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TABLE OF CONTENTS

<i>About the Journal</i>	iv
<i>Author's Guidelines</i>	v
<i>Editorial Board</i>	vii
<i>Table Contents</i>	viii
“The Enclaves of the Married and Educated People”: Characterizing the Residents of Gated Communities in Kano Metropolis <i>Mahmud Abba</i>	1-16
Ambient Air Quality and Public Health Risk Assessment in Ekpoma, Edo State, Nigeria <i>Otabor-Olubor, E., Aghagboren, U. J., Balogun, V. S., Ibanga, O. A., Osakue, P. V. & Asikhia, M. O.</i>	17-29
Exploring Socio-Demographic and Economic Factors Influencing Hepatitis B Prevalence in Gombe State, Nigeria <i>Abdulrazaq, A. A., Dardau, H., Kazaure, I. Y. A., Bappah, L., Suraj, A., John, S. & Umar, N.</i>	30-39
Detailing the Social Context of Inequality in the Rural Areas of Edo and Delta States of Southern Nigeria <i>Verere Sido Balogun, Rebecca Oghale John-Abebe, Francisca Omorodion, Andrew Godwin Onokerhoraye & Job Imharobere Eronmhonsele</i>	40-58
Understanding the Effects of Culture on Fertility Behaviour in Sokoto State, Nigeria: A Conceptual Framework <i>L. Barau, I. B. Lambu & A. Ammani</i>	59-76
Assessment of Livestock Feed Resources and Management Practices in Gumel Local Government Area, Jigawa State, Nigeria <i>Abdulmajid Abubakar</i>	77-87
Impact of the National Health Insurance Scheme on Healthcare Service Delivery in Nigeria: A Case Study of Customs Hospital, Karu Site, Abuja <i>ABIMIKU John</i>	88-106
Impact of Heat Stress and Extreme Temperature on Livestock Production in Yobe State <i>Ibrahim Yakubu Aliyu & Abdulmajid Abubakar</i>	107-119
A Review of Nigerian Federalism: Structural Inconsistences and The Difficulties in Nation-Building <i>Moshood Abiodun OLATUNJI & Hamed Afolabi OSUOLALE</i>	120-133
Analysis of Rainfall Variability in Akoka, Lagos State Using Remote Sensing Data <i>C. S. Ofordu, G. C. Ufoegbune, F. O. Ojediran, N. C. Mba & M. A. Audu</i>	134-144
Assessment of Electronic Waste Generation and Management Practice in Gusau, Zamfara State <i>Habeeb Hamisu, Murtala Dangullah, Abubakar Magaji Jibrillah, Ibrahim Suleiman, Mustapha Sani & Abubakar Abdullahi Bichi</i>	145-159
Urban Heat Island (UHI), Air Pollution, and Human Health: A Review <i>Peter Nkashi Agan, Uchenna C. Aruma & Sike-Uwbu Daude Gbana</i>	160-167

The Impact of Religion on Nigerian Politics (2015–2025) <i>ADETOYESE Adesina Ezekiel & OLATUNJI Moshood Abiodun</i>	168-181
Home, Space and the Environment: Geo-Spatial Representation of the Yoruba People in Nigerian Literature <i>David Sesan ADENIYI</i>	182-191
Assessment of Sustainable Mobility Challenges for Vulnerable Groups in Urban Kano, Nigeria: A Review of Past and Present Research <i>R. G. Aliyu & A. S. Barau</i>	192-211
Linking Irrigation Practices to Crop Productivity and Livelihood Outcomes in Odeda, Nigeria <i>Olagoke Victoria Oluwadamilola, Ayoola Kolawole Oladipupo & Adekitan Adetoun Abimbol</i>	212-222
Architectural Identity of Kano, Nigeria: Evaluation and Categorisation <i>Issia Habou & M. L. Sagada</i>	223-237
Spatio-Temporal Analyses of Urban Expansion of Gombe Metropolis <i>Garkuwa Muhammad Iliya, Muhammad Tukur Aliyu & Sadiya Atiku Umar</i>	238-251
Trend Analysis of Agroclimatic Parameters and Crop Yields in Sokoto State Northwest Nigeria <i>Yohanna Yunusa, A. T. Umar & Isah Hamisu</i>	252-264
Upcycling Plastic Waste into Building Blocks: A Sustainable Strategy for Waste Management and Construction in Kano Metropolis, Nigeria <i>Sabitu Sa'adu Da'u, Murtala Uba Mohammed, Nafiu Zakari, Aminu Sulaiman Zangina & Harisu Muhammad Muhammad</i>	265-276
Assessing Urban Heat Island (UHI) in Ife Central Local Government Area, Osun State, Using Multi-Temporal Landsat Thermal Infrared Imagery <i>Yusuf, U. G., Dakung, P. D. & Gomwalk, Y. S.</i>	277-292
Analysis of the Impacts of Land Uses Changes on Urban Heat Island and Mitigation Strategies Using GIS and Remote Sensing in Birnin Kebbi <i>Hadi Aliyu, Abdullahi Umar & Ismail U. Kaoje</i>	293-302
Microplastics Pollution in The Groundwater of Three Land Use Types, Southeastern Hungary <i>Ibrahim Sa'adu & Hồ Vũ Khanh</i>	303-314

URBAN HEAT ISLAND (UHI), AIR POLLUTION, AND HUMAN HEALTH: A REVIEW

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Abstract

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Urbanization is accelerating globally, with more than 56% of the world's population currently living in urban areas, a figure projected to reach nearly 70% by 2050. UHI is characterized by elevated urban temperatures relative to surrounding rural areas due to the prevalence of impervious surfaces, reduced vegetation cover, and anthropogenic heat emissions from buildings, transportation, and industry. This review focuses on the causal mechanisms linking UHI and urban air pollution and their combined impacts on human health. UHI alters atmospheric dynamics, often contributing to thermal inversions that trap pollutants near the ground, increasing both their concentration and duration of exposure. The health impacts associated with co-exposure to heat and pollution are multifaceted and severe. Epidemiological evidence shows increased rates of cardiovascular and respiratory disease, renal failure, heatstroke, neurological impairment, and mental health disorders. Vulnerable populations, including children, the elderly, low-income groups, and those with preexisting health conditions, face disproportionate risks due to limited access to cooling resources, medical care, and clean environments. These challenges are especially acute in cities in developing countries, where infrastructure and governance capacities are often insufficient to meet rising demands. Urban greening, including trees, parks, and green roofs, reflective building materials, permeable pavements, sustainable transportation systems, and low-emission zones, public health interventions such as heat action plans, early warning systems, and community outreach programs can all provide a panacea to reducing the tripartite effects of urban heat island, air pollution on human health.

Keywords: Urban Heat Island (UHI), Air Pollution, Public Health, Climate Resilience, Urban Sustainability.

Introduction

Urbanization has emerged as one of the most defining global trends of the 21st century. Over 56% of the world's population currently resides in urban areas, a figure projected to rise to nearly 70% by 2050 (United Nations, 2023). While urban growth brings economic opportunities and improved infrastructure, it also generates complex environmental challenges. Among the most pressing of these is the Urban Heat Island (UHI) effect, a phenomenon wherein urban regions experience significantly higher temperatures than their rural counterparts due to the modification of land surfaces and waste heat emissions from energy usage. The UHI effect is primarily driven by the replacement of natural land cover with impervious surfaces such as asphalt, concrete, and rooftops, which absorb and retain solar radiation. Additionally, the reduction in vegetation, increased building density, and anthropogenic heat from vehicles, industry, and air conditioning contribute to elevated urban temperatures. Studies have shown that urban temperatures can be

2°C to 7°C higher than adjacent rural areas, particularly during nighttime and heatwaves (Oke, 1982; EPA, 2024).

Compounding the risks posed by UHI is urban air pollution. Cities are hotspots for air pollutants such as particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), ozone (O₃), sulfur dioxide (SO₂), and volatile organic compounds (VOCs), emitted from transportation, industrial processes, and energy generation. Elevated temperatures due to UHI exacerbate the formation of ground-level ozone and intensify the dispersion and chemical reactions of airborne pollutants, thereby deteriorating air quality (Jacob & Winner, 2009). Furthermore, stagnant air conditions and heat-induced atmospheric inversions can trap pollutants near the surface, prolonging exposure durations. The convergence of UHI and air pollution has profound implications for human health. Both phenomena independently and synergistically increase the incidence of heat-related illnesses, respiratory and cardiovascular diseases, renal dysfunction, neurological impairment, and mental health disorders. Vulnerable populations, including the elderly, children, low-income communities, and individuals with preexisting health conditions, bear the brunt of these effects. Epidemiological data increasingly show that the co-exposure to high temperatures and poor air quality results in compounded health risks, leading to higher hospital admissions, reduced labor productivity, and premature mortality (Gasparrini *et al.*, 2015; Cleland *et al.*, 2023). The health burden is not uniformly distributed. Socioeconomic inequality, disparities in urban greening, housing quality, and access to cooling or medical resources all mediate the exposure and sensitivity of different populations to UHI and pollution stressors. Cities in the Global South, in particular, face heightened vulnerability due to rapid urban growth, limited infrastructure, and weaker environmental regulation. Given the intensifying impacts of climate change, the frequency and severity of heatwaves and air pollution episodes are projected to rise, making the UHI-pollution-health nexus a critical area of public health and urban planning concern. Mitigation strategies such as urban greening, reflective building materials, pollution controls, and climate-adaptive policies are gaining traction globally, but implementation gaps remain.

Causal Mechanisms Connecting UHI and Air Pollution

Urban materials like asphalt absorb more solar radiation than natural landscapes, causing surface temperatures to rise significantly. Reduced vegetation minimizes evapo-transpiration, while air conditioning and vehicles emit both heat and pollutants (Oke, 1982; EPA, 2024). Higher urban temperatures accelerate the photochemical reactions that produce ozone (O₃) and facilitate the formation of secondary aerosols like PM_{2.5}. This effect is amplified during heatwaves and stagnant atmospheric conditions (Jacob & Winner, 2009). UHI often intensifies nocturnal temperature inversions, trapping pollutants close to the ground, increasing population exposure, and prolonging their health effects (Zalakeviciute *et al.*, 2025). A study by Rybarczyk and Zalakeviciute (2025) found that in Quito, Ecuador, PM_{2.5} was not only an outcome of UHI but also a contributing factor, modifying the urban surface energy balance. Lopes *et al.* (2025) demonstrated that in Porto, Portugal, disadvantaged neighborhoods suffered disproportionately from the combined effects of heat stress and poor air quality, leading to greater hospital admissions and mortality. Cleland *et al.* (2023) observed that in U.S. cities, hospitalizations due to cardiovascular diseases increased by up to 2.4% on extreme heat days in high-UHI zones, especially when ozone levels were elevated.

Higher temperatures associated with UHI accelerate the chemical reactions responsible for the formation of secondary air pollutants, particularly ground-level ozone (O₃). This occurs through the enhanced photolysis of nitrogen dioxide (NO₂) in the presence of sunlight and volatile organic compounds (VOCs), both abundant in urban areas due to traffic and industrial activity (Jacob & Winner, 2009). Higher urban temperatures elevate energy consumption, especially for air conditioning during summer months. This increased demand often results in greater fossil fuel

combustion at power plants and from vehicle use, leading to increased emissions of these pollutants not only contribute to poor air quality but also act as precursors to ozone and smog formation (Santamouris, 2020; EPA (2024)). Urban areas frequently experience thermal inversions, particularly under calm wind conditions at night. During an inversion, a layer of warmer air traps cooler air and pollutants near the surface, reducing vertical dispersion. UHI contributes to this by warming the urban surface and altering local convection currents (Oke, 1982). Recent studies suggest that particulate matter (especially PM_{2.5}) may exacerbate the UHI effect by altering the urban surface energy balance: PM and black carbon (soot) deposited on surfaces reduce albedo, increasing solar absorption. Suspended aerosols can trap longwave radiation and enhance warming near the surface. This creates a positive feedback loop where air pollution contributes to increased urban warming, which further exacerbates pollution generation (Rybarczyk & Zalakeviciute, 2025). Vegetation plays a crucial role in both cooling urban environments and filtering air pollutants. The lack of urban greenery intensifies UHI while simultaneously reducing the natural removal of pollutants via: Dry deposition (capture on leaf surfaces), Biogenic uptake through stomata, urban greening mitigates both heat and pollution, yet its absence reinforces both problems (Nowak *et al.* 2018). UHI slows the natural cooling process at night, maintaining higher temperatures well after sunset. This prolongs the atmospheric conditions favorable to pollutant formation (e.g., ozone) and impairs nighttime dispersion (EPA 2024; Harlan *et al.* 2019).

Mitigation Strategies

Urban trees and parks reduce air temperatures by 1 to 3°C and filter PM and ozone (Nowak *et al.*, 2018). In Medellín, Colombia, green corridors reduced surface temperature by 2°C (UNEP, 2023). Cool roofs and pavements with high albedo can reduce urban surface temperatures by 20–40%, decreasing heat-related mortality by up to 25% in extreme events (Santamouris, 2020). Smart zoning, reduced traffic emissions, and expanded public transit have shown success in lowering both temperature and pollution loads (Harlan *et al.*, 2019). Cities like Ahmedabad (India) and Paris (France) use localized heat health warning systems, cooling shelters, and targeted outreach to reduce mortality (World Bank, 2022). Vegetation plays a central role in reducing urban temperatures and improving air quality. Key green infrastructure strategies include: Urban Trees and Green Corridors, Trees provide shade and promote evapotranspiration, lowering surface and air temperatures by up to 2 to 4°C in local microclimates. Tree canopies filter airborne particles and gases (PM_{2.5}, ozone, NO₂) through deposition on leaves. Example: Medellín, Colombia's "Green Corridors" reduced urban temperatures by 2°C while improving air quality (UNEP, 2023). Vegetated roofs lower indoor temperatures, reduce building energy consumption, and absorb pollutants. Green walls add vertical cooling and help insulate buildings. Effective in high-density areas where horizontal space is limited. Integrate stormwater management, biodiversity enhancement, cooling, and pollution capture. Support mental health and provide recreation in overheated areas. Urban materials with high solar reflectance (albedo) can significantly reduce surface temperatures: Cool roofs use light-colored or reflective materials to reflect solar radiation. Cool pavements (e.g., light concrete, permeable surfaces) minimize heat absorption. Studies show reflective surfaces can lower surface temps by 20 to 40°C, reducing indoor air conditioning needs and associated emissions (Santamouris, 2020). Facilitate stormwater infiltration, reduce runoff, and lower surface temperatures. Often used with vegetation for co-benefits like pollution filtration and aquifer recharge. Targeting emission sources is essential for reducing the concentration of air pollutants that exacerbate UHI and harm human health: Invest in public transport, cycling infrastructure, and pedestrian zones to reduce vehicular emissions. Implement Low-Emission Zones (LEZs) to restrict high-polluting vehicles. Promote electric vehicle adoption and phase out diesel engine. Enforce air quality standards for industrial operations, construction sites, and power plants. Deploy scrubbers, filters, and carbon capture technologies in polluting facilities. Shift from fossil fuels to renewable energy sources

(solar, wind). Encourage building retrofits and energy efficiency to reduce urban energy demand and associated emissions.

Urban planning can integrate heat and air quality considerations at the neighborhood and city scales: Promote mixed-use zoning to reduce travel distances and vehicle use. Require minimum tree canopy coverage in new developments. Avoid dense developments in heat-vulnerable zones without cooling infrastructure. Integrate urban heat mapping into planning to prioritize mitigation in high-exposure zones. Encourage orientation of buildings for natural ventilation and reduced solar gain. Use water bodies, fountains, and wetlands to promote evaporative cooling. Integrate water-sensitive urban design to co-manage heat and flooding risks. In addition to physical mitigation, health systems must prepare for and respond to climate-exacerbated environmental stressors: Provide early warnings, public advisories, emergency cooling centers, and targeted outreach to high-risk populations. Example: *Ahmedabad, India's Heat Action Plan* significantly reduced heatwave-related mortality (World Bank, 2022). Monitor heat-related illness and pollution-related health indicators through hospitals and community health networks. Mobilize emergency medical services during extreme events. Launch campaigns on heat safety, pollution risks, and self-protection strategies (hydration, staying indoors, mask use). Involve schools, community organizations, and local leaders. To ensure long-term success, cities must embed UHI and pollution mitigation into governance and policy frameworks: Align urban development with climate action plans, air quality management plans, and public health strategies. Create cross-sectoral task forces that bring together planners, health officials, scientists, and communities. Prioritize investments in heat-vulnerable and underserved communities. Support affordable housing retrofits, access to green space, and cooling infrastructure in marginalized areas. Leverage climate finance, green bonds, and public-private partnerships for sustainable urban infrastructure. Provide tax credits and subsidies for green building certifications, cool roofs, and clean energy installations.

Gaps for Future Studies

Despite a growing body of evidence linking Urban Heat Islands (UHIs), air pollution, and human health, several critical research gaps remain. Addressing these gaps is essential to developing more effective, equitable, and scalable interventions in rapidly urbanizing and climate-vulnerable regions. Below are key areas that warrant further investigation. Most existing studies examine UHI, air pollution, and health impacts in isolation or in pairwise relationships. There is a pressing need for: Integrated, high-resolution urban climate-health models that can simulate the combined effects of UHI and air pollution under different land use, demographic, and climate scenarios. Models that incorporate feedback mechanisms, such as how pollution alters urban heat, and vice versa. Inclusion of dynamic temporal factors, such as seasonal variability, diurnal patterns, and future climate projections. Much of the current epidemiological evidence is cross-sectional or based on short-term exposure data. There is limited understanding of the cumulative and chronic effects of long-term exposure to heat and pollution combinations. Long-term cohort studies linking environmental exposure to chronic diseases, including neurological disorders, cancer, and mental health outcomes, are critically needed. Studies must also differentiate between acute (e.g., heatstroke) and long-term (e.g., cardiovascular disease) health impacts. Vulnerability is not only a function of exposure but also of socioeconomic status, age, gender, disability, race, and access to resources. However, many studies lack: Granular socio-demographic data to assess how intersecting identities influence vulnerability. Focus on environmental justice, particularly in low-income neighborhoods, informal settlements, and migrant communities. Data from cities in the Global South, where populations are rapidly growing but monitoring infrastructure is often lacking. Little is known about how urban residents perceive, adapt to, or cope with simultaneous exposure to heat and pollution. Research is needed on risk perception, adaptive behaviors (e.g., use of cooling devices, mask-wearing), and community coping strategies. Studies should

evaluate the effectiveness of public health campaigns and early warning systems in modifying behavior and reducing exposure.

While many mitigation interventions (e.g., green roofs, cool pavements) are promoted, few studies rigorously quantify their health co-benefits, especially in different climate zones or urban forms. Comparative, cost-benefit analyses of interventions are needed, accounting for climate, economic, and health trade-offs. Research should investigate the maintenance, longevity, and equity of infrastructure-based solutions over time. There is a lack of anticipatory research that links UHI and pollution dynamics to future climate trajectories, including, Downscaled urban climate projections that estimate how extreme heat and pollution events will evolve by 2050 or 2100. Studies examining compound events and their cascading health impacts in urban systems. Although policy interventions exist, there is limited evidence on: Which policy mechanisms work best in different governance contexts. How to scale successful pilot programs to city-wide or national levels. The role of community participation and political will in the implementation of UHI and air quality policies.

Conclusion

Urban Heat Islands and air pollution are mutually reinforcing threats that significantly worsen health outcomes, especially in the context of climate change. They increase the incidence of heat-related illness, cardiopulmonary disease, and emerging mental and neurological effects. Vulnerable populations bear the highest burden. However, a combination of green infrastructure, reflective materials, smart urban design, and public health planning offers viable paths toward safer, more resilient cities. The convergence of Urban Heat Islands (UHIs) and air pollution represents one of the most critical and complex environmental health challenges facing urban populations in the 21st century. As urbanization intensifies and climate change accelerates, cities around the world are increasingly becoming hotspots for elevated ambient temperatures and hazardous air quality levels. These twin stressors are not only interrelated through multiple physical and chemical pathways but also act synergistically to degrade environmental quality and exacerbate human health risks.

This review has outlined the causal mechanisms through which UHI amplifies air pollution, via enhanced photochemical reactions, altered surface energy dynamics, and reduced pollutant dispersion, and has shown how air pollutants can, in turn, exacerbate the intensity of UHIs. Together, these dynamics increase exposure to harmful conditions that trigger a wide range of health outcomes, including heat-related illnesses, respiratory and cardiovascular diseases, renal stress, neurological impairments, and mental health issues. Vulnerable populations, such as the elderly, children, people with pre-existing conditions, and marginalized communities, are disproportionately affected due to social, economic, and infrastructural inequalities. Moreover, the unequal distribution of urban heat and pollution burdens raises serious questions of environmental justice, especially in rapidly urbanizing regions of the Global South. These areas often lack the resources, infrastructure, and governance capacity to effectively mitigate or adapt to rising environmental and health threats, thus widening global and intra-urban disparities.

Despite these challenges, the review also highlights a range of promising mitigation and adaptation strategies. These include: Urban greening (e.g., trees, parks, green roofs) to cool cities and remove pollutants; Reflective and permeable surfaces to reduce heat absorption and improve air flow; Low-emission zones, public transit investments, and clean energy policies to reduce emissions; Heat action plans, early warning systems, and public health surveillance to reduce health impacts. However, implementation gaps remain significant, particularly in terms of integrating heat and air quality management across sectors such as urban planning, public health, transportation, and climate policy. Many cities still lack comprehensive, equity-centered frameworks that address these issues in tandem. Going forward, it is essential that policymakers,



researchers, and urban planners pursue a multi-disciplinary and data-driven approach to managing UHI and air pollution. This should include: enhanced real-time monitoring and modeling of urban micro climates and pollutant levels; Health impact assessments that quantify the co-benefits of mitigation strategies; community engagement and education to empower local action and adaptation; Long-term climate resilience planning, especially for marginalized neighborhoods. In conclusion, the UHI pollution health nexus is a pressing global concern that demands urgent, integrated, and inclusive solutions. Addressing this challenge offers not only the potential to safeguard public health, but also to advance climate resilience, urban sustainability, and social equity in an era of rapid environmental change.

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