ARQUIVOS DE ASMA, ALERGIA E IMUNOLOGIA

Review Article

Climate change, air quality and their impact on the academic performance of children and adolescents: what does 2024 have in store for us?

Alterações climáticas, qualidade do ar e suas repercussões sobre o desempenho escolar de crianças e adolescentes: o que 2024 nos reservou?

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ABSTRACT

Climate change continues to generate a series of consequences for the planet and its inhabitants that threaten the survival of certain species and negatively affect the quality of life for all. In this article, we present a summary of three important global reports that have examined air quality: World Air Quality Report – IQAir 2024, State of the Global Climate 2024 (World Meteorological Organization), and UNICEF Report – Learning interrupted: Global snapshot of climate-related school disruptions in 2024. These publications highlight concerning data regarding the environmental conditions faced by populations worldwide and the subsequent effects on children's education. This information warrants broad dissemination to foster knowledge and awareness among the population and authorities. Increased understanding can help us minimize the adverse effects and develop more effective strategies for adapting to climate change.

Keywords: Climate change, pollution, learning, children, adolescents.

RESUMO

As alterações climáticas têm gerado para o planeta e para os seres vivos uma série de consequências que comprometem a existência de algumas espécies e afetado a qualidade de vida de todos. Neste artigo apresentamos o resumo de três importantes documentos mundiais que estudaram a qualidade do ar: "Relatório Mundial sobre a Qualidade do Ar - IQAir 2024", "Estado Global do Clima 2024" (Organização Mundial de Meteorologia), e o Relatório UNICEF "Aprendizagem interrompida: panorama global das interrupções escolares relacionadas ao clima em 2024". Estas publicações apontam dados alarmantes sobre as condições ambientais a que a população, em diferentes partes do mundo, está exposta, e a repercussão destas condições sobre a educação das crianças. Tais informações merecem ampla divulgação para que, pelo conhecimento e conscientização da população e de autoridades, possamos minimizar os efeitos adversos e encontrar formas mais adequadas de adaptação às mudanças do clima.

Descritores: Mudança climática, poluição, aprendizado, crianças, adolescentes.

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Submitted Apr 14 2025, accepted Apr 18 2025.

Arq Asma Alerg Imunol. 2025;9(1):97-105.

http://dx.doi.org/10.5935/2526-5393.20250004-en

Introduction

In February and March 2025, 3 very important documents were published regarding planetary health: the "2024 World Air Quality Report," published by IQAir[1]; the "State of the Global Climate 2024," published by the World Meteorological Organization[2]; and "Learning interrupted: Global snapshot of climate-related school disruptions in 2024," published by the United Nations Children's Fund (UNICEF).[3] These publications reveal alarming data about the environmental conditions to which populations are exposed in different parts of the world, as well as their effects on children's education. This information should be widely disseminated to foster awareness among the population and authorities, as increased understanding can help minimize the adverse effects of climate change and find more effective strategies for adapting to it.

Below we will summarize the main points of these documents.

State of the Global Climate 2024

Prepared by the World Meteorological Organization,[2] this report was published on March 19, 2025, and provides relevant information on different atmospheric parameters.

Greenhouse gases

In 2023, the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide reached their highest levels in the last 800,000 years. Data collected in real time from different locations around the planet show that the levels of these three main greenhouse gases continued to rise in 2024.

Global average near-surface temperature

The global annual mean near-surface temperature in 2024 was 1.55 ± 0.13 °C above the average observed between the years 1850 and 1900. The warmest year in the 175-year observational record was 2024, surpassing the previous record set in 2023 (1.45 ± 0.12 °C). While a single year with average warming above 1.5 °C does not indicate that the long-term temperature goals of the Paris Agreement are out of reach, it is a warning that we are putting ourselves, our economies, and our planet at increased risk. After all, in terms of global mean temperature, each of the last ten years, between 2015 and 2024, were individually the 10 warmest years on record.

Meanwhile, extreme weather continues to have devastating consequences around the world. In 2024, the oceans continued warming, sea levels continued rising, and acidification increased. The frozen parts of Earth's surface, known as the cryosphere, are melting at an alarming rate. Glaciers continue to retreat, and Antarctic sea ice has reached its second-lowest extent on record.

In response, the World Meteorological Organization and the global scientific community are stepping up efforts to strengthen early warning systems and climate services to help decision-makers and society at large become more responsive to climate issues and extreme weather. Progress is being made, but it must come faster to achieve better results. Only half of the world's countries have adequate multi-hazard early warning systems. It is more important than ever to invest in national meteorological and hydrological services to address these challenges and build safer, more resilient and aware communities. Reliable information and scientific knowledge are fundamental to effective decision-making, especially in these rapidly changing times. This report provides the latest scientific update on the state of our knowledge about key climate indicators.

Impact on the oceans

The main ways of assessing the effects of climate change on the oceans are measuring heat, global mean sea level, and acidification (pH level).

In 2024, ocean temperatures reached the highest level in the 65-year observational record, surpassing the previous record set in 2023. Over the past 8 years, each year has set a new record for ocean heat content. The rate of ocean warming over the past 2 decades (2005-2024) was more than double that observed for the 1960-2005 period.

In 2024, the global mean sea level reached a record high according to the satellite record, which began in 1993. The rate of global mean sea level rise over the past 10 years (2015-2024) was more than twice that observed in the first decade of recording (1993-2002).

Finally, ocean acidification has also increased over the past 39 years, as shown by the steady decrease in the global mean surface ocean pH. However, acidification is not increasing uniformly across regions.

Effects on glaciers

Glacier mass loss between 2021–2022 and 2023–2024 is the greatest on record. In particular, 7 of the 10 most negative annual glacier mass balances since 1950 have occurred since 2016. Exceptionally negative mass balances have been recorded in Norway, Sweden, Svalbard, and the tropical Andes.

The 2024 minimum daily extent of Arctic sea ice was the seventh lowest on record since 1979. According to satellite observations, all 18 Arctic sea ice minimums have occurred in the past 18 years.

Climate direction: El Niño/southern oscillation

El Niño and La Niña are natural climate phenomena that alter global temperature and precipitation patterns. El Niño is the name given to the abnormal warming of the waters of the equatorial Pacific, which causes intense rains and droughts in different regions of South America and goes on to affect the entire planet. La Niña is the abnormal cooling of the waters of the Pacific, leading to drier conditions in tropical areas and more frequent storms in others. Both phenomena affect air currents, influencing hurricanes, crops, and marine ecosystems and occur with irregular frequencies, lasting from months to years.

The strong El Niño of 2023/2024 followed 3 consecutive years of La Niña, which began in late 2020 and ended in early 2023. El Niño conditions, which began in mid-2023, became strong in late 2023 and dissipated in the second quarter of 2024.

Global temperature and precipitation patterns

Temperature

In 2024, most land areas were warmer than the 1991–2020 climatological average, except for a few limited areas of below-average temperatures around Iceland, parts of Antarctica, and the southern tip of South America. Record or near-record average annual temperatures were observed across large areas of the tropics, from South and Central America to the eastern region of the western Pacific. Regions outside the tropics also experienced exceptionally high annual temperatures, including eastern North America, northern Africa, northern Europe, and southern and eastern Asia.

Sea surface temperatures also reached record highs in the tropical and northern Atlantic, the tropical Indian Ocean, parts of the western Pacific, and parts of the Southern Ocean. Despite El Niño conditions earlier in the year, cooler-than-average waters were observed along the west coast of South America, with above-average temperatures most evident further west along the equator.

Precipitation

In 2024, drier conditions than the historical average (1991–2020) were observed across much of southern Africa, some locations on the west coast of Africa, as well as along the north coast of Africa. Large parts of South America, from the Amazon lowlands and northern Andes to the Pantanal wetlands, were also drier than normal, as were northwestern Mexico, some Caribbean islands, and parts of northern North America, which had abnormally low precipitation totals. The same pattern was observed in Oceania, where areas along the southern coast of Australia, parts of northern New Zealand, New Caledonia, and the central and eastern islands of Polynesia had lower than normal precipitation amounts. Rainfall below the climatological normal was also observed in southern and southeastern Europe.

However, parts of the Sahel region and central and southern East Africa, as well as Central and Western Europe, were wetter than normal in 2024 The islands western Polynesia and northern Melanesia, as well as southern New Zealand

and parts of eastern and northern Australia were also wetter than average. In North America, the Canadian Arctic Archipelago and some locations around the Gulf of Mexico also experienced above-normal humidity patterns. Above-normal total rainfall levels were observed over large areas of northeastern, eastern, and central Asia and, to a lesser extent, its southeastern, southern, and southwestern regions.

High-impact weather events

Extreme weather events in 2024 led to the highest number of new population displacement events in a single year since 2008. Prolonged new displacement events have affected significant numbers of people, particularly those in fragile and conflict-affected contexts. Accompanied by the destruction of homes, infrastructure, forests, agricultural lands, and biodiversity, these extreme weather events undermine resilience and pose significant risks to people about to move and those already on the move.

The compounding effects of multiple shocks, including intensifying conflict, drought, and high food prices, led to increasingly intense food crises in 18 countries by mid-2024. Compared to the annual peak in 2023, 8 countries had at least 1 million more people facing acute food insecurity in 2024. Reduced global cereal harvests were associated with widespread drought in 2024, which was linked in some regions, such as southern Africa, to El Niño conditions.

Tropical cyclones were responsible for many of the most destructive events of 2024. Typhoon Yagi made landfall in northern Vietnam in early September after crossing the Philippines and southern China. Fatalities and population displacement were reported in Vietnam, the Philippines, Laos, Thailand and Myanmar. Significant wind damage occurred in China and the Philippines.

In the United States, Hurricane Helene in late September and Hurricane Milton in October struck the west coast of Florida. Hurricane Helene caused exceptional rainfall and extreme flooding in the interior of the southeastern United States, especially western North Carolina. Both hurricanes caused tens of billions of dollars in damage. More than 200 deaths were associated with Helene, the highest number associated with a continental U.S. hurricane since Katrina in 2005.

In the Southern Hemisphere in December 2024, Tropical Cyclone Chido crossed Mayotte before hitting Mozambique and heading towards Malawi, causing extensive damage and significant loss of life in all 3 countries. In Mozambique, an estimated 100,000 people were displaced, homes were destroyed, and roads and communication networks were severely damaged, hampering relief efforts in areas already hosting large numbers of displaced people. Similarly, vulnerable communities in Mayotte faced increased risk from the cyclone's devastation.

Afghanistan and neighboring areas of Pakistan and Iran suffered a sequence of natural disasters in late winter and spring, with abnormal cold and snow in the highlands in late February and early March 2024. Melting snow triggered several flooding events in the following months, the worst of which affected Afghanistan between May 10 and 17. Around 35,000 hectares of agricultural land was inundated by the end of May. Several hundred deaths were reported in the floods, and the cold snap also resulted in significant loss of life.

From mid-2024 onwards, an unusually active monsoon brought major flooding to many parts of Africa's Sahel region. Monsoons are caused by seasonal changes in wind direction due to variations in temperature and pressure between the surface and oceans during the winter and summer. Almost all countries in the region reported significant damage, with flooding affecting large areas of agricultural land and leading to significant loss of life. Between March and May, flooding affected equatorial East Africa, with major loss of life in Kenya and Tanzania, as well as population displacement and the destruction of cropland and livestock. During this period, Lake Victoria reached record levels, with downstream flooding severely affecting more distant countries, such as South Sudan, later in the year.

In contrast, the lack of rainfall observed during the rainy season (late 2023 to early 2024) resulted in significant drought in northwest Africa and many interior parts of southern Africa, particularly Zimbabwe, Zambia, Botswana and Namibia. The

severe drought significantly affected agriculture and hydropower production.

In South America, Chile suffered destructive wildfires. A fire around the city of Viña del Mar on February 2-3, 2024, resulted in more than 300 deaths and damage to several thousand properties. These losses to wildfire are among the worst anywhere in the world this century.

The wildfire season was also severe in Canada, where carbon emissions from wildfires were the second highest on record since 2003, and the affected area was one of the five highest on record since 1983. The western United States also had a severe wildfire season. More than 300,000 people were displaced in these countries due to wildfires.

Drought has affected other parts of the Americas. Severe drought in Mexico and parts of Central America in 2023 persisted into the first months of 2024, while there was also significant drought across much of inland South America. The Rio Negro in Manaus, Brazil and the Rio Paraguay in Asunción, Paraguay reached record lows, and the number of wildfires in the Brazilian Amazon was the highest since 2010.

In contrast to generally dry conditions throughout South America, the state of Rio Grande do Sul in southern Brazil was severely flooded in early May. Persistent heavy rain resulted in flooding across much of the city of Porto Alegre and many surrounding areas, significantly affecting agriculture and fishing and causing over 200 deaths.

Extreme rainfall also occurred in Europe, resulting in severe flash flooding in the Valencia region of Spain on October 29 due to an upper atmospheric "pool" of air over southern Spain. This phenomenon is a region of exceptionally cold air in the middle and upper troposphere, usually associated with low pressure systems at altitude, called cyclonic vortices. Such systems are important for the formation of thunderstorms and other intense convective phenomena. The city of Turis, west of Valencia, received 185 mm of rain in 1 hour, a national record in Spain. In 6 hours, 621 mm of rain fell, and 772 mm was recorded in 24 hours. The precipitation led to exceptional flooding downstream, particularly affecting the southern part of Valencia's metropolitan area. More than 200 deaths and serious damage were reported in Valencia and neighboring areas.

Numerous significant heatwaves occurred in 2024, many with prolonged periods of record-breaking high temperatures. According to the World Meteorological Organization's 2023 State of Climate Services report, the effects of extreme heat and heatwaves are underestimated, so heat-related mortality could be many times higher than current estimates.

During summertime in the Northern Hemisphere, areas particularly affected by heatwaves included East Asia, Southeastern Europe, the Mediterranean, the Middle East, and the southwestern United States. This followed record heat in many parts of the Northern Hemisphere's tropics during the pre-monsoon period (late March to May), including Southeast Asia, West Africa and the Sahel, and Central America, as well as northern India.

Among the most significant related events was the June heatwave in Saudi Arabia, in which temperatures near Mecca reached 50 °C during the 2024 Hajj pilgrimage, resulting in at least 1,300 deaths between June 14 and 19. Most of these deaths were partially or entirely attributable to the extreme heat.

Early warning systems have proven an effective means of removing communities from harm's way before a disaster strikes or of managing the event in situ. Reliable, routine data and effective disaster risk reduction policies are crucial for saving lives. Disaggregated data on the frequency, triggers, and results of displacement can help response and development planners mitigate the effects on displaced people and host communities.

2024 World Air Quality Report[1]

This report brings together data from over 40,000 air quality monitoring stations in 8,954 locations across 138 countries, territories, and regions. The data were analyzed by IQAir's air quality scientists, who found alarming trends in the world's most polluted areas. Nevertheless, the report states that some progress is being made.

What were the main findings of the 2024 World Air Quality Report?

Only 17% of the world's cities meet the World Health Organization's (WHO) air pollution guidelines. Only 7 countries meet the WHO's guidelines for particulate matter with a diameter of less than 2.5 µm ($PM_{2.5}$), ie, an average annual concentration ≤ 5 µg/m³: Australia, Bahamas, Barbados, Estonia, Grenada, Iceland, and New Zealand.

What were the 5 most polluted countries in terms of $PM_{2.5}$ concentration in 2024?

Table 1 lists the 5 most polluted countries in 2024 according to $PM_{2.5}$ concentration.

Of the 138 assessed countries and regions, 126 (91.3%) exceeded the WHO's recommended annual $PM_{2.5}$ value of 5 µg/m³. Byrnihat, India was the world's most polluted metropolitan area in 2024, whose average annual concentration of $PM_{2.5}$ was 128.2 µg/m³. The world's seven most polluted cities were in Central and South Asia, with 6 of the world's 9 most polluted cities being in India.

Los Angeles, California was the most polluted city In the USA, while Seattle, Washington, was the cleanest.

Mayaguez, Puerto Rico was the cleanest metropolitan area in the world in 2024, with an average annual $PM_{2.5}$ concentration of 1.1 µg/m³.

In Africa, the shortage of publicly accessible, real-time air quality monitoring data is so severe that there is only 1 monitoring station for every 3.7 million people.

Brazil ranked 73rd overall. The cities of São Paulo and Salvador exceeded the WHO's $PM_{2.5}$ limit by 3 to 5 times, while Brasília exceeded it by 1 to 2 times. Wildfires in the Amazon rainforest affected vast areas of Latin America in 2024, with $PM_{2.5}$ levels in some cities in Rondônia and Acre quadrupling in September.

Oceania has been identified as the cleanest region in the world, with 57% of its cities meeting the WHO's annual $PM_{2.5}$ guideline value.

There has been notable progress in air quality monitoring in a number of countries, regions, and territories over the past 12 months. However, significant gaps remain in government regulatory systems in many parts of the world. Low-cost air quality monitors – used by scientists, citizens, researchers, community advocates, and local organizations – have proven effective for addressing these data gaps. Monitoring has increased the availability of crucial data on air pollution levels around the world.

Table 1
Five most polluted countries in 2024 according to $PM_{2.5}$ concentration

Country	Continent	Average annual concentration of $PM_{2.5}$ (µg/m³)	Number of times higher than WHO criteria
Chade	Africa	91.8	18
Bangladesh	Asia	78.0	15
Pakistan	Asia	73.7	14
Congo	Africa	58.2	14
Índia	Asia	50.6	10

$PM_{2.5}$ = particulate matter with a diameter of less than 2.5 µm.
Source: IQAir - World Air Quality Report 2024.[1]

UNICEF Report – Learning Interrupted[3,4]

According to UNICEF, extreme weather events are disrupting children's education, putting their learning and future at risk. Recent analysis revealed that at least 242 million students in 85 countries or territories had their classes disrupted by extreme weather events, including heatwaves, tropical cyclones, storms, floods and droughts in 2024, compounding the current learning crisis.

The 2024 UNICEF Report further highlights the following points:

1. Globally, at least 242 million students, from pre-kindergarten through high school, have experienced school disruptions due to weather events.
2. The classes of at least 1 in 7 students were interrupted due to climate events.
3. The schools of 85 countries or territories were affected by climate-related hazards, with 23 countries facing multiple rounds of school disruptions.
4. At least 20 countries have had nationwide school disruptions due to weather-related disasters.
5. Of the 242 million affected students, 74% percent are in low- and lower-middle-income countries, with an average score of 7 out of 10 on the Child Climate Risk Index.
6. South Asia was the worst-hit region, with 128 million students affected, followed by East Asia and the Pacific, where 50 million students were affected.
7. Worldwide, heatwaves were the most disruptive climate event for education, affecting an estimated 171 million students:
   - The highest number of heatwave-related school disruptions occurred on April 8, affecting at least 118 million children in Bangladesh, Cambodia, India, the Philippines, and Thailand;
   - The highest number of weather-related school disruptions occurred on September 9. At a time of year when schools were reopening in many parts of the world, at least 18 countries suspended classes. Typhoon Yagi affected 16 million children in East Asia and the Pacific, making it the most disruptive event in September.
8. In Africa, where more than 107 million children were already out of school, weather-related disruptions put an additional 20 million children at risk of dropping out.

In conclusion, the extreme events of 2024 have made it clear that the climate crisis is an urgent reality and show the worrying causal relationship between climate change and increasing climate-related morbidity and mortality, whether direct or indirect. Heat waves, devastating storms, and prolonged droughts show how global warming is already radically altering climate patterns and having worrying consequences for humanity. There is a consensus among scientists that these phenomena will become increasingly frequent and intense, requiring immediate responses to minimize their impact and promote adaptation. Preparing cities, improving and adapting infrastructure, public prevention policies, and investment in health and education, etc., are essential and urgent. Since the human cost and economic impact will tend to increase, monitoring climate-sensitive diseases and training in "climate medicine" should be prioritized, especially regarding the most sensitive population groups, such as older adults and children.[5-7]

The contribution of the Brazilian Society of Pediatrics' Grupo de Trabalho Saúde Planetária – Saúde Única (Planetary Health – One Health Working Group) and the Brazilian Association of Allergy and Immunology's Commission on Biodiversity, Pollution, and Climate: measures to reduce the impact of climate change on human health

Climate change is already having a direct effect on human health. Extreme events such as heat waves, floods, and wildfires have increased in frequency and intensity, worsening respiratory, cardiovascular, and neurological diseases, mental disorders, and adverse obstetric events. Health professionals play a crucial role in this scenario, not only in clinical care, but also as agents of environmental transformation. Patients must be educated about the effects of climate change and pollution, especially their consequences on vulnerable population groups, such as children, pregnant women, older adults, and patients with comorbidities. It is essential to implement action

plans to control the exacerbation of chronic disease in polluted environments and during environmental disasters. Health professionals can support policies aimed at reducing pollution and protecting the environment and can participate in local community resilience networks, especially in regions with a history of flooding and natural disasters.[8]

General guidelines for patients during environmental disasters and in extremely polluted environments

- Monitor air quality indicators, especially in areas with forest fires or environments with intense air pollution.
- In situations of maximum alert, consider temporary evacuation.
- On days with higher smog concentrations, avoid outdoor physical activity.
- Keep doors and windows closed during forest fires to prevent smoke from entering. This strategy is also useful during intense pollen emissions.
- Wear appropriate face masks (N95 or PFF2).
- Avoid areas near fires and with intense smoke.
- Avoid activities that increase pollution inside the home.
- Avoid exposure to cigarettes and other indoor pollutants, such as heavily perfumed cleaning products and harsh chemicals.
- Avoid spraying pesticides inside the home.
- Avoid lighting candles and incense, especially during forest fires.
- Avoid roasting or frying foods, especially in areas with forest fires.
- In addition to masks and goggles, wear appropriate clothing and footwear for protection against combustion products.
- Avoid unfiltered fans and air conditioners without filters. Clean the filters at least once a month.
- Use air purifiers with high-efficiency particulate air (HEPA) filters.
- Create safe spaces at home, sealing cracks and doors to minimize the entrance of smoke and pollen.
- When air quality improves after the fires or traffic-related air pollution has abated, even temporarily, air out the house to reduce indoor pollution.
- Encourage proper hydration and a healthy diet that includes fruits and vegetables from sustainable agriculture. Limit the consumption of ultra-processed foods to avoid exacerbating health conditions.
- In areas with flooding, pay attention to the civil defense guidelines.
- During floods, do not cross flooded bridges, streets, or avenues, even in vehicles. Seek shelter in a high place and wait for the water level to recede. If it is essential to travel, beware of uncovered manholes.
- Electrical appliances should be turned off during floods. Do not use electrical equipment that has been affected by floods. Turn off your residence's main circuit breaker during a flood.
- Food and drinks that have come into contact with flood water should be discarded. Do not use water from natural springs or wells in flooded areas.
- If the walls have swollen or cracked and are at risk of collapse, leave the property. Wear gloves and boots or double plastic bags over your hands and feet, if possible, when leaving the property.
- Check radio services or apps to verify safe travel routes.
- If there is sufficient time prior to the environmental disaster due to civil defense warnings, prepare kits with drinking water, clothes, medications, flashlights, and batteries; store documents in plastic bags.
- After a flood, beware of contamination by fungi, bacterial toxins, and pollutants from construction materials in domestic environments. Check the civil defense guidelines about returning home safely after a flood.
- In areas affected by extreme pollution or environmental disasters, pay attention to the mental health of victims.

Public policies to reduce environmental impact and pollution

- Identify areas at risk of natural disasters.
- Improve meteorological warning systems and satellite monitoring.
- Encourage the use of clean energy sources such as wind and solar energy.
- Increase the number of air quality monitoring stations.
- Prohibit construction in areas at risk of environmental disasters.
- Develop emergency plans for local civil defense initiatives and promote risk management policies for rapid response to environmental disasters.
- Engage in proper waste management to avoid environmental contamination and occupational hazards.
- Encourage the recycling and reduced production of plastics, since exposure to microplastics is intense and harmful to human health.
- Encourage active transportation (walking, cycling) and public transportation as strategies to promote health and reduce carbon emissions, the environmental footprint, and greenhouse gases.
- Encourage reforestation and sustainable agriculture. Monitor and rigorously enforce legislation to reduce criminal forest fires.
- Implement basic sanitation and drainage works to manage rainwater.
- Train health professionals to respond to emergencies due to environmental disasters.
- Create specific policies to protect communities exposed to chronic environmental risks, such as fluvial areas, peripheral urban areas, and Indigenous territories.
- Integrate social service, mental health, and rehabilitation initiatives for disaster victims, ensuring equitable access to health services.

Conclusions

Encouraging sustainability strengthens disease prevention, improves quality of life, and contributes to a more resilient and accountable health system. Small actions, when replicated across a network, can lead to major changes. Climate change must be addressed through evidence-based public policies and multidisciplinary initiatives focused on equity. The health sector must lead these transformations, protecting the population and promoting a healthier and more sustainable future.

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No conflicts of interest declared concerning the publication of this article.

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