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URBAN HEAT ISLAND: A SYSTEMATIC LITERATURE REVIEW USING DPSIR MODEL

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ABSTRACT:

The dramatic surge in ecological footprint due to unmanaged and unbalanced urban growth portrays a harsh reality, illustrating how the environment is being exploited on a global scale. Urban Heat Island (UHI) emerges as a prominent challenge confronting cities worldwide, commonly attributed to extensive urbanization, burgeoning populations, and human activities. However, this prompts the question: Are these factors solely responsible for UHI, or are there other underlying causes? Employing the DPSIR framework, this paper analyzes root causes, their consequences, and interconnections to formulate effective responses. Cities profoundly impact their immediate surroundings, particularly in temperature regulation and water balance. Research reveals variations in UHI values among urban locales due to shifts in land use patterns. Through a literature review, this paper explores studies elucidating key drivers exerting pressure on the environment and necessitating interventions. The observed upward trend in UHI values is linked to the expansion of built-up areas and the decline in green cover. Escalating global temperatures and air pollution, driven by rapid unplanned urbanization, exacerbate human discomfort and climate dynamics. Although various methodologies have been employed, numerical modelling studies remain limited. Natural factors influence temperature dynamics, underscoring nature's intrinsic balance. However, human interference disrupts this equilibrium. Addressing this issue necessitates the implementation of effective solutions.

KEYWORDS:

URBAN HEAT ISLAND (UHI), DRIVER-PRESSURE-STATE-IMPACT-RESPONSE (DPSIR), LITERATURE REVIEW.

INTRODUCTION

The Urban Heat Island (UHI) poses a significant and escalating challenge for humanity, driven by rapid and unchecked urbanization and industrialization. This problem arises from the ongoing replacement of natural surfaces with buildings, paved areas, and construction materials in urban environments. UHI typically manifests as higher temperatures within urban areas compared to surrounding rural areas, creating a distinct boundary of temperature variation.

British scientist Luke Howard conducted pioneering research and documented the UHI phenomenon in the 1810s. He observed that the city of London exhibited higher temperatures compared to its underdeveloped rural surroundings (Jabbar, Hamoodi, & Al-Hameedawi, 2023) (Mills, 2016). Rural and urban environments respond differently to processes involving the transfer of momentum (air flow), energy (solar heating), and mass (precipitation). These variations stem from distinct combinations of moisture, thermal, radiative, and aerodynamic properties inherent to each location. These differences influence how rural and urban surfaces manage and distribute available energy (Weston, 1988).

(T R Oke, 2015) states that urbanization fundamentally alters the surface and atmospheric properties of a region. This process involves transforming the radiative, thermal, moisture, and aerodynamic characteristics, ultimately disrupting the natural balances of solar radiation and hydrology. With increasing population density, vast land areas are rapidly transforming into urban centers, leading to the intensification of the UHI effect. During summertime, UHI reach peak intensity under clear skies and calm winds. Heavy cloud cover diminishes solar radiation, thereby reducing daytime warming in cities. Conversely, strong winds enhance atmospheric mixing, resulting in a decrease in the temperature disparity between urban and rural areas (USA EPA, 2008). Consequently, cities are experiencing escalating temperatures over time. In India, major metropolitan areas are particularly susceptible to the UHI effect, with the severity of heat accumulation necessitating further research in this field. Cities are anticipated to grow quickly in the ensuing decades, thus city planners and political decision-makers need to be aware of this and value it.

Environmental agencies and other stakeholders frequently utilize the Driver-Pressure-State-Impact-Response (DPSIR) framework to evaluate environmental challenges and formulate appropriate policy responses (Gupta et al., 2020). The DPSIR framework serves as a functional analytical tool for depicting cause-and-effect linkages in environmental challenges (Salehi & Zebardast, 2016) (Sekar, 2020). It is a framework to bridge the communication gap between scientists, political systems, and the general public by using classified indicators and combining socioeconomic and environmental factors into a framework that can be used to conduct an extensive study (Bidone, 2004) (Ness, Anderberg, & Olsson, 2010) (Salehi

& Zebardast, 2016). The systemic DPSIR framework takes into account Drivers, which are the main societal demands and cause Pressures, and acknowledges that State Changes and Impacts necessitate a Social Response (Khajuria & Ravindranath, 2012).

The DPSIR framework has its origins in the Stress–Response framework created by Statistics Canada in the 1970s (Svarstad, Petersen, Rothman, Siepel, & Wätzold, 2008). This concept was eventually developed into Pressure–State–Response (P–S–R), which was introduced by the Organization for Economic Cooperation and Development and the United Nations Commission on Sustainable Development in the 1980s (Tscherning, Helming, Krippner, Sieber, & y Paloma, 2012). The goal of the DPSIR framework is to bridge the communication gap between scientists, political systems, and the general public by using classified indicators (Tscherning et al., 2012). This model may be used to identify human-environmental systems' processes and interactions (Salehi & Zebardast, 2016).

This model presents a causal chain in which a distinction is drawn between (1) forces acting on the environment, (2) changes that occur as a result of those changes, and (3) society's responses to those changes (Niemeijer & Groot, 2008). It is made up of five components that work together to generate a causal chain. The DPSIR framework has proven to be a valuable tool for delineating the connections between the causes and effects of environmental issues, offering a substantial portion of the required environmental information (European Commission, 2001) to promote decision-making (Tscherning et al., 2012) and advances the fundamental principles of environmental sustainability (Reed, Fraser, & Dougill, 2006) (Skondras & Karavitis, 2015).

TYPES OF UHI

UHI research primarily relies on air temperatures and land surface temperature (LST). The distinction between the air temperature within a city and its surrounding areas is commonly termed the UHI effect (Zhou, Zhao, Liu, Zhang, & Zhu, 2014).

Two types of UHI are recognized: atmospheric urban heat islands (AUHI) and surface urban heat islands (SUHI). Canopy layer urban heat island (CUHI) and Boundary layer urban heat island (BUHI) are both types of AUHI, as they signify a warming of the urban atmosphere. In contrast, SUHI pertains to the relative warmth of urban surfaces compared to the surrounding rural areas. CUHI exhibits a stronger correlation with mortality during extreme heat events compared to SUHI (Huang, Li, Guo, Mansaray, & Li, 2013)

- Atmospheric urban heat islands - AUHI are characterized by warmer air in urban areas compared to cooler air in nearby rural surroundings (USA EPA, 2008). Experts commonly categorize these heat islands into two types (Tzavali, Paravantis, Mihalakakou, Fotiadi, & Stigka, 2015) (Clinton & Gong, 2013): CUHI and BUHI. Atmospheric heat islands typically display less variability in intensity than surface heat islands. On average annually, air temperatures in major cities may be 1.8 to 5.4°F (1 to 3°C) warmer than those in adjacent rural areas (T R Oke, 2016)(Tim R. Oke, 2006) (USA EPA, 2008). CUHI refers to the layer of air where people reside, extending from the ground up to below the tops of trees and roofs. CUHI is typically assessed using air temperatures obtained from weather station networks or vehicle-mounted sensors traversing the area (Huang et al., 2013). CUHI is less prominent during the late morning and daytime but intensifies after sunset due to the gradual release of heat from urban structures. The timing of peak intensity varies based on urban and rural surface properties, season, and prevailing weather conditions (Jabbar et al., 2023) (USA EPA, 2008). BUHI begin at the rooftop and treetop level and extends up to the point where urban landscapes cease to impact the atmosphere. Typically, this region extends no more than one mile (1.5 km) from the surface (T. Oke, 1982). BUHI observations, on the other hand, require more specialized sensor platforms such as tall towers, radiosonde, or tethered balloon flights (Huang et al., 2013).
- Surface Urban Heat Islands - SUHIs are characterized by temperature differences between the central area of a city and its surrounding regions within a specified radius, based on LSTs (Berdahl & Bretz, 1997) (Choi, Suh, & Park, 2014) (Mohammad & Goswami, 2021). It represents a substantial human-induced alteration of the Earth's surface, capable of influencing the local thermal climate by modifying surface energy flow balances (Mohammad & Goswami, 2021). SUHI effects regulate the exchange of sensible heat and latent heat between the land and the atmosphere, and they have the potential to exacerbate extreme climate events, such as heat waves (Choi et al., 2014). During hot, sunny summer days, the sun can elevate temperatures of dry, exposed urban surfaces, such as roofs and pavement, to levels 50 to 90°F (27 to 50°C) higher than the air temperature. Conversely, shaded or moist surfaces, typically found in more rural areas, tend to remain closer to air temperatures (Berdahl & Bretz, 1997). SUHI is commonly measured using land surface temperature (LST) data obtained through airborne or satellite thermal infrared remote sensing (Huang et al., 2013)

METHODS AND DATA

SATELLITE DATA

Remote sensing (RS) observations give useful information on the intensities and hotspots of UHI as a supplement or proxy to in-situ surface-based measurements (Mohan et al., 2012). UHI studies primarily rely on air temperatures and the retrieval of LST data from thermal infrared remote sensing. With advancements in geospatial technology, temperature data can be obtained with indirect observations through remote sensing satellites equipped with thermal bands. Remote sensing is utilized to determine land surface temperature, primarily because satellites capture data while both they and the Earth are in motion. This makes accurately capturing the fluctuating air temperature above the ground a challenging task (Veena, Parammasivam, & Venkatesh, 2020). Advancements in sensor technology enable thermal remote observation of UHI phenomena via satellite, airborne, and aircraft platforms. Surface temperature data obtained encompasses various surface properties and atmospheric influences, including surface moisture, emissivity, albedo, irradiative input, and turbulent transfer (Becker & Zhao-Liang Li, 1995). (Joshi et al., 2015) used Landsat satellite data and field measurements to estimate surface heat islands in Ahmedabad city for both the winter and summer seasons of 2013.

It's important to recognize that remote sensing is a costly method, and obtaining consistent images from urban surfaces is challenging. This difficulty arises partly due to limitations of the equipment used and partly due to atmospheric interactions. For instance, satellites orbiting the Earth spend only limited time over any given region, and there's always a chance of cloudy skies when capturing UHI images over land (Mirzaei & Haghighat, 2010). The primary technical challenge with this approach is that the surface temperature measured by sensors only reflects the spatial patterns of upward thermal radiance received by the remote sensor (Voogt & Oke, 2003). Surface Urban Heat Island (UHI) and atmospheric UHI exhibit differences in how turbulence and velocity affect ambient air temperature. This can lead to significant variations between observed surface temperature and air temperature within street canyons. To maximize the use of measured data, it's essential to predict atmospheric UHI from surface data using sensor-view models (Veena et al., 2020).

FIXED WEATHER STATION DATA

Surface Heat Island studies utilize thermal satellite images, remote sensing, and GIS tools, among other methods, to analyze temperature variations. Consequently, SHI is observable at all times. On the other hand, Atmospheric Heat Island tends to be more prevalent at night and less significant during the daytime. Measurements of AHI intensity often involve the use of fixed weather stations and mobile traverses. Computational and experimental studies are primarily focused on understanding AHI dynamics. As measurement devices have improved, additional factors like air velocity, turbulence, and pollution levels are also being measured to understand their relationship with UHI intensity. The simplest and most accurate method is station observation, which is always used as the true measure to confirm the air temperature calculated from other methods. Station observation offers the benefits of long-term records and frequent observations (Jabbar et al., 2023). Meteorological weather station data serves as another method for determining temperatures in both urban and rural areas (Amirtham, 2016)(Aslam, Krishna, Beig, Tinmaker, & Chate, 2017). This data is particularly valuable for analyzing temperatures within cities, especially for estimating AHI intensity.

In 1820, Luke Howard conducted an analysis of ten years of daily temperature measurements in London, which confirmed the existence of London's heat island—a region characterized by elevated temperatures (Mills, 2006)(Landsberg, 1981). (Thomas, Sherin, Ansar, & Zachariah, 2014) conducted 12 mobile surveys over a period from January 2011 to March 2013 to measure near-surface air temperature. (Borbora & Das, 2013) investigated temperature variations at two sites within the urban core and two sites located away from the city of Guwahati. (Nunez & Oke, 1977) conducted measurements of radiation fluxes, air velocity, and temperature, which were later incorporated into an urban canopy model.

Despite its advantages, field measurement as an independent approach has several limitations. The development and installation of measurement devices around a city are often costly and time-consuming. Additionally, only a limited number of parameters can be measured simultaneously using stationary or mobile stations, making it challenging to demonstrate the three-dimensional spatial distribution of quantities within urban areas. Moreover, approximations are frequently necessary to estimate quantities for inaccessible points. Simple correlations between measurements and UHI characteristics may not yield consistent generalizations due to the multitude of parameters influencing UHI formation (Mirzaei & Haghighat, 2010).

NUMERICAL MODELLING

Indian studies are still in the early stages of numerical modelling and analyzing heat island formation in urban areas. This process necessitates accurate inputs and high computational resources. The heat island phenomenon, resulting from microclimate changes induced by human alterations of urban surfaces, is under extensive investigation globally. It is commonly quantified using the term Urban Heat Island Intensity (UHII), representing the maximum temperature difference between urban and surrounding rural areas (Kolokotroni, Giannitsaris, & Watkins, 2006). For instance, maximum UHI intensities were observed during sunny days in Saskatoon under clear and calm conditions (Ripley, Archibold, & Bretell, 1996). Additionally, negative heat island intensity, indicating that rural areas were warmer than urban areas, was reported in Reykjavik (Steinecke, 1999)

(L. Yang, Qian, Song, & Zheng, 2016) discovered that Computational Fluid Dynamics (CFD) numerical results are in line with field test results. Their study digitally simulates the urban thermal environment in summer, using Computational Fluid Dynamics (CFD) technology to provide theoretical insights for future urban planning and spatial arrangement. CFD, or Computational Fluid Dynamics, is a versatile platform that integrates mathematics, physics, and computation through software. It is extensively utilized across various scientific and technical fields (Veena et al., 2020). Many researchers have used numerical simulations to analyze energy balance and predict the occurrence of heat islands (Nakata-Osaki, De Souza, & Rodrigues, 2015). A General Circulation Model (GCM), also known as a global climate model, is a mathematical model used on a planetary scale to simulate interactions among the atmosphere, ocean, land surface, and ice systems. These models operate at resolutions of about 100 to 200 kilometers and are derived from fundamental fluid dynamics equations based on physical laws (Veena et al., 2020). Numerical models typically offer higher spatial resolution compared to satellite data (Mirzaei & Haghighat, 2010). Currently, CFD studies are increasingly favoured worldwide because they can achieve superior spatial resolution compared to other numerical models such as mesoscale meteorological models and remote sensing data (Toparlar, Blocken, Maiheu, & van Heijst, 2017).

RESULTS AND DISCUSSION

DRIVING FORCE

The driving forces encompass both natural (biophysical) and human-induced (socio-economic) factors that contribute to environmental pressures. Examples of driving forces include the demand for agricultural land, energy, water, food, transportation, and housing (Giupponi, 2002) (Kristensen, 2004) (Wood & Halsema, 2008). In numerous studies, the term "Driving Forces" is used to refer to economic sectors that create Pressures, including industry, agriculture, and transportation. Some other describe (Maxim, Spangenberg, & O'Connor, 2009):

- According to the European Environment Agency (EEA) 2002, Combinations of descriptors for economic sectors, structural characteristics of the economic system, demographics, and social characteristics
- According to the European Environment Agency (EEA) 2000, Patterns of resource utilization, quantities of polluting products, and inherent properties of these products also contribute
- According to the European Environment Agency (EEA) 2005 and Millennium Ecosystem Assessment (MEA) 2003, Societal trends, demographics, developments in economic, socio-political, science and technology domains, as well as cultural and religious factors, all play roles in driving forces.

The intensity of a UHI is primarily influenced by two categories of factors: (1) artificial factors, which include urban area extent, population density, and emissions of heat from human activities; and (2) environmental factors, such as geographic location (e.g., latitude, proximity to water bodies), topography, and climate of the urban areas (Roth & Chow, 2012). Several factors contribute to the Urban Heat Island (UHI) effect, including anthropogenic heat emissions, surface cover types, climatic conditions, air pollution, and others. (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017) highlighted the role of man-made materials and anthropogenic heat in UHIs. They emphasized the contribution of asphalt concrete pavements to UHI effects and discussed the negative impact of UHIs on urban water bodies, leading to decreased water quality due to excessive heat. The urban heat island effect is worsened by urbanization, land changes, construction, energy use, and transportation. Farming, schools, housing, construction, industry, and trade activities all add to this, causing cities to be hotter than rural areas.

The size and arrangement of urban buildings influence wind patterns and the capacity of urban materials to absorb and release solar energy. Urban geometry, determined by the size and spacing of buildings in the city, also affects wind flow, as well as the absorption and release of energy (Protection & Programs, n.d.). Buildings act as wind barriers, causing a decrease in wind speed by up to 60% within built-up areas. This reduction in wind speed limits the transfer of heat from surfaces to the air, leading to greater heat retention (Jabbar et al., 2023). In densely developed regions, surfaces and structures are obstructed by neighbouring buildings, creating substantial heat blocks that are difficult to dissipate. Cities characterized by numerous narrow streets and tall buildings can form urban canyons, hindering natural airflow and cooling effects. Urban structures alter net radiation levels, as building walls absorb significant solar radiation instead of releasing it into the atmosphere, resulting in heightened heat retention (T R Oke, 1981). Urban planning should prioritize improving quality of life, which includes considerations for temperature, humidity, and water management (Amin, Sajak, Jaafar, Husin, & Mohamad, 2022)(Khamaia, Boudhiaf, Khechekhouche, & Driss, 2022).

Strong winds and cloud cover act as barriers to the formation of heat islands. Moreover, geographical features play a significant role in influencing the heat island effect. For instance, nearby mountains may obstruct wind flow into the city or create specific wind patterns within urban areas (Nandi & Dede, 2022). The Urban Heat Island is influenced by meteorological conditions and surrounding environmental features, including materials, sky view factor, vegetation, and traffic (Hamoodi, Corner, & Dewan, 2017).

The UHI effect primarily stems from factors such as decreased sky view factors, materials with high heat capacity, anthropogenic heat emissions, limited evapotranspiration, and diminished turbulent convection. Parameters influencing the UHI include wind patterns, solar radiation, anthropogenic heat generation, sky view factors, urban canopy characteristics, building materials, ventilation, and land surface types. Changes in these parameters are assessed to evaluate heat intensity at specific locations (Blocken, 2015)(Nakata-Osaki et al., 2015)(Veena et al., 2020). Transitioning from agricultural to urban areas worsens the urban heat island effect by absorbing more heat and reducing vegetation. Residential zones contribute to dense infrastructure and energy consumption. Construction and industrial activities generate heat, reducing greenery and intensifying the heat island effect.

PRESSURES

Pressures refer to human activities resulting from Social and Economic Driving Forces, leading to environmental changes or influencing human health. They are distinct from stressors, which are the components of the state altered by pressures (Bradley & Yee, 2015) Pressures encompass the effects of driving forces on the environment, including resource exploitation (such as land, water, minerals, and fuels), pollution, and waste or noise production (Wood & Halsema, 2008). The relationship between pressure and its induced changes varies. Some pressures may lead to short-term effects like land use changes or deforestation, while others may have long-term impacts such as climate change. Additionally, certain pressures may only become significant under specific environmental conditions (Bowen & Riley, 2003). Atmospheric emissions, applied chemicals, construction, landscaping, human behaviour, and product choices can all contribute to the UHI effect by exerting various pressures on the urban environment.

The UHI signifies a decline in environmental quality and has the potential to alter microclimates over the long term (Nandi & Dede, 2022). The primary causes of UHI include the substantial heat generated by urban structures, which should ideally absorb and re-radiate solar energy, as well as anthropogenic heat sources. The UHI phenomenon arises from several factors. Dark surfaces, prevalent in urban areas like roads and buildings, absorb more solar radiation, leading to higher daytime temperatures compared to suburban and rural regions. Materials like concrete and asphalt commonly used for pavements and roofs in cities possess distinct thermal properties and radiative characteristics, altering the city's energy balance and resulting in elevated temperatures compared to rural surroundings.

According to (Santamouris, Paraponiaris, & Mihalakakou, 2007), (H Akbari, Pomerantz, & Taha, 2001), and (T. Oke, 1982), the following are the causes of UHI: Reduced evapotranspiration due to decreased vegetation, Increased absorption of solar radiation caused by low albedo, Hindered airflow due to higher rugosity, and Elevated levels of anthropogenic heat release. The unforeseen climate changes we are experiencing today are not solely attributable to natural processes but are largely the result of unnecessary human interventions associated with urbanization (Veena et al., 2020). Anthropogenic activities stem from human actions and can arise from various sources such as industrial processes, buildings, vehicles, and human metabolism. It encompasses energy consumption across heating homes, operating appliances, transportation, and industrial operations powered by electricity. The population parameter can also contribute to anthropogenic heat, as higher population densities result in increased energy consumption (Jabbar et al., 2023). To accommodate the needs of urban amenities, forests are being cleared on a large scale. This destruction of plant life significantly reduces the efficiency of cooling systems, leading to a decrease in the cooling process.

According to (Taha, 1997), Urban Heat Island is exacerbated when non-reflective and water-resistant impervious materials replace natural vegetation at the surface. Improper city planning is also cited as another factor contributing to the intensification of the UHI effect (K. Li & Lin, n.d.). Climate change and biodiversity loss are acknowledged as significant environmental issues. Forests play a crucial role in mitigating these challenges by absorbing substantial amounts of carbon dioxide from the atmosphere and storing carbon both above and below ground over extended periods (Moomaw, Masino, & Faison, 2019). Changes in how land is used also affect the properties of the land surface. For instance, materials like concrete and asphalt have notably different thermal qualities (thermal inertia/heat capacity) and surface radiative traits (albedo and emissivity) compared to materials commonly found in rural areas (Hamoodi et al., 2017).

As per (Bouyer, Musy, & Huang, 2009), albedo represents the ratio of reflected solar energy to incident solar energy. It is influenced by factors such as surface arrangement, materials, pavements, and coatings. When the albedo of urban surfaces is low, they absorb more solar energy, leading to an increase in urban temperature, thereby contributing to the creation of the urban microclimate. Urban materials alter the energy balance of urban surfaces by absorbing solar energy instead of reflecting it, resulting in elevated surface temperatures and overall ambient temperatures. Moreover, the absence of vegetation in urban areas diminishes natural cooling through evapotranspiration, further impacting the energy balance. Emissions from various sources contribute to heat-trapping gases, worsening the greenhouse effect and urban heat island effect. Construction materials like concrete absorb heat, disrupting natural cooling. Landscaping choices and human behaviour further intensify heat retention. Coordinated efforts across sectors are needed to promote sustainability and resilience in urban development, crucial for mitigating the UHI effect and improving urban environments.

STATE

Pressures exerted on the environment lead to changes in its 'state', which refers to the quality of different natural resources (such as air, water, soil, etc.) concerning the roles these resources play. The 'state of the environment' encompasses the physical, chemical, and biological conditions, influencing the support of both human and non-human life, as well as the depletion of resources (Kristensen, 2004). The urban heat island (UHI) effect can impact various aspects of the built environment, weather patterns, air quality, biodiversity, human health, lifestyle, and demographic structure in urban areas.

During heat waves, the absence of vegetation and surface moisture has been identified as key factors contributing to the formation of the UHI (D. Li & Bou-Zeid, 2013). The UHI phenomenon results in discomfort for urban residents and poses increased vulnerability to heatwaves during the dry season, particularly in regions with local dry-wind circulation patterns (Athukorala & Murayama, 2021) (Nandi & Dede, 2022). Presently, greenhouse gas emissions have led to a 1°C rise in the global average temperature over the past 150 years (Nandi & Dede, 2022). As temperatures increase in cities, the demand for cooling energy also rises in line with escalating energy consumption. Additionally, higher temperatures require more energy for cooling buildings and maintaining comfort levels, leading to increased spending for both individuals and governments. During summer, energy demand may surge by 2-4% for every 1°C rise in temperature (H Akbari et al., 2001).

The increasing use of air conditioners exacerbates the effect even further. The exacerbation of warming effects is intensified by heat transfer mechanisms and pollution into the environment, particularly in built-up areas that utilize heat-absorbing materials with minimal green vegetation (Rahmat & Mutolib, 2016)(Skelhorn, Levermore, & Lindley, 2016) (Klok & Kluck, 2018). During summertime, there's a significant rise in the usage of air conditioners to ensure human comfort. While air conditioners keep the interior of buildings cool, they release the absorbed heat back into the atmosphere (Okwen, Pu, & Cunningham, 2011). Consequently, as energy generation increases, air pollution levels also rise. For instance, in the United States of America (USA), fossil fuels are predominantly utilized for power generation. Emissions from most power plants, such as Sulfur Dioxide (SO2), Nitrogen Oxide (NOx), and other pollutants, contribute to greenhouse gas emissions, thereby exacerbating global warming and climate change (Jabbar et al., 2023). Population growth, economic expansion, and the consumption of fossil fuels are intricately linked, with fossil fuel consumption exhibiting a linear relationship with population growth. The heightened consumption of fossil fuels ultimately leads to the production of by-products that contribute to the greenhouse gas (GHG) effect (Veena et al., 2020).

This exacerbates the situation, contributing to climate change (Adinna, Christian, & Okolie, 2009). However, the UHI effect can provide some comfort during the winter season by maintaining elevated warmth in urban areas (Mobaraki, 2012)(Shahmohamadi, Che-Ani, Ramly, Maulud, & Mohd-Nor, 2010)(Nuruzzaman, 2015). The urban heat island effect not only increases air and ground surface temperatures in cities but also raises water temperatures due to stormwater runoff over low albedo impervious surfaces. These elevated water temperatures can lead to thermal stress in aquatic species and have substantial effects on aquatic habitats by altering chemical processes, water quality, and ecosystem health (Timm, Ouellet, & Daniels, 2020).

Elevated temperatures worsen air quality by promoting the formation of pollutants, affecting human health and biodiversity. Microbial communities may shift, posing potential health risks. Urban vegetation, including trees and plants, suffers from heat stress and air pollution, impacting ecosystems and human well-being. Residents, particularly vulnerable populations, face heightened risks of heat-related illnesses and altered lifestyles due to limited outdoor activity and increased reliance on air conditioning. Furthermore, the UHI effect can influence demographic structures by shaping migration patterns and settlement preferences. In sum, the UHI effect underscores the need for comprehensive strategies to mitigate its impacts and promote sustainable urban development for the well-being of both people and the environment.

IMPACT

Changes in environmental conditions can affect various aspects such as human health, ecosystems, biodiversity, amenity value, and financial value. The impact of these changes can be assessed based on the extent of environmental harm they cause. In response to these impacts, social efforts are made to address the identified problems. This includes implementing policy measures and planning actions aimed at resolving the issues and promoting environmental sustainability (Giupponi, 2002)(Kristensen, 2004)(Wood & Halsema, 2008). The UHI effect poses significant challenges to air quality, climate regulation, disease transmission, pest regulation, recreation opportunities, lifespan, economic prosperity, and job productivity in urban areas.

Several studies have indicated that the intensity of the UHI tends to be lower during summer afternoons but higher during winter nights in various locations worldwide (Jabbar et al., 2023). During summer, particularly in tropical and desert regions, the effects can be severe. This can pose challenges for residents living in urban centers. Exposure to extreme heat can lead to heat stress, causing health issues and even fatalities, especially among individuals with limited endurance (Voogt & Oke, 2003). Prior research has indicated a significant impact on human comfort and health due to escalating temperatures in various cities globally. Instances include Hong Kong, Bangkok, and Delhi, where mortality rates rose from 4.1% to 5.8% for each 1°C increase above a temperature threshold of approximately 29°C (Kotharkar, Ramesh, & Bagade, 2018).

Extreme temperatures, whether hot or cold, can significantly impact human health by exacerbating respiratory or cardiovascular diseases and increasing the risk of mortality. The UHI effect further amplifies these risks, particularly for urban populations, making them more vulnerable to heat-related illnesses. Health impacts resulting from the UHI effect can lead to human mortality and disease. For instance, land surface temperatures during summer can soar to as high as 60°C. In the United States, the Centers for Disease Control and Prevention reported that UHI contributed to nearly 8,000 fatalities between 1979 and 2003 (Jabbar et al., 2023).

Alterations in ecosystem quality and functionality impact human welfare by influencing the production of ecosystem goods and services, ultimately affecting human well-being (Lysak, 1974). Researchers in South Asia investigated alterations in human comfort levels attributed to heat islands, employing several thermal comfort indices such as the Physiologically Equivalent Temperature (PET), Temperature Humidity Index (THI), and Relative Strain Index (RSI) to analyze external conditions. The PET parameter was calculated based on Emmanuel and Johansson values to evaluate ambient factors affecting thermal comfort (Marzban, Sodoudi, & Preusker, 2018)(Stocker, Plattner, & Dahe, 2014).

SUHIs are primarily caused by thermal pollution, which adversely affects water quality. Water temperature plays a crucial role in all aspects of aquatic life, especially the metabolism and reproduction of various aquatic species. Elevated temperatures from warm stormwater runoff can induce rapid temperature changes in aquatic ecosystems, posing significant stress. When water temperature fluctuates by more than 1-2°C within 24 hours, species like brook trout experience thermal shock and stress (Protection & Programs, n.d.). (Heaviside, Macintyre, & Vardoulakis, 2017) explored the link between urban heat islands and health implications. They found that urban areas tend to have higher temperatures due to differences in land surface and building structures. Heat exposure is associated with adverse health effects, especially among older adults and those with pre-existing health conditions, leading to increased hospitalizations and mortality rates.

The urban heat island (UHI) effect profoundly impacts various aspects of urban life and the environment. It exacerbates air pollution, disrupts natural climate regulation mechanisms, facilitates the spread of diseases, disrupts ecosystems, limits outdoor recreation opportunities, shortens lifespans, hampers economic prosperity, and reduces job productivity. Elevated temperatures and poor air quality associated with the UHI effect pose significant health risks and economic challenges, particularly for vulnerable populations and outdoor industries. Addressing these challenges requires coordinated efforts to mitigate the UHI effect and promote sustainable urban development practices that enhance environmental quality and human well-being.

RESPONSES

The DPSIR framework includes an important component called Action or Response, which can be implemented at any level of the causal network (Bradley & Yee, 2015). Responses in this framework refer to actions taken by society and government groups or individuals to prevent, mitigate, or adapt to environmental changes. These responses can also aim to modify behaviours contributing to health risks, provide medical treatments, or address social and economic impacts on human well-being caused by human activities (Yee et al., 2012). Responses involve decision-making processes. There are two main groups of definitions for responses based on the decision-making pattern and scale considered relevant. One group links responses solely to policy actions, while the other identifies responses from various societal levels, including government, private, or non-governmental sectors, as well as groups and individuals.

Responses may aim to control driving forces or pressures, either to prevent or mitigate them, to maintain or restore the state of the environment, to accommodate impacts through adaptation measures, or even to deliberate "do nothing" strategies (Lysak, 1974)(Gabrielsen & Bosch, 2003)(Perrings, 2005).

1. RESPONSES TO DRIVERS

Responses may involve implementing policies or making economic decisions aimed at directly influencing sectors to control Driving Forces. There could be more reflection of solar radiation when high albedo materials are in the street and roadway (Bretz, Akbari, & Rosenfeld, 1998). If the impermeable pavements are replaced with pervious pavements which will allow water to infiltrate, it can be expected that it will be able to reduce the temperature to a reasonable extent. They found that surfaces with high albedo materials and urban trees have a significant contribution to reversing the heat island (Hashem Akbari, 2019). Common urban materials include concrete, asphalt, tile, and glass, often discussed in the literature. These materials have varying albedo values, determined by their colour, which represents the proportion of sunlight reflected without absorption. According to (Balany, Ng, Muttil, Muthukumaran, & Wong, 2020), using high-albedo materials can decrease the need for cooling energy by reducing the heat absorbed through a building's structure. This not only has a direct effect but also indirectly lowers the urban air temperature nearby. Conversely, materials like concrete and asphalt, often dark-coloured and with low albedo, absorb more direct solar radiation, exacerbating the urban heat island effect. The replacement of conventional materials with cool materials has led to a reduction in the surface temperature by 6–9 ◦ C and 8.5–10 ◦ C for exposed asphalt and concrete (O'Malley, Piroozfar, Farr, & Pomponi, 2015; Tsoka, 2017; X. Yang, Zhao, Bruse, & Meng, 2013).

Aspect ratio (AR) or height-to-width ratio (H/W) refers to the ratio of the height of a canyon (like a street canyon between buildings) to its width. This parameter is crucial for studying how urban geometry affects outdoor conditions, particularly temperature and the energy needed to cool buildings.
(Ali Toudert & Mayer, 2006) conducted research on

thermal comfort in urban street canyons using ENVI-met modelling in Ghardaia, Algeria. They investigated how different aspect ratio (AR) values affect thermal comfort. Results showed a slight temperature decrease with higher AR, suggesting improved thermal comfort in hot, dry climates (Balany et al., 2020). The orientation of streets plays a significant role in changing the microclimate in urban areas. It affects how much direct sunlight the surfaces of the street canyon receive. (Algeciras, Tablada, & Matzarakis, 2018) utilized the RayMan tool to examine how asymmetrical street canyons impact heat comfort. Their findings indicated that in such streets, those oriented east to west experience the highest thermal stress.

Effective urban planning with ample open space and pathways for air circulation can significantly mitigate the urban heat island effect. To address the UHI effect, a holistic approach is necessary. This involves implementing green building standards, cool roofs, and green infrastructure in construction policies. Agriculture policies can promote urban agriculture and sustainable farming. Equity policies should ensure access to cooling amenities for all communities. Integrating urban planning with sustainable transportation and fostering partnerships are vital. Ultimately, prioritizing sustainability, equity, and resilience in urban development can create healthier and more livable cities while mitigating the impact of urbanization on the environment and public health.

2. RESPONSES TO PRESSURES

Responses may also involve implementing regulations deploying technology to limit human activities, or making decisions aimed at modifying human behavior to control Pressures. Shade trees have a massive canopy and can shade houses and pedestrians from direct sunshine and keep them cool. Shade trees also aid the evapotranspiration process to reduce the temperature (Sailor, 2006). Expanding vegetation cover primarily involves planting trees around residential and commercial buildings. The best course of action is to preserve existing trees and allow them to mature fully, maximizing their ability to store carbon and provide essential environmental benefits as part of a thriving forest ecosystem (Moomaw et al., 2019). (Hwang, Lum, & Chan, 2015) studied the thermal behaviour of 10 urban parks in Singapore. They observed that the air temperature within these parks was notably cooler, ranging from 7.7°C to 12°C, compared to the surrounding areas. The cooling effect of the parks was influenced by factors such as the presence of tree canopy and the layout of the parks. The increased amount of water bodies may reduce temperature due to their evaporative action and enhanced wind speed (Robitu, Inard, Groleau, & Musy, 2004). It is expected that if there is a sufficient amount of free space and channels to circulate the wind, it will help to minimize the effect of the urban microclimate.

(Theeuwes, Steeneveld, Heusinkveld, & Holtslag, 2012)conducted a study on the influence of green vegetation and water surfaces in urban areas on the UHI effect. They discovered that every 10% increase in vegetative cover could lower the temperature by 0.6K, emphasizing the significant reduction potential of trees. Trees planted in densely populated areas have a greater impact on improving comfort levels compared to those in open spaces or on the windward side. (Kong et al., 2017) studied the effects of 12 tree species on thermal comfort in densely populated areas. They discovered that trees with large crowns and dense canopies are effective in reducing mean radiant temperature, thereby enhancing thermal comfort (Park et al., 2019). Trees with sparse leaves offer better cooling compared to those with scattered leaves. Additionally, the position of trees influences temperature reduction and thermal comfort, as their arrangement affects sensible heat and temperature variation (Kleerekoper, Taleghani, van den Dobbelsteen, & Hordijk, 2017; li, Zhan, &Lan, 2017).

(Rui, Buccolieri, Gao, Gatto, & Ding, 2018) conducted a study revealing that reducing the quantity of grass and shrubs and replacing them with trees had minimal impact on microclimate improvement. However, shrubs were observed to effectively reduce soil surface temperature. (Edmondson, Stott, Davies, Gaston, & Leake, 2016) demonstrated that incorporating a mix of trees and shrubs in non-domestic greenspaces lowered mean maximum daily soil surface temperatures in the summer by 5.7°C compared to areas with herbaceous vegetation alone. (Skelhorn, Lindley, & Levermore, 2014) discovered that increasing green area cover by 5% with shrubs or new trees lowered surface temperatures by about 0.5°C.

To tackle the urban heat island (UHI) effect, a multifaceted approach is needed. This includes regulating emissions from vehicles and industries, promoting green spaces and vegetation through land use policies, and encouraging sustainable behaviours through public awareness campaigns and incentives. Investment in green infrastructure projects and collaborative efforts between stakeholders is also crucial for effective UHI mitigation, leading to more sustainable and resilient urban environments. Proforestation maximizes public benefits by prioritizing nature-based carbon sequestration and ecosystem services such as biodiversity enhancement, water and air quality improvement, flood and erosion control, public health promotion, low-impact recreation, and preservation of scenic beauty (Moomaw et al., 2019).

3. RESPONSES TO STATE

Responses may also directly influence the State of the environment, human condition, or human health. Dark roofs absorb heat from sunlight, warming the houses, whereas light-coloured roofs, with comparable insulation properties, do not significantly warm up as they reflect solar radiation (H Akbari et al., 2001). Therefore, selecting a lighter colour for roofing can help lower temperatures. Green roofs have multiple benefits in mitigating the urban heat island effect. They absorb heat and purify the air, thereby maintaining lower temperatures. Through evapotranspiration, plants use heat energy, cooling the surroundings. Additionally, green roofs delay runoff, extending the period of cooler temperatures in cities (Getter & Rowe, 2006). Again, implementing green roofs can help achieve energy balance for buildings by reducing energy demand.

(Herath, Halwatura, & Jayasinghe, 2017) conducted a study in Sri Lanka where they introduced green walls as a strategy to mitigate the urban heat island effect. They discovered that incorporating 50% green walls in the designated area could lead to a temperature decrease of up to 1.86°C. Additionally, in the humid climate of Hong Kong, vertical greenery systems were found to achieve a maximum temperature reduction of 8.4°C within an urban canyon.

Green infrastructure and other stormwater management practices aim to decrease stormflow volume and pollutant loads by employing methods like infiltration, retention, and evapotranspiration to capture stormwater (Timm et al., 2020). Addressing the multifaceted impacts of the UHI effect requires a comprehensive approach integrating home improvement, environmental restoration, medical treatments, and various strategies. Home improvement measures like installing cool roofs and enhancing natural ventilation can mitigate heat absorption in buildings and reduce energy consumption. Environmental restoration efforts, including green infrastructure projects and urban green space expansion, enhance heat mitigation, air quality, and biodiversity. Implementing medical treatments and interventions for heat-related illnesses, along with public health outreach programs, is crucial for protecting vulnerable populations during heat waves. Additionally, promoting community engagement, sustainable practices, and climate adaptation measures fosters resilience and mitigates the socioeconomic impacts of the UHI effect. By integrating these strategies, cities can create healthier, more resilient urban environments for current and future generations.

4. RESPONSES TO IMPACT

Responses may also aim to quantify or compensate for the social and economic impacts of human conditions on human well-being. According to (Sailor, 2006) mitigating the urban heat island effect can be achieved through two methods: increasing the albedo of urban surfaces and enhancing evapotranspiration (H Akbari et al., 2001). Impermeable pavements hinder water infiltration, limiting the cooling effect of evapotranspiration. Replacing impermeable pavements with pervious ones allows water to infiltrate, which can significantly reduce temperatures by keeping pavements cooler (Sailor, 2014)

Trees help mitigate the heat island effect by releasing moisture through evapotranspiration (Dimoudi & Nikolopoulou, 2003). Trees play a direct role in reducing the UHI effect by absorbing carbon dioxide (CO2). In densely populated urban areas, the large gathering of people leads to significant CO2 emissions, contributing to temperature increases. Planting more trees can help alleviate this situation by absorbing CO2 (Heisler, 1990).

(Elsayed, 2012) suggests strategies to mitigate UHIs, including improving land management, increasing vegetation cover, using highly reflective roof tiles, and raising awareness among urban planners and policymakers about environmental impacts. Understanding the health effects of UHIs is crucial for policymakers, given the current and future health risks in urban populations amidst climate change. Policymakers need to consider various exposures in urban environments that can amplify or alter the direct impacts of heat on health (S. & J.K., 2022). Addressing the UHI effect requires a comprehensive approach, including mitigation measures, compensation for losses, and community engagement. Mitigation efforts involve green infrastructure, energy-efficient buildings, and improved urban planning. Providing financial support and assistance to vulnerable populations is essential. Community engagement, research, and integration of UHI mitigation into urban development plans are crucial for resilience and sustainable development. Overall, combining these strategies can create healthier, more resilient urban environments.

SUMMARY OF THE KEY FINDINGS FROM THE LITERATURE REVIEW

- The intensity of the urban heat island (UHI) effect varies between cities due to differences in land-use patterns. Studies indicate that UHI values increase with expansion in built-up areas and a reduction in green cover. Additionally, UHI intensity tends to be lower during summer afternoons and higher during winter nights in many locations worldwide (Jabbar et al., 2023).
- (Roth, 2002) demonstrated that the intensity of the urban heat island (UHI) was lower during summer afternoons but higher during winter nights.
- (Veena et al., 2020) report highlighted that internationally, the maximum recorded urban heat island (UHI) intensity reached as high as 12 degrees Celsius, while in India, the observed maximum UHI intensity was around 8-9 degrees Celsius.
- (Lawrence, Akbari, Gartland, & Konopacki, 1998)(Bretz et al., 1998) investigated the impact of albedo on roofing materials, varying from 0.20 to 0.60. They observed a significant temperature reduction of 2.5°C for roofing with a 0.60 albedo compared to those with a 0.20 albedo.
- (Theeuwes et al., 2012) discovered that for every 10% increase in vegetative cover, the temperature decreases by 0.6K, emphasizing the significant cooling effect of trees. Contrary to expectations, they found that the presence of water bodies does not reduce temperature; instead, it exacerbates the urban heat island effect.
- (Edmondson et al., 2016) demonstrated that a

combination of trees and shrubs in non-domestic greenspaces reduced mean maximum daily soil surface temperatures by 5.7°C in the summer compared to herbaceous vegetation alone.

- (Algeciras et al., 2018) used the RayMan tool to investigate the effect of asymmetrical street canyons on heat comfort, finding that east-west street orientation was the most thermally stressed in asymmetrical streets.
- (Herath et al., 2017) implemented green walls and vertical greenery systems as UHI mitigation strategies, finding significant temperature reductions of up to 1.86°C with 50% green walls in Sri Lanka and up to 8.4°C reduction in Hong Kong's humid climate.
- (Hwang et al., 2015) investigated the thermal performance of urban parks in Singapore, discovering that air temperatures in parks were significantly cooler (7.7-12°C) than in surrounding areas, with factors such as tree canopy and spatial arrangement influencing cooling effects.
- (Skelhorn et al., 2016) demonstrated that increasing green area cover by shrubs or new trees by 5% reduced surface temperature by approximately 0.5°C, indicating the significant role of green infrastructure in temperature reduction.
- The challenge lies in translating scientific knowledge into actionable plans and policies, incorporating proper design and planning. The future potential lies in connecting disparate researchers to foster collaboration and effective communication, reducing isolation and enhancing collective efforts towards addressing urban heat island challenges (Mills, 2014)(Tim R. Oke, 2006).

FUTURE DIRECTIONS

Future research in the realm of urban heat island (UHI) mitigation should embrace an integrated approach that synergizes rurbanization strategies with proforestation efforts, fostering sustainable urban-rural linkages and enhancing the resilience of human-environment systems.

Future research in urban heat island (UHI) mitigation should focus on community engagement and participatory approaches to rurbanization and proforestation. Emphasizing social equity and inclusive development, studies should assess ecosystem services of green spaces to mitigate UHI effects and enhance resilience. Empowering local stakeholders through participatory research and tailored projects is essential for building community resilience amidst rapid urbanization.

Investigation of the causal pathways linking UHI exposure to adverse health outcomes, including heat-related morbidity and mortality, respiratory diseases, and vector-borne illnesses, using epidemiological and spatial analysis techniques.

Future research in urban heat island (UHI) effects should integrate GIS and machine learning algorithms. This will enable a comprehensive analysis of land use, surface temperature, and socio-economic factors, aiding urban planning. Integrated urban climate models considering multi-scale interactions will enhance predictive capabilities for assessing future UHI scenarios under varied conditions, crucial for sustainable urban development.

Future research should delve into microclimate studies within urban areas, focusing on factors like street orientation, building materials, and vegetation distribution to understand their impact on the urban heat island (UHI) effect. Additionally, investigating micro-scale features such as urban canyons, green roofs, and water bodies can provide valuable insights into mitigating UHI intensity and spatial patterns in diverse urban contexts.

By addressing these research gaps and exploring emerging trends, scholars can advance our understanding of UHI dynamics, inform evidence-based policies and interventions, and promote sustainable urban development practices to mitigate the adverse impacts of UHI on human health, ecosystems, and well-being.

CONCLUSION

Combating the urban heat island effect demands a holistic understanding of its driving forces, pressures, states, impacts, and responses. Rapid urbanization has led to significant land use changes, including the encroachment of fallow and agricultural land, exacerbating the UHI effect. Anthropogenic factors such as transportation and industrial emissions further intensify this phenomenon by releasing substantial heat into the atmosphere, contributing to rising urban temperatures.

Population density and growth rates in urban areas directly correlate with increased energy consumption, which amplifies heat release and exacerbates the UHI effect. Moreover, high urban temperatures can accelerate chemical reactions, leading to the formation of pollutants like low-level ozone, impacting human health and comfort negatively.

Using the DPSIR model, we delineated the cause-effect relationship of the UHI, illustrating how driving forces exert pressure on land resources, resulting in elevated land surface temperatures (LST) and subsequent health impacts. To address these challenges, proactive responses are necessary, including mitigating driving forces, alleviating pressures, restoring the urban environment, and adapting to healthier and more comfortable living conditions.

Proforestation and rurbanisation emerge as promising strategies to combat the UHI effect. Urban greenery, through increased transpiration and shade provision, can effectively lower city temperatures, mitigate air pollution, and enhance biodiversity. Proforestation emphasizes the importance of nurturing existing trees to their full potential, complementing afforestation and reforestation efforts. Sustainable development practices offer a pathway towards a peaceful, healthy, and eco-friendly urban life, with numerous mitigation strategies accessible for adoption in daily routines.

In conclusion, our systematic literature review, employing the DPSIR model, illuminates the complexities of the UHI effect and underscores the urgency of concerted action. By integrating scientific understanding with proactive responses, cities can mitigate the adverse impacts of the UHI effect, fostering resilient, sustainable, and livable urban environments for present and future generations. While development is crucial, its trajectory depends on our choices. Simple mitigation strategies can be adopted in our daily lives, paving the way for a healthy environment. We don’t need to do anything complex to save our lives and the environment. Let us embark on this journey towards a cooler, healthier, and greener urban future.

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