove particles and clean the lungs.

7.3.1 Public health

Quitting smoking restores taste, smell, energy, and breathing, while protecting others from secondhand smoke linked to cancer, heart disease, and SIDS. It also reduces deforestation, chemical use, and cigarette butt pollution, which harm ecosystems [33, 82]. Low-dose CT (LDCT) is recommended for high-risk adults (50–80, ≥ 20 pack-years, current or recent smokers) to detect lung cancer early, though risks include false positives and radiation. Screening ends after 15 years of cessation or if surgery is not feasible, with cessation support remaining the most effective way to reduce disease risk [83].

Numerous studies [62, 64, 81, 84–88] have investigated the effects of different tobacco control measures on smoking behaviors and public health, leading to the following conclusions:

- Smoke-free policies: Workplace and public smoking bans reduce smoking rates, secondhand smoke exposure, and related hospitalizations, while also increasing quit rates.

- Support for quitting: Targeted financial incentives and subsidies encourage quit attempts, though long-term success varies.

- Health warnings and media campaigns: When widespread and risk-focused, they moderately reduce smoking, especially alongside other measures.

- Advertising restrictions: Comprehensive bans lower smoking rates, while partial bans are less effective, particularly among youth.

- Tobacco tax increases: Higher prices reduce smoking, with a 10% rise decreasing prevalence by 2%–3%, especially among youth and low-income groups.

- Youth sales restrictions: Effective only with strict enforcement and limited impact when used alone.

7.4 Notes

- Tar: Refers to the "total aerosol residue" from cigarette combustion, defined as what remains after nicotine and water are removed. It contains carcinogenic agents, such as polycyclic aromatic hydrocarbons. Despite its name and black, viscous form, cigarette tar is unrelated to road asphalt.

- Nicotine: A hygroscopic, oily alkaloid that forms water-soluble salts with acids and penetrates the skin easily. It makes up 0.6%–3.0% of dried tobacco and occurs in other solanaceous plants (e.g., tomatoes, potatoes, eggplants) but at far lower levels. Nicotine has mild stimulant effects, similar to caffeine, and may reduce stress, according to smokers.

- Alpha particles: They penetrate living tissue up to ~40 μm, about the size of a typical cell. Their short range and high ionizing energy make them extremely destructive, producing thousands of ion pairs. For example, one alpha particle crossing 1 cm of air generates ~20,000 ion pairs, and DNA damage from internal alpha exposure is about 20 times greater than from equal-energy photon radiation.

8. Conclusions

In conclusion, tobacco smoking poses significant health risks not only due to its chemical carcinogens but also because of the ionizing radiation from radioactive substances like polonium-210 (Po-210). This under-recognized hazard adds to the broader health and environmental challenges posed by tobacco use. Public health initiatives remain critical in mitigating these risks. Comprehensive tobacco control policies – such as smoke-free regulations, taxation, cessation programs, and health education – have proven effective in reducing smoking prevalence and its associated health burdens. Additionally, targeted measures, like low-dose CT lung cancer screenings, can aid in early detection among high-risk populations, improving treatment outcomes. Ultimately, the most impactful step is smoking cessation, which not only improves individual and public health but also addresses the environmental damage linked to tobacco farming and waste. Integrating these efforts ensures a multidimensional approach to combating the ongoing tobacco epidemic.

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Conflict of Interest

The authors declare no conflicts of interest.

Author details

Constantin Kappas[1,2*], Vasiliki Softa[1,2], Fotini Kosma[2], Tamam Nissren[3], Abdelmoneim Suleiman[4] and Kiki Theodorou[1]

1 Department of Medical Physics, University of Thessaly, Larissa, Hellas.

2 Department of Public and One Health, University of Thessaly, Karditsa, Hellas

3 Department of Physics, College of Sciences, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia

4 Department of Radiological Sciences, College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Sciences, Al-Hofuf, Saudi Arabia

*Address all correspondence to: kappas@uth.gr

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Chapter 6

Invisible Fault Lines: Health Inequities and Resilience in Informal Urban Settlements

Samson Oboche Agbo

Abstract

Rapid urbanization in Africa has outpaced the capacity of health systems to adapt, exacerbating health inequities and creating unique challenges in delivering equitable and resilient care [1,2]. Urban poor populations, especially those living in informal settlements, face disproportionate burdens of communicable and non-communicable diseases due to overcrowding, poor sanitation, limited access to essential services, and weak health infrastructure [3]. These vulnerabilities underscore the urgent need to reconfigure health systems to address the complex interplay between urban growth, poverty, and health. Building resilience within African health systems requires integrating lessons from fragile settings and recognizing urban contexts as critical determinants of population health [4]. Decentralization and community-based governance models are pivotal in strengthening equity, efficiency, and adaptive capacity, particularly in fast-growing cities [5]. Such approaches align with global commitments under the Sustainable Development Goals, especially universal health coverage (UHC) and the call for inclusive, people-centered systems [6]. This chapter critically examines the intersection of urbanization and health in Africa, highlighting pathways to build resilient health systems capable of addressing current challenges while preparing for future shocks. It draws on evidence from the Lancet Commission on the future of health in sub-Saharan Africa, which emphasizes innovation, governance reforms, and stronger partnerships as essential for achieving longer and healthier lives for all Africans by 2030 [7]. Ultimately, addressing urban health inequities through resilient systems is not only a technical necessity but also a moral imperative for sustainable development across the continent.

Keywords: health inequities, resilience, informal settlements, LMICs, community health

Preamble

Urbanization is one of the defining forces of the twenty-first century, reshaping health landscapes across the globe. Nowhere are the stakes higher than in informal settlements – spaces where millions of urban residents live amid precarious housing,

inadequate infrastructure, and systemic neglect. The environmental conditions in these contexts – poor sanitation, unsafe water, overcrowding, and pollution – are not isolated technical challenges. Rather, they are embedded in deeper systems of exclusion, inequality, and political marginalization that perpetuate health inequities across the life course and across disease categories.

This chapter examines the health challenges of informal urban settlements through a systems and equity lens. It argues that health outcomes cannot be improved by addressing environmental risks alone but must account for the intersecting social determinants – poverty, gender inequality, insecure tenure, and lack of access to essential services – that constrain opportunities for healthier lives. Drawing on systems thinking and social–ecological models, the chapter highlights the importance of recognizing interlinkages between the environment, governance, health systems, and community agency.

Central to this analysis is the recognition that community-led resilience is not theoretical but a lived reality. Informal settlement residents are at the forefront of innovation, from slum upgrading initiatives and participatory governance to digital health solutions and cross-sectoral partnerships. Their agency demonstrates that resilient cities cannot be constructed solely through top-down policies; they must emerge from empowered communities working collaboratively with governments, donors, and practitioners.

The chapter concludes by emphasizing the urgent need to close data gaps, dismantle institutional silos, and shift governance and financing structures toward more inclusive, participatory, and equity-oriented systems. Only by integrating community power with structural reforms can societies advance health equity and realize the potential of cities as engines of health and resilience in the urban century.

1. Introduction

1.1 Urbanization and the expansion of informal settlements in low- and middle-income countries

Urbanization has emerged as a defining demographic trend of the twenty-first century, particularly across low- and middle-income countries (LMICs). While cities offer opportunities for economic advancement, education, and service access, rapid urban growth in LMICs is frequently unaccompanied by adequate planning or infrastructure investment [1]. This has resulted in a parallel expansion of informal settlements, or slums, which now house over one billion people globally – a figure expected to rise significantly in the coming decades [2].

These informal urban areas, often located on the peripheries of cities or in marginal lands, are characterized by insecure tenure, overcrowded and substandard housing, inadequate access to clean water, sanitation, and waste management, and a general absence of basic public services [3, 4]. In Sub-Saharan Africa, for example, over 55% of the urban population lives in slums [1]. These environments not only reflect economic and spatial exclusion but also institutionalized neglect, which has direct and indirect implications for population health.

1.2 Typology of informal settlements and their public health relevance

Informal settlements are not monolithic. They vary widely in form, governance, and stability, ranging from long-established peri-urban communities to newly formed squatter settlements. However, what unites these typologies is the lack of official recognition, planning oversight, and investment in health-related infrastructure [5]. The environmental and social conditions in these spaces create cumulative and chronic exposures to health risks, including communicable and non-communicable diseases (NCDs), maternal and child health vulnerabilities, injury risks, and mental health disorders [4, 6].

Despite their demographic significance, the health systems in many LMICs fail to systematically address the needs of residents in informal urban settings, leading to a widening of health inequities [6, 7]. These populations are often invisible in official statistics, underrepresented in service planning, and underserved by public health systems [7].

1.3 Urban poor situation analyses: Unmasking invisible vulnerabilities

Situational analyses (SITAN) of urban poor populations by organizations such as UNICEF and UN-Habitat have provided sobering insights. In Kenya, a 2018 SITAN found that urban poor children suffered from higher rates of stunting and lower immunization coverage than their rural peers, contrary to traditional assumptions about urban advantage [8]. In South Sudan, the 2021 SITAN revealed that informal settlements in towns like Juba suffer from poor health service access, high maternal and child mortality, and limited WASH (water, sanitation, and hygiene) infrastructure [9]. These findings underscore how the "urban health advantage" is deeply stratified and often bypasses the poorest communities.

Moreover, informal settlements are highly vulnerable to climate shocks, flooding, and infectious disease outbreaks. The COVID-19 pandemic further amplified these inequalities, as lockdowns and mobility restrictions exposed the fragility of livelihoods, social safety nets, and access to healthcare in dense, underserved urban areas [7, 10].

1.4 Framing health inequities and the case for resilience

This chapter adopts a systems-thinking approach to examine how structural and environmental determinants in informal settlements interact to shape health outcomes. Health inequities in these areas are not simply the result of individual or behavioral factors but stem from historical patterns of exclusion, weak governance, spatial segregation, and chronic underinvestment in public goods [10, 11]. At the same time, these communities exhibit diverse forms of adaptive capacity and social resilience – often through informal networks, grassroots organizing, and community-led innovations [1, 11].

Resilience in this context refers to both the capacity of urban poor populations to absorb shocks and adapt to long-term stressors such as climate change, displacement, and health system neglect [12]. Understanding and supporting this resilience are critical to advancing urban health equity.

1.5 Objectives and structure of the chapter

The overarching goal of this chapter is to examine how health inequities are produced, sustained, and potentially mitigated in informal urban settlements. The chapter will first review the key environmental and social determinants of health in these settings. It will then apply a systems-thinking lens to identify drivers of risk and opportunity. The latter sections will explore case studies and programmatic approaches that demonstrate community-led resilience and innovation. Finally, the chapter will present policy and planning implications, highlighting how equitable urban health systems can be designed to include, rather than exclude, the urban poor.

2. Understanding informal urban settlements

2.1 Characteristics and spatial distribution

Informal settlements – also known as slums, unplanned neighborhoods, or peri-urban settlements – are increasingly shaping the spatial and social landscapes of cities, especially in LMICs. These settlements are typically characterized by inadequate access to basic services (clean water, sanitation, electricity), poor housing structures, overcrowding, insecure land tenure, and a lack of formal recognition by planning authorities [1]. In many cities, they emerge in hazardous locations such as floodplains, hillsides, dumpsites, or industrial zones, where land is cheaper or unregulated but unsafe [3].

Globally, more than one billion people reside in informal settlements, with the majority concentrated in Sub-Saharan Africa, South Asia, and parts of Latin America [13]. In cities like Nairobi, Lagos, Dhaka, and Kinshasa, informal settlements comprise up to 60% of the total urban population [1, 9]. The spatial expansion of these areas often outpaces formal urban planning processes, leading to a mismatch between population growth and the provision of infrastructure and social services [14].

The internal layout of these settlements is frequently dense, with narrow alleys and little to no provision for roads, drainage, or public spaces. Housing structures vary, often constructed with scrap materials, lacking ventilation, and exposed to environmental hazards such as flooding or heat stress [5]. The spatial isolation of these communities – whether physical, political, or economic – reinforces patterns of exclusion and limits upward mobility.

2.2 Socioeconomic and legal dimensions

Informal settlements reflect broader patterns of inequality and marginalization. Residents are often low-income earners engaged in informal or precarious labor markets such as domestic work, street vending, day labor, or waste picking [4]. Many lack formal employment contracts, health insurance, or social protection, making them particularly vulnerable to economic shocks and health crises – as seen during the COVID-19 pandemic [7].

Legally, informal settlements exist in a gray area. Residents may lack secure land tenure or legal recognition of their homes, leading to fears of eviction, demolitions, restricted access to credit, and underinvestment in housing

improvements [15]. In some cases, settlements persist for decades without being granted legal status, despite housing multiple generations and contributing significantly to the urban economy. The lack of legal protection also limits residents' ability to demand services, participate in decision-making, or hold local authorities accountable [3].

Compounding these socioeconomic vulnerabilities are cultural and linguistic barriers. In many cities, informal settlements are home to migrants – both rural-to-urban and international – who may not speak the dominant language or possess formal documentation. These barriers affect access to education, healthcare, and political representation, deepening cycles of exclusion [9, 16].

2.3 Governance, service delivery, and land tenure issues

The governance of informal settlements is often fragmented, contested, or absent. Municipal governments may lack jurisdiction, resources, or the political will to extend services to these areas. In some cities, authorities deliberately neglect informal settlements in an attempt to discourage further growth or to avoid legitimizing unauthorized developments [17]. In others, service delivery is left to a patchwork of NGOs, community-based organizations, or private actors, leading to inconsistent quality and coverage [18].

Where state institutions are weak or absent, informal systems of governance may emerge. These can include local elders, youth groups, religious leaders, or informal landlords who mediate disputes and negotiate access to resources. While these structures can foster community resilience and solidarity, they are also susceptible to corruption, elite capture, or gender bias [6, 11].

Land tenure remains one of the most intractable issues. Insecure land rights limit residents' ability to improve housing or invest in infrastructure. They also deter state investment, perpetuating a cycle of disrepair and deprivation. Many residents fear eviction without compensation, particularly in cities undergoing rapid gentrification or urban redevelopment [16, 19]. Some cities have experimented with upgrading and regularization programs, but these efforts are often piecemeal, politically sensitive, or poorly resourced.

2.4 Population groups most affected

While informal settlements affect broad swathes of urban populations, certain groups bear a disproportionate burden of risk. Women and girls, for instance, face heightened exposure to gender-based violence (GBV) due to insecure housing, poor lighting, and a lack of private sanitation facilities [9]. Their caregiving responsibilities also place them on the frontlines of managing health, water, and food insecurity within the household [20].

Children in informal settlements are exposed to multiple deprivations – malnutrition, unsafe play environments, exposure to pollutants, and limited access to education and healthcare [8]. Adolescents, especially girls, face early pregnancy, school dropouts, and exploitation in informal labor markets [21].

Older adults and people with disabilities face barriers to mobility, chronic stress, and social isolation. Migrants and ethnic minorities may encounter systemic discrimination in accessing services, while internally displaced persons often settle in informal areas without durable legal or social protections [22, 23].

Together, these intersecting vulnerabilities demand urgent attention from policymakers, urban planners, and public health professionals. Understanding the structural characteristics, social dynamics, and governance challenges of informal settlements forms a necessary foundation for designing interventions that are inclusive, equitable, and resilient.

3. Environmental determinants and health outcomes

Urban informal settlements in LMICs represent concentrated zones of environmental risk. The convergence of overcrowding, substandard infrastructure, inadequate basic services, and environmental neglect creates conditions that are hazardous to health. Unlike planned urban areas, these settlements often fall outside formal zoning, environmental monitoring, or sanitation infrastructure, leaving residents exposed to a complex mix of environmental determinants that directly and indirectly affect their physical and mental well-being [17, 22].

3.1 Air and water pollution

Air pollution is a growing concern in informal settlements due to the use of biomass fuels, open burning of waste, vehicular emissions, and proximity to industrial sites. Many households rely on firewood, charcoal, or kerosene for cooking and heating in poorly ventilated spaces, resulting in dangerously high levels of indoor air pollution. Women and children, who spend more time indoors, are especially vulnerable to respiratory infections, chronic obstructive pulmonary disease (COPD), and asthma [4, 24]. Outdoor air pollution is further compounded by the lack of green spaces, unpaved roads, and dust during dry seasons.

Water pollution also poses serious health threats. In many informal settlements, water sources such as wells, rivers, and communal taps are contaminated with fecal matter due to poor drainage and a lack of sanitation infrastructure. Illegal or unsafe connections to municipal water systems increase the risk of contamination. Without reliable clean water, residents are at risk of waterborne illnesses such as cholera, typhoid, and diarrheal diseases – especially among children under five [9, 18].

The lack of water quality regulation in these areas means that outbreaks often go undetected or are addressed late. The 2020 COVID-19 pandemic further exposed the critical role of clean water in maintaining hygiene and preventing transmission in densely populated informal settlements [7].

3.2 Sanitation, drainage, and waste management

Inadequate sanitation is a defining characteristic of informal settlements and a leading contributor to the disease burden. Many areas lack private toilets, leading to shared, overcrowded, or unsafe latrines and, in some cases, open defecation. This practice contaminates soil and water, attracts flies and vermin, and perpetuates the transmission of gastrointestinal diseases [3, 5].

Drainage systems, if present at all, are often informal and poorly maintained. During rainy seasons, blocked or absent drains lead to widespread flooding, particularly in low-lying or reclaimed swamp areas. Standing water becomes a

breeding ground for disease vectors such as mosquitoes and flies, increasing the incidence of vector-borne diseases like malaria and dengue [14].

Solid waste management is typically unregulated. Without formal municipal waste collection, residents resort to dumping waste in rivers, roadsides, or abandoned lots, creating dangerous living environments. In some settlements, informal waste pickers play a crucial role in recycling, but they often do so under hazardous conditions, lacking protective equipment and facing exposure to toxic substances [6, 15].

These environmental failings are interconnected. Poor sanitation and waste management exacerbate water pollution; lack of drainage worsens flooding; and inadequate waste disposal contributes to air and soil contamination. Together, they create a reinforcing cycle of exposure and vulnerability that disproportionately affects children, women, the elderly, and people with chronic health conditions [8].

3.3 Climate-related hazards: Floods, heat, and disease vectors

Climate change has intensified environmental risks in informal settlements, which are often located in ecologically sensitive or marginal lands. Residents face a range of climate-related hazards, including frequent and severe flooding, extreme heat, and increased vector-borne disease transmission [20, 25].

Flooding is one of the most common and destructive climate-related threats. In settlements without drainage or flood control, even moderate rains can displace families, damage homes, and interrupt access to food, education, and health services. Flooding also contaminates water sources and spreads fecal matter and industrial waste, leading to outbreaks of leptospirosis, cholera, and skin infections [3, 16].

Rising temperatures and the urban heat island effect are of growing concern in overcrowded settlements built with corrugated iron, plastic sheeting, and other heat-retaining materials. These structures often lack insulation or ventilation, making them dangerously hot, especially during heatwaves. Older adults, infants, and individuals with cardiovascular conditions are particularly vulnerable to heat stress and heat-related mortality [12].

Vector ecology is also shifting due to changes in rainfall and temperature. Warmer climates extend mosquito breeding seasons and allow vectors such as *Aedes aegypti* to thrive in urban environments, increasing the risks of malaria, dengue, chikungunya, and Zika virus transmission [22, 25].

Despite bearing the brunt of climate change, informal settlements are often excluded from municipal climate adaptation and disaster risk reduction plans, leaving residents to rely on informal mechanisms or community-based coping strategies [14, 26].

Impacts on communicable diseases and NCDs are as follows:

The cumulative environmental risks in informal settlements have profound effects on the transmission of communicable diseases. Respiratory infections, gastrointestinal illnesses, vector-borne diseases, and skin infections are endemic due to poor air quality, inadequate sanitation, and unsafe housing [17, 18].

NCDs are also on the rise. Prolonged exposure to indoor and ambient air pollution is linked to cardiovascular disease, stroke, and COPD. The lack of physical space, recreational areas, and access to nutritious food fosters sedentary lifestyles and poor diets, contributing to obesity, hypertension, and diabetes [5, 21].

Moreover, environmental degradation contributes to injuries and disabilities. Unstable housing structures, poor lighting, and a lack of walkways increase the risk of falls, burns, and accidents – especially for children and older adults [21].

Crucially, both communicable diseases and NCDs interact and amplify vulnerability. A resident with chronic respiratory disease due to air pollution is more likely to suffer severe outcomes from an acute respiratory infection or heat stress. This syndemic nature of health risks demands a more integrated and systemic approach to urban health in informal settings [25].

3.4 Links to maternal, newborn, child, and mental health

Women and children bear a disproportionate share of the health impacts linked to environmental determinants in informal settlements. Pregnant women exposed to indoor air pollution are at higher risk of low birth weight, stillbirth, and hypertensive disorders [9, 22]. The lack of sanitation infrastructure puts women and girls at risk of urinary tract infections, reproductive tract infections, and increased exposure to GBV, especially in unlit or shared latrine areas [20].

Children are particularly susceptible to environmental hazards. Unsafe drinking water, poor hygiene, and food insecurity contribute to stunting, wasting, and under-five mortality. Diarrheal diseases remain among the leading causes of child death in informal urban areas [8]. In addition, exposure to neurotoxins from polluted environments (e.g. lead, heavy metals) can impair cognitive development and school performance [3].

Mental health is often overlooked but is profoundly affected by environmental stressors. Overcrowding, noise pollution, lack of privacy, and repeated exposure to floods or evictions can contribute to chronic anxiety, depression, and post-traumatic stress disorder [10, 24]. These conditions are often unrecognized and untreated due to stigma and limited access to mental health services (**Figure 1**).



Figure 1.
Environmental hazards and health outcomes in informal settlements. Source [4].

4. Social determinants and structural inequities

Health outcomes in informal urban settlements are not solely the result of environmental exposures; they are profoundly shaped by underlying social determinants and entrenched structural inequities. These determinants – poverty, lack of education, informal employment, gender disparities, exclusion from healthcare systems, and systemic discrimination – interact in complex ways to reinforce poor health and limit access to opportunity [6, 10]. Understanding these drivers is essential for designing equitable urban health interventions and for breaking the cycles of marginalization that characterize informal settlements across LMICs (**Figure 2**).

4.1 Poverty, education, and employment

Poverty is perhaps the most pervasive determinant of poor health in informal settlements. The urban poor often live in environments that offer few economic opportunities and require daily negotiation for basic needs such as food, shelter, and safety. These economic constraints affect not only the ability to access health services but also the capacity to maintain healthy diets, afford medications, or prioritize preventive care [16, 27].

Education is closely intertwined with poverty and health. Low levels of education – particularly among women – are associated with higher fertility rates, lower child immunization rates, and delayed healthcare-seeking behavior [9]. In many informal settlements, access to quality education is limited by distance, cost, lack of documentation, or the need for children to contribute to household income through labor. The resulting educational deficits perpetuate poverty and health inequities across generations [8].

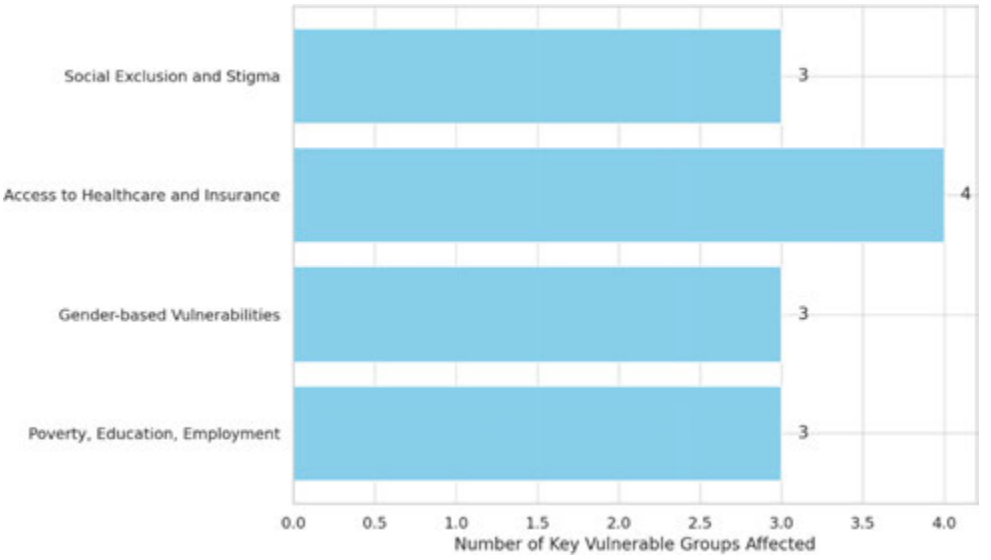


Figure 2.
Social determinants and their relative impact in informal settlements. Source [16].

Employment in informal urban areas is predominantly unregulated, insecure, and often hazardous. Residents are frequently employed in low-wage jobs without contracts or protections, such as street vending, domestic work, or waste picking [4, 24]. These jobs expose individuals to environmental toxins, physical injury, and exploitation. They also offer no sick leave or insurance, leaving workers to bear the cost of illness or injury alone. This economic precarity limits long-term health investments and sustains vulnerability to shocks.

4.2 Gender-based vulnerabilities

Gender is a critical lens through which urban health inequities must be understood. Women and girls living in informal settlements face a double burden: they are both disproportionately exposed to environmental and social risks and are frequently excluded from decision-making processes that shape their communities [20]. The absence of safe, private sanitation facilities contributes to urinary tract infections and reproductive health problems, while also exposing women to sexual violence when they must travel long distances or use facilities after dark [1, 22].

GBV is prevalent in many informal settings, exacerbated by overcrowding, unemployment, and weak rule of law. Domestic violence, sexual exploitation, and early marriage are persistent risks, particularly for adolescent girls [9]. Women also bear the primary responsibility for caregiving, which includes fetching water, caring for sick family members, and maintaining household hygiene. These roles, although vital, increase their exposure to environmental contaminants and disease vectors [3].

Social norms and cultural expectations can further limit women's access to healthcare, particularly reproductive and maternal services. In some contexts, women may require permission from male relatives to seek care or may avoid health facilities due to stigma or discriminatory treatment by providers [5]. Programs that fail to address these gendered realities risk perpetuating exclusion and reinforcing harmful power dynamics.

4.3 Access to healthcare and insurance

Despite their proximity to urban health infrastructure, residents of informal settlements are often excluded from formal healthcare systems. Barriers to access include unaffordable user fees, discrimination by health providers, lack of documentation, and fear of arrest or eviction when visiting public facilities [4, 6]. In many countries, national health insurance schemes require identification, proof of address, or formal employment status – criteria that many informal settlement residents cannot meet [25].

Out-of-pocket spending remains the primary method of accessing care in informal urban areas. This leads to catastrophic health expenditures, delayed treatment, and reliance on informal providers or pharmacies with questionable quality control [21]. For women, children, migrants, and people with disabilities, these barriers are magnified by intersecting vulnerabilities.

Emergency care is especially problematic. Ambulance services, emergency obstetric care, and trauma services are rarely available in or near informal

settlements. Delays in reaching care can result in avoidable deaths, particularly for newborns, pregnant women, and victims of violence or accidents [9, 20].

Digital health innovations, mobile clinics, and community health worker (CHW) programs have shown promise in expanding service access. However, these initiatives require adequate investment, community trust, and policy integration to be sustainable and equitable. [17]

4.4 Social exclusion and stigma

Residents of informal settlements are frequently viewed as "illegal occupants" or "squatters" by authorities and society at large. This perception contributes to systemic exclusion from services, denial of legal protections, and marginalization in political processes [7]. In some cases, settlements are actively demolished or ignored in city planning documents, reinforcing their invisibility and exclusion [1].

Social stigma further affects health outcomes. Residents may internalize shame associated with where they live, which impacts mental health and limits social cohesion. Individuals with certain health conditions – such as HIV/AIDS, tuberculosis, mental illness, or disabilities – may face compounded stigma, resulting in isolation and reluctance to seek care [10, 24].

Migrants and ethnic minorities are particularly vulnerable to discriminatory treatment in housing, employment, and health services. In some settings, they are scapegoated during disease outbreaks or political crises, further compounding their exclusion [6, 19]. These experiences of stigma and marginalization have profound psychosocial impacts, often leading to increased anxiety, depression, and reduced community engagement.

Building inclusive urban health systems requires not only infrastructure but also legal reforms, community empowerment, and the dismantling of systemic discrimination. Programs that engage residents as co-designers of interventions and recognize their lived expertise are more likely to succeed and sustain their impact [1, 11].

5. Systems thinking for urban health

5.1 Overview

Urban health challenges in informal settlements are deeply interconnected, driven by multiple overlapping determinants, including environmental degradation, social inequality, weak governance, and health system gaps. Addressing these challenges through linear or siloed interventions has proven insufficient. A more effective approach requires systems thinking – an analytical framework that recognizes complex interdependencies, dynamic feedback loops, and the nonlinear nature of urban health outcomes [18, 22]. When combined with a social–ecological model, systems thinking provides a powerful lens through which to understand and respond to the layered determinants of health in urban informal settings.

5.2 Conceptual framework: Systems thinking and social–ecological models

5.2.1 Conceptual framework: Interlinking systems thinking with the social–ecological model for urban health in informal settlements

Systems thinking involves shifting from fragmented approaches to a holistic understanding of how elements within a system interact (**Figure 3**). In the context of urban health, this means recognizing that health outcomes are not solely determined by healthcare access or individual behavior but emerge from the interactions among environmental, social, economic, and political subsystems [2, 27].

The social–ecological model complements this approach by illustrating how health is shaped across multiple levels – individual, interpersonal, community, organizational, and policy [3]. In informal settlements, an individual's risk of contracting disease is not just a function of their personal hygiene but also of community sanitation, social norms, local governance, and national policies on housing and urban development.

For example, poor drainage (an environmental factor), combined with weak local government action (a governance factor) and reliance on informal labor (an

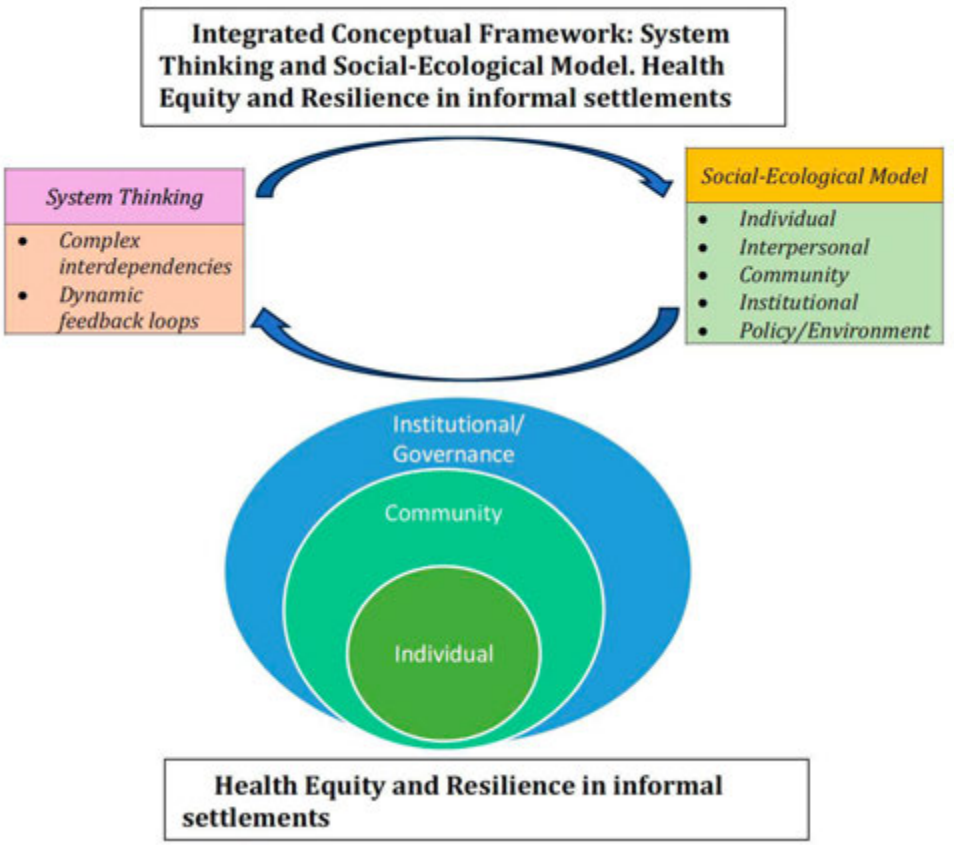


Figure 3.
Integrated Conceptual Framework.

economic factor), leads to increased exposure to waterborne diseases, especially for children (a health outcome). This highlights the need for solutions that cut across sectors and scales, targeting not just symptoms but root causes.

Foundation of the framework is as follows:

Urban health outcomes in informal settlements are **not isolated phenomena** but arise from a web of interconnected determinants:

- **Environmental degradation** (e.g. poor sanitation, waste accumulation, water pollution)
- **Social inequality** (e.g. exclusion, unemployment, gender-based vulnerabilities)
- **Weak governance** (e.g. lack of planning, insecure tenure, informal governance)
- **Health system gaps** (e.g. poor access, inadequate coverage, weak primary care)

Linear responses – targeting a single issue like water access or vector control – fail because they **ignore the reinforcing nature of other stressors**. Hence, a **systems approach** is essential.

5.2.2 Systems thinking: A meta-analytical lens

- **Dynamic feedback loops**: For example, poor waste management → increased disease burden → overburdened health systems → lowered trust → reduced service uptake → worsened outcomes.
- **Non-linearity**: A small policy change (e.g. legal land tenure) may trigger significant health and economic benefits downstream, whereas large investments in clinics alone may have limited impact without upstream changes in water and housing.
- **Leverage points**: Systems thinking helps identify where **targeted, multi-sectoral interventions** can dramatically shift outcomes (e.g. community-based health insurance coupled with WASH investments).

5.2.3 Social–ecological model layers (modified)

This model complements systems thinking by categorizing the **layers of influence**:

- **Individual**: Knowledge, behavior, mental health, and self-agency.
- **Interpersonal**: Household dynamics, caregiving, and gender roles.
- **Community**: Local norms, informal networks, and community structures.
- **Institutional/Governance**: Access to services, trust in institutions, and recognition.

Component	Mapped determinant	Feedback loop/influence
Governance	Structural	Absence of recognition leads to exclusion → informal services fill gaps → underreporting
Housing & environment	Environmental	Poor housing increases disease risk → school or work absenteeism → intergenerational poverty
Social norms & inequality	Social	Gender roles limit care-seeking → delayed treatment → worsened outcomes
Health system access	Structural	Lack of ID or residency status → no access to care → dependence on informal providers

Table 1.
Combined analytical view – achieved by merging these models.

- **Policy/Environment**: Urban planning, environmental regulations, and housing policy.

Each layer **interacts with and reinforces the others**, necessitating an integrated response (**Table 1**).

This **intersectional mapping** provides **actionable entry points** for interventions – such as improving civil documentation systems, ensuring legal recognition of slums, or integrating informal health providers.

5.2.4 Implications for research and practice

- This integrated framework provides a **clear roadmap** for multi-sectoral, scalable interventions in LMIC urban slums.
- It facilitates **cross-sector alignment** (urban planning, health, environment, and social welfare).
- It empowers practitioners to **prioritize leverage points**, monitor system-level changes, and enhance community resilience (**Table 2**).

5.3 Interlinkages between environment, policy, health systems, and behavior

One of the core insights of systems thinking is the recognition of interlinkages – how different sectors influence one another in urban health systems. In informal settlements, environmental conditions such as air and water pollution, waste accumulation, and housing quality are directly affected by broader urban planning and governance decisions [1, 17].

For instance, the lack of formal recognition of informal settlements can prevent municipalities from investing in water infrastructure. This, in turn, leads to reliance on unsafe water sources, which causes diarrheal diseases and increases healthcare costs, undermining household finances and education due to lost income and school days [9, 25].

Health systems themselves are shaped by these same policies. Where urban policies exclude informal settlements, healthcare infrastructure is underdeveloped or absent, leading to higher reliance on unregulated private providers and traditional

Determinant	Example in settlements	Impact on health outcomes
Poverty & unemployment	High proportion of informal jobs, daily wage dependency	Limited access to care, poor nutrition, and vulnerability to shocks
Inadequate housing & WASH (water, sanitation, and hygiene)	Overcrowded shelters, poor sanitation, and unsafe water	Higher rates of diarrheal diseases, tuberculosis (TB), and cholera
Gender inequities	Early marriage, gender-based violence (GBV), and exclusion from decision-making	Increased maternal mortality, poor sexual and reproductive health (SRH) outcomes
Weak governance & policy gaps	Limited regulation of informal settlements	Fragmented service delivery, inequitable resource allocation
Climate & environmental risks	Flooding, heatwaves, pollution exposure	Increased NCD burden, vector-borne, and respiratory diseases
Migration & displacement	Refugee/ internally displaced persons (IDP) influx, loss of livelihoods	Overstretched services, higher mental health risks

Table 2.
Key determinants of health inequities in LMIC settlements.

healers [4]. The behaviors of residents – such as delaying care-seeking, relying on self-medication, or avoiding formal services – are shaped by past experiences, affordability, and trust, creating a behavioral feedback loop [24].

Another example is maternal health. Environmental stressors (e.g. extreme heat, water scarcity), social dynamics (e.g. gender norms, early marriage), and policy exclusions (e.g. lack of a national ID to access insurance) converge to limit pregnant women's access to timely antenatal and delivery care [9, 22]. Addressing maternal mortality, therefore, requires integrated interventions that simultaneously improve the physical environment, empower women, and reform access policies (**Table 3**).

5.4 Feedback loops and vulnerability pathways

Systems thinking emphasizes the importance of feedback loops – where the output of a system influences future operations of that same system. In informal urban contexts, both reinforcing and balancing feedback loops are at play.

A reinforcing loop can be seen in poverty and ill-health. Poor urban residents often live in polluted, overcrowded environments that contribute to ill-health. Ill-health reduces income due to lost workdays and medical expenses, which further limits the ability to improve living conditions, perpetuating the cycle [10, 27]. Similarly, stigmatization of slum dwellers can lead to underinvestment in public services, reinforcing their marginalization and vulnerability [19].

A balancing loop can occur when communities mobilize to address gaps through self-organization, such as building latrines, organizing waste disposal, or supporting community health volunteers [11]. These actions can temporarily stabilize local systems but may also become strained without institutional support.

Vulnerability pathways describe the cascading nature of risks in complex systems. For instance, a climate shock, such as flooding, can displace families, destroy homes, contaminate water sources, and interrupt health and education services. These disruptions disproportionately affect children, pregnant women, and

Bottleneck	Consequence	Resilience/Mitigation strategy
Weak health system governance	Poor coordination, policy fragmentation	Establish intersectoral governance & taskforces
Inadequate health financing	Dependence on donors, out-of-pocket payments	Expand fiscal space; innovative financing (insurance, bonds)
Limited human resources for health	Burnout, attrition among community health workers (CHWs), and skill gaps	Scale-up CHW training, incentives, and supportive supervision
Supply chain inefficiencies	Frequent stock-outs, poor last-mile distribution	Strengthen logistics, utilize digital tracking, and implement pre-positioning.
Low community engagement	Limited trust in services, poor uptake	Mobilize community health committees and co-design programs
Poor data & monitoring systems	Weak planning and an inability to track inequities	Invest in DHIS2, digital registries, and real-time dashboards
Climate shocks & disasters	Service disruptions, higher mortality	Climate-adaptive PHC, pre-crisis preparedness plans

Table 3.
Bottlenecks and resilience strategies in LMIC settlements.

the elderly, creating long-term effects on physical health, mental health, and livelihood security [26, 28].

These pathways demonstrate that single-point interventions – such as distributing mosquito nets or building a health post – while important, are insufficient unless embedded within broader systemic change. Effective responses must engage across multiple leverage points: upgrading infrastructure, reforming tenure policies, improving service delivery, and strengthening social safety nets.

5.5 Systems mapping and strategic leverage points

In practical terms, applying systems thinking to urban health involves mapping systems to identify key leverage points – places where small changes can produce significant impacts (**Table 4**) [27]. These may include:

(1) Information flows (e.g. increasing awareness of rights or environmental risks).

(2) Rules and incentives (e.g. zoning reforms to include informal settlements in planning).

(3) Power to self-organize (e.g. supporting local health committees or women's groups).

(4) Paradigm shifts (e.g. shifting how slums are perceived – from problem zones to hubs of resilience and innovation).

(5) Interventions that combine these leverage points are more likely to transform urban health systems and address underlying inequities than isolated technical fixes.

Category	Key factors
Structural determinants	Poverty, governance, political instability, conflict, and donor dependency
Socioeconomic determinants	Education, income inequality, gender inequities, and employment opportunities
Environmental determinants	Housing quality, WASH (Water, sanitation, and hygiene), and climate change impacts
Health system determinants	Access to essential services, financing gaps, workforce shortages, and drug supply issues
Community & social determinants	Social cohesion, cultural norms, community participation, and trust in institutions

Table 4.
Key determinants of health inequities

6. Community-led resilience and innovations

While the structural challenges in informal settlements are profound, they are not met with passivity. Across LMICs, communities living in these marginal urban spaces have demonstrated remarkable resilience and innovation in responding to threats, filling service gaps, and improving health outcomes. These efforts often emerge not in isolation but through collective agency, strategic partnerships, and adaptive practices built on local knowledge and lived experiences. Community-led interventions – ranging from climate-smart infrastructure to participatory planning – offer valuable lessons for reimagining equitable urban development and health systems [1, 11].

6.1 Case studies: Slum upgrading, climate-smart designs, and health outreach

One of the most well-documented approaches to improving informal settlements is slum upgrading. This includes physical infrastructure improvements (e.g. roads, drainage, housing), access to basic services (e.g. water, sanitation), and land tenure security. Notable examples include the Kibera Integrated Water, Sanitation and Waste Management Project in Nairobi, Kenya, and the Baan Mankong program in Thailand, which empowered communities to plan and implement their own housing solutions with government and NGO support [14, 15].

In South Africa, the VPUU (Violence Prevention through Urban Upgrading) project combined physical infrastructure development with social services to reduce crime and improve health outcomes in Cape Town's informal settlements. These interventions were successful in part because they were co-designed with communities and implemented in phases, with iterative feedback and learning. [5]

Climate-smart designs are also emerging, often from necessity. In flood-prone areas of Bangladesh and India, communities have built elevated homes and floating toilets, designed canals for floodwater diversion, and planted trees for shade and soil retention. These innovations – though low-tech – are climate-resilient and affordable, addressing immediate needs while improving long-term health and environmental outcomes [26, 28].

Community health outreach is another pillar of resilience. In Kampala, Uganda, residents of informal settlements partnered with local authorities to implement

targeted malaria and cholera prevention campaigns, combining clean-up drives with education and door-to-door visits. These initiatives were especially successful when combined with localized data collection and peer engagement [17].

6.2 CHWs and digital tools

CHWs have long served as a bridge between underserved populations and formal health systems. In informal urban settings, CHWs are often the most accessible and trusted health actors, particularly in areas where clinics are distant or overloaded. CHWs provide basic services such as immunization reminders, maternal and newborn care, malaria testing, family planning education, and referrals for advanced care [4, 22].

What distinguishes resilient CHW programs in informal settlements is their embeddedness in the community and their adaptability. For example, during the COVID-19 pandemic, CHWs in Nairobi's Mathare and Mukuru settlements not only provided health education and distributed personal protective equipment but also conducted community surveillance using mobile phones and geo-tagging tools. These efforts helped identify outbreak hotspots and facilitated a quicker response from local authorities and NGOs [7].

Digital innovations have significantly expanded CHWs' capabilities. Mobile health (mHealth) platforms like M-TIBA in Kenya and CommCare in India allow CHWs to register clients, schedule visits, record symptoms, and access guidelines in real-time. These tools also support data aggregation and analysis, enabling local governments to plan services more effectively [3, 25].

Moreover, digital dashboards and open-source mapping platforms (e.g. Ushahidi, OpenStreetMap) have allowed residents to map service gaps, hazards, and health trends themselves, increasing visibility and accountability. However, digital inclusion must be prioritized – ensuring that women, older adults, and persons with disabilities have access to devices, connectivity, and digital literacy training [9].

6.3 Participatory planning and health governance

Participatory governance is foundational to resilience. It refers to processes in which residents are involved in identifying problems, setting priorities, allocating resources, and evaluating progress. When genuine and sustained, participatory governance builds social capital, enhances local accountability, and ensures that interventions reflect community priorities and context [6, 10].

In Latin America, the Favela-Bairro program in Rio de Janeiro and community health committees in Lima, Peru, empowered informal settlement residents to collaborate with local governments on sanitation, housing, and health programs. In both cases, participation was not symbolic – it included decision-making power and budget management, resulting in higher satisfaction, better health outcomes, and reduced tensions between authorities and residents [24].

In Ghana, participatory budgeting exercises in Accra's slums brought together health workers, youth, and municipal leaders to co-design maternal health and sanitation improvements. These processes also served to build trust between historically marginalized groups and state institutions [16].

In cities like Mumbai, the Society for the Promotion of Area Resource Centres (SPARC) has partnered with women's savings groups to drive slum-upgrading

projects. By leveraging financial literacy, collective bargaining, and data collection, these women have become influential actors in local health and development planning [11].

6.4 Public-private and grassroots partnerships

No single actor can address the complex needs of informal urban settlements. Effective community resilience depends on multi-stakeholder partnerships that leverage the strengths of grassroots groups, local governments, private sector actors, and international agencies. When built on transparency and mutual respect, these partnerships can catalyze resources, scale innovations, and institutionalize community leadership [1, 19].

One notable example is the Clean India Mission (Swachh Bharat Abhiyan), which mobilized communities, municipalities, and businesses to eliminate open defecation. In urban informal settlements, partnerships between NGOs and sanitation companies enabled the deployment of mobile toilets, waste collection services, and behavior-change campaigns.

In Nairobi, the Mathare Youth Sports Association (MYSA) partners with local clinics and NGOs to provide peer education, sports-based mental health programming, and HIV prevention. Youth leaders are trained as mentors and mobilizers, demonstrating how sport and social capital can enhance urban health [8].

The private sector also plays a role in resilience. In Dhaka and Lagos, mobile network operators have partnered with health NGOs to provide SMS-based health alerts and emergency hotlines for urban slums. Others have contributed by investing in clean energy, water purification systems, or low-cost diagnostic tools adapted for slum contexts [25].

Crucially, grassroots partnerships often fill gaps that state actors overlook. Women's cooperatives, faith-based groups, and informal savings clubs frequently serve as informal safety nets, providing food, loans, or shelter during crises. Recognizing and supporting these networks is essential for inclusive urban development [26, 27].

7. Challenges and gaps in current approaches

Despite growing recognition of the need for inclusive urban health and planning, existing approaches to addressing the challenges of informal settlements remain fragmented, under-resourced, and inconsistent. Structural and systemic barriers persist, undermining efforts to advance equity, resilience, and health in these marginalized spaces. This chapter examines four critical domains of persistent gaps: data and visibility, institutional coordination, political economy, and the scalability of community-driven innovations.

7.1 Data and visibility issues

A foundational obstacle to effective programming in informal settlements is the lack of accurate, disaggregated, and timely data. Residents of these areas are often invisible in national censuses, household surveys, or health information systems due to the informal nature of their dwellings, irregular land tenure, or absence from official maps [13, 22]. Consequently, health risks and service gaps remain unquantified, making it difficult to allocate resources equitably or evaluate impact.

Moreover, many slum communities are excluded from administrative boundaries, creating confusion over service jurisdiction and leaving them unrepresented in urban planning processes [24]. This invisibility further limits the ability of governments and development actors to assess vulnerabilities, plan interventions, and measure progress toward Sustainable Development Goals (SDGs), particularly SDG 3 (health and well-being) and SDG 11 (sustainable cities and communities).

Innovative methods such as community-led mapping, participatory enumeration, and geospatial tools offer promising alternatives [29]. However, these methods are not yet systematically integrated into national statistical systems or policy-planning frameworks, limiting their influence on institutional decision-making.

7.2 Weak institutional coordination

Urban health and informal settlement issues span multiple sectors and institutions, yet the absence of effective coordination mechanisms impedes integrated action. Ministries of Health, Housing, Environment, and Local Government often work in silos, guided by competing mandates, disjointed data systems, and conflicting funding priorities [3].

At the municipal level, fragmented responsibilities for water, sanitation, waste management, public health, and land administration lead to inefficiencies and policy incoherence [30]. This lack of coordination is especially detrimental in informal settlements, where multi-sectoral determinants of health converge – from environmental exposures to infrastructure deficits and social vulnerabilities.

Efforts to establish cross-sectoral platforms, such as urban health working groups or city task forces, remain underfunded or underutilized. Furthermore, development partners often implement short-term, project-based interventions without alignment with national frameworks or local capacities, leading to duplication and missed opportunities for sustainable impact [4, 6].

7.3 Political economy and marginalization

Informal settlements are often the result of political neglect and structural inequality, rather than planning failure alone. Their continued marginalization is not accidental but reflects entrenched power dynamics in land markets, urban governance, and service allocation [10, 11].

Many local authorities view informal areas as illegal, transient, or undesirable, resulting in policies of evasion, eviction, or containment rather than inclusion [7]. This exclusion is compounded by residents' lack of formal land tenure, political representation, or legal protections – rendering them voiceless in city planning and vulnerable to exploitation or displacement [1, 11].

The political economy of urban health investment also is a disadvantage to informal settlements. Capital-intensive infrastructure projects often prioritize central business districts or affluent neighborhoods, sidelining slums as cost-inefficient or high-risk. Moreover, donor funding and private investment tend to favor high-visibility interventions with rapid returns, leaving behind slower but more equitable community-led development efforts.

Tackling these structural exclusions requires a rights-based approach, including legal recognition of informal settlements, reforms in land and housing policies, and greater civic participation in decision-making.

7.4 Scaling community innovations

While community-led initiatives have demonstrated effectiveness in addressing health and infrastructure challenges in informal settlements, most remain isolated, small-scale, and donor-dependent. Innovations such as neighborhood health committees, climate-resilient shelter prototypes, and mobile health outreach have shown positive outcomes [26], yet they rarely transition from pilot projects to systemic solutions.

One barrier to scaling is the lack of formal institutional support or financing mechanisms for grassroots efforts. Community-based organizations often face challenges in accessing grants, participating in policy dialogs, or influencing urban planning processes. Moreover, innovations are often evaluated using narrow metrics that fail to capture co-benefits such as social cohesion, empowerment, or climate resilience [31].

Building enabling ecosystems for community innovation requires supportive policy environments, co-creation platforms, technical assistance, and flexible financing modalities. Public–private partnerships and donor-supported innovation labs can play a catalytic role – provided they respect and center the knowledge, leadership, and rights of urban poor communities [25, 29].

8. Conclusion and future directions

This chapter has examined the invisible but profound inequities shaping health outcomes in informal urban settlements, where systemic marginalization intersects with fragile infrastructures to erode resilience. The evidence underscores that resilience cannot be reduced to community coping strategies alone but must be understood as a dynamic outcome of structural determinants, including governance, housing, sanitation, and access to primary care. A transformative response requires shifting from fragmented, short-term interventions toward sustained, equity-oriented investments that address both proximal health needs and the distal social determinants that entrench vulnerability.

By reframing informal settlements as critical sites of innovation rather than zones of neglect, policy and research must converge to build integrated systems that elevate lived experiences into actionable knowledge. Strengthening resilience in these spaces will demand multi-sectoral governance, participatory planning, and scalable health delivery models aligned with urban realities. Ultimately, addressing the "invisible fault lines" in health equity is not only central to advancing universal health coverage (UHC) but also essential for realizing the broader sustainable development agenda in rapidly urbanizing contexts.

8.1 Summary of key findings

8.1.1 Key findings

This chapter has illuminated the often-overlooked yet deeply embedded inequities that shape health outcomes in informal urban settlements. These settings – marked by exclusion from formal planning, weak infrastructure, and systemic neglect – expose how health inequities are not simply the result of individual

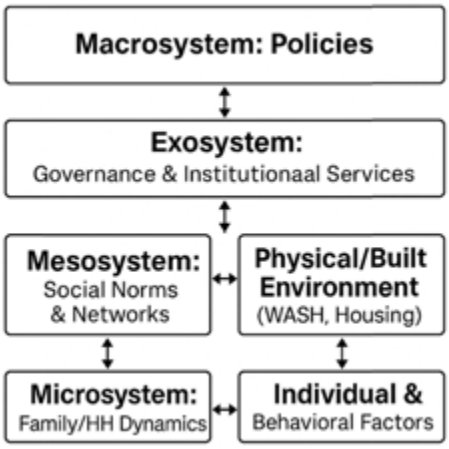
vulnerabilities but are produced and perpetuated by structural determinants such as insecure housing, inadequate sanitation, limited access to primary care, and fragmented governance [3].

The evidence presented underscores that resilience in these environments cannot be reduced to community coping or adaptation strategies alone. Rather, resilience must be reframed as a systems-level outcome, emerging from the interaction between socio-political structures, ecological determinants, and community agency [17]. A transformative response demands a decisive pivot away from fragmented, short-term interventions toward long-term, equity-driven investments that address both proximal health needs and the distal drivers of vulnerability [4].

By repositioning informal settlements as spaces of innovation, resourcefulness, and potential – rather than zones of neglect – research, policy, and planning can begin to coalesce around integrated, inclusive systems that elevate community voices into policy action [18]. Building resilient urban health systems will require multi-sectoral governance, strengthened participatory mechanisms, and scalable delivery models that align with the lived realities of marginalized urban populations [6].

Crucially, the integrated application of Systems Thinking and the Social–Ecological Model within this chapter offers more than descriptive utility; it provides a dynamic, actionable framework for understanding and intervening in the complex web of urban health determinants (**Figure 4**) [22]. This integrative lens enables practitioners and policymakers to identify feedback loops, leverage points, and interdependencies across environmental, social, and institutional domains [7].

Ultimately, addressing the "invisible fault lines" in health equity is not only fundamental to achieving UHC but is also pivotal for realizing the SDGs in rapidly



Legend:
Double arrows: Feedback loops (e.g., poor governance reinforces poverty, which limits education and worsens health)
Bold boxes: Leverage points (e.g., slum upgrading, social protection, UHC)

Figure 4.
Urban health determinants and resilience in informal settlements.

urbanizing contexts [14]. The path forward lies in embracing complexity, fostering inclusive governance, and investing in urban systems that leave no one behind.

8.2 Priorities for research, policy, and practice

8.2.1 Research priorities

The current knowledge base remains skewed toward rural health or formal urban systems, with insufficient data on the lived experiences, health metrics, and resilience capacities of slum dwellers. Research must prioritize the following:

Disaggregated, community-generated data for service planning and monitoring [23].

Longitudinal studies on environmental exposures and health outcomes in informal settlements.

Evaluations of cross-sectoral and participatory urban health interventions.

Gendered analyses of climate vulnerability and access to care.

Building such evidence requires democratizing research, supporting South-based institutions, and integrating community voices as co-producers of knowledge [17].

8.2.2 Policy priorities

Policy transformation must begin with the formal recognition of informal settlements in national and subnational development frameworks. Governments must do the following:

Integrate urban poor populations into national health strategies and urban master plans [18].

Align land, housing, WASH, and climate policies to support slum upgrading and infrastructure equity [14].

Ensure public financial systems allocate targeted resources to underserved urban areas.

Create mechanisms for civic participation in planning and decision-making [11].

International donors and UN agencies must avoid vertical, siloed programming and instead support long-term, integrated, and area-based approaches that strengthen local systems and governance [4].

8.2.3 Practice priorities

In operational terms, the focus must shift toward inclusive urban health systems that are community-driven, culturally responsive, and environmentally resilient. This includes:

Scaling proven community-led interventions, such as health outreach, digital tools, and early warning systems [20].

Strengthening the role of CHWs through training, fair remuneration, and supportive supervision.

Investing in climate-resilient infrastructure and sustainable waste management systems in slum areas.

Establishing public–private–people partnerships that enable co-investment and innovation while safeguarding community rights [13].

Frontline workers and grassroots organizations should be recognized not only as service extenders but also as co-designers of health systems.

8.3 Building inclusive, resilient urban health systems

To chart a path forward, we must reconceptualize health systems for the urban poor not as extensions of formal clinical infrastructure but as ecosystems of care, resilience, and rights. A resilient urban health system recognizes the interdependence between health, housing, environment, and livelihoods – and is responsive to shocks such as pandemics, climate hazards, and economic downturns [2, 25].

Such systems require the following:

(1) A systems thinking approach that maps urban health as a dynamic interaction of social, environmental, economic, and political subsystems.

(2) Robust community platforms that anchor health promotion, surveillance, accountability, and emergency response.

(3) Interoperable data systems that capture informal settlements, feed into planning, and support real-time decision-making.

(4) Flexible financing models that pool domestic and external resources to ensure sustainability and equity.

(5) Governance models must also evolve to be deliberately inclusive, giving voice and decision-making power to marginalized groups – particularly women, youth, and persons with disabilities – in health system design and oversight [16, 28].

8.4 Final thoughts

Informal settlements are not marginal peripheries – they are central to the future of cities and health equity. The resilience of their residents, the ingenuity of grassroots responses, and the urgency of climate and health threats call for a transformative agenda – one that is rights-based, equity-driven, and locally anchored. The "invisible fault lines" of urban inequality can be mended through systems that recognize every life, every settlement, and every voice as integral to a healthier, more just urban world.

Figure 5 describes the conceptual framework of health inequities – a layered concentric model showing structural determinants (poverty, governance, climate change), intermediate determinants (housing, WASH, education, gender, access), and health outcomes (maternal and child mortality, infectious diseases, NCDs, mental health).

Figure 6 describes pathways of resilience – a flow diagram illustrating the progression from stressors → immediate impacts → system/community response → adaptive mechanisms → resilient outcomes.



Figure 5.
Conceptual framework of health inequalities in LMIC settlements.

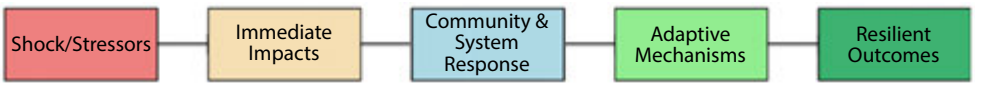


Figure 6.
Pathway of resilience in fragile LMIC settings.

Figure 7 describes the comparative burden of disease in LMIC informal settlements versus the general population.

- **Type**: Clustered bar chart or pie/donut comparative split.
- **X-axis**: Categories of health outcomes (e.g. *Maternal Mortality Ratio [per 100,000], Under-5 Mortality [per 1,000], Prevalence of Infectious Diseases [%], NCD Burden [%]*).
- **Y-axis**: Rate or % (depending on the metric).
- **Bars/Colors**: Two colors – *informal settlements* versus *general LMIC population*.
- **Key insight**: Makes inequalities visible at a glance.

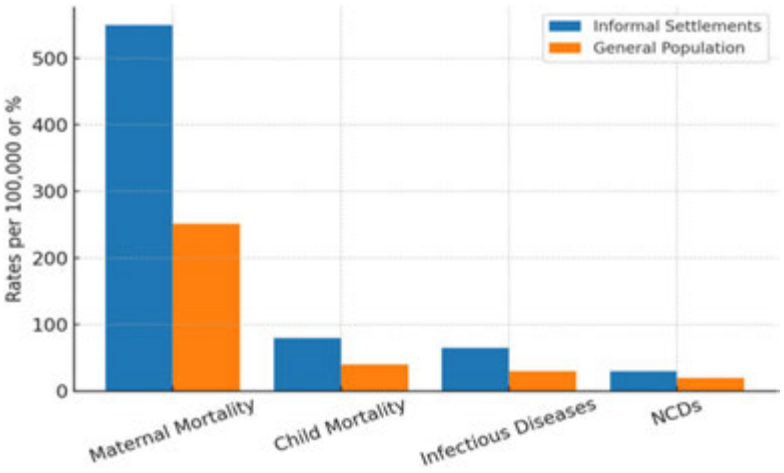


Figure 7.
Comparative burden of disease – relative burden of diseases in LMIC informal settings versus general population.

- **Data source suggestions**: WHO Global Health Observatory, UNICEF, and the World Bank.

Figure 8 shows the Timeline of Global and Regional Milestones.
Figure 9 describes the integration of community health platforms into urban/peri-urban LMIC systems.



- **1978**: Alma-Ata Declaration (Primary Health Care).
- **2000**: Millennium Development Goals (MDGs).
- **2005**: WHO Commission on Social Determinants of Health.
- **2015**: Sustainable Development Goals (SDGs).
- **2016**: New Urban Agenda (Habitat III).
- **2019**: UHC High-Level Meeting (UNGA).
- **2021–2022**: COVID-19 resilience strategies in LMICs.
- **2023–2025**: African Union/WHO strategies on urban health equity.

Figure 8.
Timeline of global and regional milestones.

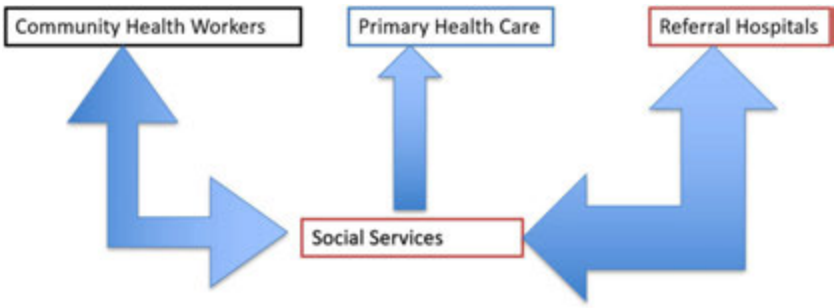


Figure 9.
Integration of community health platforms.

- **Type**: Flow schematic/system diagram.
- **Structure**:
  - **Level 1 (Base)**: *CHWs* and *Community-Based Organizations*.
  - **Level 2 (Linkages)**: *Primary Health Care Units → Referral Hospitals*.
  - **Level 3 (Cross-cutting)**: *Social services (water, sanitation, housing, nutrition)*, *digital health tools (mHealth, GIS)*.
  - **Level 4 (Enablers)**: *Governance*, *Financing*, *Community Engagement*.
- **Design cue**: Arrows showing bi-directional flow (referrals, feedback, data).
- **Purpose**: Demonstrates how CHW platforms can be systematically integrated into fragile and urban systems.

Acronyms and abbreviations

AIDS	Acquired immunodeficiency syndrome
ALNAP	Active Learning Network for Accountability and Performance in Humanitarian Action
APA	American Psychological Association (also known as APA referencing style, which is widely used in academia)
CHW	Community health worker
COPD	Chronic obstructive pulmonary disease
COVID	Coronavirus disease (COVID-19)
GBV	Gender-based violence
GIS	Geographic Information System
HIV	Human immunodeficiency virus
ID	Infectious disease (in some contexts: Identity Document, but here "Infectious Disease" fits the public health context)

MYSA	Mathare Youth Sports Association (Kenya-based NGO; commonly cited in urban health and resilience work)
NGO	Non-governmental organization
SDG	Sustainable development goal
SDI	Slum Dwellers International
SITAN	Situation analysis
SMS	Short message service (mobile phone text messaging)
SPARC	Society for the Promotion of Area Resource Centres (India; key partner of SDI).
TIBA	Tackling Infections to Benefit Africa (multinational research program, often referred to as the "TIBA Partnership")
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
VPUU	Violence Prevention Through Urban Upgrading (South Africa-based initiative)

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Conflict of interest

The authors declare no conflicts of interest.

Notes/Thanks/Other declarations

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The insights and reflections in this chapter also build upon decades of collaborative engagement with global and national health partners, whose dedication to addressing inequities in low- and middle-income country (LMIC) contexts continues to be a source of inspiration.

Unless otherwise stated, all errors or omissions remain the responsibility of the author.

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Author details

Samson Oboche Agbo
Sam-Divine Health Vanguard International CIC, Africa Saving Lives Konsult (ASLK), Juba, United Kingdom

*Address all correspondence to: agbosam@gmail.com

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Chapter 7

Socially Stabilizing Communities for Human Trafficking Survivors

An Goldbauer

Abstract

Some trafficked survivors feel disjointed as systems fail to provide stable housing. Shelters and group homes notoriously put up barriers, claiming they are at full capacity when they are not. Contractual arrangements are not upheld, and instead, some agencies shift their allegiance to outside service providers at the expense of the staff and survivors. The staff members do not receive support, and the victims are failed by the very system meant to protect them. Shelters may have barriers to entry due to their rules and regulations that cannot accommodate the person for a number of reasons. Stable communities and infrastructures are needed.

Keywords: anti-trafficking programs, accreditation, barriers, board members, business models, care plans, communities, donors, domestic violence shelters, Freedom Network, host housing, infrastructure, insurance, investors, MOUs, NCMEC, onboarding, Polaris, U.S. Department of Defense, International Institute of Clinical Sexology, Polaris Project, APHA, CARF, Joint Commission

1. Introduction

Vulnerabilities exist in urban areas. Housing instability and financial exclusion hinder sustainable urban development, affecting public health and safety. Criminal penalties, fines, and arrests are costly to communities, and in 2023, more than 18,000 people a week ended up homeless, according to the National Alliance to End Homelessness. More than 55% of the global population lives in urban areas, and this number is predicted to rise to 68% by 2050 [1].

The U.S. Department of Defense defines trafficking in persons (TIP) as the exploitative measures traffickers use, which involve recruiting, grooming, and employing coercive measures, control, and debt bondage. Traffickers exploit vulnerable people who experience financial hardships and housing insecurities for commercial purposes [2].

The author uses "survivor" and "victim" interchangeably. An individual may vacillate between the two identities depending on whether the individual is experiencing abuse, a lack of self-agency, or living under the constraints of the abuser(s) or systems, such as serving time in prison or wearing an ankle monitor because of criminal charges.

A survivor or victim is an individual with lived experience of human trafficking. It is important to note that not everyone with lived experience identifies as either one [1].

There are several issues affecting survivors who have been either labor or sex trafficked or have experienced some form of trafficking, sexual assault, and exploitation, as captured in a National Survivor Study released by Polaris. Human trafficking survivors reported that agencies failed them when they did not fulfill the services or only fulfilled partial services. Systems meant to provide stability often served as barriers to entry and access to trauma-informed care. Survivors reported racking up charges for arrests they experienced as a result of their traffickers enlisting them into a system of criminal activities. Polaris released a report in 2023 concluding that systems fail human trafficking survivors [3].

Polaris National Study (PNS) in 2018 found that homelessness and housing insecurity place people at risk of trafficking [4].

Since the Supreme Court's ruling in Grants Pass v. Johnson, homeless people can now be placed under arrest and are at risk of ending up in systems that further fuel their trauma. The ruling in Grants Pass v. Johnson does not view arresting homeless people as a violation of the Eighth Amendment, which otherwise would protect against cruel and unusual punishment by the government. Survivors with dependents living in poverty made less than $25,000 annually [3, 4].

According to the National Constitution Center (NCC), the Eighth Amendment states, "Excessive bail shall not be required, nor excessive fines imposed, nor cruel and unusual punishments inflicted" [5].

A Wilson Study for Science and Justice and the Fines and Fees Justice Center report on the magnitude and long-term effects of fines and fees, which push people even deeper into the justice system that benefits from collecting the debt but ultimately costs states billions [6].

Changes in the power dynamics between staff and survivors affected relationships and hindered collaboration, limiting survivor choices. The Anti-Trafficking Review released a study conducted by Romero et al. on U.S. anti-trafficking programs. A review of policies and procedures for housing programs showed that more than three-quarters had policies and procedures in direct conflict with standards of trauma-informed approaches [7].

Several cities and states have demonstrated the failures of Housing First. Senior Advisor Judge Glock at the Cicero Institute cites a UCLA study that shows 75% of the homeless population has serious mental comorbidities and another 75% is diagnosed with substance use. Glock draws attention to these illnesses as areas in need of attention and treatment, emphasizing that housing alone is not a treatment for mental illness or substance use [8].

Paul Webster, senior fellow at the Cicero Institute, draws attention to the inefficiencies in the leadership running housing programs [9].

2. Methods

The author referenced government sites for documents and updates, academic journals, newspapers, and industry-related websites – some from the anti-trafficking industry, business sector, insurance industry, legal sector, and human rights industry – and draws from his own experience in working within the human rights sector and the

home health and hospice industry. A review was performed on the common findings reported by reputable organizations, such as Polaris, Freedom Network, NCMEC, and the NCC, among many others that have contributed knowledge to the anti-trafficking, housing, and homeless industries. The author proposes a conceptual model for a pilot study for future research and researchers to conjointly develop and use with key people to inform and refine the model, ultimately bringing it to fruition in collaboration with others from the industry and those with lived experience. Polaris has conducted due diligence with research, shedding light on what has not gone well and what has proven to work best for survivors.

3. Organizations

Organizations may perpetuate systemic harm due to inadequate infrastructure resulting from insufficient investment in overhead, including administrative and operational costs. Chief Executive Officer's (CEOs) and Executive Directors (EDs) face challenges in building and sustaining programs with weak infrastructure, lack of administrative support, and insufficient operational budgets. Underfunding these costs is one of the root causes within organizations. Bridgespan Group terms this "The Nonprofit Starvation Cycle" [10].

Many board members are not properly onboarded or do not receive clear job descriptions. Board members are reportedly uninformed about the organization's mission and their role in evaluating the performance of the organization's EDs, leading to inadequate oversight that often results in direct conflicts and is not in the organization's best interest. These issues are considered systemic problems, according to a study by BoardSource [11].

In another survey by Boardable, 26.02% of board members had only been provided with documentation on the day of their board meeting, compared to 61.13% who had received documentation a week before to review their agendas [12].

Most programs can show outputs, but they often mistakenly list these as measured outcomes. Associate Professor of Operations Management at the Georgia Institute of Technology, Morvarid Rahmani, distinguishes output from outcome. She describes this distinction as output versus impact. Activities are tangible results, but outcomes are the changes that result from outputs or activities. Service providers generally do not measure whether the homeless population they serve has successfully transitioned into permanent housing and can live self-sufficiently. A lack of site inspections and oversight was reported, and contractual agreements were neither enforced nor corrective actions taken, resulting in high staff turnover and inadequate contract management training. Unsafe housing or services were not tracked, with a high return to homelessness reported. Chief Impact Officer Jen Riley notes that a common mistake among grant seekers is holding unrealistic goals and expectations. An outcome may be an attainable, long-term goal that brings about positive change in communities. However, it may be unsustainable because it is unrealistic, such as seeking funding to end world hunger in six months [9, 13, 14].

3.1 Faulty and lack of measurements

The definition of who is homeless or who counts as homeless can considerably blur the data, resulting in an inaccurate measure. Definitions continue to undergo modifications without addressing the systemic rise in homelessness worldwide. Hail-Jares credits feminist scholar Sophie Watson for insisting on redefining homelessness to more accurately reflect the spaces that are often hidden and not counted as homelessness [15].

The Center for American Progress (CAP) released a report that found a discrepancy in the 2020 homeless census. Inaccurate enumeration and miscalculations resulted in distorted statistics [16].

Familial trafficking is sometimes inaccurately listed as child abuse or child sexual abuse, as opposed to sex trafficking or sexual exploitation, because family members or third parties exploit a child [17].

The way NPOs measure success is not by whether they resolved their cases. Instead, NPOs report the number of clients and activities that demonstrate the effectiveness of their programs. NPOs can demonstrate how many clients they serve, but how many end up back on the streets or remain homeless is not tracked [14].

An audit conducted on the California Interagency Council on Homelessness (Cal ICH) reported that two counts are needed to accurately reflect the homeless population: sheltered and unsheltered homelessness for people who sleep in places not generally used for sleeping. The Joint Legislative Audit Committee completed an audit in 2024, showing that programs receiving funding in California were not able to show outcomes after spending $24 billion over five years [18].

In a study conducted on the costs of human trafficking crime, the authors reported that the government spent $447 million to combat human trafficking, and, citing the U.S. Government Accountability Office, the authors noted that it is challenging to monitor projects and conduct evaluations on outcomes [19].

Thomas and Strickland, authors who studied Benefits Tracking, determined that there was no central data system in place to track victims of traffickers. Instruments are needed to aid in understanding how at-risk adults enter these unlicensed systems. When law enforcement shut down sites to assist in early prevention, the traffickers turned around and started up in another location. This recycling of unlicensed personal care homes perpetuates the victimization of at-risk adults who are moved from one location to another [20].

Data are lacking to determine precisely how many trafficking survivors end up incarcerated or deported without ever being identified as trafficked victims. In 2016, the National Survivor Network (NSN), as cited by Polaris, conducted a survey on criminal arrests and detentions of survivors. Polaris reported that 91% of 130 trafficking survivors had been arrested and had criminal convictions directly related to their trafficking experiences [21].

Continuums of Care (CoCs) operate as a network utilizing resources, but not all resources are earmarked for homeless projects. Housing First is found to have serious flaws in its research methodologies, which claim it is cost-saving, according to the Cicero Institute, which cites research from the National Academies of Sciences' systematic review of Housing First [9].

3.2 Criticisms of governance and housing

Senior advisor to the Cicero Institute, Judge Glock, states that the homelessness problem has persisted for over 20 years. Street homelessness has increased since the government mandated the Housing First strategy, also known as permanent supportive housing units (PSH) nationwide, despite advocates insisting that there has been a decline. The decline was due to the relocation of people from one type of model to another. These models were classified as transitional government housing versus permanent government housing. The transitional government housing was classified as homeless, while the permanent government housing was not [8].

A national study on Housing First found that permanent supportive housing was far from cost-effective. CoC did not address the person's need for sober living, nor did it provide group therapy or mental health care. Instead, stakeholders prioritized selected services based on restrictive grant requirements rather than the needs of the homeless individual and their family [22].

3.3 System failures

An organization in Jacksonville, Florida, closed its group homes because its eight-year, $1.9 million contract could not support the staff required to supervise the youth living at the group homes. The terms of the contract were not upheld, and it failed to meet its obligations. Reports came in that the youth were unsupervised, including reports of sexual assault by a counselor. Over the course of nine years, 1,800 calls were made to the police to report that youths had not returned by curfew. Injuries included a youth whose foot was amputated in a train incident; other alleged incidents included sexual assault and a homicide committed by an 18-year-old living in the neighborhood, along with two other youths who resided at the group home [23].

The Continuum of Care Reform (CoCR) model was implemented in California in 2017, aimed at high-acuity youth placement with either complex behavioral challenges, disabilities, or victims of commercial sexual exploitation due to trauma or substance use disorder, with some overlap of these comorbidities. The model was set up as a fee-for-service model. Community-based organizations were not financially stable. In 2020, 632 missing children reports were filed, with 20 reports listing psychological breakdowns, assault and battery, alleged rape, and fentanyl overdose at five unlicensed sites. Contracts could not fulfill the requirements due to the high costs associated with providing high-acuity care to youth, and the fee-for-service per youth did not cover the necessary infrastructure to run the programs efficiently. By 2020, both in-county Short-Term Residential Treatment Programs (STRTPs) had shut down. The Civil Grand Jury determined that DFCS did not account for the full cost of providing a CoC, which would encompass Santa Clara County departments and any third-party providers. Without this information, it was deemed challenging to determine whether financial decisions were made prudently in serving youth [24].

In one study by Kerman et al. (2023) on safety in homeless shelters, shelter staff reported a rise in mortality related to drug overdoses. The review of shelters found that no studies had been conducted on rates of shelter-based victimization or evaluated any interventions to improve safety measures in shelters. Violence is an

issue at shelters and a standard narrative coming from individuals subjected to these same conditions, whether fleeing domestic violence (DV) or living on the streets. Data are limited, lacking any examination or investigation of where exactly victimization occurs [25].

Polaris reports verified cases of sex trafficking recruitment at homeless shelters, DV shelters, runaway and homeless youth (RHY) shelters, group homes, and several other shelter programs between 2015 and 2017 [4].

The right-to-shelter movement has existed for over 40 years, according to a California Law Review article on "The Negative Right to Shelter." Urban camping in California is publicly prohibited and deemed a criminal activity, for which a person may end up losing all their personal belongings and facing fines. Since most homeless people do not have money, these fines, when left unpaid, accumulate against a person, disqualifying them from government assistance programs and receiving services. This sends the individual on a trajectory of homelessness and an endless cycle of punishments. Twenty-five percent of the full-time or part-time employed population cannot afford rent, and 72% of major U.S. cities have a ban or several bans on urban camping. Criminalization is met with a range of punitive measures, from fines to incarceration of up to six months. Camping is considered an activity of self-directed choice rather than one that involves seeking safety from harm. Physical and sexual assault is among the most common reasons people opt out of shelters [26].

The criminalization of survivors of human trafficking, prosecuted as sex offenders, will affect their employment, ability to obtain housing, and ability to be with their children. The authors argue that a large and significant number of people trafficked are convicted of crimes related to their trafficking situations and are serving as sex offenders in prison, who, upon release, then have to disclose to their parole officer with whom they will have an intimate relationship. In addition, they are prohibited from many other entitlements, such as possessing a phone with a camera [27].

In the international anti-trafficking industry, reviews of evaluations on anti-trafficking have focused mainly on progress rather than achievement. Evaluations are not mandatory, and government, public, and private funding agencies do not have fully proven instruments to determine whether a program has fully met its outcomes [28].

3.4 Corruption, wasteful spending, withholdings, and misappropriation

Nonprofits Insurance Alliance (NIAs) is a steward in managing funders. Investors earn public trust when their leadership is competent in managing operations and finances. NIA recommends a simple acronym to onboard leaders new to their positions and reduces the chances of failure. The acronym stands for Fraud, Inexperience, Negligence, and Ego (FINE) and suggests that leaders receive guidance to minimize risks, thereby fostering a healthy and transparent culture. Inexperienced leaders or those with egos may lack regard for compliance, internal controls, and transparency, putting their agencies at risk [29].

Stanford Graduate School of Business authors Rhode and Packel released a paper on Ethics and Nonprofits, determining that the corporate sector is not the only sector in the business industry afflicted with greed. Reports of misuse and abuse of public and private funding have been under scrutiny. Misappropriation

involves the misallocation of funds and resources, often by avoiding transparency or failing to justify expenditures. Dissonance can erode socially responsible decision-making [30].

On April 5, 2020, the founder and CEO of Sharity, in an opening statement to the Florida House Committee on Integrity and Ethics, revealed that she had served as CEO of Harbor House of Central Florida for nearly a decade before being told she was fired without any explanation. She provided evidence that the CEO of the Florida Coalition Against Domestic Violence (FCADV) had mismanaged funds and had turned away 47,520 survivors, leaving them without resources. That same year, in 2018, the Florida Department of Law Enforcement reported 215 DV deaths [31].

In the case of public housing, several residents reported that an employee coerced them into having sex with him or risked eviction. The residents lived in one of the low-income housing units in the Jacksonville Authority Housing complex in Jacksonville, Florida. In another case, former Mayor Lenny Curry called for the Jacksonville Housing Chief's resignation, as it turned out, after a year of investigation, Fred McKinney had slept with a member of his staff and fathered a child with a tenant. HUD and the DOJ took a federal position against sexual harassment in housing due to frequent occurrences and reports of sexual harassment issues [32, 33].

Calls for federal reform of the CoC Program, whose purpose is to end homelessness, are based on recent performance audits for five jurisdictions that report systemic deficiencies as the root problem and call for federal program reform to insist that providers demonstrate that results are achieved. These deficiencies ranged from missed site inspections to inequity and inconsistent corrective action plans. Reimbursements lacked receipts, and one system was found to operate as a silo, in addition to unsanitary conditions [8].

National Fair Housing Alliance (NFHA) filed a lawsuit against HUD for withholding Fair Housing Funds to assist victims in North Carolina who lost their homes due to flooding [34].

Global Policy Journal's authors Mendel and Sharpov weigh in on international law and human rights. The authors contend that, due to the lack of data demonstrating the ineffectiveness of certain anti-trafficking initiatives, it is imperative to reallocate the funding. The anti-trafficking sector they address is law enforcement and the criminal justice system, which continues to receive financial backing [35].

4. Barriers to entry: Lack of access to safety

The Housing and Urban Development (HUD) completed a study for the Violence Against Women Act (VAWA) of 2022. It was determined that access to housing is plagued by barriers to entry, lacks technical assistance, and operates in isolation, preventing collaboration with community partners and the coordination of services [36].

Domestic violence shelters assert that they are operating at full capacity due to financial constraints or insufficient bed availability. Staff are not always trained in recognizing the threads between human trafficking and DV; there are still a number of DV shelters that do not include human trafficking survivors. Polaris recommends considering the terms of funding, as some of the conditions may not be set in stone and may allow DV shelters to update their policies, incorporating victims from all

forms of interpersonal violence, and not just limiting this to intimate partner violence. Limited capacities for beds, lack of training, and bias about the industry also play a role in turning away trafficked survivors [37].

Outside of a shelter, services are limited, and individuals often lack access to essential resources. They are isolated from the rest of their population, having no access to support groups and being unable to stay for any reasonable length of time, keeping them entrapped in an endless cycle from which they cannot escape – social determinants of disease, illness, and decline in mental health. In the United States, three women a day are victims of homicide cases related to DV [38].

Labor or sex-trafficked survivors do not belong in public arenas, such as public shelters, since this exposes them to the risk of traffickers finding them. Polaris recommends that DV shelters train their staff and work with survivors and service providers to include labor and sex-trafficked survivors [4].

4.1 Different models of temporary housing

The various temporary housing models include emergency shelters, youth shelters, group homes, short-term residential therapeutic programs, transitional residential shelter care facilities, host families and host homes, hotels, motels, rehousing, and tent cities, also known as encampments. These temporary solutions are basic and include case management and referrals. The goal is to ensure that the person is safe and their basic needs are met, including access to showers, beds, cots, and meals [39].

The National Center for Homeless Education (NCHE) defines homeless children as children and youth living in alternative arrangements that may involve sharing with other people they do not know, utilizing the hospitality industry, or resorting to campgrounds or trailer parks. Abandoned children and youth are admitted to hospitals or await foster care placement. Communities are turning to alternative measures by converting vacant hotels and motels into shelters using funds from the American Rescue Plan [40].

4.2 Population disparities and vulnerabilities

Children and youth are the most vulnerable, often lacking the ability to be heard, seen, or understood. Human Trafficking Legal Center's board member, Jose Alfaro, an advocate for trafficking survivors, speaks out about boys who are trafficked and go unnoticed, even in dire situations. When parents throw their kids out, they expose them to sex predators who are quick to offer help. The National Center for Missing and Exploited Children (NCMEC) reports that 1 in 7 of the more than 29,000 cases in 2024 were likely victims of sex trafficking [41, 42].

Ranch Hand Rescue, on their website, posted statistics on male child sexual exploitation (CSE), citing the National Longitudinal Study, which found that 3.5% of 20,000 adolescents were sex trafficked and 67.9% of them were boys. Other high-risk cases included boys of color, as well as nonheterosexual and non-cisgender kids and youth [43].

Evidence exists that youth in foster care placements in the United States are at risk for commercial sexual exploitation. An estimated 60% of all child sex trafficking victims are children who were in the welfare system [44].

NGOs received over $6 billion from the former Biden-Harris administration after witnesses working for the Oversight Project under President Mike Howell testified in a hearing, detailing the information to the House Committee on Homeland Security. Unaccompanied alien children from other countries were delivered to sponsors in the United States, leading to more than 300,000 children being unaccounted for. Staff were hired without undergoing background checks or completing fingerprinting. Many of the sponsors had received either incomplete or minimal background checks [45].

Homeless youth are significantly more likely to be drawn into survival sex work in exchange for food, clothes, shelter, hormones, drugs, or education to fulfill necessities. In a peer-reviewed study on homeless youth living in San Francisco, 11% of those aged 15 to 24 who engaged in survival sex work experienced mortality within the first six years. The study sheds light on the high percentage rate of homeless youth deaths. High-risk behaviors led to early death, ranging from starvation to drug overdose, HIV-related illnesses, poor health-related drug use, Hepatitis B and C, homicide, or death by suicide. Homeless youth suffer a disproportionate risk for morbidity [46].

The next population often overlooked is the elderly population, who may live in nursing homes, assisted living facilities, or senior centers. It is far more advantageous for a family of traffickers to run an unlicensed home caring for elders and those with disabilities. Movement from one unlicensed home to another is not unusual, as traffickers benefit from victims' Social Security or disability checks and other types of governmental or state supplemental income, referred to as Benefits Trafficking. According to Polaris (2018), traffickers target people who are disabled to obtain their Social Security benefits or those of disabled family members and use their situation to exploit them or traffic them for money. People with disabilities may need financial assistance to cover the costs of their medications, surgeries, or education (Polaris, August 15, 2018) [47].

Black women make up 40% of sex trafficking survivors who experience housing instability and placement instability in systems of care, which places women and girls at high risk of exploitation [48].

American Indians and Alaska Natives are targets for impostors posing as promoters, urging tribal governments to invest financing for economic development. Without proper vetting, the risk of failure is high because of the impostors' intent to defraud tribes [49].

4.3 Landlords' challenges

Landlords have experienced tenants not living up to the terms of their lease. Freedom Network recommends that anti-trafficking programs establish relationships with landlords and provide education on the issues that many survivors face. Landlords are, and should be, part of the anti-trafficking team. Freedom Network emphasizes the importance of establishing a transparent relationship among the landlord, case worker/advocate, and survivor, while maintaining the survivors' public health information (PHI) and details about their charges as private. Freedom Network has developed a detailed handbook and videos from their webinars for Housing Providers [39].

HUD enforced a policy in April 2025 titled "What Housing Providers Should Know." This policy only applies to landlords who accept Section 8 vouchers, not

those in the private market. VAWA was amended in 2022 during its reauthorization, and HUD and the Attorney General of the United States are required to enforce the provisions of VAWA as outlined in the Fair Housing Act (FHA) [50].

5. Accreditation enforces accountability

Commission on Accreditation of Rehabilitation Facilities (CARF) and The Joint Commission, both nonprofit organizations (NPOs), offer high-standard surveys and on-site inspections to evaluate whether organizations seeking accreditation are well suited to receive it. Organizations must comply to receive accredited status. Organizations prepare by running mock surveys, which essentially serve as internal audits to determine their readiness to undergo a rigorous survey. These agencies oversee mental health treatment programs, addiction recovery programs, housing programs, healthcare services, and child and youth services. In the late 1990s, The Joint Commission developed sentinel events and focused on safety and quality of care. Sentinel events are crucial for preventing mortality related to hazards and vulnerabilities within a system, utilizing a Root Cause Analysis and Actions (RCA^2) [51, 52].

Medicaid is managed care, but not all Medicaid recipients have the same coverage. This all hinges on the state in which the recipient resides. Each state serves as its own fiduciary – determining which services to include or exclude. Each plan is capitated, meaning it cannot spend more than a predetermined dollar amount. The main purpose of managed care programs (MCOs), including nonprofits and for-profit entities, is to offer affordable care to the recipients at a fixed monthly charge. This is supposed to ensure access to services (determined at the state level) and enable a coordinated, managed system. Changes in 2025 now require states to address, screen for, and monitor social determinants of health [53].

A white paper by Freedom Network in 2019 on Standards of Care (SOCs) in the anti-trafficking field urged the need for everyone working with survivors in this field to receive training to meet SOCs, and not just licensed professionals [54].

6. Business models

Sinan Alhir, author and business expert with over four decades of experience, defines community as a shared domain where identity is rooted in mutual engagement and an exchange of sharing and learning. Without mutual engagement, there is no community [55].

Nonprofit organizations (NPOs) and not-for-profit organizations (NFPOs) are mission-driven and often neglected compared to the business model (BM) concept, which focuses on operations and earnings but lacks clarity. Boards of directors oversee nonprofits and have fiscal responsibilities to the organization's mission and its donors [56, 57].

6.1 Investors, grantmakers, and feasibility studies

Feasibility studies will determine the need for a proposal to build homes, shelters, and other suitable facilities for various types of business projects or

economic development initiatives. This will enable the application for funding through state and federal grants, as well as from lenders and investors, prior to securing capital. Professional subject matter experts should conduct feasibility studies to ensure the project's viability. According to BIA.gov, the Federal Trade Commission (FTC) warns that scams do exist, and the populations most vulnerable are Alaska Native populations and American Indians, who are less likely to report these. Professionals who submit credentials will still need to be vetted by government agencies [49].

The MacArthur Foundation and the Urban Institute allocated $5 million for The Just Home Project, enabling four communities to address the links between homeless individuals with justice involvement and housing instability. The Urban Institute recognizes that the longer an individual remains homeless, the more likely they are to end up in the criminal justice system [58].

7. Survivors' recommendations

Seventy-five percent of survivors reported that they needed time to recover from trauma and sought behavioral and mental health services from providers sensitive to their needs. About 60% stated that they needed employment training, and 69% wanted to find suitable employment to earn a living wage, enabling them to live independently. About 65% percent wanted to receive medical, dental, and mental health care. Overall, they reported that they needed to be heard. These needs include criminal justice, legal, and supportive services, such as anti-trafficking programs. Few survivors have access to mental health care or support in seeking employment, with many excluded from financial systems that would give them time to heal and work on their trauma, but they end up living in poverty. Many struggled with working multiple jobs [3].

8. Holistic models of care mirrored after the Hospice Medicare Benefit Program

The first U.S. hospice, Hospice Inc., was established in 1971. The American Public Health Association (APHA) played a significant role in bringing this public health issue to the attention of politicians at the federal, state, and local levels, involving government health agencies in responding to the public's need to address dignity in dying, self-agency, and family involvement. Promoting care for the dying included pushing for benefits from health care and public health providers. End-of-life care was inadequately addressed, with dire consequences that resulted in suffering and neglect. Hospice care is delivered under one umbrella, involving an interdisciplinary team who provide services and coordinate care. Hospice is an excellent example of a holistic model of care. It is patient-centered care [59].

Terminal illness is a universal experience that affects 2.5 million people annually in the United States. Human trafficking is a universal experience that affects more people and their families, with a statistic of over 1 million people annually in the United States, according to Hope for Justice, despite the lack of nationally aggregated data [60].

HEAL Trafficking, cofounded by Dr. Hanni Stoklosa, a chief medical officer, defines human trafficking as a public health problem [61].

Human trafficking is a universal problem because it affects every country in the world. The United Nations Office on Drugs and Crime reports that it is one of the most sought-after enterprises [62].

9. The grant and funding climate

According to the Grants Office website, awarded grants ended the temporary hold on federal financial assistance. Existing awarded grant monies should continue to be disbursed. This does not apply to individual programs subject to judicial action. Any new grant funding will be reviewed, modified, or withdrawn while the administration continues its fact-finding process. The Grants Office recommends exploring funding options. State and locally sourced grants may not be affected by federal actions. Private and corporate foundations, such as NPOs and corporate philanthropy groups, may help fill some gaps and fund programs. Private funders have a history of providing funding when public funding is not available. Industry partnerships would entail businesses seeking public–private partnerships. The Grants Office reminds everyone that this is not the end of the federal grant programs [63].

10. Conclusion

We seem to lack mutual agreement, and therefore, we do not have a community centered on eradicating homelessness, nor can we guarantee the stability of survivors. We have partial commitments; we agree on some elements but not all of them. How are we building assets, elements, and language that support and define a community? Sinan Alhir clearly reminds us that, without mutual engagement, there is no community.

Studies have shown that over 20 years have passed, and we have not solved the homeless crisis. Reports of survivors living in shelters, domestic violence shelters, trafficked from group homes, foster care, and shelters, and those involved in survival sex all need services, medical and mental health care, and stability. We continue criminalizing and wrongfully convicting human trafficking victims as sex offenders or charging them with other crimes they committed at the hands of the trafficker. There is a lack of knowledge about what happens to human trafficking victims at the judicial level, but also within states.

We continue to receive reports of opioid overdoses. Substance use is common among survivors who, at the behest of the trafficker, are chemically controlled or, while on the run, cope using substances. Living on the streets is a daunting endeavor, but sleeping in a shelter is reported to be even more so; this is one of the reasons why individuals opt out of spending the night in shelters. We turn individuals away because we either misclassify them or do not have the personnel, services, or treatments to shelter them from harm temporarily. When shelters do take in people with substance-use disorders, there are reports of mortality cases. We have read about group homes shutting down due to a lack of staff or staff not receiving the support needed to supervise youth. We read about shoddy ratings that misled the

state of Florida and some private philanthropists into believing the praises given to the group home in Jacksonville, Florida, when in fact these were run without proper supervision, resulting in youth not returning at curfew, reports of sexual assault, endless calls made to police, and the shooting death of a taxi driver. We need to close the gaps and not turn off oversight of programs. Unmet contractual terms, a lack of follow-up, and a lack of understanding of what it takes to budget were some of the issues reported. Contractual terms should include everyone involved in systems of care – these range from volunteers (yes, they do cost money because organizations must train them). In addition, budgeting for contract personnel (a good organization will have those with lived experience train contract personnel to understand what works and does not work when working with victims and survivors). Shelters, residential treatment programs, Section 8 landlords, all outside service providers, vendors, pharmacists, law enforcement, transporters, and all other relevant parties need to operate as a community when programs offer holistic services under one umbrella. We need community care programs that are not piecemeal and are accredited to eventually work with the insurance industry for full and partial coverage, offset by grant monies and private funds. The survivor model program should be under one umbrella, similar to hospice and home health services, which cover services under a single program with some exceptions during peak intervals. Philanthropists who have a vision and are keen to bring about change are needed, but first, we must connect with politicians and present this model in the same way it was presented as a pilot study for terminal care.

Abbreviations

APHA	American Public Health Association
BM	Business Model
Cal ICH	California Interagency Council on Homelessness
CARF	Commission on Accreditation of Rehabilitation Facilities
CAP	Center for American Progress
CEO	Chief Executive Officer
CFO	Chief Financial Officer
CoCs	Continuums of Care
CoCR	Continuum of Care Reform
CSE	Child Sexual Exploitation
DCF	Department of Children Family
DFCS	Department of Family and Children's Services
DV	Domestic Violence
EDs	Executive Directors
FCADV	Florida Coalition Against Domestic Violence
FHA	Fair Housing Act
FNUSA	Freedom Network USA
FTC	Federal Trade Commission
GP	Global Policy
HUD	Housing Urban Development
MCOs	Managed Care Organizations
NCC	National Constitution Center
NCMEC	National Center for Missing and Exploited Children
NFHA	National Fair Housing Alliance

NGOs	National Governmental Organizations
NIAs	Nonprofits Insurance Alliance
NFPOs	Not-for-Profit Organizations
NPOs	Non-Profit Organizations
NSN	National Survivor Network
PHI	Public Health Information
PNS	Polaris National Study
RHY	Runaway Homeless Youth
PSH	Permanent Supportive Housing units
RCA2	Root Cause Analysis 2
SA	Sexual Assault
SSIR	Stanford Social Innovation Review
STRTP	Short-Term Residential Treatment Program
TIP	Trafficking in Persons
UCLA	University of California, Los Angeles
VAWA	Violence Against Women Act

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Author details

An Goldbauer
International Institute of Clinical Sexology, Miami Shores, Florida, USA

*Address all correspondence to: dr.angoldbauer@gmail.com

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Chapter 8

Perspective Chapter: The Role of Environments and Social Networks in Human Health

Joan Camilo Piedrahita Mejía, Sebastián Gaviria Londoño, Adriana Arango Castiblanco and Hernando Alonso Martín Forero

Abstract

The impact that environments have on human functioning for the development of capacities, the creation of resilience, and the prevention of psychological effects and biological diseases will depend on the exposure scenarios in which people live, as these can generate vulnerability or protection for health. Therefore, it is important to reflect on the need to guarantee housing, urban, psychosocial, and community conditions that promote physical well-being, spirituality, sports, sociability, and mental health in individuals. This is to foster the autonomous and free development of personality that improves interactions between empathetic, community-based beings. Understanding urban environments in human health opens up new interpretations of the role of space in social interactions and how we communicate in the physical and digital worlds.

Keywords: healthy environments, mental health, psychological well-being, social determinants, positive psychology

1. Introduction: Adolescence and development

Of the stages of neurodevelopment that are important for shaping personality and behavior throughout life, we must discuss adolescence. Adolescence is defined as a period of human development involving intense physical, psychological, and psychosocial changes during which children transition into adulthood; it begins with puberty and ends when bio-psychosocial development ceases. The World Health Organization (WHO) considers adolescence to be between the ages of 10 and 19, while youth is between the ages of 19 and 25. The American Academy of Adolescent Health and Medicine defines it as between the ages of 10 and 21, distinguishing three stages: early, middle, and late. It is useful to know these stages in order to differentiate between normal variations and abnormalities in physical and psychosocial development [1].

The most relevant physiological changes are the development of secondary sexual characteristics; the complete maturation of the gonads and adrenal glands; and the peak of bone, fat, and muscle mass. On the contrary, adolescents want to

be independent while their self-perception changes; they build their self-esteem and struggle with the constant transformation of their desires, tastes, and life plans, achieving most of the psychosocial goals necessary to enter adulthood. Piaget noted that during this stage, individuals move from concrete to abstract thinking with a view to the future, which characterizes maturity. Cognitive development, with the ability to think abstractly, is achieved around age 12; moral development regarding right and wrong occurs between ages 15 and 16; and later, a life plan with realistic and practical vocational goals is established. It is worth highlighting the psychosocial goals that every adolescent should achieve (see **Table 1**) [1].

All human development goals are permeated by the use of the internet and the new communication needs that accompany us throughout our lives, creating new forms of interaction with the environment, communities, and people.

Goals	Early adolescence	Middle adolescence	Late adolescence
Independence	• Less interest in parents. • Emotional void: behavior and mood are altered. • Lower academic performance.	• Maximum conflicts with parents; more time with friends. • Struggle for independence.	• Reacceptance of parental values and advice; a new relationship with parents. • Doubts about accepting responsibility. • Continued dependence on parents.
Body image	• Concern about their bodies and changes: Am I normal? • Insecurity about appearance, comparing themselves to others.	• Acceptance of your body. • Interest in making it more attractive.	• Acceptance of changes. • The image is only a concern if there is an anomaly.
Friends	• Interest in and friendships with friends of the same sex. • Feelings of tenderness lead to fears and homosexual relationships. • Can be positive: sports and music; negative: alcohol and drugs.	• Maximum integration with friends and their values. • Maximum danger of risky behavior.	• Less important friends and groups. • More time spent on intimate relationships (couples' form).
Identity	• Improved cognitive abilities (concrete thinking and the beginning of abstract thinking). • Self-interest, fantasies. • Unrealistic and idealistic vacation goals. • Greater need for privacy (diary). • Sexual feelings emerge. • Lack of impulse control, dangerous, risky behavior.	• Increased intellectual capacity. • Broader range of feelings (values those of others). • Omnipotence. • Immortality leads to high-risk behavior.	• Established abstract thinking. • Practical and realistic vocational goals. • Delimitations of religious, moral, and sexual values. • Ability to commit and set boundaries.

Source: Study by Hidalgo and González [1].

Table 1.
Physical, psychological, and social aspects of the stages of adolescence.

2. Use of social media

Today, social dynamics are largely driven by virtual interaction, thanks to advances in technology, the need for rapid communication, the SARS-CoV2 pandemic, distance learning, and the economy. These factors have led many teenagers to prefer interacting on social networks such as Instagram®, Twitter®, Tik Tok®, and Facebook® in search of acceptance in social groups [2]. However, this dynamic affects the level of attention needed and measures acceptance in likes, which translates into approval and acceptance of their own self-esteem for having more followers. Otherwise, anxiety disorders can be generated due to misinformation and the banality of the situation.

Early adolescence is especially vulnerable, as social media could normalize unhealthy behaviors related to body image, which refers to an individual's opinions, feelings, and ideas about their appearance. This can create false expectations of thinness regarding body image and insecurities in women, as well as an obsession with bodybuilding in men, in addition to an increase in eating disorders, which are three times higher in women at the age of 15. The American Psychiatric Association states that the prevalence of eating disorders in adolescence and adulthood is 10%, manifested by anorexia nervosa in both stages and bulimia, which is more common in adolescence [3].

Cyberbullying is a form of deliberate and repeated aggression that occurs through digital technologies. It is a public health problem in this population, as victims feel anger, sadness, and shame [4]. This affects their psychological and social well-being, although research is controversial regarding the increased likelihood of suffering from anxiety and depression (due to multiple causes). However, researchers agree that high levels of intensity (frequency and time spent) can be linked to insomnia, daytime sleepiness, lack of concentration, social withdrawal, loneliness, cyberbullying, the onset of chronic diseases, and suicidal behavior, all of which are harmful to the health and protection of adolescents [5].

Depression and social media use have been the most studied disorders, and the duality of the results can be explained by two reasons: the displacement of physical activity, games, and time with family and friends; and social compensation, which refers to the fact that interaction with social media can be healing for adolescents with pre-existing mental health problems, as it allows them to connect with other people [5].

Active social media use refers to direct exchanges with others (posting statuses, commenting on posts, liking posts), while passive use involves consuming information without direct exchanges (viewing posts or scrolling). The latter is likely to have a greater negative effect on individuals who are sensitive to the behavior of others, possess high levels of personal insecurity, and have a constant need to boost their self-esteem. This is consistent with the hypothesis of individual susceptibility to the effects of social media use [5] (see **Figure 1**).

The revolution in new information and communication technologies (ICT) over the last 20 years has transformed lifestyles and social reality [7]. Although there is a duality in the use of social media, it is important to understand that excessive or incorrect use can be a risk factor for adolescents' mental health, mainly for depression, anxiety, internet or substance addiction, as well as eating disorders, obesity, cyberbullying, behavioral problems, low self-esteem, among others [5, 7]. However, it also increases opportunities to interact with people from all over the

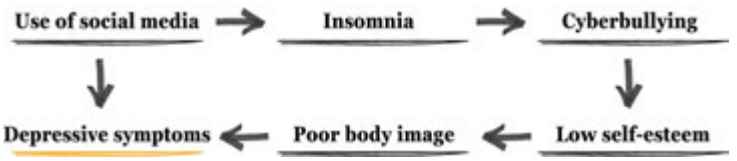


Figure 1.
Negative effects on adolescents' mental health due to social media use.
Source: Adapted from the study by Kelly Y. et [6].

world, access social support, develop new skills, and help create one's own identity. These spaces can be used to promote health and prevent disease [8], generating a positive impact, especially when considering the three issues that most influence adolescents: sexual health, body image, and addiction [7].

Understanding the characteristics of this stage of development, its needs, and interactions with social media can help health professionals, parents, and adolescents make better decisions for managing the risks that may arise from the inappropriate use of social media.

3. Healthcare environments

Environments play an important role in shaping human well-being, requiring interdisciplinary organization to articulate theories from psychology, psychiatry, neuroscience, and public health, as well as taking social determinants into account.

Mental health in the field of psychiatry has shifted from a focus on diagnosing pathologies to a more comprehensive perspective on the contextual factors that influence psychological suffering. According to Stainbrook [9], the ecology of mental illness shows that social conditions, poverty, structural violence, and isolation are risk factors for the emergence of disorders such as depression, anxiety, or psychosis. Social psychiatry broadens the biomedical view and highlights the role of adverse environments as structural determinants of emotional distress [9].

Similarly, Peen et al. [10] highlighted that there are multiple significant differences in the prevalence of mental disorders between rural and urban areas due to environmental factors such as overcrowding, noise, insecurity, and lack of green spaces. This underscores the need to incorporate environmental variables into mental health prevention and intervention strategies.

3.1 The blue zones

This concept refers to regions of the world where people live longer and healthier lives, thanks to the interaction between biological, psychosocial, environmental, and cultural factors. In his 2016 research, Buettner [11] identified that some areas, such as Okinawa (Japan), Sardinia (Italy), and Nicoya (Costa Rica), have high social cohesion, healthy diets, constant contact with nature, and a sense of purpose. These environmental and community conditions strengthen emotional resilience, which prevents cognitive decline, demonstrating that healthy environments promote longevity and emotional well-being in people living in areas with these characteristics [11].

Environmental stimuli directly affect the activation of brain structures involved in emotions. According to Agromartín [12], the physical and social environment can modify serotonin, dopamine, and cortisol levels, affecting mood, motivation, and stress response. Tala added that practicing positive emotions, such as gratitude, has neuroprotective effects, strengthening the immune system and improving brain function [13].

Bronfenbrenner [14] proposed that human development occurs in interconnected ecological systems: microsystem (family, school), mesosystem (interaction between microsystems), exosystem (social institutions), macrosystem (cultural values), and chronosystem (temporal dimension). Each of these levels directly influences the psychological well-being of the individual. A healthy environment involves simultaneous intervention at all levels of the human ecosystem, including actions between families, communities, institutions, and policies that help to guarantee dignified and safe conditions. This includes the spaces that everyone shares, such as the home, school, work, parks, among others [14].

Every day, new research is added that demonstrates the influence of the environment on human psychology and the well-being of societies, based on the quality and peace offered by their spaces in relation to cognitive and attention processes. This makes sense if we analyze societies in terms of time and the changes that occur due to the needs brought about by wars, violence, natural disasters, pandemics, and all the social conflicts that force structural changes.

3.2 Psychological restoration

Some authors, such as Berman [15], compare the effects of natural environments on cognitive functioning, especially in the restoration of directed attention, demonstrating that nature presents intriguing stimuli that capture attention in a modest and ascending manner, allowing directed attention capacities to recover, unlike urban environments, where attention is dramatic and requires being directed to avoid accidents, making them less restorative.

Hartig et al. [16] investigated psychophysiological stress recovery and targeted attention restoration in natural versus urban environments, demonstrating that natural environments more rapidly decrease diastolic blood pressure when sitting after a stressful task in a room with a view of trees compared to a room without a view. They also reported changes in blood pressure after walking in a nature reserve, which indicated greater stress reduction compared to the urban environment. Attention tests improved slightly after a walk in a nature reserve, while they decreased in the urban environment [16].

Ulrich [17] demonstrated that exposure to green spaces significantly reduces stress, improves sustained attention, and promotes positive emotional states. Other researchers who support this premise include Kjellgren and Buhrkall [18], who, in 2010, compared real natural environments with simulated artificial environments and concluded that direct experience with nature produces greater restorative benefits.

Environmental stimuli affect the activation of brain structures involved in emotions; the physical and social environment can modify circulating levels of serotonin, dopamine, and cortisol, which alter mood, motivation, and response to stress [12]. From a neurobiological perspective, contact with natural environments activates areas of the brain linked to emotional regulation and the perception of well-

being, especially the practice of positive emotions such as gratitude, which has a protective effect by improving brain function and strengthening the immune system [13]. The convergence between physiological and psychological approaches reinforces the hypothesis that environmental infrastructure has a direct impact on the mental health of inhabitants and on the social, political, and economic development of communities.

It is important to create spaces for dialog, discussion, and constant reflection on the adaptations and transformations of spaces because they are part of the history and future of the communities.

3.3 Social conditions and well-being

Some social determinants can act as opportunities or barriers to well-being; the unequal distribution of services, public spaces, decent employment, and education directly influences the mental health of populations, especially in neglected or ignored peripheral urban or rural contexts [19]. Since 1986, the WHO has stated that environments must offer participatory, dignified, and sustainable conditions to generate processes that promote comprehensive human development [20]. By 2004, the WHO proposed that environments should be understood as a system of political, social, and institutional relationships that can be intervened in to prevent psychosocial effects in communities [21].

Work is a fundamental environment for occupational and organizational well-being, where most people spend a large part of their lives. Authors such as Royero [22] and Peralta et al. [23] have documented high levels of emotional exhaustion, overload, and chronic stress among workers in the health and education sectors in their research, which coincides with the absence of adequate physical spaces, fair workloads, and empathetic leadership — all of which are considered favorable structural conditions.

Collective actions in vulnerable territories with community participation can lead to improvements in mental health. Machado et al. [24] demonstrated that community ownership of the environment reinforces active citizen participation and the promotion of healthy environments on an ongoing basis, especially when there are structural limitations on the part of state institutions, as it increases the sense of belonging, social cohesion, and collective self-efficacy — factors known to be associated with higher levels of subjective well-being and emotional resilience [25].

4. Conclusion(s)

Analyzing the processes of personality development, social media use, and interaction with physical environments in terms of mental and physiological health is vitally important for understanding the power of physical and digital spaces in human psychology today. This knowledge will enable people to make better decisions about interacting with environments that improve their cognitive processes and well-being, based on available scientific evidence.

Contact with natural environments has been shown to yield better results in various studies on attention, positive emotional states, stress reduction, and blood pressure. These aspects contribute to well-being and more stable mental health.

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Conflict of Interest

The authors declare no conflict of interest.

Author details

Joan Camilo Piedrahita Mejía[1*], Sebastián Gaviria Londoño[1], Adriana Arango Castiblanco[2] and Hernando Alonso Martín Forero[2]

1 University of Antioquia, Medellín, Colombia

2 National University of Colombia, Bogotá D.C., Colombia

*Address all correspondence to: jcamilo.piedrahita@udea.edu.co

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Urbanization is transforming societies across the globe at an unprecedented pace. While cities offer opportunities for economic growth, innovation, and improved quality of life, they also create complex environmental and social challenges that directly affect human health. Rapid population growth, increasing pollution, climate change, changing lifestyles, and widening inequalities are reshaping the health landscape of urban populations. *Urban Environments and Human Health* explores the intricate relationships between urban development, environmental exposures, and public health outcomes. This book brings together interdisciplinary perspectives to examine how urban infrastructure, environmental pollutants, social determinants, and lifestyle factors influence human health in modern cities. The chapters address critical topics such as the impact of urbanization on public health, climate change and its growing health implications, exposure to ultrafine particles and other environmental hazards, and the health risks associated with tobacco use and urban living. The book also highlights pressing issues, including health inequities in informal settlements, the role of social networks and community resilience, and strategies to support vulnerable populations. By integrating scientific research with policy-oriented insights, this volume provides a comprehensive overview of the challenges and opportunities for improving health in urban environments. It emphasizes evidence-based solutions, sustainable urban planning, and community-centered approaches to create healthier and more resilient cities. This book will be a valuable resource for researchers, public health professionals, urban planners, environmental scientists, policymakers, and students interested in understanding and addressing the complex links between urban environments and human health.

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