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The Potential of Urban Green Infrastructure in Mitigating Urban Heat Islands in the Semi-arid Regions

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Abstract
Cities and towns around the world are at a crossroads as a result of a variety of urban challenges, including urban heat islands. Urban greening as a potential strategy for reducing urban heat is receiving increased attention due to the combined trends of urban heat island intensification and global climate change. This article brings to the fore, the significance of Green Infrastructure forms deployed in cities and assesses how they help in the mitigation of the phenomenon in semi-arid regions. The objective of this review paper is to create a better knowledge and understanding of the benefits of green infrastructure in this region. This will contribute to the understanding of how urban dwellers utilize different forms of vegetation in an urban context and help geographers, engineers, ecologists, sociologists, and professionals in urban design towards better city planning, revitalization as well as gentrification. Understanding the terms used to describe urban greenery and vegetation within the scope of the study, as well as their definitions, is necessary to comprehend the scope of the discussion of green infrastructure and urban heat islands in this article. The review shows, increased vegetation has been extensively documented as the most efficient approach for reducing urban heat islands. The study adopted a narrative review of the literature on articles from peer-reviewed journals that fall under the purview of the study.
Keywords: Green Infrastructure, Urban Heat Islands, Semi-arid Regions

Introduction
Urbanization and industrialization have led to an increase in population in our cities and towns, and as a result, more than 54% of people on Earth now live in cities. These enhance our comfort and material well-being, but they also raise a variety of challenges that are of concern to the urban inhabitants, such as air pollution, global warming, industrial waste, and in particular rising urban temperatures (Azmi et al., 2021; Saaroni et al., 2018). Additionally, numerous studies have shown that one of the most notable environmental issues plaguing urban areas is the localized climatic phenomenon known as the urban heat island (UHI), which

is characterized by higher temperatures inside the city than in the surrounding rural areas. This temperature difference (Saaroni et al., 2018) reiterates can be attributed to a number of factors, including the size of the city's population and its physical characteristics, such as the concentration of its built-up area, the materials used to construct the building structures and ground surfaces, and the distribution of anthropogenic activities, all have an impact on how much of this urban-rural heat flux is observed. (UHI) has garnered a great deal of attention recently and is becoming increasingly significant across the globe as urban centers rapidly expand. It is also reported by (Balany et al., 2020; Humaida et al., 2023) that the concept was not a major global concern until the twenty-first century, when anthropogenic sources increased and disrupted the energy balance. Large amounts anthropogenic emissions of carbon dioxide and urban development replace green vegetation, transforming UHI into a mini-global warming over an urban area. Furthermore, this can be attributed to the substantial heat produced by urban structures, which absorb and radiate solar energy, as well as by anthropogenic heat sources, which are the primary contributors to UHI. When compared to its surroundings, the two heat sources raise the temperatures in an urban area.
Urban heat island (UHI) poses an increasing risk to human health and puts pressure on urban infrastructure systems, particularly during the summer. The degradation of the living environment, rise in energy use, elevation of ground-level ozone, as well as an increase in morbidity and mortality rates due to heat stress particularly, among the vulnerable urban population like the elderly and children are some of the negative effects of UHI. A study by Mancebo (2018) cited two events in Western Europe where mortality rates increased dramatically during a summer heat wave with consistent temperatures of over 40 C, in 2003 and 2006, and opined that cities may become genuinely uninhabitable in the near future, and suggested that combating UHIs — either by reducing their severity or adjusting to them — became a key urban policy challenge. He further reiterates that a lot need to be done as most urban areas are not climate-adaptive owing to their current configuration consequently, due to their unique climate conditions, which can be summed up in the concept of the "urban heat island," cities are home to many of the emerging risks associated with climate change in both the global north and south.

Similarly, in the hot semiarid regions due to the combination of climate change and the rapid growth in urban populations in Africa, many urban areas are encountering exacerbated urban heat island (UHI) effects, especially in the ward semi-arid regions. It is important to understand UHI effects in order to develop suitable adaptation and mitigation strategies. However, little work has been done in this regard in Africa (Li et al., 2021).
It is imperative to highlight that, in an urban century with anthropogenic warming causing severe repercussions such as the heat island effect, keeping cities cool has become a high priority for human health, energy conservation, and greenhouse gas emission reduction. Dryland urban cities, primarily located in the semi-arid environments, face greater challenges than cities in cool and wet climates (Ladan et al., 2022). Therefore, increasing the amount of green area and man-made blue spaces (such as pools and fishponds) will reduce the UHI effect by allowing the land to cool through photosynthesis and evaporation. Although it was demonstrated that both had a cooling effect on their surroundings, a study by Humaida et al (2023) found that urban parks and other green areas had greater cooling effects than bodies of water. With its reflective surfaces and canopy shades, the green vegetation on land disperses cooling energy throughout the surrounding area.

This study aims to identify various green infrastructure techniques that have been applied in the studies under review to reduce the impact of UHI and enhance human thermal comfort and also examines the significance of green infrastructure in minimizing urban heat islands.

Methods

This study generates a literature from previous studies. The reviewed literature was identified through a keyword search in two academic database platforms: Scopus and Google scholar, these databases primarily cover (articles, conference proceedings, books, etc.) including publications in peer-reviewed scientific journals from 2018 to the date. The search in the two databases yielded over 400 publications. The phrases "Green Infrastructure" AND "Urban Heat Island", "Urban Heat Island Mitigation" AND "Green Infrastructure", "Urban Heat Island" AND "Semi-Arid Climate" were used as broad search terms, and the search was restricted to the years 2018 to date. The keywords will enable us to locate the papers discussing all UHI mitigation strategies for semiarid regions. Papers that were not written in English were removed. Additionally, only proceedings from international conferences and peer-reviewed scientific journals were included; other official publications like reports and theses/dissertations were excluded.

The phrases will enable us to retrieve the papers dealing with all mitigation measures to mitigate the effect of UHI. Only papers written in English were included and papers not written in English were removed. In addition, only peer-reviewed scientific journals and international conference proceedings were included and other official publication such as chapters of books, reports, thesis/dissertation were not considered. The papers were classified according to the types of mitigation measures. As indicated by the title, this paper focused on GI as a mitigation measure. However, it was found that many of the papers were not merely dealing with GI. This review focused only on materials that were accessible online.

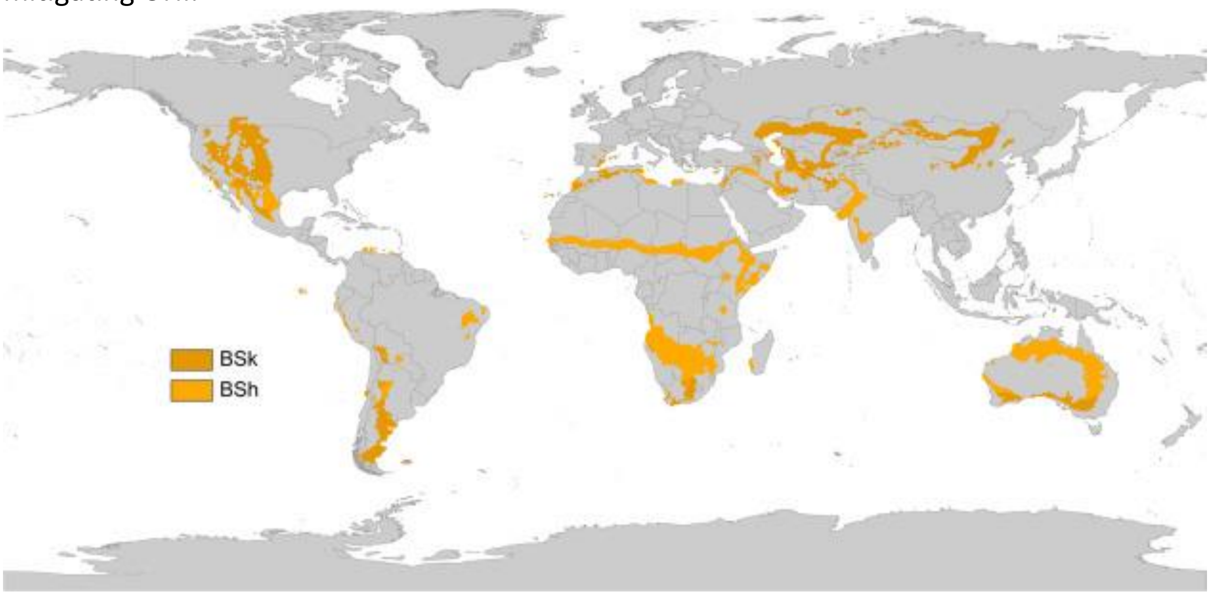
There were about 400 papers found after searching the database. We used the following inclusion criteria to narrow down our review, and we chose papers that:

i. publications in English peer-reviewed journals from 2018 onwards
ii. Specifically addressing Urban Heat Island Mitigations focused on all forms of Green Infrastructure, and
iii. Urban Heat Island Mitigations in Semi-Arid Climate

A total of 27 records were chosen for a thorough review after the filtering process to make up the remaining data, downloads, and analyses of each publication were performed.

Semiarid Regions

In the well-known Köppen-Geiger global climate classification, semiarid regions are categorised as "dry," and as well, locations where precipitation does not exceed potential evapotranspiration and cities that end up receiving less than 500 mm of rainfall yearly (Meerow et al., 2021) The fragile ecosystem in the warm, semi-arid region, which is already hot and dry, is seriously threatened by the climate crisis. The areas housed more than 14% of the world's population in 2000 and make up about 15% of the planet's natural land surface. These ecosystems are extremely vulnerable to the intense interactions between human activity and climate change (Ladan et al., 2022). Making cities cool has become a growing priority for human health, energy efficiency, and greenhouse gas abatement in an urban century where anthropogenic climate change is having significant effects like the heat island effect. Compared to cities in wetter climates, semi-arid and dry urban areas face more challenges (Maskooni et al., 2021). A total of 1.1 billion people live in the already dry and hot semi-arid environment, making them among the poorest and thus vulnerable in the midst of the environmental crisis (Ladan et al., 2022). To ensure the long-term viability of this fragile environment, it is critical to better understand the benefits of urban green infrastructure in mitigating UHI.



Fig, 1 Global distribution of hot (BSh) and cold (BSk) semiarid regions according to Köppen-Geiger climate classification (Garcia-Franco et al., 2018)

Results
Green Infrastructure
Originally, the term "Green Infrastructure" GI was used to refer to wetlands, parks, and floodways that offer services for controlling flooding and water infiltration. A network of natural and artificial vegetation, including trees (street), parklands, rain gardens, private gardens, watersheds, green and cool roofs, and green walls, has been used to expand the definition in more recent years to encompass a wide range of ecological and sustainability targets (Imran et al., 2019). The concept which surfaced to boost resilience within urban thresholds, GI is also being described as an "interconnected system of greenery that try to preserve natural systems as well as provide various services to the human population." It encompasses both human induced and natural greening, ranging from parks and street trees to green roofs, gardens, and green pedestrian areas. GI is identified as a crucial urban infrastructure that is crucially significant to transport systems. It is thought to contain efficient techniques to mitigate the negative impacts of UHI and therefore, regulate urban microclimate through evapotranspiration and shading (Balany, Ng, Muttil, et al., 2020). This describes all forms urban greenery as part of GI which will go in a long way in minimizing the impact UHI on urban microclimate in the semiarid regions.
In the same vein, Almaaitah et al (2021) further explains that, the term "green infrastructure" (GI) refers to natural systems that replicate hydrology, control surface energy processes via evaporation, shadowing, and emissivity modification, and enhance air flow and heat transfer. Though the focus of this review is on GI, this explanation includes some blue infrastructure elements that are in some cases inseparable. Many studies were unable to make a clear distinction. It is also reported as a system of multifunctional green space facilities known as "green infrastructure" (GI) can improve accessibility between already established natural areas and ecological cohesion while also enhancing urban dwellers quality of life and well-

being (Dipeolu et al., 2020). It is important to highlight that; GI is always aimed at sustainability of cities as it seeks to provide greenery for long time viability of cities.
GI as presented by various scholars in this context refers to vegetated green surfaces and other environmental features at various spatial scales that provide goods and services related to human sustenance while also supporting biodiversity, carbon sequestration, flood protection, and protection against rising urban temperatures.

Types
Many scholars have presented a variety of practices that use or mimic natural systems to constitute urban green infrastructure. A list of 11 green infrastructure features was compiled by Meerow et al (2021) these includes Bio retention basins and planters, Curb openings, Domed overflow structures, Grade control Structures Infiltration trenches, (Non-tree) vegetation, Sediment traps, Stormwater harvesting basins, or rain gardens, Trees and tree pits, and Vegetated or rock swales. Similarly, Leal et al (2021) in their study identified the network of green infrastructure in a city to include the following features, Public parks and gardens, Greenways, Residential and other streets, Sports and recreational facilities, Private/semi-private gardens, Green roofs and walls, Squares and plazas, Natural green space, Utility areas, and Agricultural and other productive lands.
In their study on The potential of Blue-Green infrastructure as a climate change adaptation strategy (Almaaitah et al., 2021) they provided Common applications of Green Infrastructure to include Green roof (Intensive; Semi-Intensive, Extensive), Permeable pavement, Planted Infiltration Pits, Swales, Vegetated Open Areas, Tree Plantings, Urban Agriculture, Rain Garden and Constructed Wetland (Almaaitah et al., 2021). It is evident from the various examples of green infrastructure that they encompass both the blue and grey forms, indicating that there is no distinct difference between the blue, grey, and green infrastructures.
Another important type of urban green infrastructure is the Broad-Leaved Vegetation which contributes greatly in regulating urban microclimate. Air temperatures in urban green spaces have been found to be about 1 °C lower than those in the nearby rural areas. This cooling effect is a result of evapotranspiration in the ecosystem as well as shading from broad-leaved vegetation (Chiabai et al., 2018).

Trees
One of the most important types of green infrastructure is trees. Urban greening in general, and urban trees and forests in particular, are widely regarded as the most efficient methods for urban cooling. These methods primarily involve shading and lowering ground surface temperatures, but they can also occasionally involve evapotranspiration, also the most efficient trees for cooling have been found to have large, dense crowns (Saaroni et al., 2018). Through evapotranspiration, shade trees in urban forests cool the air. Additionally, trees reduce wind speed when they are covered in leaves. Similarly, Trees are regarded as the most popular GI strategy, according to a study by Wong, et al (2020), observed that numerous studies have shown that this strategy consistently reduces temperature while also enhancing human comfort. The canopy of a tree provides shade, which reduces direct solar radiation. Evapotranspiration also releases water vapour into the atmosphere, which raises the relative humidity level.
The evidence indicates that trees, whether placed alone or in groups, provide significant cooling effects in their surroundings during the daytime due to evapotranspiration and sun shading. Almaaitah et al (2021) also affirms that tree shade reduces solar radiation by up to

96.5%, resulting in a better cooling effect. A tree in the middle of the front yard has been found to be able to lower the physiological equivalent temperature (PET) by 1 to 1.5°C. Similarly, maximum daily summer air temperatures would drop by 1.7°C if trees were planted everywhere in the cities (Saaroni et al., 2018). When water use is taken into account, shade trees surpass other vegetation such as grass as an urban heat mitigation strategy (Meerow et al., 2021). In the same study, Meerow et al further reitrate that the cooling effect of trees varied greatly by species, but overall they estimated a 0.2°C drop in air temperature for every percentage increase in total tree canopy cover.

Urban Parks

Most urban parks are made up of various kinds of greenery, such as grass, trees, and a variety of low-growing shrubs. Large tree-covered areas in particular, often called "urban forests," are the most efficient sources of cooling, particularly during the day. Large grassy areas in parks were found to be successful cooling agents at night, however, if they are not properly irrigated, they may become warmer than the surrounding area during the day (Atri et al., 2021; Wong, et al., 2020; Saaroni et al., 2018). In a similar vein, Shao & Kim, (2022) in their study further emphasises the advantages of urban parks by showing how a 100 m^2 wooded park within a city block bordered by 15 m-tall buildings reduced the air temperature on a nearby canyon street by 1 ^{0}C. Also Shao & Kim's (2022) study shows how urban parks can control the temperature in nearby urban areas, improving thermal comfort and lowering energy consumption.

In their study on the performance of green infrastructure in arid and semi-arid urban environments Meerow et al (2021) observed that, Other park characteristics (size, form, and foliage) were discovered to have an impact on cooling. Parks with bigger expanses and more canopy coverage experienced a greater cooling effect that extended beyond the park's boundaries.

According to Shao & Kim (2022), the average maximum cooling effect of a park is up to 1.0 ℃, with the range of the temperature difference between the park and the surrounding environment being 0.5 to 3 ℃. The same study revealed that air temperature may drop by about 1.69 °C and the mean radiant temperature by 14.80 ℃ when a park's sky view factor drops from 0.9 to 0.1. These studies have demonstrated the significance of urban parks as part of urban green infrastructure for regulating the microclimate within cities. Thus, all parties involved, particularly urban town planners, should promote the establishment and maintenance of urban parks in townships and cities in semi-arid regions.

Green Roof

Rooftop applications are increasingly utilising vegetation's potential cooling benefits. Green roofs have numerous advantages for the urban environment. It has been identified as an effective sustainable design tool for mitigating UHI effects at various scales (Sahnoune et al., 2021). Green roof offers several advantages, including sound and thermal isolation, reduction of urban heat island effect and air pollution, and reduction of flood hazards in urban areas (Uçar et al., 2020). Green roofs can provide additional mitigation benefits. In the summer, they reduce the surface temperature of the rooftops and the energy required for cooling, while in the winter, they reduce heat losses.

Green roofs were estimated to save 5% of annual energy use (up to 25% in summer) (Lucertini & Giustino, 2021). In a similar vein, Green roofs which account for only 5% of the total area of

the city, were found to reduce surface temperature in the boundary layer by up to 0.5°C (Sahnoune et al., 2021). It is also reported by Chidambaram et al (2022) that, they minimise the urban heat island effect, lower cooling loads, and improve thermal comfort inside buildings in hotter climates. showed that by improving the thermal capacity of the roofs, green roofs help to cool down buildings in the summer and raise temperatures in the winter. However, it is important to stress that green roofs are more peculiar with developed cities in the global north.
In general, it is clear that green roofs are advocated as a climate change adaptation strategy that includes urban climate regulation due to their ability to reduce air and surface temperatures, thereby giving inhabitants a more comfortable environment.

Urban Agriculture
Urban farming, urban gardening, or urban agriculture are all terms for the activity of growing, processing, and providing food in or near a village, town, or city, is known to perform social and environmental functions in addition to economic functions. Environmental functions include improving air and water quality, as well as pollination and biological control functions (Azunre et al., 2019; Mancebo, 2018). Urban agriculture can help to reduce the effects of urban heat islands by providing shade and increased evapotranspiration, resulting in more cooling and clean air, a study conducted at the University of Manchester, reports a 10% increase in the amount of green, through urban agriculture, can contribute to decreasing surface temperatures in urban centers by up to 4 °C (Azunre et al., 2019).
It is possible for urban gardens, agricultural lands, fruit and street trees, parks, and forests (forms of urban agriculture) to reduce solar radiation, increase evapotranspiration, and subsequently reduce temperatures via evapotranspiration and shading (Mancebo, 2018). a few essential ecosystem services provided by urban agriculture that are particularly essential to minimizing and preparing for the effects of climate change include: Air purification by filtering gases, aerosols, and particulates; carbon storage; microclimate improvement; and reduction of the urban heat island effect (Manikas et al., 2020).
Another important form of green infrastructure is Urban forests which are also widely recognized as a viable solution for urban heat island mitigations, improving ecosystem services, human well-being, and biodiversity (Athanasios et al., 2021). However, despite the fact that urban forests exist in some countries, there have been few studies on them (Balany et al., 2020). Urban forests encompass almost all types of green infrastructure. Ren et al (2018), reported that, (Balany et al., 2020). The term "urban forest" refers to all of the trees and vegetation found in urban areas, as well as the soil, air, and water that sustains them. The use of "trees and vegetation in streets, parks, gardens, marketplaces, educational institutions, river and creek embankments, railway pathways, urban gardens, green walls, outdoor spaces, and green roofs". Therefore, it is crucial to explore all types of green infrastructure that can flourish in a particular location in order to implement the one that will have the greatest impact on reducing the negative effects of urban heat islands in that region.

Benefits
Green infrastructure serves a multifaceted purpose as a UHI mitigation and adaptation strategy. Different types of GI of various sizes, and forms, could be viewed as environmental system for various city structures to provide ecological benefits to city dwellers, these includes lowering land surface temperature (LST) and minimising surface urban heat islands, using evaporation and transpiration to cool surfaces and the environment, lowering building energy

requirements and greenhouse gas emissions, enhancing human health and thermal comfort, decreasing the urban mortality associated with UHI (Shao & Kim, 2022). Similarly, it is also revealed by a study that increasing the amount of green space in urban areas can be an efficient approach for mitigating UHI effects by changing the city's surface energy balance by reducing heat retention in urban surfaces and increasing evapotranspiration. These two mechanisms are critical in reducing the UHI effect (Imran et al., 2019). They further maintain that, Direct shading from vegetation on urban surfaces is another benefit of vegetation, which also decrease heat storage and enhances night time cooling.
The GI approach is usually recognised as a climate - resilient way to minimize the effects of UHI because of its numerous functions and potential benefits for the urban environment, including its ability to boost biodiversity and enhance air quality in cities (Imran et al., 2019). Multiple scholarly research has demonstrated how the use of green infrastructure increases human comfort and urban sustainability, additional measures must be taken to increase the proportion of green space in cities for mitigating and adaptation purposes. Other benefits reported by Serrone et al (2022) includes lowering land surface temperature and reducing the effect of urban heat islands, Cooling the urban environment through evaporation and transpiration, lowering the energy demands for buildings and emissions related to greenhouse gases, enhancing human health and thermal comfort of the urban dwellers, and lowering the morbidity, mortality, frequency, and intensity of climate-related tragedies caused by urban heat islands.

Conclusion

Numerous studies have examined the potential value and imperatives of using vegetation to regulate the urban microclimate, particularly in mitigating the effects of urban heat islands, which are without a doubt one of the most threatening environmental challenges for urban dwellers in both the global north and south. By providing environmental services, green infrastructure is crucial for improving thermal comfort in urban areas. There is also substantial evidence that green infrastructure mitigates the problems associated with environmental sustainability, in particular with regard to regulating urban climate and enhancing the liveability of built environments by maintaining ecosystems. UGI is being encouraged both internationally and locally. While UGI has gained political support and recognition as a viable adaptation option, its incorporation into urban planning practises remains inadequate. There is little comparative data to help urban planners determine what type and quantity of UGI would be most efficient particular in the semiarid environment. This review has demonstrated how establishing and increasing urban greenery has numerous benefits that may either directly or indirectly ameliorate the effects of UHI. Green infrastructure promotes well-being and ameliorates environmental sustainability concerns. It should be promoted in threatened urban centers. City planners should take into account potential UHI effects more when starting new construction projects or making changes to ongoing ones. Additionally, more citizen involvement is required to promote quicker response times and hasten the implementation of city plans. In order to keep our cities sustainable, it is important to better maintain the valuable ecosystem services that already exist in urban green infrastructure for the sustainability of the semiarid environment.

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