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Mitigating urban heat island effects in urban environments: strategies and tools

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Abstract. In the twenty-first century, urban heat islands (UHIs) have become a major problem for humanity as a consequence of urbanization and industrialization. The main causes of UHI are the vast amounts of heat generated by urban structures as they consume and re-radiate solar energy and anthropogenic heat sources. The two heat sources cause an urban area's temperature to rise above its surroundings, a phenomenon known as Urban Heat Island (UHI). Many approaches, methods, models, and investigative tools have been implemented to study and analysis this phenomenon. In general, green areas in cities are thought to be an effective approach to mitigate urban heat island effects and bring comfort to residents. The improvement of microclimatic conditions in urban environments is mostly influenced by evapotranspiration. Most of the studies show a rising trend in the UHI, which is linked to decreased plant cover and land-use changes. The main objectives of this paper were to explain the concept, formation factors, and influential factors of UHI. In addition, the most common strategies and tools that are applied in mitigating rising temperatures in urban areas were reviewed and summarized. The finding of several studies showed that increasing urban vegetation areas in addition to optimizing their spatial distribution and configuration is an effective strategy to reduce the impact of UHI.

1. Introduction

When the temperature in an urban area is significantly different from that of the surrounding countryside, we speak about UHI. Building construction and impermeable surfaces like asphalt, walkways, and pavement are the primary causes of urban heat islands (UHI) [1]. Voogt [2] describes a UHI as an accidental climatic change that occurs when the atmosphere and surfaces of urbanized regions are warmer than their non-urbanized surroundings. Urbanization alters the surface and atmospheric climate, resulting in a changed thermal climate that is warmer than the surrounding non-urbanized areas, especially at night. In 1818, Luke Howard noticed that the city had an artificially high temperature relative to the countryside, and this was the first time UHI was reported [3] and introduced in 1833. Manley (1958) was the first to use the term UHI in the literature [4]. Climate change and meteorological factors have been linked by several of these researches, which found a strong correlation between UHI and certain properties of the earth's surface [5], a shift in the direction of the local wind [6], higher energy use in the urban areas [7], through ground-level ozone generation, air pollution [8] and eventually affecting residents' physical and emotional well-being [9]. The amount and kind of heat created by urban structures may be influenced by a variety of other factors, such as the building materials and the view of the sky. Land use/land cover (LULC) refers to a collection of man-made and natural elements, as well as their geographical distributions; it is one of the most important elements influencing the amount and distribution of LST in urban settings. There is a major impact on the ambient environment due to the replacement of natural land cover with artificial impermeable surfaces such as asphalt, concrete, and metal, such as these: decreased evapotranspiration, increased storage and transmission of sensible heat energy, and decreased airflow [10]. Changes in LULC have been linked to LST advancement in many studies, especially in locations where the highest temperatures are associated with bare land and built-up areas, whereas lower temperatures are linked to water bodies and vegetation [11]. Large amounts of construction material are crammed into a small area in a typical metropolis, allowing high-intensity solar radiation to be captured. Because of the reduced sky view in cities, long-wave radiation's capacity to release heat is limited, resulting in increased heat storage in building structures due to typical street canyon designs. In simple uniform surfaces as well as heterogeneous and complex ones, a surface's albedo is defined as its hemispherically and wavelength-integrated reflectance. The quantity of solar radiation absorbed by building envelopes and urban structures is reduced by using high albedo materials, which keeps their surfaces cooler. Urban albedos are typically in the range of 0.1 to 0.2. However, in some cities, these values can be higher. North African towns (albedos of 0.3 to 0.45) are good examples of high albedo urbanized regions, whereas most US and European cities have lower albedos (0.15 to 0.2) [12]. One of the main causes of high air temperatures in cities is the low albedo, which is light reflected in contrast to light that is absorbed by the atmosphere. Albedo values and sky views are thus considered two crucial components for creating UHIs [13]. Global population growth has resulted in more congested cities becoming a driving force of human development. In addition, serious concerns such as air pollution and heat waves. As people migrate to large cities and away from rural regions, urban growth is becoming a frequent worry across the world. The growth of the urban population has economic and environmental effects [4]; however, ecological changes have received a lot of attention as a result of climate change and global warming, which have direct ramifications for human existence. Lenzholzer [14] noted that the urban climate differs significantly from that of the rural and that even inside a city; the microclimate fluctuates explaining that the urban environment is very different from the countryside, and even the intra-urban microclimate varies among places in the same town. Environmental damage continues to be exacerbated by pollution, land-surface changes, and urban heat. The surface of the earth [15], the abrupt decline in plant cover, and the continual growth of man-made surfaces, like roads and structures, radiative flow, and urban microclimates are affected by all of these factors, resulting in increased urban heat and the formation of urban hot spots [16]. Physiologically, thermal comfort is described as a state in which the brain communicates happiness with the temperature surroundings. Because "pleasure" is a very personal concept, this term encompasses a broad variety of experiences [17]. In the study of urban climatology, the surface temperature is crucial. It affects the energy exchanges that affect the comfort of city dwellers, modulates the air temperature of the lowest layers of the urban atmosphere, is central to the energy balance of the surface, helps to determine the internal climates of buildings, and modulates the air temperature of the lowest layers of the urban atmosphere.

2. Types of UHIs

According to Srivanit and Hokao [18], there are two forms of UHI:

- Surface urban heat islands (SUHIs) are measured using land surface temperature (LST). Estoque [19] focused on SUHI, which is presented at all times of the day and night but is highest during the day owing to solar radiation. US EPA 2008 [20] Numerous landscape variables were explored in order to help explain regional differences in surface temperatures in areas, and the implications of the results were addressed in the contexts of landscape and urban design, as well as SUHI research.
- Atmospheric urban heat islands (AUHIs) are characterized by warmer air in urban areas contrasted with colder air in adjacent rural areas. It is divided into two subcategories:

  1. Canopy layer urban heat islands or (Near-surface temperature (Ta)): are found in the layer of air below the tops of trees and rooftops where people reside. It is the temperature of a shielded thermometer at the height of two meters above the ground that is a critical input parameter in earth's surface modelling and hydrological models. Zhou [21]. It has been extensively used in several domains, including the modelling of glacier melting, calculation

of evapotranspiration, global climate change, and simulation of agricultural growth, urban heat island, and drought monitoring [5]. Station observations, climate reanalysis datasets, and remote sensing are three methods for obtaining Ta data. The most direct and accurate technique is the observation station; it is usually utilized as the reference point for correlating the Ta determined by other techniques.

2. Urban heat islands in the boundary layer start at the rooftop to treetop height and continue up until the point when urban landscapes do not influence the atmosphere. This zone usually doesn't extend more than one mile (1.5 km) from the ground [16].

The Canopy layer and Boundary layer have a direct influence on people's lives and take into account the complicated interaction of the surface and above-ground climates [22]. Zhou [11] presented a new high-resolution daily Ta estimate technique for both clear and overcast skies. They used multivariable regression models built at the CLDAS scale to estimate Ta at the MODIS scale. They suggested a new technique for estimating Ta that uses MODIS LST, DEM, DDL, and a reanalysis weather dataset as input variables to overcome the constraints of the traditional Ta interpolation technique for hydrological modelling in glacierized basins. The suggested technique may be used to estimate Ta for hydrological modelling in ungauged glacierized basins, according to the results. Firozjaei [23] proposed a new method for estimating the NSTLR (NLST) depending on the Adjusted Land Surface Temperature by combining remote sensing imagery, such as Landsat images, MODIS products, land cover maps, ASTER Digital Elevation Model and the (DEM), and weather data from the weather station and self-deployed machines. Firozjaei [24] examined remote sensing data, including the effect of surface features on LST feature space for NSTLR modelling using Landsat 8 pictures, MODIS products, and the surface characteristics like DEM and land use of the Balikhli-Chay. The Split Window (SW) approach was used to determine the LST, and spectral indices were used to represent surface biophysical characteristics. The NSTLR was calculated for different types of surface biophysical characteristics, land use, and sun local incidence angle because of their effect on the LST feature space. The findings showed that for different dates, the predicted NSTLR value based on the LST-DEM feature space was varied. In addition, the value of NSTLR determined under various topographic and biophysical situations varied. Mohammed [25] used (LST) from thermal infrared satellite images, including MODIS daily LST with a spatial resolution of 1 kilometre and landsat8 LST with a pixel size of 100 m, to represent spatial variance, as well as (DEM) to show elevation variance. The statistical software SPSS was used to determine the temporal variance of the model as independent factors and the air temperature data as correlated variables. Schwarz [26] looked into the use of LST and Ta data for different UHI/SUHI indicators. Spearman rank correlations were used to analyse the relationship between LST as well as air temperatures (hypothesis 1), and an analysis of variance (ANOVA) was employed to quantify the effect of a land cover category (independent variable) on moving route air temperatures Ta and LSTs (dependent variables). The results demonstrated a considerable interaction between the air and the LSTs. The best correlation was found between air temperature point observations, and LSTs averaged across the traverse's surrounding measurement points. The temperatures of the land surface and the air varied statistically based on the types of land cover.

3. Associated determinants of urban heat islands

3.1. Formed factors of UHIs

According to Ackerman [27], the phenomenon of UHI can cause air temperatures in cities to be 2–5°C higher than in adjacent rural regions. In urban areas, UHI is primarily caused by a larger proportion of man-made impermeable surfaces and a lower proportion of natural land cover. The replacement of natural land covers like a plant, soil, and water with artificial impermeable surfaces like asphalt, concrete, and metal has severe environmental consequences, including reduced evapotranspiration, increased storage and transmission of sensible heat, and decreased air circulation [28]. Greater absorption of daylight by dark-colored rooftops, the physicochemical characteristics of common materials in city areas, the increasing influence of heat in the urban area caused by urban morphology affecting shading and airflow, as well as the deficiency in green areas in the city all contribute to the urban heat island effect. According to previous research, UHI has a close association with meteorological indices and earth surface features such as climate change [5], a shift in the direction of the local wind [6], rising energy use in cities [7], ground-level ozone generation pollutes the air [29] and as a result, affects individuals' comfort and physical health temperature and cooling rates are two key markers of the urban heat island [9]. Based on this temperature and cooling rates data, it was established that urban physical variables, particularly the floor area ratios and buildings coverage ratio, had a significant impact on the quality of life in cities. Building attributes that influence the presence of the urban heat island phenomena had a substantial influence on the size of the UHI. In urban settings, a number of variables, including (vegetation, constructed areas, level, slope, aspect, and Land use/land cover) influence variation and the intensity of the LST. Choudhury [30] pointed out that landscapes and urban LST have a negative link, whereas built-up spaces with urban LST have a favorable relationship. Other studies found an adverse relationship between elevation and urban LST and various links between LST and slope aspect [31]. Several studies examined the impact of land surface components on LST using "normalized form" RS spectral indices (e.g., the Normalized Difference Vegetation Index (NDVI) as well as the Normalized Difference Built-Up Index (NDBI)) as proxies for surface vegetative cover, built-up areas, and other land surface components, concluding that greenery, impervious cover, surface soil, and water contents are all important factors for LST [32]. These indices, for example, were used to classify Landsat imaging time series in order to look at the geographic factors that influence LST patterns in Chinese Suzhou and Hong Kong. The authors observed that NDBI, followed by NDVI, had the biggest influence on LST [33]. Recently, Hamoodi [34] studied the impact of military and political conflicts on the urban thermal environment, such as wars, political turmoil, informal settlements (slums), and anthropogenic practices (such as scraping orchards, agricultural lands, and electricity generators), with a focus on the Baghdad metropolitan area's surface urban heat island (SUHI). Rizwan [35] looked into UHI to see whether it was a reliable indication of urban heating. The daily patterns of UHII depending on air and surface temperature, as well as variances in temperature in city and rural locations, were investigated and addressed. The complete air temperature Ta-based UHII patterns in one city and four rural areas of Hong Kong were determined. The UHII was derived using a regionally averaged air temperature difference to determine the variance in air temperature among an urban/suburban region as well as the surrounding rural area. The debate includes reported air temperature and surface-temperature dependent UHII trends in order to undertake a complete analysis. UHII has been shown to effectively reflect urban heating at night and early in the morning. However, the lower and negative UHII at solar peak time (during the day when solar radiation is the primary source of heat) does not appear to represent urban heating. As a result, landscape design for the area's sustainable urban growth should take into account the production and consequences of UHIs, as well as possible mitigation and adaptation techniques.

3.2. Impact of UHIs

In cities, increased industrialization and urbanization have resulted in significant pollution concerns. Sulphur dioxide, particulate matter, nitrogen oxides, carbon monoxide, and other pollutants have a direct impact on human health as well as historical monuments and structures. Increased temperatures in cities have resulted in substantial economic and health difficulties affecting more than half of the world's population [32]. The phenomenon of the urban heat island (UHI) has been proven to have several detrimental repercussions in terms of energy usage, thermal comfort of the human body, residents' health, wellness, and quality of the air. As a result of human activity, UHI impacts have been thoroughly documented, posing considerable difficulties to urban systems, residents' lives, and ecosystems. Most researchers, however, have found that UHI causes a significant rise in energy use in summer for cooling. At the same time, UHI has had a negative influence on the thermal environment of cities; external thermal comfort, people's health as well, and air quality are all factors to consider. Global warming's effects (including those on human well-being and health, diverse ecosystems, and energy and water consumption levels) may be amplified in metropolitan areas. Climate change, changes in local wind patterns, increased energy usage in cities, air pollution through the generation of ground-level ozone, and eventually impacting residents' comfort and physical health are all linked to UHI. Energy consumption, storm water run-off management, environmental disturbance, community health, and changing climatic conditions are all examples of UHI consequences. UHI has several negative consequences, including a worsening of the living environment and an increase in energy usage, a rise in the amount of ozone in the atmosphere at ground level, as well as a rise in mortality rates. UHI can have social, economic, or environmental consequences. Heat waves, for example, do not simply create modest discomfort; excessive heat waves can cause a variety of health concerns as well as significant energy usage. The presence of UHI increases energy demand, especially in the summer, resulting 7% increase in CO2 equivalent yearly emissions. High-heat exposure Long-term stress in hot surroundings can hurt the human body's health, resulting in a variety of diseases, severe disorders, and even death. There is a collection of research on urbanization's influence on China's climate. Better techniques and homogenized data were used to re-estimate the influence of the population on local climate patterns. Assessed the climatic consequences of urbanization and demonstrated the processes at work in combination with three key factors that influence the local climate of China (urban land use, AH, and aerosols). Several studies on cities' effects on climate extremes and also related urban adaptation techniques are presented. Urbanization had a bigger influence on severe weather than it does on regular weather. High-resolution simulations conducted in Shanghai in July–August 2013 demonstrated strong feedback between both the UHI and the super-heat wave.

4. Data and methods of measuring UHIs

4.1. Weather station data

Meteorological stations are a set of devices for forecasting weather and climate and from the old traditional methods of measuring temperature, humidity, precipitation, wind speed, and others. They are often spread in the form of networks, but one of their main disadvantages is their high cost and limited coverage of hard-to-reach areas, especially rugged areas, which caused their uneven distribution, and consequently, the limited data that can be obtained and their lack of accuracy the farther the point is from the weather station.

4.2. Remotely sensed data

In comparison to meteorological station data, UHIs may now be observed from afar. Remote sensing by satellite and aircraft platforms provides greater geographical coverage. Increasingly, researchers are using satellite technology to measure surface temperatures and quantify UHI impacts in heavily populated areas. Remote sensing technologies have helped show the role of land use patterns in long-term surface temperature increases through the integration of thermal remote sensing and urban micrometeorology [1]. New paths for the observation of UHIs and the investigation of their cause have opened up with the development of thermal remote sensing technology, which uses satellite and aircraft platforms.

5. Results and discussion

This paper highlighted relevant studies on the UHI sources in urban and their main impact on human health and the influence of green spaces on the development of the cooling effects, the mitigation of heat islands, and the supply of thermal comfort in urban settings. The rising recognition of the role of green spaces, particularly parks, in the development of cooling effects has resulted in the publishing of several studies on the issue using various approaches and at various sizes during the last ten years. This work was collected based on technique and scope of study due to the large quantity and variety of publications published on this topic. The development of UHI is acknowledged to be the ambient warmth caused by the heat generated by certain metropolitan settings. The study on urban parks and green spaces has been evaluated as part of a larger literature review. The literature has several review studies on it, and they have researched the articles on the entirety of green infrastructure from a broad viewpoint. Numerical modelling and satellite technology looked to be frequently used as research tools for the UHI. We aimed to fill a gap in the literature by conducting review research on multi-green areas and their cooling effect. The elements that contribute to the establishment of UHI may be divided into two categories: controlled and uncontrollable. The control elements are mostly design and planning-related, which people can affect to some degree, while the uncontrollable ones are environmental but also nature-related, which we can affect. The principal causes of heat in a specific place were recognized as the anthropogenic source of heat and solar radiation.

5.1. Effective strategies for mitigating UHIs

It is well-known that many strategies have been adopted to reduce the influence of UHIs in cities around the world. Measurements (field observations, scale models, and thermal remotely sensing) and simulations by computer have previously demonstrated the benefit of green infrastructure (vegetation covers, forests, green spaces, and parks) in lowering urban heat islands. To minimize high heat intensity owing to the aforementioned concerns, limiting human heat emission and making appropriate design changes, including the high albedo surfaces and use of cooler roofing, suitable building materials, and excellent building design, have all been recommended [48]. Many studies have recorded widely and efficiently applied methods for reducing the effects of urban UHI, with financial and environmental benefits predicted. There are three types of mitigation strategies that have been proposed: (1) reducing human heat release (e.g., switching off air conditioning units); (2) better roof design (e.g., green surface roofs, roof spraying cooling, reflective roofs, and so on); and (3) other design elements (e.g., humidification, higher albedo, photovoltaic canopies, and so on) [48]. Green spaces, green surface roofs, and permeable surfaces are capable of reducing heat and reducing energy inputs because of the evaporation and transpiration that occurs. Building roofs and pavements might be coated or painted with cool materials that have high albedo and infrared remittance to reduce solar absorption and boost the ability to reflect solar radiation. The common strategies and tools have been documented in the literature for mitigating the effect of UHI, illustrated below:

5.1.1. Vegetation covers

Vegetation reduces the heat island effect by warming the air rather than cooling them. By shading surfaces and reducing solar heat input through evapotranspiration and the conversion of incoming solar energy to latent heat, vegetation lowers air temperatures. Furthermore, the lower temperature causes less long-wave radiation to be released from the ground and leaves, in contrast to the surrounding artificial hard surfaces, reducing the radiant burden on individuals. The microclimatic influence of trees, in particular, is achieved through several processes: (1) the use of shade to reduce solar heat gain on windows, walls, and roofs as building surface temperatures are decreased by shade, the building's long-wave interaction with the sky is reduced. The characteristics of green urban areas and green spaces have a good impact on the urban microclimate: (a) the increased incidence of solar radiation absorption (b) the low thermal conductivity and heat capacity of trees when compared to the construction materials of buildings and urban places in cities (c) the cooling of the air through transpiration; (d) a lowering in infrared radiation (e) reducing the airflow close the soil (f) the collection of dust and contaminants in the air (g) the noise insulation given by the presence of trees. Green areas in cities can assist in offsetting UHI effects by providing a cooling effect [17] as well as a supply of fresh air. Furthermore, vegetation might help alleviate and adapt to severe climatic consequences that are expected soon, like CO2 absorption by (vegetation trees) and reduced energy use because of lower temperatures induced by green areas. Reduced air pollution and noise levels are other benefits of urban green areas, as are their positive impacts on human health. Green spaces are also a vital asset for preserving the urban quality of life because of the ecological and social advantages they provide. Evaporative cooling (energy used for transpiration rather than heating the air), shading (directly shadowing and intercepting solar radiation), and albedo effects (altering the reflection and absorption of solar radiation) are all well-known ways for vegetation to help reduce urban temperatures. Although improved urban planning approaches and highly reflecting construction materials can assist in reducing the negative impacts of rising urban temperatures on building roofs and walls, vegetation management can also help to mitigate the harmful effects of rising urban temperatures. The major techniques for mitigating the UHI impact in cities are urban greenery and cool surfaces: Tree planting around a building or using reflective surface roofs has a direct influence on the structure's energy balance and cooling needs. In this manner, as trees are planted and the albedo of a city changes, the energy balance changes, resulting in climatic changes across the city. Depending on the climate and soil conditions, air temperature decreases of 1 to 3 °C can be obtained beneath the canopy in green regions due to the combined impact of shade and evapotranspiration.

Smaller green zones strategically organized or clustered around buildings should be heavily encouraged from a planning standpoint. This is not to say that vast urban parks are ineffective in terms of enhancing urban climate; rather, they are seen as a luxury in a densely populated area, particularly when fast urbanization occurs. When trees are properly positioned around buildings, the energy needed to enhance thermal comfort is greatly decreased, giving as much shade as available during the warmer months and as little shadow as available during the cold season. The impact of plants on temperature and humidity balance, the engagement of dust and toxic gases, and the regulation of air movement all contribute to the improvement of urban microclimate.

5.1.2. Evapotranspiration

High temperatures are reduced by trees in two ways: (a) through shadow, with solar radiation absorbed or reflected by the leaves of trees; (b) by evaporation just at the local level, by cooling the air owing to the use of energy to transpiration instead of heating. The most significant method by which trees help to the reduction of high urban temperatures is evapotranspiration (ET), which seems to be the sum of evaporation plus plant transpiration. Increased forest cover in a city decreases summer heat more than it increases wintertime cold. There is evidence that planting trees surrounding residential buildings may minimize cooling and heating costs by reducing summer heating and by providing wind protection. Properties with mature trees, in the opinion of many real estate professionals, outperform those with equivalent but less mature trees. Cooling costs may be reduced by 1.9% to 2.5% for each household tree, which provides a significant financial incentive to live in places with a lot of tree cover. The price of a home decreases as the distance from a park or other open space increases. A statistically significant correlation between property value and proximity to green space has been found. In a subtropical climate, Duarte looked at the micro-scale cooling effects of plants in urban contexts, especially during the daytime hours. Compared to central park and pocket parks, the scenario with dense trees along the sidewalk showed the lowest air temperature readings and a more even distribution of the cooling effect of vegetation. Despite the slight changes in air temperature across the three situations, the two comfort indices utilized show that falling means radiant temperatures, particularly in the scenario, induce increasing levels of comfort (central park), demonstrating a park cool island effect, an oasis effect even amid high-rise skyscrapers in a dense environment. None of these options would alter long-term warming trends. The study area's progressive growth and completion of vegetation may have a positive influence on the urban environment and microclimate, enhancing present conditions. A tree's overall yearly benefits come from energy savings, improved air quality, lower carbon dioxide levels, and rainfall absorption. Increased forest cover in a city decreases July heat more than it increases wintertime cold. Planting trees around residential structures may reduce both cooling and heating expenses owing to lower summer heating and a wind-shielding effect. As a consequence, the findings of this study are important since energy consumption for air conditioning can be reduced, especially during the summer months, if trees contribute to air cooling. Oliveira evaluated the thermal performance of a tiny green area and its effect on the surrounding atmosphere's meteorological characteristics for (a) determining if, no matter how little, this green urban space has a cooling effect on the neighbouring environment on warm and dry weather, and how this impacts bioclimatic parameters, (b) to investigate whether urban factors such as highway design and direction have an impact on the thermal performance of the green space, (c) to look at the effect of proximity to the plant and exposure to the sun on the thermal properties of the area surrounding the green space. Green areas in urban environments may offer a cooling impact called the "park cool island," according to the research. On hot and dry days, this cooling effect is more visible in places with UHI than in places with a Mediterranean climate.

5.1.3. Water bodies

Because the water body has a high thermal capacity and inertia, it has a lower LST and a strong UCI. It acts as an extra cold source in the green space buffer, changing the GCI efficiency. GCI effects will be strengthened by increasing vegetation and water body fractions or decreasing impermeable surfaces. Conversely, rapid evaporation creates "oasis effects" in water bodies and helps cool the surrounding surface air. In the summer, water bodies serve as urban cooling islands (UCI) due to the temperature differential.

5.1.4. High albedo surfaces
High albedo surfaces have high solar reflectance and infrared remittance to limit solar radiation absorption and enhance the capacity to reflect solar radiation. There are certain ways to make pavements cooler and more permeable. To aid in the resolution of both heat island and storm water run-off issues in the built environment through measurements and modelling of a set of pavement test sections showed permeable interlocking concrete pavers have the highest permeability, according to the data. In the summer, an increase in albedo can greatly reduce the high surface temperature throughout the day. Permeable pavements may have lower surface temperatures than impermeable pavements when wet. The cooling effect is greatly dependent on the amount of moisture available near the surface layer and the pace of evaporation. Separate and related simulation research conducted by UCPRC found that, if planned properly; full-depth permeable pavements can carry both light and heavy-duty traffic while preserving the run-off volume gathered from a typical California storm event. The results showed that combining reflective and permeable pavements might be used to solve both heat island mitigation and storm water run-off control challenges in the built environment.

5.1.5. Other strategies
There are some other strategies to mitigate UHI effects. Recently, some studies have advised reducing the effect of heat islands on individuals, such as Agriculture which has a tremendous impact on the ecology across the globe, decreasing heat emissions from man-made objects, and planting trees [48]. At the building level, it would also be possible to improve heat reflection first from the roof and create roof gardens or rooftop gardens. Through construction designs and patterns, building clusters would create shade from adjacent structures [48], with the height ratio and distance between buildings also being considered. Urban landscape changes must be considered at the municipal and neighbourhood level, as well as expanding communal or planting trees spaces and enhancing urban and local planning. Green spaces in cities are regarded to be an efficient way to reduce UHI effects and provide relief to city dwellers. The potential of urban green areas to influence the surrounding area in addition to red heat the actual space is referred to as the cooling effect of urban green spaces. The important issues are the strength and volume of the cooling impacts of urban green spaces, which may play a critical role for urban planners in dealing with urban heat islands.

6. Conclusions
In this paper, previous studies in the field of urban heat islands, the fundamental principles, and the most recent approaches and strategies to mitigate UHIs were reviewed and summarized. The different elements that contribute to the formation of UHI have been examined and documented. Strategies and instruments are employed to comprehend the creation, determination, and reduction of UHI. The benefits and drawbacks of various methodologies were also discussed. According to the data, direct sunlight heat plus human heat are the primary causes of UHI. The major sources of UHI production are LCLU changes and increasing impervious surface areas, which lead to increases in UHI intensity. While the increasing vegetation cover, water bodies, and high albedo surfaces can reduce UHI, provide cooling, and provide thermal comfort for residents. However, UHI intensity is influenced by LCLU patterns, seasons, and day/night. Surface temperature data was obtained using meteorological stations and remote sensing techniques, and the surface temperature was derived through numerical modelling and computer simulation using multiple applications. The finding provides helpful recommendations for reducing UHI, as well as a feasible avenue for resolving urban climate challenges sustainably. It was also concluded that approaches for calculating UHI reductions with changes in planning and design parameters are required.

7. References
[1] J. A. Voogt and T. R. Oke 2003 Thermal Remote Sensing of Urban Climates, *Remote Sensing of Environment*, vol. 86, no. 3, pp. 370–384, doi: 10.1016/S0034-4257(03)00079-8.
[2] J. A. Voogt 2008 Urban Heat Islands: Hotter Cities, *America Institute of Biological Sciences*, no. September, pp. 1–2.

[3] M. Kolokotroni, I. Giannitsaris, and R. Watkins 2006 The Effect of the London Urban Heat Island on Building Summer Cooling Demand and Night Ventilation Strategies, *Solar Energy*, vol. 80, no. 4, pp. 383–392, Apr., doi: 10.1016/j.solener.03.010.
[4] Gartland Lisa 2008 Heat Islands: Understanding and Mitigating Heat in Urban Areas. Earthscan. London, UK, pp. 181.
[5] A. J. Arnfield 2003 Two Decades of Urban Climate Research: A Review of Turbulence, Exchanges of Energy and Water, and the Urban Heat Island, *International Journal of Climatology*, vol. 23, no. 1, pp. 1–26, Jan. 2003, doi: 10.1002/joc.859.
[6] S. L. Wu and C. X. Li 2012 A Modified SSOR Preconditioning Strategy for Helmholtz Equations. *Journal of Applied Mathematics*, vol. 2012, pp. 1–10, doi: 10.1155/2012/365124.
[7] M. A. White, R. R. Nemani, P. E. Thornton, and S. W. Running 2002 Satellite Evidence of Phenological Differences between Urbanized and Rural Areas of the Eastern United States Deciduous Broadleaf Forest, *Ecosystems*, vol. 5, no. 3, pp. 260–273, doi: 10.1007/s10021-001-0070-8.
[8] H. Akbari and L. S. Rose 2008 Urban Surfaces and Heat Island Mitigation Potentials, *Journal of the Human-Environment System*, vol. 11, no. 2, pp. 85–101, doi: 10.1618/jhes.11.85.
[9] J. Kim and X. Zhou 2012 Landscape Structure, Zoning Ordinance, and Topography in Hillside Residential Neighborhoods: A Case Study of Morgantown, WV, *Landscape and Urban Planning*, vol. 108, no. 1, pp. 28–38, Oct. 2012, doi: 10.1016/j.landurbplan.07.011.
[10] T. N. Carlson, J. K. Dodd, S. G. Benjamin, and J. N. Cooper 1981 Satellite Estimation of the Surface Energy Balance, Moisture Availability and Thermal Inertia., *Journal of Applied Meteorology*, vol. 20, no. 1, pp. 67–87, Jan., doi: 10.1175/1520-0450(1981)020<0067:SEOTSE>2.0.CO;2.
[11] W. Zhou et al 2017 Estimating High Resolution Daily Air Temperature Based on Remote Sensing Products and Climate Reanalysis Datasets over Glacierized Basins: A Case Study in the Langtang Valley, Nepal, *Remote Sensing*, vol. 9, no. 9, Sep., doi: 10.3390/rs9090959.
[12] H. Taha 1997 Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic heat, *Energy and Buildings*, vol. 25, no. 2, pp. 99–103, doi: 10.1016/s0378-7788(96)00999-1.
[13] R. Giridharan, S. Ganesan, and S. S. Y. Lau 2003 Daytime Urban Heat Island Effect in High-Rise and High-Density Residential Developments in Hong Kong, *Energy and Buildings*, vol. 36, no. 6, pp. 525–534, Jun. 2004, doi: 10.1016/j.enbuild.12.016.
[14] H. Breuer, Lenzholzer, S 2016 Weather in the City: How Design Shapes the Urban Climate, *Hungarian Geographical Bulletin*, vol. 65, no. 2, pp. 198–199, doi: 10.15201/hungeobull.65.2.10.
[15] J. Rhee, S. Park, and Z. Lu 2014 Relationship Between Land Cover Patterns and Surface Temperature in Urban Areas, *GIScience and Remote Sensing*, vol. 51, no. 5, pp. 521–536, Sep., doi: 10.1080/15481603.2014.964455.
[16] T. R. Oke 1982 The Energetic Basis of the Urban Heat Island, *Quarterly Journal of the Royal Meteorological Society*, vol. 108, no. 455, pp. 1–24, doi: 10.1002/qj.49710845502.
[17] J. N. Georgi and D. Dimitriou 2010 The Contribution of Urban Green Spaces to the Improvement of Environment in Cities: Case Study of Chania, Greece, *Building and Environment*, vol. 45, no. 6, pp. 1401–1414, Jun. 2010, doi: 10.1016/j.buildenv.12.003.
[18] M. Srivanit and K. Hokao 2009 Thermal Infrared Remote Sensing for Urban Climate and Environmental Studies: Methods, Applications, and Trends, *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 64, no. 4, pp. 335–344, doi: 10.1016/j.isprsjprs.03.007.
[19] R. C. Estoque and Y. Murayama 2017 Monitoring Surface Urban Heat Island Formation in a Tropical Mountain City Using Landsat Data (1987–2015), *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 133, pp. 18–29, Nov., doi: 10.1016/j.isprsjprs.2017.09.008.
[20] US EPA 2008 Reducing Urban Heat Islands: Compendium of Strategies. Cool Pavements.
[21] D. Zhou, S. Zhao, L. Zhang, G. Sun, and Y. Liu 2015 The Footprint of Urban Heat Island Effect in China, *Scientific Reports*, vol. 5, pp. 2–12, doi: 10.1038/srep11160.

[22] F. Yuan and M. E. Bauer 2007 Comparison of Impervious Surface Area and Normalized Difference Vegetation Index as Indicators of Surface Urban Heat Island Effects in Landsat Imagery, *Remote Sensing of Environment*, vol. 106, no. 3, pp. 375–386, Feb., doi: 10.1016/j.rse.2006.09.003.

[23] M. K. Firozjaei et al 2019 A New Approach for Modeling Near Surface Temperature Lapse Rate Based on Normalized Land Surface Temperature Data, *Remote Sensing of Environment*, vol. 242, no. June, p. 111746, Jun., doi: 10.1016/j.rse.2020.111746.

[24] M. K. Firozjaei et al 2019 Modeling the Impact of Surface Characteristics on the Near Surface Temperature Lapse Rate, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives*, vol. 42, no. 4/W18, pp. 395–399, Oct. 2019, doi: 10.5194/isprs-archives-XLII-4-W18-395.

[25] Z. T. Mohammed 2019 Near Surface Spatial Air Temperature Modelling Using Remote Sensing Techniques For Climate Dataset.

[26] N. Schwarz, U. Schlink, U. Franck, and K. Großmann 2012 Relationship of Land Surface and Air Temperatures and its Implications for Quantifying Urban Heat Island Indicators-An application for the City of Leipzig (Germany), *Ecological Indicators*, vol. 18, pp. 693–704, Jul., doi: 10.1016/j.ecolind.2012.01.001.

[27] B. Ackerman 1985 Temporal March of the Chicago Heat Island., *Journal of Climate and Applied Meteorology*, vol. 24, no. 6, pp. 547–554, doi: 10.1175/1520-0450(1985)024<0547:TMOTCH>2.0.CO;2.

[28] P. Scroll and D. For 2012 An Assessment of Satellite Remotely-Sensed Land Cover Parameters in Quantitatively Describing the Climatic Effect of Urbanization, no. September, pp. 37–41.

[29] H. Akbari, M. Pomerantz, and H. Taha 2001 Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas, *Solar Energy*, vol. 70, no. 3, pp. 295–310, doi: 10.1016/S0038-092X(00)00089-X.

[30] D. Choudhury, K. Das, and A. Das 2019 Assessment of Land Use Land Cover Changes and its Impact on Variations of Land Surface Temperature in Asansol-Durgapur Development Region, *Egyptian Journal of Remote Sensing and Space Science*, vol. 22, no. 2, pp. 203–218, Aug., doi: 10.1016/j.ejrs.2018.05.004.

[31] H. Shafizadeh-Moghadam, Q. Weng, H. Liu, and R. Valavi 2020 Modeling the Spatial Variation of Urban Land Surface Temperature in Relation to Environmental and Anthropogenic Factors: A Case Study of Tehran, Iran, *GIScience and Remote Sensing*, vol. 57, no. 4, pp. 483–496, May, doi: 10.1080/15481603.2020.1736857.

[32] J. S. Silva, R. M. da Silva, and C. A. G. Santos 2018 Spatiotemporal Impact of Land Use/Land Cover Changes on Urban Heat Islands: A Case Study of Paço do Lumiar, Brazil, *Building and Environment*, vol. 136, pp. 279–292, May, doi: 10.1016/j.buildenv.2018.03.041.

[33] H. Jelodar et al 2019 Latent Dirichlet Allocation (LDA) and Topic Modeling: Models, Applications, A Survey, *Multimedia Tools and Applications*, vol. 78, no. 11, pp. 15169–15211, Nov., doi: 10.1007/s11042-018-6894-4.

[34] M. N. Hamoodi 2021 Investigating the Effects of Armed and Political Conflicts on the Land Use/Cover Change and Surface Urban Heat Islands: A Case Study of Baghdad, Iraq, *Journal of the Indian Society of Remote Sensing*, vol. 49, no. 7, pp. 1493–1506, Jul., doi: 10.1007/s12524-021-01330-9.