Open Access

Advances in Environmental and Engineering Research

LIDSEN Publishing Inc.

Concept Paper

Nexus Between Heat and Air Pollution in Urban Areas and the Role of Resilience Planning in Mitigating These Threats

Jim Anbazu [1, †, *], Nana Serwaa Antwi [2, †]

1. University of Cincinnati, 2600 Clifton Ave, Cincinnati, Ohio, USA; E-Mails: anbazujk@mail.uc.edu; jim.anbazu98@gmail.com
2. Politecnico di Milano, Via Bonardi 3, 20133, Milano, Italy; E-Mails: nanaserwaa.antwi@mail.polimi.it; serwaaantwi37@gmail.com

† These authors contributed equally to this work.

* **Correspondence:** Jim Anbazu; E-Mails: anbazujk@mail.uc.edu; jim.anbazu98@gmail.com

Academic Editor: Anthony Brazel

Special Issue: Urban Heat Island Effect

Adv Environ Eng Res
2023, volume 4, issue 4
doi:10.21926/aeer.2304047

Received: February 14, 2023
Accepted: October 10, 2023
Published: October 17, 2023

Abstract

Urban heat island (UHI) effects are evident in many cities globally. Studies have revealed that UHI impacts air pollution and vice versa. However, it is observed that these two severe problems are addressed independently instead of interrelatedly. The study seeks to provide an in-depth understanding of the relationship between air pollution and heat and how they constantly shape urban areas for planning and future research purposes. A global shift from sustainable planning practices to building urban resilience exists in line with this. This study delves further into identifying resilient approaches to combating UHI effects and air pollution. The systematic review of existing literature revealed a complex relationship between air pollution and urban heat islands. On one end, air pollution contributes to the heating of urban areas. Similarly, urban heat island effects have an impact on air quality. These two threats appeared to be significant contributors to climate change. The study recommends that adopting resilient planning practices could play a vital role in mitigating these problems. The

whole idea of resilience is to plan so that crises are anticipated, planned, and accounted for. This can be done by addressing the root causes of these problems since they are interrelated through adaptive planning, governance, and management.

Keywords
Climate change; air pollution; Urban Heat Island (UHI) effects; resilience planning

1. Introduction

Urbanization, an inevitable process of human growth, has been and continues to be an essential global trend in the twenty-first century [1, 2]. It characterizes the rapid increase in a country's urban population relative to its rural population. The world's urban population has increased from 30% in 1930 to 55% in 2018 and is expected to rise to 68% by 2050 [3]. [4] also predicted that two-thirds of the world's population will reside in urban areas by 2030. Now, what is the motivation behind this urban population acceleration? People tend to move to urban areas for better living conditions and prosperity [5]. Henderson makes a case that a country is fully urbanized when 60 to 90% of its national population resides in cities, using upper-middle income as a metric. Beyond the remarkable shift in population from rural areas to urban areas, [6] posits that urbanization also preempts the transition from agricultural production to industries and services - made possible through urbanization agglomeration economies. This also represents increased production as well as emissions and adverse effects. While urbanization is trailed by industrialization, [7] makes a case with Africa and the Middle East, which have unarguably urbanized with minimal industrialization, indicating that urbanization and industrialization are not metonymic. Demonstrably, urbanization not only concerns population, industrialization, income brackets, geography, economy, and the national definition of the 'urban' [6, 8]. Contemporarily, the rate at which cities are growing is seen as a crucial development concern [9]. There have been extensive discussions on how urbanization drives economic growth in countries globally. In this context, urbanization is depicted as an inevitable progression of human societies [10]. It promotes infrastructure investment, expands markets, and improves income levels and access to education [11]. In other assertions, the continuous transition of cities has worsened rather than improved the standard of living migrants, existing settlers, and the environment through the consumption of resources [12]. Urbanization takes many forms and manifests in sprawls, growing poverty and inequality trends, crime and violence, climate change and disasters, waste management issues, and environmental insecurity [13]. Thus, it is arguably the major contributor to the numerous threats that cities face due to the inability of city authorities to keep up with the rapid growth of their jurisdictions. Among these threats are air pollution and urban heat island effects, which are the focus of this research.

Air pollution is a significant problem in many cities globally. According to [14] billions of people live in areas where the air quality is below the World Health Organization standards and raises various human health, environmental, and aesthetic concerns. As a global health threat, air pollution accounted for 6.4 million deaths globally in 2015, 2.8 million from indoor air pollution, and 4.2 million from outdoor air pollution, increasing to about 7 million deaths in subsequent years [15, 16]. [15] posits that household air pollution began declining in the 1990s due to the lens of

renewable energy; however, these successes are offset by accelerated urban growth, industrialization, increased vehicular use, and the use of pesticides and other toxic chemicals. The air quality in cities is primarily the result of a complex interaction between natural and anthropogenic environmental conditions that have constantly shaped cityscapes and aggravated the air pollution challenge. However, [17] makes a case that there are varied levels of urbanization and air pollution in countries due to differences in science and technology, economic development, culture, geography, and history. This is extensively discussed by [1, 18, 19] demonstrating how the urbanization process encourages the expansion of construction sites and activities, intense industrial activities, increased energy generation and consumption as well as vehicular movement increment - all of which contribute to Particulate Matter (PM2.5), ultimately affecting human lives negatively. These anthropogenic events like traffic, industries, power plants, significant land use change, and trade account for the emission of gases that degrade air quality [8, 20, 21]. [19] classify these pollutants into three groups: Heavy metals like lead, particulate matter, and persistent organic pollutants, mainly exposed to humans through inhalation and ingestion. Inhalation particularly, on the basis that particles produced by all combustion processes are small enough to be inhaled into the lung as primary emissions or as secondary particles via atmospheric transformation like sulfate particles [22]. These groups are possible due to further classifications based on their source, chemical composition, means of release into the atmosphere, and size [21]. When exposed to it (indoors or outdoors, for a short or long term), these air pollutants can cause severe respiratory and cardiovascular diseases, as well as digestive and urinary infections and even complications during pregnancy [19, 23-25].

Interestingly, not only do these emissions degrade the environment, but they also account for the changes in these climatic conditions. A commonly known phenomenon is global warming, which refers to climate effects spurred on by emissions from human activities that serve as blankets over the surface of the earth, absorbing infrared radiations that are emitted by both the land and the ocean and keeping them warmer than they would otherwise be [26]. The Intergovernmental Panel on Climate Change (IPCC) reported that global temperatures have increased by 0.85°C from 1800 to 2012 and are predicted to increase by 2.6°C by 2065, especially on surface lands [27]. The heating of surface land and the worsening of air temperatures that has reportedly been happening in urban areas is what we characterize as the urban heat island effect. Urban heat island (UHI), a phenomenon in which urban areas are warmer than surrounding rural areas, is a problem in cities that climatic changes have exacerbated. According to [28] these climatic changes are fueled by urban expansions, constructions, and other human activities. Cities become hotter throughout the day, becoming more noticeable after sunset as heat stored during the day is slowly released over the night. Disturbingly, this cycle of increased temperature is at an all-time high during the summer, implying that the effects of urban heat islands will also be significant during this period [29]. This effect has resulted in uncomfortable living conditions in urban areas and, as a result, raises concerns about public health and the environment. It is seen that these two human-induced effects are interrelated. However, limited research discusses the heat and air pollution nexus.

As cities continue to urbanize, climate change effects are predicted to exacerbate [30-33]. Research has revealed that anthropogenic activities are the significant causes of climate change. Attributing climate change impacts and human activities has been essential to climate change research for decades [34]. Human activities such as deforestation, burning fossil fuels, waste generation, and other human-induced events generate greenhouse gases (GHGs), which result in

climate change. Thus, air pollution through anthropogenic activities correlates with urbanization and is directly linked to global warming and climate change impacts. At the center of all these is that human activities lead to the emission of harmful gases that degrade air quality and increase global warming effects that account for the heating of urban areas [35, 36]. Unfortunately, little evidence explains the interlinkages between these two risks through a lens of cause-effect relationships. This research argues that understanding these human-induced effects (air pollution and urban heat island effects) provides a clear framework for initiating measures to mitigate their impacts on humans and the environment. Furthermore, resilient planning has been a contemporary approach in dealing with numerous problems globally. To fit it into the study context, the research explores resilient planning practices that have been or can be adopted to solve these complex, interlinked societal threats to achieve a sustainable, livable, and resilient status globally. Therefore, to contribute to the existing body of literature, this research addresses the following questions: How are UHI effects and air pollution connected? What is the growing impact of these two threats? What resilient approaches are available and have been implemented in dealing with UHI and air pollution in cities? In an attempt to address these questions, the research relies on existing literature to provide empirical explanations of air pollution, its causes and effects, and urban heat island effects. The focus is on the factors that connect these two threats and how they fit into the broader climate change cause. Ideally, the best way to address a problem is to understand the root causes of the specific issue [37]. Establishing the nexus between heat and air pollution would play a significant role in planning for resiliency in cities globally.

2. Literature Review

2.1 Air Pollution: Causes and Effects

Cities across the globe are suffering from severe air quality problems due to the rising urban population, combined with changes in land use activities [20]. Air pollution has been a significant environmental concern in industrialized countries such as the United States and Europe. [38] reflected on how Nitric oxide and Sulfur dioxide caused heavy acidification concentrated in the air for long distances and the incidence of Ozone being a challenge in urbanized and industrialized areas in the USA in the early 1970s. This viewpoint is also shared by [39], especially on releasing high amounts of sulfurous smog into the atmosphere by industrialized areas in both countries. [39] further detailed how the USA and Europe developed air quality standards to tackle this problem. However, the slow implementation of these emission controls rendered it a lost cause. Due to these human events, it is estimated that future air quality will be characterized by various factors, including the adverse impacts of climate change, as the demands for energy, electricity, and other emission-related activities keep growing [40]. Generally, air pollution is a mix of hazardous substances of human-induced emissions from industrial, commercial, residential, transportation, and agricultural land uses, as well as natural emissions such as smoke from wildfires, which people often cause; ash and gases from volcanic eruptions; and gases, like methane, which is emitted from decomposing organic matter in soils. [41] defined air pollution as the manipulation of the quality of the air in natural or unnatural ways, which affects the health and well-being of humans and other species. In simple terms, [42] postulates that air pollution is the eminent presence of unwanted and harmful substances in the air in sufficient quantities to produce adverse effects. In the context of this study, air pollution is defined as the release of toxic substances from anthropogenic and natural

activities that constantly degrade the quality of the air we breathe, both indoors and outdoors, and as a result, create undesirable health and environmental outcomes.

Air pollution has been linked directly to worsening health outcomes in numerous studies. According to [42], air pollution is one of the prime public health hazards. [16] reported that air pollution accounts for about 7 million deaths annually. The World Health Organization (WHO) also revealed that 9 out of 10 (91%) people inhale air that exceeds the World Health Organization's clean air guidelines, especially in low and middle-income countries [43]. This is a severe problem because polluted air is arguably associated with developing non-communicable diseases, including cancer, diabetes mellitus, chronic respiratory disease, stroke, and neurological conditions [41, 44]. About 4.2 million people die due to ambient air pollution, and 3.8 million premature deaths each year due to exposure to smoke and cooking fires [43]. In addition, about 21 million deaths are recorded annually due to cardiovascular diseases [22]. It is not just about presenting the statistics but understanding the magnitude of which air pollution impacts human health. The causes of these health disorders are attributed to the types of air pollutants that are being released or emitted. The common pollutants include particulate matter (PM), sulfur dioxide (SO_2), ground-level ozone (O_3), nitrogen dioxide (NO_2), and carbon monoxide (CO) [45]. Most of these pollutants result from human activities such as industrialization, power and energy generation, combustion, automobiles, wars, and nuclear activities [41]. Ground-level ozone and particulate matter (PM) are common air pollutants that seriously risk human health and the environment. The World Health Organization estimates that PM contributes to approximately 800,000 premature deaths yearly and 6.4 million lost years of healthy life in cities [23]. Chemicals like sulfates, nitrates, carbon, and mineral dust comprise particulate matter (PM). PM is present in emissions from vehicles and industries from fossil fuel combustion, cigarette smoke, and burning organic debris, such as wildfires. Fine particulate matter (PM 2.5), a subtype of PM, is 30 times thinner than human hair. It can be profoundly inhaled into lung tissue and cause significant health concerns. PM 2.5 is responsible for most of the health impacts caused by air pollution and has received significant international attention [42]. [42] further argues that exposure to PM 2.5 gives rise to chronic obstructive pulmonary disease, respiratory tract infections, asthma, shortness of breath, and even COVID-19, contributing to global mortality and morbidity toll. Other pollutants, such as volatile organic compounds and polycyclic aromatic hydrocarbons, contribute to health problems and are primarily found in particulate matter.

Air pollution also significantly impacts the environment through intricate interactions in the atmosphere and the resulting outcome of changes in climatic conditions. Not only are greenhouse gases (GHG) and air pollutants released from the same sources, but many air pollutants can affect climate change owing to interactions with solar radiation. Climate change's impacts on air quality have been extensively discussed in the literature [46, 47]. The changes in temperature and atmospheric water vapor concentration, among other climatic variables, influence direct emissions and the generation of secondary pollutants caused by climate change [48]. Furthermore, [49, 50] opine that the changes in climatic conditions (weather patterns) increase and distribute air pollutants, which contributes to an increase in poor air quality. For instance, according to [51], allergic diseases from pollen and fungi are expected to increase as climate changes. In addition, extremely hot and cold days were reported to raise cardiovascular mortality rates in China, with females, older persons, and those with lower educational attainment being more vulnerable [52]. Also, anomalies in cold temperatures raised the risk of ischemic stroke, while anomalies in hot

temperatures increased the chance of hemorrhagic stroke [53]. On the other hand, emissions from anthropogenic activities contribute to the depletion of the ozone layer and consequently contribute to climate change. [41] mentions that air pollution accounts largely for acid rain, which threatens water and soil and damages trees, plants, and buildings. Global warming has become a prominent issue in the 21st century because it affects humans and the environment. The emission of greenhouse gases from human activities has constantly increased the protective temperature effect (greenhouse effect) and, as a result, accounts for global warming, which is detrimental to humans and the environment. For example, carbon dioxide (CO_2) emissions globally from burning fossil fuels, trees, solid wastes, and other biological materials. It is estimated that about 7,738 million metric tons of carbon dioxide were produced from using fuel around 2015-2016 globally [54]. These gases contribute primarily to the greenhouse effect, especially in urban areas. A familiar effect is the heating of urban areas. A concept commonly known as the urban heat island effect, discussed in the next section, is one of the many effects of global climate change. Even though greenhouse gases do not pollute the atmosphere directly and, as a result, should not be linked to air pollution, these gases, when emitted, go through many processes that end up depleting the air quality and intensifying climate change effects.

2.2 Urban Heat Island Effects on Cities

The rapid growth and urbanization of cities have transformed them into heat islands. These transformations are characterized by the replacement of vegetation and permeable surfaces with concrete and asphalt surfaces (impervious/impermeable), which absorb and reflect energy differently, as well as human activities that have exacerbated the release of particulate matter like carbon monoxide [55, 56]. Moreover, it accounts for heat accumulation, making these areas hotter than their surrounding rural landscapes [56]. The urban heat island (UHI) effect has become a widely recognized phenomenon as heat accumulation continues to characterize urban climate, which is caused by urban constructions and human activities [28]. [57] revealed that these urban constructions absorb heat during the day and re-emit it after sunset, creating temperature differences between urban and rural areas. Literature shows that many urban areas globally experience the UHI effect, which is predicted to worsen if urbanization and urban development continue [28]. This is consistent with the assertion of [58] that cities usually have higher air temperatures than the countryside. Similarly, the IPCC estimates that as global temperatures continue to rise due to climate change, the risk of extreme heat events is also predicted to rise [59]. [56] Bhargava et al. (2017) report that the annual mean temperature of a city with more than one million inhabitants can be 1-3°C warmer than its surrounding rural areas. [60] also revealed that the UHI effect can increase air temperature between 5-15°C. Numerous city studies have shown how heat stress worsens, especially during the summer [28, 61-63].

The reduction in vegetation and evapotranspiration, absorption of shortwave radiations from the sun in low albedo materials, air pollution, and anthropogenic heat release through combustion processes are events that worsen UHI effects [59, 64]. [65] provides a similar assertion that the constant increase in hard and heat-absorbing surfaces, the density of cities, and the depletion of the natural environment are factors that are increasing urban heat island effects. Urban sprawl also increases heat waves and more frequent extreme events than compact cities [64]. Thus, given that urban areas are predicted to proliferate, UHI effects could escalate as these areas continue to get

larger and denser. Furthermore, increased engineered materials in our cities influence UHI due to their high heat storage capacity and low albedo [66]. Materials that contain hydraulic, radiative, and thermal elements used in modern construction differ entirely from traditional construction materials [67]. In addition, technological advancements have increased the need for heating, cooling, and energy usage in general. The most significant are air conditioning systems, which, although successful at boosting human comfort, intrinsically produce more heat [67]. Given today's cities' density, more air conditioners are required to operate buildings properly. This increases the electricity demand. [68] discovered that an increase in temperature by one °C tends to increase electricity by 2-4%.

Today, the adverse effects of urban heat islands (UHI) are evident in many cities and have been documented in the literature. For example, according to [69], urban heat islands contribute to rising temperatures, global warming, and climate change through increased greenhouse gas emissions. When there is a high energy demand, there is a high output of energy, which leads to a rise in the usage of fossil fuels for energy production. Combusting fossil fuels releases pollutants into the atmosphere, such as sulfur dioxide, nitrogen oxides, carbon monoxide, and carbon dioxide (CO_2), with CO_2 contributing significantly to the greenhouse effect, which contributes to global warming as well as acid rain and smog [56]. Ground-level ozone depletion is also a crucial effect of UHI in many cities. UHI arguably increases energy demand and consumption and contributes to health disorders (discomfort, respiratory difficulties, heat cramps, non-fatal heat stroke) and heat-related mortality [59, 70]. The heat island effect raises energy demand for air conditioning and strains the electricity infrastructure during peak hours [71]. There are also linkages between UHI and water quality issues. Excessive temperatures equally increase water temperature, affecting aquatic species' metabolic and reproduction processes.

3. Methodology

Following the precedence that the study relied primarily on secondary data, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were adopted in conducting an in-depth analysis of urban heat islands and air pollution. The rationale for adopting PRISMA stems from the weaknesses of traditional literature review methods to ensure quality and in-depth analysis. It is an evidence-based approach that includes a checklist and a flow chart (see Figure 1). Numerous individuals and organizations have extensively accepted and applied it to increase quality reviews. This approach helped streamline the most valuable studies for this study, ensuring that the articles selected are of the utmost quality and provide relevant contributions to all research sections. Efficiency was enabled while assisting in carefully keeping a record of all scholarly works included or excluded in the final consideration of this study.

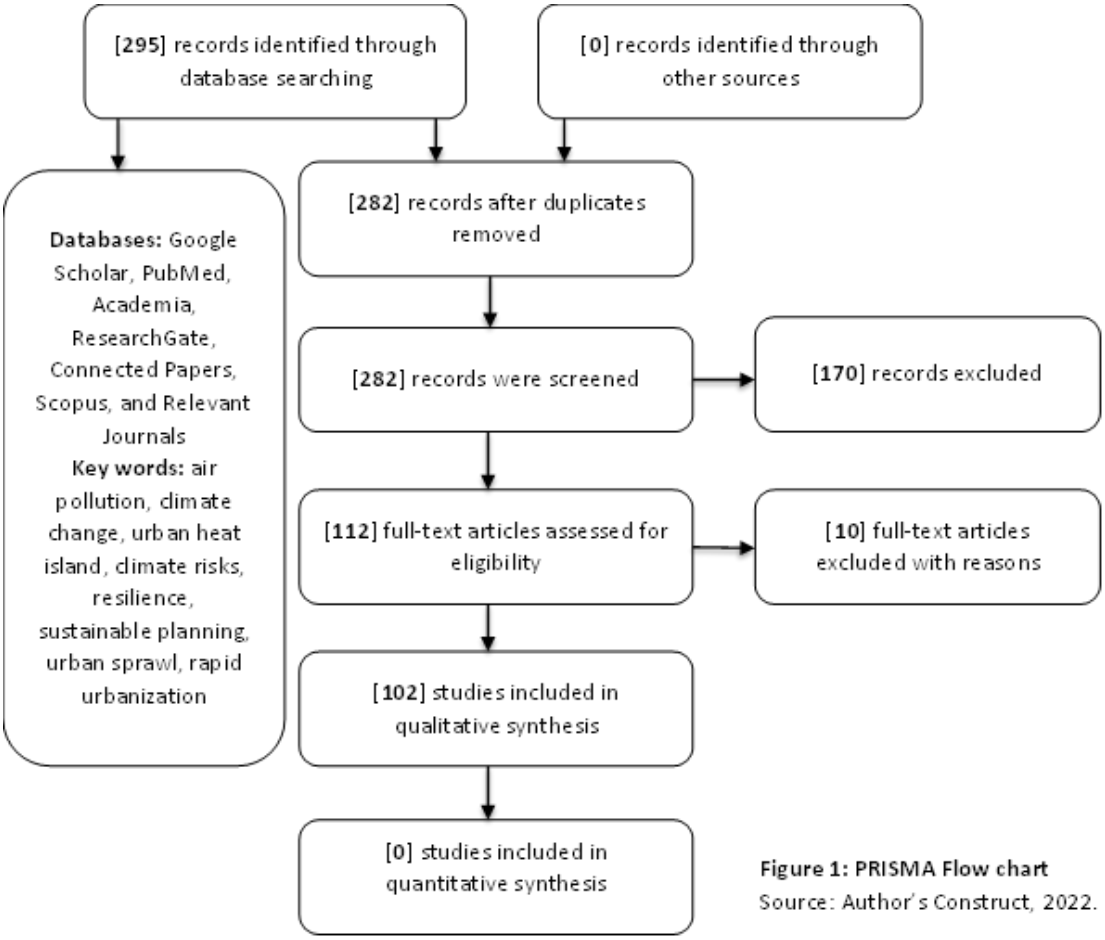

Figure 1 PRISMA Flow chart. Source: Author's Construct, 2022.

4. Discussions & Recommendations

4.1 Nexus Between Urban Heat Islands and Air Pollution

Understanding the relationship between urban heat islands and air pollution would play a significant role in adopting measures to mitigate these challenges, as they are constantly shaping cities and creating unsuitable living conditions for inhabitants. This study adopts a cause-effect approach to investigate how these phenomena are related. Preliminary research has revealed meaningful connections between them, explored in this section.

There are shreds of evidence from the literature that explains how air pollution relates to urban heat island effects. Air pollution, as mentioned previously, refers to the release of harmful substances from anthropogenic and natural activities that constantly degrade the quality of the air we breathe indoors and outdoors, creating undesirable health and environmental outcomes. Depleting the air quality is attributed to human activities that emit pollutants such as particulate matter (PM), sulfur dioxide (SO_2), ground-level ozone (O_3), nitrogen dioxide (NO_2), and carbon monoxide (CO), [72] as well as natural emissions. Air pollution is directly linked to human health concerns, global warming, and climate change. On the other hand, urban heat islands are instances where urban areas experience intensive heat temperatures compared to their rural landscapes. This effect emanates from the continuous urbanization and sprawling of cities, depletion of the vegetation cover and an increase in impervious surfaces, air pollution, and technological

advancements. Similarly, urban heat island effects raise crucial health concerns and contribute to global warming, climate change, and ecosystem depletion. Based on these, it can be inferred that there is a correlation/linkage between these issues. Thus, from one perspective, air pollution appears as a cause and effect of urban heat island effects. From another angle, urban heat islands contribute significantly to air pollution. The common thing that emanated from the literature is that these two threats are triggered by urbanization and anthropogenic activities and account for global warming and climate change. To better present these findings, a cause-effect framework was developed to conceptualize the relationship between air pollution and urban heat islands (Figure 2).

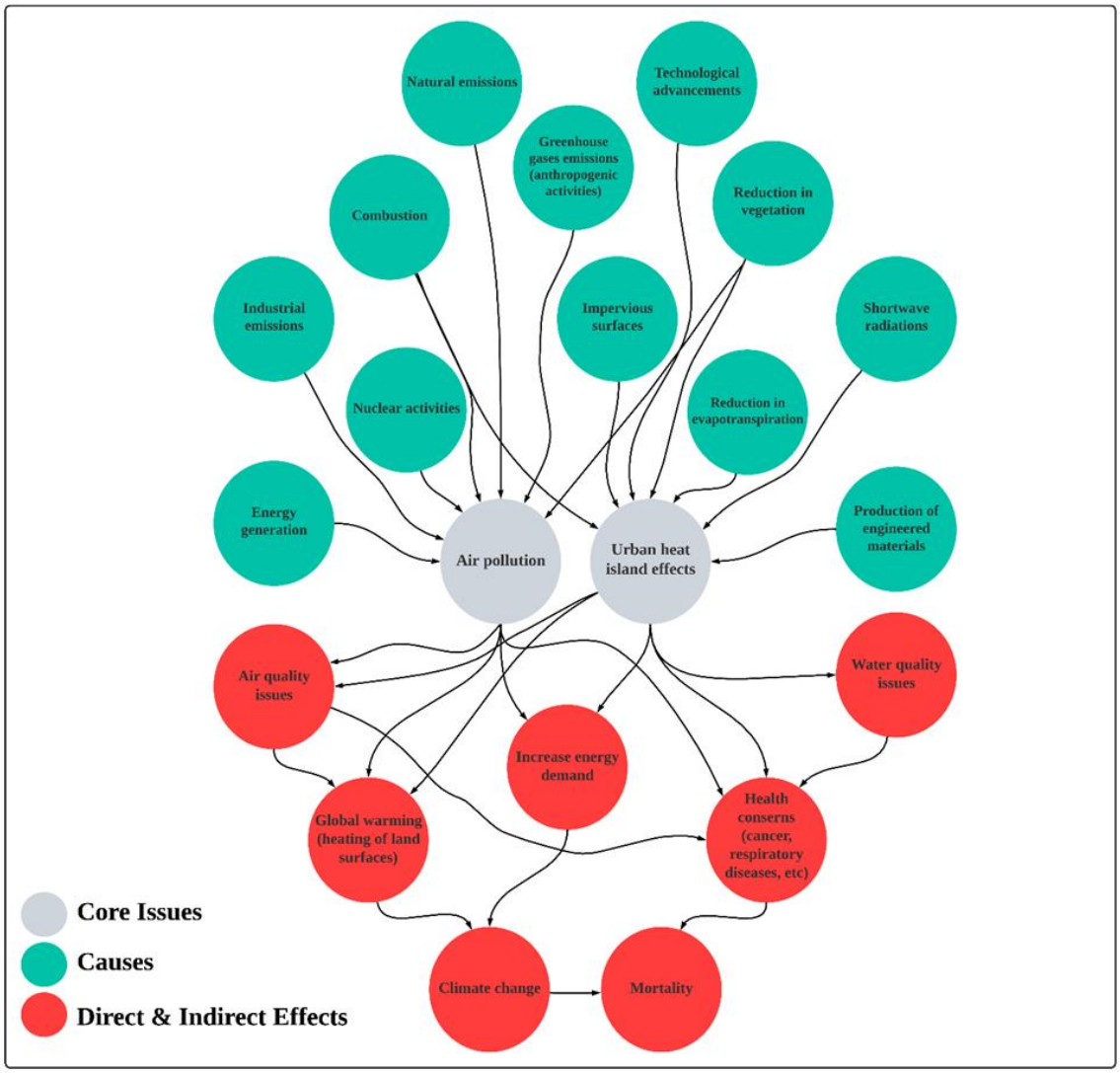

Figure 2 Relating Air Pollution with Urban Heat Island Effects Using a Cause-Effect Framework. Source: Author's Construct, 2022.

The framework provides a conceptual understanding of air pollution and urban heat island effects. A complex relationship emanates from understanding these two concepts. Air pollution appears to be a contributing factor to urban heat islands. Air pollution caused by emissions from various sources, both anthropogenic and natural, contributes to the urban heat island threat through high ozone concentration levels, which prevent warm air/heat from rising, and those worsen heat island effects. [73] reported that urban areas could warm up to 0.70 ± 0.26°C at night

because of air pollution. The potential exists to increase the longwave radiation energy received at the urban land surface due to the atmospheric pollutants' superior ability to absorb and emit radiation compared to water vapor and greenhouse gases in the longwave atmospheric window during the night. Similarly, [74] confirmed in a study conducted in the United States about crop yield reduction that continuous air pollution has consequently contributed to warmer temperatures and, as a result, affected crop yields. These assertions confirm [57] findings on the need to mitigate urban heat island effects by addressing air pollution and its causes.

Also, it can be revealed that similar factors account for these issues, such as human-induced emissions and the reduction in vegetation cover. This is primarily because these two threats fall under the broader cause of rapid urbanization and urban sprawl. Rapidly growing cities tend to increase emissions through numerous activities and degrade the natural environment (accounts for an increase in impervious surfaces). These are two primary causes of air pollution and rising heat concentration in urban areas. It has been argued that the natural environment could minimize pollution because trees function as filters. In addition, the effect of urban heat islands is an increase in energy consumption and generation, which circles back to air pollution because energy generation in cities globally relies on fossil fuels, a significant contributor to air pollution. Furthermore, air pollution and urban heat island effects contribute to global warming and climate change and have health-related risks of morbidity and mortality.

About the framework, it is evident that there is an inexhaustible comparison between these two. Based on this assessment and findings, the study recommends that air pollution and urban heat island effects be considered inextricably linked. Thus, implementing mechanisms to mitigate urban heat islands could incorporate air pollution and vice versa. The study goes further to propose the adoption of resilient approaches to reduce these risks. A brief overview of some of these practices is highlighted in the next section.

4.2 Resilience Planning and Practices

Resilience planning is increasingly becoming an essential concept in planning urban environments for the future. In contrast with sustainable planning practices that offer vague approaches to dealing with urban problems, [75] argues that resilience thinking and planning provide strategic and novel mechanisms in planning for urban areas. The concept is still gaining ground in current planning practices and has been synthesized in some cities' planning and development processes. [76] also argues that the resilience planning approach encompasses both mere responsiveness and readiness for crises. Thus, we do not have to wait for a problem to happen before we solve it but rather prevent it from happening. This is in tandem with the position of [77] that predictions on the impacts of phenomena like urban heat islands on indoor and outdoor air quality are necessary to devise strategies and policies while necessarily retrofitting spaces and buildings for safe use. An essential aspect of resilience planning is that it is systematic and proposes that transformation happens at more minor scales. This nascent field has been proven effective in steering cities through strengthening adaptive governance and management [78] by fostering learning, participation, and understanding of complex socio-ecological interactions [79]. Numerous studies like [80] explain the role of resilient planning in building sustainable, livable, and resilient cities. In the context of this study, concentration is put on the resilient planning practices that can be adopted to mitigate air pollution and urban heat island effects in cities.

Resilient planning practices suggest that all relevant stakeholders should be at the forefront of every process that is being taken to curb such a challenge [81]. It further requires that planning at more minor scales tends to be effective [82]. Given that the causes and effects of air pollution and UHI are closely related, developing policies and programs, socio-ecological systems on the grounds of adaptation and collaboration, as well as clarifying and controlling resource use and desirability, could be effective ways of dealing with these intertwined problems [83]. In addition, planning at the local or site scale should be given ample importance [84]. Aside from informing policies and programs geared toward improving urban environments, specific resilient approaches should be utilized. For instance, implementing nature-based solutions, including green infrastructure projects and programs, should be vital for mitigating air pollution and UHI effects [85]. Nature-based Solutions (NBS) are the best solution for mitigating urban heat islands [86]. In 2015, the European Commission defined NBS as solutions inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits, and help build resilience. Such solutions bring more wide-ranging nature and natural features and processes into cities, landscapes, and seascapes through locally adapted, resource-efficient, and systemic interventions [87]. These solutions are intended to re-nature cities and sustain them in the face of natural and anthropogenic factors [88].

According to [89], there are three types of NBS: Ecosystem-Based Adaptation (EBS), Green Infrastructure (GI), and Ecosystem-Based Services. Green Infrastructure and ecosystem-based adaptation provide the best results for urban heat islands. GIs are intended to mimic the natural environment, thus restoring the ecological system of urban areas [90]. It is regarded as a resilient approach because of its characterization as a “safe-to-fail” approach to planning [91]. GIs are effective in many cities globally and are contributing to resolving complex urban issues. It also successfully integrates social, economic, and environmental factors into its design, thus portraying the multifunctional ability of these projects [92]. For example, NBS such as linear parks, green streets or street trees, and green squares can be implemented. Linear parks are swaths of green public land that run alongside roads, rivers, and canals, among other things [93]. Greening streets and squares can also help regulate the city's microclimate [94]. Green infrastructure, such as urban forests, may also be explored for shading and evaporative cooling in urban areas.

Green roofs can equally be considered a mitigation strategy for urban heat islands. Green roofs increase the process of evapotranspiration in urban areas through soil and plants on rooftops, which transmit available energy within these sections into latent heat [95]. Vertical gardens are another effective alternative to mitigating urban heat islands as they help improve indoor and outdoor air quality. They provide much green space, and the plants can absorb gas, airborne dust, and carbon dioxide [96]. This is especially relevant as they are more effective in absorption than street trees, which may be meters apart- circulating polluted air better and faster [97]. Urban forests or parks are green areas within an urban area. According to [98], these areas have a lower air and surface temperature and thus form a PCI [99, 100]. Essentially, these urban forests have a constant cooling effect regardless of their size, which is something to pay attention to. Suppose these urban forests can provide the urban setting with continuous and faster cooling and air circulation. In that case, they must be conserved and increased to serve the metropolitan area even more. [101] agrees with this assertion, stating that urban forests decrease urban air temperatures by providing tree canopies - a key determinant in temperature reduction.

Aside from these, green corridors, also known as healthy corridors, may be explored. These are planned and connected linear spaces that connect several cities. They are typically designed to host a variety of uses, such as recreational, microclimate regulation, and cultural, among others, to ensure the sustainable use and preservation of the urban landscape [102]. Stakeholders and the entire citizenry of these metropolitan areas must be engaged in developing and maintaining all the aforementioned NBS. Despite their proven importance, some cities still rely on grey infrastructures (due to path dependency) and are reluctant to switch to GIs [103]. It can be attributed to the understanding of the importance and need for GIs. This is regrettable as, according to [104], grey infrastructure provides short-term benefits but may not cope with the increased escalation of climate change hazards. This emphasizes the importance of implementing more mitigating and adaptive, resilient, cost-effective, sustainable, and environmentally friendly strategies when planning and designing sustainable cities. There is also the need to implement measures to bridge the knowledge gap to encourage adoption and implementation. The above-mentioned nature-based solutions and others not mentioned and yet to be discovered can effectively solve these urban problems.

Ideally, designing policies, programs, and projects geared toward resolving air pollution and UHI effects should target the root causes while mitigating the existing impacts of these challenges. Thus, resiliency means more than just adaptation. It involves putting suitable measures in place to prevent future crises. This can only be done if the causes of these problems are targeted and addressed. An effective revision of the planning process is to foster adaptive, solid, and collaborative measures and incorporate the vital aspects of resilience planning approaches. It is important to note that resiliency is not a plan. However, an approach to planning those stresses developing novel and prior crisis approaches through effective collaboration and coordination of small-scale and large-scale activities. Also, this study suggests that resilient planning efforts should target the most vulnerable population.

5. Conclusions

Air pollution and urban heat islands are challenges constantly shaping urban areas globally. These issues create unsuitable living conditions for the urban populace. To address these issues, the study argues that understanding the interlinkages between these two problems is worth understanding. Providing a conceptual understanding could contribute to planning for urban resilience. Based on this, the study sought to understand the connection between air pollution and heat in urban areas through a cause-effect lens. The study further explores the role of resilience planning in mitigating these threats. Findings from the study revealed a complex connection between air pollution and UHI effects. Primarily, these risks result from rapid urbanization and urban sprawl, which tend to increase anthropogenic activities that contribute to releasing harmful substances. Air pollution appeared to be a significant cause of urban heat island effects. These problems are similar because they account for global warming, climate change, and health issues (morbidity and mortality). Furthermore, the study discovered that adopting resilient planning practices could play a vital role in mitigating these problems. The whole idea of resilience is to plan so that crises are anticipated, planned, and accounted for. This can be done by addressing the root causes of these problems since they are interrelated through adaptive governance and management. Future research could build upon understanding the complex relationship between these two concepts. The causes and effects

highlighted in this research can be extended and carefully examined. Also, resilient planning approaches can be explored in-depth to understand how they can be appropriately integrated with contemporary planning practices.

6. Limitation

The study focused on providing a concise understanding of the relationship between air pollution and urban heat island effects and the role of resilience planning and practices in mitigating these threats. Despite the in-depth and quality analyses, the study reserves room for future research considerations. It was identified that specific nuances surrounding resilience planning and practices and how they can effectively reduce the impacts of these two phenomena, even as the world continues to urbanize, need to be more adequately addressed in the literature. This is a gap that further studies may investigate as a way of continuously revising approaches that serve to remedy these challenges.

Author Contributions

Jim Anbazu and Nana Serwaa Antwi were both involved in the conceptualization, drafting, and writing of the content of this study, as well as other ancillary elements like references and abstracts. For each section of this work, the authors contributed to this regard.

Competing Interests

The authors have declared that no competing interests exist.

References

1. Wang S, Gao S, Li S, Feng K. Strategizing the relation between urbanization and air pollution: Empirical evidence from global countries. J Cleaner Prod. 2020; 243: 118615.
2. Helbling M, Meierrieks D. Global warming and urbanization. J Popul Econ. 2022; 36: 1187-1223.
3. World Health Organization. 2018 Revision of World Urbanization Prospects [Internet]. Geneva, Switzerland: World Health Organization; 2018. Available from: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.
4. Vlahov D, Galea S. Urbanization, urbanicity, and health. J Urban Health. 2002; 79: S1-S12.
5. Rahman M. Urbanization & Environment [Internet]. Berlin, Germany: ResearchGate; 2022. Available from: https://www.researchgate.net/publication/362718629.
6. Henderson JV. Urbanization and growth. In: Handbook of economic growth. Amsterdam, Netherlands: Elsevier; 2005. pp. 1543-1591.
7. Gollin D, Jedwab R, Vollrath D. Urbanization with and without industrialization. J Econ Growth. 2016; 21: 35-70.
8. Wang Y, Yao L, Xu Y, Sun S, Li T. Potential heterogeneity in the relationship between urbanization and air pollution, from the perspective of urban agglomeration. J Cleaner Prod. 2021; 298: 126822.

9. Soininvaara I. The politics of urbanization: From a global imperative to national struggles [Internet]. Berlin, Germany: ResearchGate; 2022. Available from: https://www.researchgate.net/publication/360702675.
10. Castells M. The space of flows. Rise of the network society. The information age: Economy, society and culture. Oxford, UK: Blackwell; 1996.
11. Choy LH, Li VJ. The role of higher education in China's inclusive urbanization. Cities. 2017; 60: 504-510.
12. Stone Jr B. Urban sprawl and air quality in large US cities. J Environ Manage. 2008; 86: 688-698.
13. Kanchana C. Challenges of Urbanization towards Sustainable Development [Internet]. Berlin, Germany: ResearchGate; 2022. Available from: https://www.researchgate.net/publication/364785057.
14. Jorquera H, Montoya LD, Rojas NY. Urban air pollution. In: Urban Climates in Latin America. Cham: Springer International Publishing; 2019. pp. 137-165.
15. Landrigan PJ. Air pollution and health. Lancet Public Health. 2017; 2: e4-e5.
16. Beng R, Landrigan PJ, Balakrishnan K, Bathan G, Bose O'Reilly S, Brauer M, et al. Pollution and health: A progress update. Lancet Planet Health. 2022; 6: e535-e547.
17. Zhang L, You S, Zhang M, Zhang S, Yi S, Zhou B. The effects of urbanization on air pollution based on a spatial perspective: Evidence from China. Front Environ Sci. 2022; 10: 1058009.
18. Liu H, Cui W, Zhang M. Exploring the causal relationship between urbanization and air pollution: Evidence from China. Sustain Cities Soc. 2022; 80: 103783.
19. Kampa M, Castanas E. Human health effects of air pollution. Environ Pollut. 2008; 151: 362-367.
20. Mayer H. Air pollution in cities. Atmos Environ. 1999; 33: 4029-4037.
21. Bernstein JA, Alexis N, Barnes C, Bernstein IL, Nel A, Peden D, et al. Health effects of air pollution. J Allergy Clin Immunol. 2004; 114: 1116-1123.
22. Cohen AJ, Anderson HR, Ostro B, Pandey KD, Krzyzanowski M, Kuenzli N, et al. Mortality impacts of urban air pollution. In: Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors, vol.2. Geneva: World Health Organization; 2004. pp. 1353-1433.
23. Brauer M, Reynolds C, Hystad P. Traffic-related air pollution and health in Canada. CMAJ. 2013; 185: 1557-1558.
24. Glencross DA, Ho TR, Camina N, Hawrylowicz CM, Pfeffer PE. Air pollution and its effects on the immune system. Free Radical Biol Med. 2020; 151: 56-68.
25. O'Neill MS, Jerrett M, Kawachi I, Levy JI, Cohen AJ, Gouveia N, et al. Health, wealth, and air pollution: Advancing theory and methods. Environ Health Perspect. 2003; 111: 1861-1870.
26. Houghton J. Global warming. Rep Prog Phys. 2005; 68: 1343.
27. IPCC. The Intergovernmental Panel on Climate Change [Internet]. Geneva, Switzerland: IPCC; 2014. Available from: https://www.ipcc.ch/.
28. Yang L, Qian F, Song DX, Zheng KJ. Research on urban heat-island effect. Procedia Eng. 2016; 169: 11-18.
29. Myrup LO. A numerical model of the urban heat island. J Appl Meteorol Climatol. 1969; 8: 908-918.
30. Altieri A, Gedan KB. Climate change and dead zones. Glob Chang Biol. 2015; 21: 1395-1406.
31. Dunlap RE, Brulle RJ. Climate change and society: Sociological perspectives. Oxford: Oxford University Press; 2015. pp 1-28.

32. Karl TR, Melillo JM, Peterson TC. Global climate change impacts in the United States: A state of knowledge report from the US Global Change Research Program. Cambridge: Cambridge University Press; 2009.
33. Trumble JT, Butler CD. Climate change will exacerbate California's insect pest problems. Calif Agric. 2009; 63: 73-78.
34. Engels A. Anthropogenic climate change: how to understand the weak links between scientific evidence, public perception, and low-carbon practices. Energy Emiss Control Technol. 2016; 2016: 17-26.
35. Dincer I. Renewable energy and sustainable development: a crucial review. Renew Sustain Energy Rev. 2000; 4: 157-175.
36. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and health impacts of air pollution: A review. Front Public Health. 2020; 8: 14.
37. Percarpio KB, Watts BV, Weeks WB. The effectiveness of root cause analysis: What does the literature tell us? Jt Comm J Qual Patient Saf. 2008; 34: 391-398.
38. Daly A, Zannetti P. Chapter 2-Air pollution modeling - An overview. In: Ambient Air Pollution. Cairo: The Arab School for Science and Technology; 2007. pp. 15-28.
39. Parrish DD, Stockwell WR. Urbanization and air pollution: Then and now. Eos. 2015; 96: 10-15. doi: 10.1029/2015EO021803.
40. Nsanzineza R, O'Connell M, Brinkman G, Milford JB. Emissions implications of downscaled electricity generation scenarios for the western United States. Energy Policy. 2017; 109: 601-608.
41. Kumar P. What Impact Has Air Pollution on Health of Human Beings and Environment? Is There Any Relation Between COVID-19 & Air Pollution? [Internet]. Berlin, Germany: ResearchGate; 2021. Available from: https://www.researchgate.net/publication/35268739.
42. Wahab M. Health impacts of air pollution. Environmental sustainability-preparing for tomorrow. IntechOpen. 2021. Doi: 10.5772/intechopen.98833.
43. World Health Organization. Ambient Air Pollution [Internet]. Geneva, Switzerland: WHO; 2021. Available from: https://www.who.int/data/gho/data/themes/air-pollution/ambient-air-pollution.
44. Beelen R, Raaschou Nielsen O, Stafoggia M, Andersen ZJ, Weinmayr G, Hoffmann B, et al. Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet. 2014; 383: 785-795.
45. Shah PS, Balkhair T, Knowledge Synthesis Group on Determinants of Preterm/LBW births. Air pollution and birth outcomes: A systematic review. Environ Int. 2011; 37: 498-516.
46. Heald C, Henze D, Horowitz L, Feddema J, Lamarque JF, Guenther A, et al. Predicted change in global secondary organic aerosol concentrations in response to future climate, emissions, and land use change. J Geophys Res. 2008; 113: D5.
47. Lin G, Penner JE, Zhou C. How will SOA change in the future? Geophys Res Lett. 2016; 43: 1718-1726.
48. Kinney PL. Interactions of climate change, air pollution, and human health. Curr Environ Health Rep. 2018; 5: 179-186.
49. Jacob DJ, Winner DA. Effect of climate change on air quality. Atmos Environ. 2009; 43: 51-63.
50. Fiore AM, Naik V, Leibensperger EM. Air quality and climate connections. J Air Waste Manage Assoc. 2015; 65: 645-685.

51. Beggs PJ. Climate change, aeroallergens, and the aeroexposome. Environ Res Lett. 2021; 16: 035006.
52. Chen J, Zhou M, Yang J, Yin P, Wang B, Ou CQ, et al. The modifying effects of heat and cold wave characteristics on cardiovascular mortality in 31 major Chinese cities. Environ Res Lett. 2020; 15: 105009.
53. Xue T, Guan T, Zheng Y, Zhang Q, Guo J, Liu Y, et al. Quantifying the contribution of temperature anomaly to stroke risk in China. Environ Res Lett. 2020; 15: 105014.
54. Akinyemi TO, Ramonu OJ. Mitigation of CO2 emissions in transportation and industrial processes using renewable energy technologies: A review. Eur J Eng Technol Res. 2019;4: 58-66.
55. Uttara S, Bhuvandas N, Aggarwal V. Impacts of urbanization on environment. Int J Res Eng Appl Sci. 2012; 2: 1637-1645.
56. Sharma P. Urbanization and development. Popul Monogr Nepal. 2003; 1: 375-412.
57. Bhargava A, Lakmini S, Bhargava S. Urban heat island effect: It's relevance in urban planning. J Biodivers Endanger Species. 2017; 5: 2020.
58. Shahmohamadi P, Che Ani A, Maulud K, Tawil NM, Abdullah N. The impact of anthropogenic heat on urban heat island formation and energy consumption balance. Urban Stud Res. 2011; 2011: 497524.
59. Oke TR. The energetic basis of the urban heat island. Q J R Meteorol Soc. 1982; 108: 1-24.
60. Santamouris M. Energy and Climate in the Urban Built Environment. Boca Raton, FL: CRC Press; 2013.
61. Tran H, Uchihama D, Ochi S, Yasuoka Y. Assessment with satellite data of the urban heat island effects in Asian mega cities. Int J Appl Earth Obs Geoinf. 2006; 8: 34-48.
62. Chen XL, Zhao HM, Li PX, Yin ZY. Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. Remote Sens Environ. 2006; 104: 133-146.
63. Sahota G, Khandaker NI, Zarine A, Shami M. The urban heat island effect and its impact on climate change and landscape of Phoenix, AZ [Internet]. Jamaica, NY: York College; 2020. Available from: https://academicworks.cuny.edu/yc_pubs/293/.
64. Stone B, Hess JJ, Frumkin H. Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? Environ Health Perspect. 2010; 118: 1425-1428.
65. Rossi F, Pisello AL, Nicolini A, Filipponi M, Palombo M. Analysis of retro-reflective surfaces for urban heat island mitigation: A new analytical model. Appl Energy. 2014; 114: 621-631.
66. Golden JS, Kaloush KE. Mesoscale and microscale evaluation of surface pavement impacts on the urban heat island effects. Int J Pavement Eng. 2006; 7: 37-52.
67. Grimmond S. Urbanization and global environmental change: Local effects of urban warming. Geogr J. 2007; 173: 83-88.
68. Akbari H, Pomerantz M, Taha H. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy. 2001; 70: 295-310.
69. EPA. Heat Island Impacts. Washington, DC: United States Environmental Protection Agency; 2016. Available from: https://www.epa.gov/heatislands/heat-island-impacts.
70. Hondula DM, Georgescu M, Balling Jr RC. Challenges associated with projecting urbanization-induced heat-related mortality. Sci Total Environ. 2014; 490: 538-544.

71. Santamouris M. Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. Sci Total Environ. 2015; 512: 582-598.
72. Architects A. Scoping Study For Policy Initiatives To Minimise Urban Heat Island Effect For Low Carbon Urban Growth. India: Shakti Sustainable Energy Foundation; 2014.
73. Cao C, Lee X, Liu S, Schultz N, Xiao W, Zhang M, et al. Urban heat islands in China enhanced by haze pollution. Nat Commun. 2016; 7: 12509.
74. Liu X, Desai AR. Significant reductions in crop yields from air pollution and heat stress in the United States. Earths Future. 2021; 9: e2021EF002000.
75. Vale LJ. The politics of resilient cities: Whose resilience and whose city? Build Res Inf. 2014; 42: 191-201.
76. Mehmood A. Of resilient places: Planning for urban resilience. Eur Plann Stud. 2016; 24: 407-419.
77. Mirzaei PA. Recent challenges in modeling of urban heat island. Sustain Cities Soc. 2015; 19: 200-206.
78. Sellberg MM, Ryan P, Borgström S, Norström AV, Peterson GD. From resilience thinking to resilience planning: Lessons from practice. J Environ Manage. 2018; 217: 906-918.
79. Biggs R, Schlüter M, Schoon ML. Principles for building resilience: Sustaining ecosystem services in social-ecological systems. Cambridge, UK: Cambridge University Press; 2015.
80. Pickett ST, McGrath B, Cadenasso ML, Felson AJ. Ecological resilience and resilient cities. Build Res Inf. 2014; 42: 143-157.
81. Bostick TP, Holzer TH, Sarkani S. Enabling stakeholder involvement in coastal disaster resilience planning. Risk Anal. 2017; 37: 1181-1200.
82. Frazier TG, Thompson CM, Dezzani RJ, Butsick D. Spatial and temporal quantification of resilience at the community scale. Appl Geogr. 2013; 42: 95-107.
83. Feng L, Liao W. Legislation, plans, and policies for prevention and control of air pollution in China: Achievements, challenges, and improvements. J Clean Prod. 2016; 112: 1549-1558.
84. Voghera A. The River agreement in Italy. Resilient planning for the co-evolution of communities and landscapes. Land Use Policy. 2020; 91: 104377.
85. Jain R, Brar TS, Kamal MA. Environmental impact and mitigation benefits of urban heat island effect: A systematic review. Archit Eng Sci. 2022; 3: 230-237.
86. Hayes AT, Jandaghian Z, Lacasse MA, Gaur A, Lu H, Laouadi A, et al. Nature-based solutions (nbss) to mitigate urban heat island (UHI) effects in Canadian cities. Buildings. 2022; 12: 925.
87. Ranagalage M, Ratnayake SS, Dissanayake D, Kumar L, Wickremasinghe H, Vidanagama J, et al. Spatiotemporal variation of urban heat islands for implementing nature-based solutions: A case study of Kurunegala, Sri Lanka. ISPRS Int J Geo Inf. 2020; 9: 461.
88. European Commission. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities. Luxembourg: European Commission; 2020.
89. Mahmoud IH, Morello E, Lemes de Oliveira F, Geneletti D. Nature-Based Solutions for Sustainable Urban Planning. Berlin, Germany: Springer; 2022.
90. Benedict MA, McMahon ET. Green infrastructure: Linking landscapes and communities. Island press; 2012.
91. Groffman PM, Matsler AM, Grabowski ZJ. How reliable-and (net) beneficial-is the green in green infrastructure. Agric Resour Econ Rev. 2023; 52: 189-200.

92. Mell IC. Green infrastructure: Reflections on past, present and future praxis. Landscape Res. 2017; 42: 135-145.
93. Crewe K. Linear parks and urban neighbourhoods: A study of the crime impact of the Boston south-west corridor. J Urban Des. 2010; 6: 245-264.
94. Perini K, Chokhachian A, Dong S, Auer T. Modeling and simulating urban outdoor comfort: Coupling ENVI-Met and TRNSYS by grasshopper. Energy Build. 2017; 152: 373-384.
95. Li D, Bou Zeid E, Oppenheimer M. The effectiveness of cool and green roofs as urban heat island mitigation strategies. Environ Res Lett. 2014; 9: 055002.
96. Ekren E. Advantages and risks of vertical gardens. Bartın Orman Fakültesi Dergisi. 2017; 19: 51-57.
97. Susca T, Gaffin SR, Dell'Osso G. Positive effects of vegetation: Urban heat island and green roofs. Environ Pollut. 2011; 159: 2119-2126.
98. Kleerekoper L, Van Esch M, Salcedo TB. How to make a city climate-proof, addressing the urban heat island effect. Resour Conserv Recycl. 2012; 64: 30-38.
99. Declet Barreto J, Brazel AJ, Martin CA, Chow WT, Harlan SL. Creating the park cool island in an inner-city neighborhood: Heat mitigation strategy for Phoenix, AZ. Urban Ecosyst. 2013; 16: 617-635.
100. Spronken Smith R, Oke T. Scale modelling of nocturnal cooling in urban parks. Boundary Layer Meteorol. 1999; 93: 287-312.
101. Staley DC. Urban forests and solar power generation: Partners in urban heat island mitigation. Int J Low Carbon Technol. 2015; 10: 78-86.
102. Jiang Y, Huang J, Shi T, Li X. Cooling island effect of blue-green corridors: Quantitative comparison of morphological impacts. Int J Environ Res Public Health. 2021; 18: 11917.
103. Johns CM. Understanding barriers to green infrastructure policy and stormwater management in the City of Toronto: A shift from grey to green or policy layering and conversion? J Environ Plan Manage. 2019; 62: 1377-1401.
104. Kumar P, Debele SE, Sahani J, Aragão L, Barisani F, Basu B, et al. Towards an operationalisation of nature-based solutions for natural hazards. Sci Total Environ. 2020; 731: 138855.