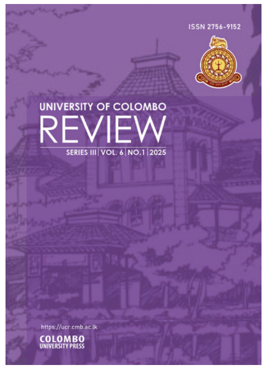

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Urban Heat Island phenomenon in Colombo: An analysis of its causes, impacts, and mitigation strategies

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ABSTRACT

Global warming is a significant environmental problem that currently affects a wide variety of organisms. The Urban Heat Island (UHI) phenomenon, in which urban areas have hotter temperatures than nearby rural or suburban areas, is caused by urbanization. However, global warming amplifies the effects of UHI, which in turn may intensify global warming trends. Weather patterns, species behaviors and habitats, water resources, and air quality are all significantly impacted by this temperature increase. As a result, many nations experience negative effects on their social, economic, health, and environmental conditions. This article focuses on Colombo, a rapidly developing city in Sri Lanka, as a case study to investigate the causes, impacts, and mitigation methods of urban heat islands. The study primarily utilizes secondary data collection methods, drawing information from research articles, journals, publications, annual reports, relevant books, and credible online sources. The secondary data were analyzed qualitatively and presented descriptively. The research findings reveal the pronounced urban heat island effects in Colombo. the city's Urban Heat Islands (UHIs) have a number of negative effects, such as elevated emissions of air pollutants, weakened human health, changed weather patterns, and worsened water quality. The loss of natural landscapes, the thermal properties of urban materials like concrete and asphalt, heat-retaining urban geometry, and increased human activity are some of the contributing factors to these effects. Greenhouse gas emissions and population growth contribute to UHI as well as to climate change. Furthermore, topography may influence the distribution of local temperature distribution. The study suggests several measures to lessen these issues in Colombo, such as creating sustainable urban infrastructure, increasing the number of trees and other vegetation, installing green roofs or reflective cool roofs, putting cool pavements in place, adapting smart growth principles, and encouraging effective transportation systems.

KEYWORDS:

Urban Heat Islands, Global warming, Air quality, Health, Population, Geometry, Weather, Transport

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Introduction

The United Nations (UN) estimates that by 2050, roughly 66% of the world's population will live in cities, up from 54% in 2014. In highly developed regions like North America, Latin America and the Caribbean, and Europe, where 82 percent, 80 percent, and 73 percent of the population, respectively currently live in cities (Estoque & Murayama, 2017). However, while the percentage of people living in cities is still relatively low in less developed regions like Asia and Africa, where the average is 40 and 48 percent, respectively, the urbanization rate in these less developed regions is higher than that of the highly developed regions (Estoque & Murayama, 2017). According to UN estimates, by 2050, there will be 2.5 billion more people living in cities worldwide, with Asia and Africa bearing the brunt of this increase. Therefore, by the middle of the century, the percentage of people living in cities in these areas is predicted to increase to 64 percent and 56 percent, respectively (United Nations, 2018). This pattern demonstrates the growing importance of urban settings throughout the Global South. Urbanization presents significant environmental problems in addition to its many socioeconomic benefits (Estoque & Murayama, 2017).

The loss of vegetation cover in urban areas due to the growth of impermeable surfaces, such as parking lots, buildings, pavements, and other constructed infrastructure, is a major environmental issue brought on by fast and poorly planned urbanization. According to Li and Meng (2018), this phenomenon has a number of other negative effects on the environment, including pollution, climate change, greenhouse gas emissions, degradation of the quality of the air and water, and disturbance of ecological cycles. Another notable negative effect of urbanization is the UHI phenomenon. It describes the phenomenon whereby urban areas have higher surface and atmospheric temperatures than the surrounding rural areas. It was first described in 1818 (Howard, 1818). "Heat Island" refers to "built-up areas that are hotter than nearby rural areas," according to the US Environmental Protection Agency (US EPA). The annual mean air temperature of a city with 1 million people or more can be 1.8 - 5.4°F (1-3°C) warmer than its surroundings (Fernando, 2019). Due to their already hot microclimate, cities are experiencing the worst effects of urbanization, including UHIs brought on by rising temperatures (Asmone, 2016).

Accordingly, the impact of urban heat islands is also noticeable in Colombo, Sri Lanka's urban setting (Manavandu, 2008). The process of urbanization in Colombo has changed dramatically since the implementation of liberalized economic policies in 1977. Economic patterns, social attitudes, lifestyles, and the urban environment have all changed significantly as a result of these policies. One significant effect of this rapid urbanization is the development of UHIs in Colombo, which are mostly caused by a decrease in green space and an increase in built-up areas (Manavandu, 2008). In other words, this has been significantly impacted by population growth, increased commercial activity, and urban development. Furthermore, after 1990, inappropriate land use and inadequate planning contributed to the fast population growth and significant environmental effects (Nirubaa, 2021).

The Western Province has the most housing units, with 558,755 residents, making Colombo the most densely populated city in Sri Lanka (15,101 people/ km^2), according to the 2012 Population and Housing Census. Therefore, the loss of vegetation in the city as a result of urban expansion causes urban heat increase and its effects to increase annually. Thus, the primary focus of this research is to examine the causes, effects, and strategies for managing urban heat island formation in Colombo.

Research Questions and Objectives

In looking at UHI in Colombo, this article examines three questions. First, what are the key factors contributing to the intensity and spatial distribution of the Urban Heat Island effect in Colombo? Second, how does the Urban Heat Island phenomenon affect thermal comfort, public health, and the urban environment in Colombo? Third, what mitigation strategies have been implemented or proposed to reduce the intensity of the UHI effect in Colombo, and how effective are they?

Through an examination of these questions, this article aims to evaluate the drivers, consequences, and mitigation strategies of the Urban Heat Island effect in Colombo, Sri Lanka. More specifically, the article seeks to identify and assess the key factors contributing to the Urban Heat Island effect in Colombo, examine the socio-environmental impacts of UHIs, particularly on thermal comfort and public health and evaluate current and potential strategies for mitigating the Urban Heat Island effect and enhancing urban climate resilience.

Research Methodology

Data Collection and Analysis Method

The research primarily relies on secondary sources including research articles, journals, publications, annual reports, books, and official internet sources, were gathered and analyzed. The collected secondary data were analyzed qualitatively, and the findings are presented descriptively in this study.

Literature Review

UHIs represent a significant and growing environmental challenge in many rapidly urbanizing cities worldwide, and Colombo is no exception. As Sri Lanka's economic and administrative capital, Colombo has undergone substantial urban expansion in recent decades, contributing to increased thermal accumulation, particularly in densely built-up areas. This literature review critically examines existing academic research on the causes, spatial dynamics, ecological impacts, and mitigation efforts related to UHIs in Colombo. In doing so, it identifies both the thematic focus of prior studies and the limitations that underscore the need for more applied and policy-oriented research.

A notable contribution to understanding the spatial and temporal evolution of land surface temperatures (LST) in Colombo is offered by Ranagalage, (2017), Employing satellite-derived Landsat data from 1997, 2007, and 2017, the study demonstrates a clear intensification of UHI effects over time, correlating positively with the expansion of built-up areas, as measured by the Normalized Difference Built-Up Index (NDBI). While the study effectively maps the spatial progression of heat accumulation, it remains largely descriptive, with limited focus on translating its findings into actionable urban planning or mitigation strategies.

Expanding on spatial analysis, Ranagalage et al., (2018) apply geospatial techniques to assess hot and cold spot clustering of Surface Urban Heat Islands (SUHI) across 557 administrative divisions in the Colombo District. Their analysis reveals that approximately 32.7% of divisions remained persistent heat hotspots from 1997 to 2017, particularly in densely urbanized zones. This long-term assessment is valuable for understanding exposure trends; however, the study offers minimal engagement with intervention strategies or community-based adaptation measures.

In a related study, Perera et al., (2015) explore the relationship between urban morphology and localized thermal conditions using the Local Climate Zones (LCZs) framework. Through the application of the Surface Heat Island Model (SHIM), they illustrate how the replacement of low-rise buildings with mid- and high-rise structures has exacerbated UHI effects in specific zones. Their findings underscore the influence of vertical urban growth on microclimatic variation. Nonetheless, the study is primarily oriented toward classification and modeling, with limited exploration of how such insights might inform zoning regulations or urban design practices.

From an ecological standpoint, Kithsiri Dissanayake et al., (2020) examine UHI effects in environmentally sensitive areas, including the harbor, coastal belt, and central business district, through the Urban Thermal Field Variance Index (UTFVI). Their findings indicate that impervious surfaces and low-albedo materials significantly intensify heat stress, while green cover contributes to thermal regulation. Although the study highlights the ecological dimensions of UHI, its recommendations for urban green infrastructure or climate-sensitive planning remain general and underdeveloped.

Fernando (2019), adopts a socio-infrastructural perspective, identifying key anthropogenic drivers of UHI in Colombo. He notes that densely populated and highly commercialized areas, particularly Pettah experiences elevated thermal conditions due to traffic congestion, human activity, and limited vegetative cover. The study also points to infrastructure developments such as the Ratmalana Airport and large-scale urban expansion under the Western Province Megapolis initiative as exacerbating factors. While Fernando (2019) offers a nuanced view of Colombo's urban dynamics, the study lacks detailed proposals for mitigation or governance interventions.

A more policy-oriented lens is introduced by Asmone (2016), who emphasizes the role of institutional and regulatory frameworks in addressing UHI. Documenting a 45% decline in Colombo's green cover over a 15-year period, the study attributes this loss to poorly enforced environmental legislation and unregulated residential encroachment. Uniquely among the reviewed works, Asmone (2016), strongly advocates for legal reforms and strategic urban greening initiatives, highlighting the critical need for governance in mitigating UHI and promoting urban sustainability.

Collectively, these studies provide a comprehensive understanding of the multifaceted nature of UHI in Colombo. They offer valuable insights into spatial and ecological patterns, the role of urban expansion, and the influence of infrastructural and morphological changes on local climate dynamics. However, a common limitation across the literature is the tendency toward descriptive analysis, with insufficient attention given to practical mitigation strategies, policy implementation, or integrative urban planning approaches tailored to Sri Lanka's context.

This review thus reinforces the relevance and necessity of the present study, which aims to bridge the gap between empirical understanding and applied urban climate governance. By emphasizing localized, actionable solutions for UHI mitigation, the study contributes to advancing both academic discourse and policy development in Colombo's pursuit of sustainable and climate-resilient urban futures.

Study Area

The research process in this study focuses on Colombo, Sri Lanka (6°54'N, 79°52'E) as a case study. As shown in figure 1, Colombo is situated in a lowland region characterized by a typically hot and humid climate that is influenced by the seasonal wind reversal of the Asian monsoon. From late May to late September, the monsoon blows from the southwest (SW), while from late November to mid-February, it blows from the northeast (NE). Throughout the year, the air temperature and humidity levels remain high. Wind speeds are generally low, especially during the inter-monsoon periods (March–April and October–November). The annual rainfall in the area amounts to 2300 mm, with two distinct peaks during specific seasons. Under clear sky conditions, Colombo experiences intense solar radiation. However, there is a high likelihood of cloud formation, especially in the afternoon. The primary daily sunshine duration varies between 5 hours in June and 9 hours in February (Climate of Sri Lanka, 2019) (Samanthilaka, 2014). Colombo City serves as the primary industrial, commercial, and economic center of Sri Lanka. Its metropolitan area accounts for over 80% of the country's industrial output and 50% of its Gross Domestic Product. The city area itself spans a size of 37.29 km^2 (Subasinghe et al., 2016).

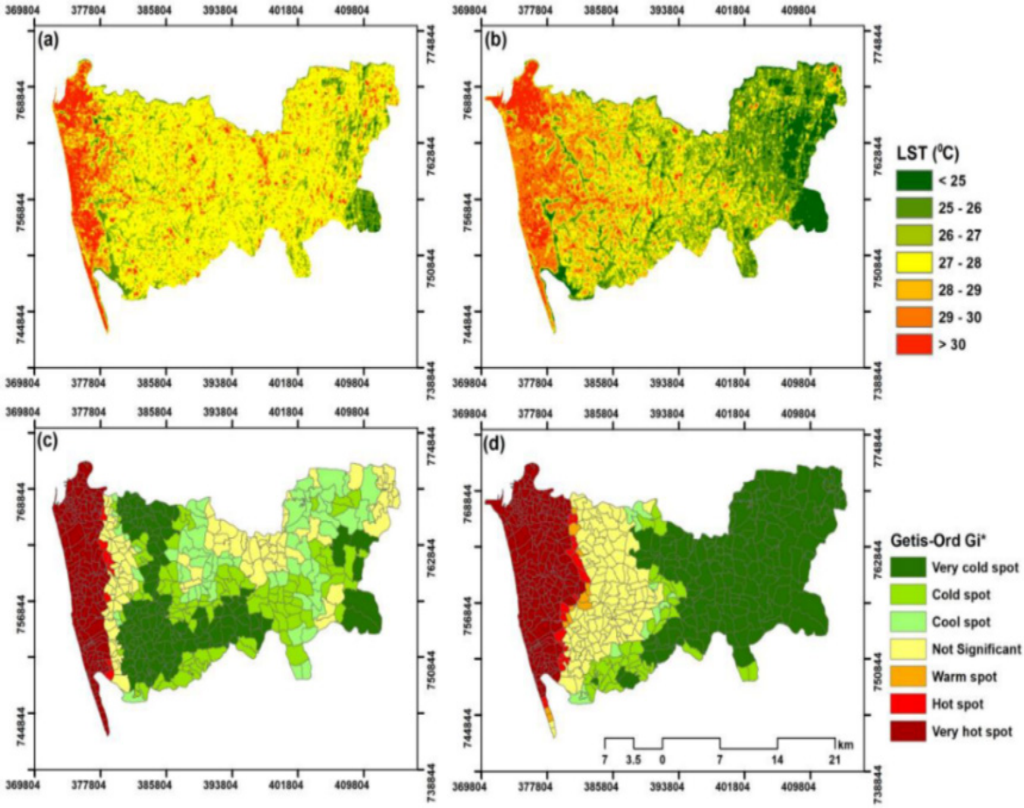

Figure 1: Spatial distribution and thermal clustering patterns in the Colombo District (a) Land Surface Temperature (LST) in 1997, (b) Land Surface Temperature (LST) in 2017, (c) Hot and cold spot analysis of LST in 1997 indicating significant spatial clustering of high and low temperature zones, and (d) Hot and cold spot analysis of LST in 2017, highlighting shifts in thermal intensity and urban heat island dynamics over the two-decade period. Source : (Ranagalage et al., 2018).

Discussion and Result

Causes of Urban Heat Island formed in Colombo, Sri Lanka

As illustrated in figure 2, urbanization and industrialization have significantly intensified the UHI effect in Colombo, resulting in intensified localized thermal impacts. The widespread use of synthetic building materials, anthropogenic heat emissions, complex urban geometry, low-albedo impervious surfaces, decreased vegetation cover, and air pollution are all contributing factors. Heat produced by automobiles, power plants, air conditioners, and other human activities, as well as heat retention and reradiation by dense urban structures, are the main causes of elevated urban temperatures. Furthermore, building materials absorb and store large amounts of solar radiation, which is then re-emitted. This process is made worse by the smaller sky view factor found in compact urban environments. Samanthilaka, (2014) states that Colombo's surface and ambient temperatures have been steadily rising because of the absorption and storage of solar energy by both natural and man-made features, including walls, rooftops, paved surfaces, and artificial landscapes.

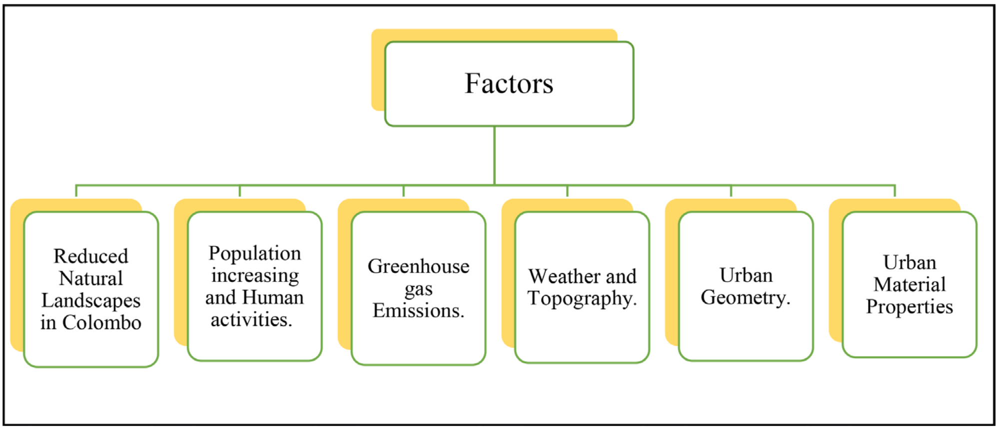

Figure 2: Factors Contributing to UHI Formation in Colombo

The diagram illustrates the primary contributors to UHI development in Colombo, including urban material properties, urban geometry, increased population and human activities, weather and topography, greenhouse gas emissions, and the reduction of natural landscapes. These factors interact to increase surface and air temperatures in urban areas, exacerbating thermal discomfort and environmental degradation.

Reduced Natural Landscapes in Colombo

Trees, vegetation, and water bodies help cool the urban atmosphere through shading, transpiration, and evaporation. In contrast, urban areas dominated by hard, dry surfaces such as parking lots and buildings lack these cooling effects, contributing to increased urban temperatures (Perera & Samanthilaka, 2014). The underlying surface of Colombo has changed significantly as a result of urbanization in recent years, which has led to a steady decline in natural ecological features like green areas and water bodies. As a result, the water content of the urban surface has decreased (Manavandu, 2008). Between 1956 and 2010, Colombo experienced a notable decline in urban green cover. In 1956, green spaces spanned 14.54 km^2, comprising 35.67% of the city's land table. By 2010, this had dropped to 9.06 km^2 or just 22.23%. The loss of 5.49 km^2 reflects significant urban expansion and human-driven land use change (Wickramasingha, Subasingha, & Ranwala, 2016). A closer examination reveals that since 2001, Colombo has seen a remarkable rate of decline in green space, with annual declines of 0.46 km^2 (1980-1988), 0.39 km^2 (1988-1997), 0.37 km^2 (1997-2001), 1.37 km^2 (2001-2011), and 0.71 km^2 (2011-2015) (Asmone, 2016). Alongside the nation's impressive economic growth, Colombo

City has seen significant infrastructure development. The city's land cover and land use have changed significantly as a result. Colombo's natural landscape has clearly diminished because of the conversion of vacant spaces and wooded areas into urban settlements, administrative structures, and industrial parks (Pusella, 2017). One of the main causes of the urban heat island phenomenon in the city's precincts is the depletion of natural elements (Samanthilaka, 2016).

Urban Material Properties

A significant amount of incoming radiation is typically absorbed by built surfaces and then released as heat. Because of their unique thermal characteristics, the building materials used in urban areas concrete, brick, tar, and asphalt have low albedo and increased absorption of solar radiation (Ranagalage M. , Estoque, Zhang, & Murayama, 2018). These materials also exhibit a high heat capacity, which enables them to hold onto heat and release it gradually at night. The underlying surface characteristics of Colombo have changed over time as a result of the growth of asphalt roads and concrete buildings (Manavandu, 2008).

A 500-meter road from Ratmalana to Borupana, south of Colombo, was paved using an asphalt mixture made of shredded and molten plastic taken from municipal waste, according to an engineering and real estate-focused Asset Group (Pusella, 2017). Under identical solar conditions, built-up areas absorb more heat than natural surfaces due to their low albedo and thermal properties. As a result, the built-up areas absorb more solar radiation, which causes the heat island effect to form more quickly and emit more heat into the atmosphere.

Urban Geometry

Building layout and spatial distribution in an urban environment have a big impact on wind patterns and the ability of urban materials to absorb and release solar energy. In densely populated areas, structures and surfaces blocked by nearby buildings become large thermal masses with a limited ability to efficiently dissipate heat (Mohajerani & Bakaric, 2017). Urban canyons are created when tall buildings and a lot of narrow streets combine to obstruct natural wind flow and its cooling effects. In contrast to other cities around the world, Colombo's streets are remarkably small. Furthermore, there is a high density of structures of various heights in the Colombo Municipal Council (MC) area due to the ongoing development of high-rise buildings (Perera, 2014).

In urban settings, heat from the sun is reflected and absorbed multiple times between buildings and between buildings and the ground. Additionally, air pollutants are adept at absorbing ground radiation, which causes the temperature in the urban area to continuously rise. The heat island effect eventually arises in the city center as a result of these factors, which produce a zone of low pressure and high temperatures over the city (Perera & Samanthilaka, 2014).

Population Increase and Human Activities

The Colombo District's urban population grew by about 23% between 2001 and 2012. The population increased from 1,699,241 in 1981 to 2,449,364 in 2017, demonstrating a steady upward trend over time. As per the 2011 census, 1,802,904 people, or 77.6% of the district's total population, lived in urban areas (Ranagalage et al., 2017).

Land use in Colombo has changed significantly as a result of this notable population growth. This urban growth has been influenced by a number of factors, such as the port's development, the building of vast road and rail networks, and the concentration of Colombo's commercial, industrial, financial, recreational, and administrative facilities. Due to internal migration brought on by these developments, urban settlements have grown, and more hotels and corporate headquarters are now situated within the city (Pusella, 2020).

Environmental problems have also been made worse by the expanding population, especially with regard to air pollution. Many industrial manufacturing companies, particularly in places like Ratmalana, release waste gases into the atmosphere without proper filtration systems and operate with little regard for the environment (Dissanayake, Kurugama, & Ruwanthi, 2020). Furthermore, almost 60% of all emissions in Colombo come from vehicles, making them a significant source of air pollution. Most of the fleet is made up of antiquated models, some of which are more than 15 years old and do not have contemporary exhaust control systems (Dissanayake, Kurugama, & Ruwanthi, 2020).

A significant section of the Colombo Municipal Council (CMC) area - roughly 64 percent - has been determined to be extremely vulnerable to the UHI effect because of these human pressures (Ranagalage et al., 2017). Likewise, more than half of the regions under the jurisdiction of the Dehiwala-Mount Lavinia Municipal Council and Sri Jayewardenepura Kotte are also impacted. Despite its smaller size, the Kolonnawa Urban Council (UC) area exhibits a 71% susceptibility to UHI (Fernando, 2016). Furthermore, because of their low albedo surfaces, dense urban structures, and concentrations of residential and industrial development, the central, northern, southeastern, and eastern parts of the city, as well as the areas close to the Colombo Harbor, show higher UHI intensity (Ranagalage et al., 2017).

Weather and Topography

Calm and cloudless weather intensifies heat islands by maximizing the amount of solar radiation that strikes urban surfaces and reducing heat dissipation. In contrast, heat island formation is suppressed by strong winds and cloud cover. Furthermore, the heat island effect is influenced by geographical features. Particularly, mountainous terrain with elevations above 2.5 km characterizes the central region of Sri Lanka's southern half (Ranagalage et al., 2017).

There is a wide variety of topographical features in the central highlands' core regions, such as ridges, peaks, plateaus, basins, valleys, and escarpments. However, aside from a few minor hills that rise sharply in the lowlands, the remainder of the island is primarily level. The spatial distribution of winds, seasonal rainfall, temperature, relative humidity, and other climatic factors are greatly influenced by these topographical features, particularly during the monsoon season (Ranagalage, 2017).

Greenhouse Gas Emissions

Particularly, aerosols are prevalent in contaminated cities like Colombo. Together with greenhouse gases, these pollutants contribute significantly to the absorption and reradiation of long-wave (infrared) radiation, which impedes the process of natural radiative surface cooling. An important contributing factor to the UHI effect seen in Colombo, Sri Lanka, is the pseudo-greenhouse effect created by this phenomenon (Fernando, 2016).

Impacts of Urban Heat Island

Colombo experiences warmer temperatures than surrounding rural areas. As a result, the urban heat island (UHI) effect has several negative impacts on the environment, public health, social well-being, and the economy. During extreme heat events, the UHI effect increases the demand for cooling in homes and workplaces, potentially leading to power outages. Furthermore, two of the most significant consequences of UHI are its adverse impacts on human health and the environment.

Industrial emissions, waste heat, and decreased vegetation all contribute to urbanization, which is fueled by population growth and rural-to-urban migration. Higher surface temperatures, trapped longwave radiation, and decreased latent heat flux are the results of these factors. Serious health effects, such as dehydration, renal failure, cardiovascular and respiratory problems, and increased risks for children and the elderly, are caused by the ensuing thermal stress. Source: (Singh, Singh, & Mall, 2020).

Effects on Human Health

In densely populated cities like Colombo, the effects of UHIs have a major impact on people's health. The high nighttime temperatures are an important issue since they restrict the body's capacity to cool down and recuperate from heat stress during the day. Constant exposure to heat can lead to non-fatal heat strokes, exhaustion, heat cramps, respiratory problems, general discomfort, and even heat-related death. These impacts are exacerbated in Colombo, where high humidity levels coincide with high temperatures, especially for vulnerable populations like the elderly, small children, and people with underlying medical conditions (Nirubaa, 2021; F. Ruzaik 2020).

Similar trends have been observed in nations such as the United States, where an average of 1,000 fatalities per year are caused by extreme heat (UN, 2018). While there is still a lack of comprehensive national data on heat-related mortality in Sri Lanka, local studies show that urban centers are becoming increasingly concerned about heat-induced illnesses, particularly during the hottest dry months. Because high temperatures can affect judgment, mobility, and emotional regulation, people with mental health or cognitive disorders such as dementia and depression are disproportionately impacted in both contexts (Perera & Samanthilaka, 2014).

Furthermore, the effects of heat on behavior are also significant. There may be a link between heat stress and aggression, as evidenced by research conducted in the United States that showed violent crimes rose by 4.58 incidents per 100,000 population for every 1°C increase in temperature (Berman, Burkhardt, & Bayham, 2020). Anecdotal and observational reports indicate that similar tensions escalate in urban Colombo during prolonged heat waves, potentially influencing social behavior and public safety, even though there are few statistical analyses of this kind in Sri Lanka (Ranagalage et al., 2017).

According to an FECT - Federation for Environment, Climate, and Technology review on climate change linked to global warming, Sri Lanka's maximum temperature increased by 2.60 degrees Celsius per 100 years, while the minimum temperature increased by 1.70 degrees Celsius every 100 years between 1960 and 1990. In fact, over the past century, the average annual temperature in the Colombo district has increased from about 27 °C to 28.50 °C (Ranagalage et al., 2017). Sensitive groups, including children, the elderly, and people with pre-existing medical conditions, are therefore especially vulnerable to these occurrences (Fernando, 2016).

The UHI effect has been linked to serious health consequences, according to recent studies, especially in cities like Colombo. In two large hospitals, respiratory disorders have been linked to about 45% of all outpatient morbidity. Even excluding pneumonia, influenza, and URTIs, respiratory illnesses remain to rank as the second most common cause of hospitalization in Sri Lanka over the previous five years and the second most common cause of death for children between the ages of five and fourteen (Fernando, 2016). Additionally, it has been estimated that Colombo's fine particulate matter (PM_{10}) health-related economic burden is Rs. 32 billion (Nirubaa, 2021). These results emphasize the crucial connection between rising public health risks, especially respiratory ailments associated with air pollution and high temperatures, and urban environmental degradation, which is made worse by the UHI effect.

Effects on the Environment

Climate and weather patterns, ecosystem functioning, water resources, and air quality are all impacted by the UHI effect in Colombo. The UHI effect increases the concentration of air pollutants such as sulfur dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds, and particulate matter which in turn deteriorate air quality. Surface-level ozone, a dangerous pollutant, can form more quickly in UHIs when pollutant production and elevated temperatures combine (UN, 2023).

As shown in figure 3, air pollutants contribute to acid rain and negatively affect the quality of Colombo's water resources. The increase in pavement and rooftop surface temperatures, which raises stormwater runoff, is one prominent consequence of the UHI effect. The initial temperature of rainwater can be raised from about 70 ^{0}F (21 ^{0}C) to over 95 ^{0}F (35 ^{0}C) by pavements heated to 100 ^{0}F (38 ^{0}C), according to studies. This can have an impact on aquatic ecosystems and water quality (Ritcher & Roser , 2023).

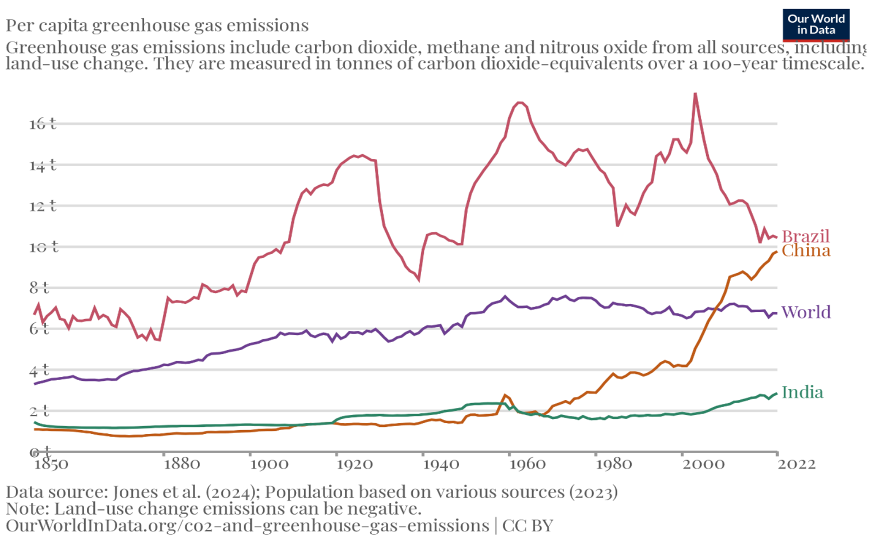

Figure 3: Impact of UHIs on the Environment

The role of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), from a variety of sources, including industrial operations and changes in land use, is highlighted in this figure. By trapping longwave radiation, these emissions, which are expressed in tons of carbon dioxide equivalents over a 100-year timescale. Source: (Ritcher & Roser , 2023)

Heated stormwater runoff typically enters storm sewers and raises the temperature of receiving water bodies, including lakes, ponds, rivers, and streams. Warmer water reduces dissolved oxygen levels, which negatively impacts aquatic life. Aquatic organisms may experience thermal stress or mortality due to abrupt temperature changes. In the Kelani River, for instance, this has been noted. UHI also increases water demand, which is especially problematic in water-scarce areas of Colombo (Ranagalage et al., 2017).

The risk of heat-related effects on the environment and human activities rises with the size and density of urban areas, as illustrated in Figures 3. Sri Lanka and other developing nations must recognize these risks and adopt preventive strategies to lessen them in the future. In order to protect the urban environment and public health, it is critical to identify vulnerable areas and put mitigation strategies into place.

Suggested Strategies for mitigating the Urban Heat Island effects in Colombo

Improving human thermal comfort in Colombo, Sri Lanka, has made addressing the UHI effect a top priority. The two main categories of mitigation strategies are those that involve design-oriented interventions and those that try to lower anthropogenic heat emissions. Roof modifications, the use of high-albedo materials, the use of humidification techniques, and the incorporation of photovoltaic canopies are examples of design-related measures. With an emphasis on choosing suitable building materials, maximizing sky view factors, and using strategic spatial planning, these tactics work best when applied early in the architectural and urban planning process.

Most UHI mitigation strategies are based on the following principles: using trees, awnings, and narrow urban spaces to provide shade and shelter; incorporating high-reflectance or high-emissivity surfaces to enhance radiative cooling; adopting reflective pavements and water-retentive surfaces such as vegetation, open water, and permeable coverings; and considering the thermal storage properties of materials, including the use of massive walls and roof insulation. These themes allow for the following classification of UHI mitigation strategies:

Scientific and Rational Planning of Urban Layout

Dense urban layouts hinder air circulation, intensifying the UHI effect. Environmental sustainability must thus be given top priority in Colombo’s future urban planning and construction, including the revitalization of older urban areas (Asmone, 2016). Included in this are the proactive creation of effective public transportation systems to lower private vehicle exhaust emissions and the incorporation of topographical and landscape elements into building designs to guarantee ecological and functional compatibility.

Building orientation, road widths, and architectural forms should be assessed in relation to Colombo’s topography, latitude, and wind patterns. These design decisions can promote natural ventilation and solar access. In addition to encouraging the development of urban breezeways that increase wind flow into the city and improve atmospheric circulation, these factors will allow buildings located within the municipal area to receive enough sunlight and natural ventilation (Singh, Singh, & Mall, 2017). By putting such strategies into practice, the local microclimate could be greatly improved and risks associated with urban heat could be reduced.

Enhancing the Ecological Environment of Colombo

Currently, a sizable amount of Colombo's urban land is set aside for residential and commercial purposes, which causes the city's green areas to gradually disappear. Through transpiration, vegetation not only supplies the vital oxygen needed for human respiration but also plays a significant part in controlling and enhancing the local microclimate (Rasmiya Niyas & F. Ruzaik, 2022).

Colombo could use the three-dimensional greening concept to increase the city's rate of greening. This strategy can greatly lower heat absorption on building surfaces and help cool ground surfaces. It includes greenery on building roofs, walls, rooftop gardens, vertical gardens, and the encouragement of natural ventilation. In Colombo, for instance, the strategic use of operable windows and the planting of trees around buildings are recognized as important preventive measures against overheating (Samanthilaka, 2014). By reducing solar heat gain and providing shade, these actions lower indoor and outdoor temperatures. However, the size of the development determines how effective they are; they work best in low-rise buildings or on the lower levels of high-rise structures.

Furthermore, water bodies need to absorb a lot of heat during evaporation because their heat capacity is higher than that of soil, which helps to regulate temperature. Therefore, the preservation and management of the ponds and wetlands that encircle the city should be given top priority in Colombo's urban planning and development. Furthermore, creating ecological buffer zones such as lakes, grasslands, and forests between urban areas can improve the amount of natural area covered and promote the ecological sustainability of the city.

Enhancing Underlying Surface Materials for Alleviating the Urban Heat Island Effect in Colombo

One effective strategy for mitigating the UHI effect in Colombo is to modify surface materials and enhance their thermal properties. Traditional paving materials such as limestone slabs, granite, and marble can help reduce the Urban Heat Island effect when they possess high albedo, reflecting a significant portion of solar radiation. However, their high thermal mass means they can still absorb and slowly release heat, so their effectiveness depends on both surface color and placement within the urban environment. In contrast, environmentally sustainable materials with high albedo and moderate thermal mass, such as colored rubber stone and permeable concrete, offer promising alternatives (Estoque & Murayama, 2017). When combined with strategic landscaping and the intentional use of vertical vegetation structures, these materials can contribute to a composite vegetation system that enhances radiation absorption and improves heat dissipation. This integration not only helps regulate the local microclimate but also contributes to better air quality by absorbing harmful gases (Tang, 2015).

Public Transport Strategy and Exhaust Emissions Management

Emission standards and public transportation policies should be reviewed and adjusted on a regular basis as part of a responsible strategy to address urban transportation issues. Initiatives like the Western Region Megapolis Transport Master Plan and the National Transport Policy in Sri Lanka place a strong emphasis on improving public transportation's accessibility and efficiency in order to lessen environmental pollution and traffic jams (Mohajerani & Bakaric, 2017).

Promoting public transportation in Colombo can reduce air pollution and traffic congestion. It also supports a transition to low-carbon mobility and helps address fuel shortages. For instance, despite making up less than 10% of all vehicle kilometers, public buses contribute roughly 60% of all passenger kilometers, indicating their capacity to efficiently transport large numbers of commuters while taking up less road space (Tang, 2015). Conversely, private vehicles, such as cars and motorcycles, account for more than 60% of vehicle kilometers but only about 25% of passenger kilometers (Tang, 2015). This disparity emphasizes the necessity of giving public transportation systems top priority in Colombo's urban mobility plans.

Conclusion

The Earth's climate is changing rapidly, and one clearly observable phenomenon intensified by this change is the UHI effect, where cities like Colombo experience higher temperatures than surrounding rural areas. This study highlights how factors such as the loss of natural greenery, widespread use of heat-absorbing building materials, dense urban design, population growth, and human activities combine to worsen this problem. These changes not only raise temperatures but also impact energy use, public health, and the local environment, demonstrating the close interconnection between urban development and climate-related challenges.

To effectively tackle UHI in Colombo, a thoughtful and coordinated approach is essential. This includes careful urban planning that allows for natural airflow, reduces heat buildup, and expands green spaces to cool the city through shade and evaporation. Upgrading surfaces with reflective and permeable materials can also help reduce heat absorption. Additionally, improving public transportation and managing vehicle emissions are critical to lowering heat generated by traffic and improving air quality.

While focused on Colombo, these findings offer valuable lessons for many tropical cities facing similar pressures from rapid urban growth and climate change. Success depends on strong cooperation between policymakers, urban planners, and the community, all working together toward creating healthier, more comfortable cities. By implementing this integrated approach, Colombo can lead the way in developing climate-resilient and livable tropical cities.

Conflicts of Interest

The author declares that there is no conflict of interest.

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