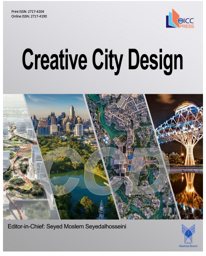

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Green infrastructure's impact on thermal condition in arid & semi-arid cities: a systematic review

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Systematic Review

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Abstract:

Aims: Research shows that the urban heat island (UHI) effect raises temperatures in cities, while green infrastructure helps mitigate heat, especially in arid and semi-arid regions. However, more targeted studies are needed on its cooling capacity in these climates.
Methodology: In leading study, A systematic review was conducted to analyze research articles focused on arid and semi-arid cities. By detailed and targeted searches in valid databases based on keywords and then monitoring them, 31 selected articles were selected for final analysis. Research reviewed were divided into three categories based on the studied scale.
Findings: The first category, studies that examined the cooling effect of green infrastructure in the whole city (41.94%), studies that examined the effect of green infrastructure on several parts of the city (35.48%), the effect of green infrastructure on one part Checked from the city (22.58%). Most of the research reviewed has investigated the generalities of green infrastructures such as vegetation or trees and lawns on a large scale and has less focused on the specific features and details of green infrastructures, as well as the combination of urban green infrastructures with different urban forms.
Conclusion: Although large green infrastructures significantly improve the temperature conditions of cities, the contribution of small and medium infrastructures, such as urban parks in dry and semi-dry cities, should be addressed because the development of such spaces is often faced with less intervention and cost. By modifying plant cover types and structural characteristics of vegetation and tree canopies, the cooling capacity of existing green infrastructure can be enhanced in dry and semi-arid cities, a topic that has been less explored in reviewed studies. In addition to all these cases, the urban green infrastructure program, based on its cooling capability, should be considered part of urban land use planning in dry and semi-dry cities to achieve the most optimal result.

Keywords: Dry cities; Semiarid cities; Green infrastructures; Urban heat; Cooling effect

1. Introduction and literature

Climate change is one of the most significant challenges of the present era. Over time, it is clear to everyone-even those without specialized knowledge-that there is a dramatic climate change. According to all scientific accounts, the Earth has been warming since 1850 [1]. Cities face an exceptionally high level of risk from climate change-amplified hazards [2]. Overheating is a significant challenge for cities, with a significant effect on the microclimatic comfort, health, and well-being of the urban population and associated implications for infrastructure planning and energy demand [3, 4]. The signs of climate change are already evident at the global level. The average temperature rose by 0.74 ºC in the 20th century, ice cover fell by 40%, and sea levels rose by 17 cm [5]. Climate change is inevitable due to increased concentration of long-lived greenhouse gases in the atmosphere. These gases trap solar radiation, which is reflected from the Earth and is then emitted back to the surface [6]. As a result, climate change is one of our time's top imperative global challenges. Therefore, to address this imperative, it is necessary to control and decrease the emissions of greenhouse gases [7].
Urban climates are commonly characterized by higher air temperatures at the densely built core of cities and relatively

lower temperatures in the surrounding rural regions [8, 9]. Referred to as the urban heat island (UHI) effect, higher urban temperatures are caused by anthropogenic heat released from vehicles, power plants, air conditioners, and other heat sources, and heat stored and re-radiated by massive and complex urban structures [10]. The UHI effect is reducible by utilizing building and urban design strategies like using highly reflective building materials, using roofs, appropriate building designs, and managing and placing vegetation [10]. On the other hand, urban and peri-urban vegetation modifies surface and atmospheric temperatures in cities due to its evapotranspiration, shading, and albedo effects [11–14]. Consequently, enhancing or conserving green infrastructure in cities has been postulated as a strategy that would serve to temper temperatures [13–16]. An additional advantage of urban vegetation is that it increases nighttime cooling in cities by eradicating heat stored in the city's surface through direct shading. These vegetated surfaces, like green walls and roofs, gardens, green spaces, lawns, and trees, to different extents can capture solar radiation, ultimately reducing the UHI [11–17].

Several studies have explored the cooling effects of green infrastructure. Amiri et al. [18] and Shashua-Bar et al. [19] found that urban vegetation can reduce temperatures in hot, arid cities in Iran and Israel [20]. Oliveira et al. [15] and Lin [21] examined the cooling impact of vegetated urban spaces in Portugal and subtropical China, respectively. Cavan et al. [14] investigated the influence of different urban morphologies on land surface temperatures (LSTs) in Addis Ababa, Ethiopia, and Dar es Salaam, Tanzania, discovering that residential areas with extensive green spaces in both cities had lower surface temperatures [20]. Additionally, Conway et al. [22], Goldreich [23], Jonsson [24], and Botswana, as shown by Jonsson [24], whose research corroborated this statement [20].

The impacts of UHI are more extreme in dry and semi-dry regions. These regions suffer from high summer temperatures and low rainfall amounts. The increase of urban lands and the impacts of UHIs also appear to be at high risk of harming the population [25]. Nevertheless, research on urban regions in the dry and semi-dry areas, where UHI impact on the surface is probably severe, is scanty [25].

Depending on the climate and the vegetation cover characteristics, the shading, reduction in surface temperature, lower heat absorption and retention, and evapotranspiration by plants cool the air, reducing the risk of heat-related mortality [19, 26]. Vegetation, especially trees, cools the surface of hot and arid cities by providing shade, evapotranspiration, intercepting solar radiation, and forming the park cool island effect [27, 28]. The cooling impact becomes more effective during mid-day [19, 28] and is noticeable at the neighborhood scale [29]. Water-conserving ground vegetation cover also provides cooling benefits at the pedestrian scale [30]. Although there have been studies on the impact of land use and land cover on temperature [31, 32], more studies are needed about the cooling impact of UGI, specifically in developing countries and semiarid regions [33]. There still needs to be more clarity surrounding cooling capacity and its impact on subtropical desert urban climate [34]. Heat islands expand at night in arid and semiarid cities, while cool islands can be observed during the daytime [30, 35, 36]. However, these cities face diurnal thermal stress, making daytime heat mitigation strategies necessary [37].

Despite the increasing warming and the great importance of the cooling effect of green infrastructure in the semi-arid and arid cities of the world, no study has yet focused on the classification and purposefulness of the studies conducted in this regard.

The leading study with the aim of a systematic review of scientific findings regarding the studies conducted in the field of investigating the impact of green infrastructure on improving temperature conditions and thermal comfort (climate resilience) in arid and semiarid cities of the world to provide a platform for future studies in this field in the future.

2. Methods

The following article employs a systematic review method, which differs from traditional critical and meta-analysis reviews by not focusing on statistical analysis of evidence. Instead, it aims to identify geographical patterns, theoretical trends, and methodological gaps. For the search process, three significant databases, Google Scholar, Web of Science, and Scopus, were used, combining terms such as 'cooling', 'vegetation', 'green infrastructure', 'urban heat island', 'thermal comfort', and 'temperature'. The search results were limited to the most recent journal papers, using Bowler et al. [12]. The selected articles were required to meet the following criteria:

1. The publication must be in English.
2. The article must concern itself with studies in dry and semi-dry regions and cities, either explicitly mentioned in the article or using the Köppen-Geiger classification method [38] to classify a dry climate, at least during summer.
3. It should be a study evaluating each category of green infrastructure, meaning that research not explicitly including all elements of the following categories was excluded:

- Land cover level (or vegetation cover)
- Green roofs and green walls
- Green spaces
- Canopies (trees or plants)
- Water levels and dams

4. Studies conducted on a global scale, in large areas, or using community land models were excluded [39–42].
5. Articles where the sites were not specified were excluded.
6. Studies that were only qualitative and their research and analysis methods were only qualitative interpretation were excluded.

The screening process of studies related to the impact of green infrastructure on cooling and thermal comfort in arid and semi-arid regions is illustrated in Fig. 1.

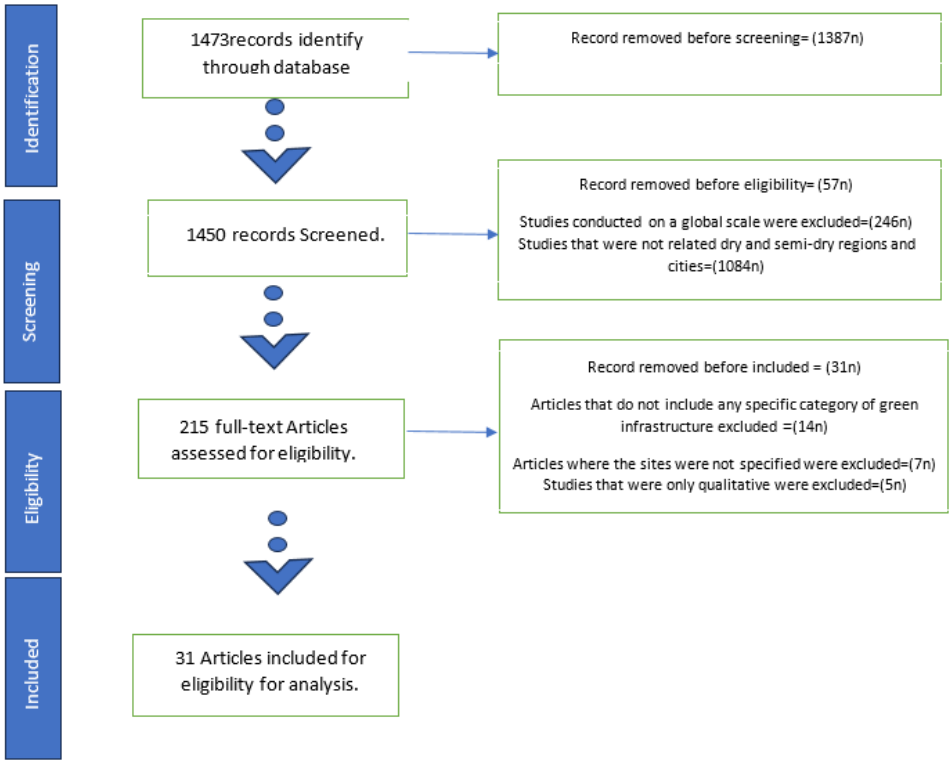

Figure 1. Screening research related to green infrastructure's impact on cooling and thermal comfort in arid and semi-arid Regions.

2.1 Classification of studies based on geographical area

The geographical pattern of the articles shows that the articles were mainly written in Asia (3.48%), North America (22.5%), Europe (13%), Africa (13%) and South America (3.2%). Figure 2 shows the geographical pattern of the studies (geographical locations and the number of studies conducted in each location).

In a country-based analysis, a strong geographic bias towards the three countries of Iran (12.16%), the United States of America (12.16%), and Iraq (9.67%) was observed. Most studies (96.77%) were in the Northern Hemisphere and at higher latitudes, while studies in the Southern Hemisphere (3.23%) were less common.The number of studies conducted in each country is presented in Fig. 3.

In a city-based analysis, research in the three cities of Tehran (Iran), Phoenix (USA), and Ankara (Turkey) contributed the most, with two studies each, and other cities were mentioned in one study each.

These figures show the growing interest of academics in developing countries in the thermal benefits provided by green infrastructure in arid and semiarid climates, while developed countries (except the USA) study these aspects less in these climates. One of the main causes of this can be the concentration of most of the dry and semi-dry cities in the world in developing countries. (It should be noted that developing countries are more vulnerable to climate change

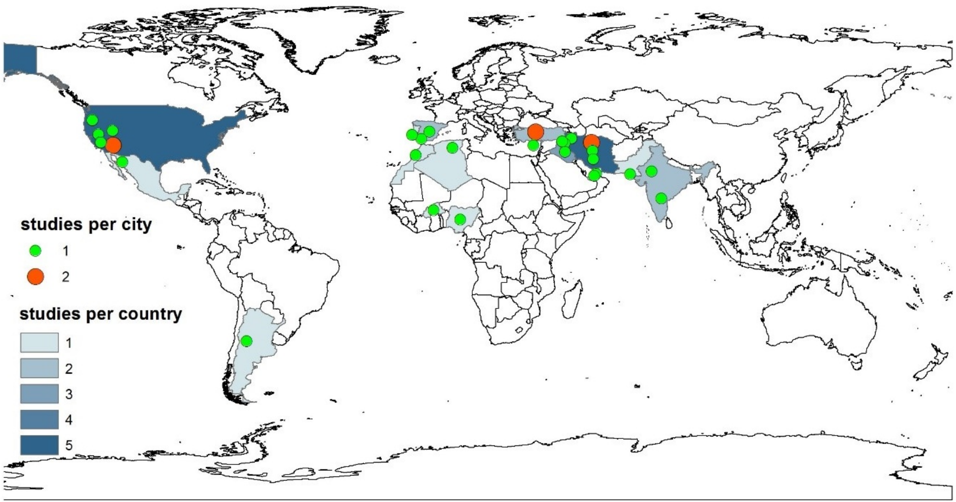

Figure 2. Geographical pattern of the studies.

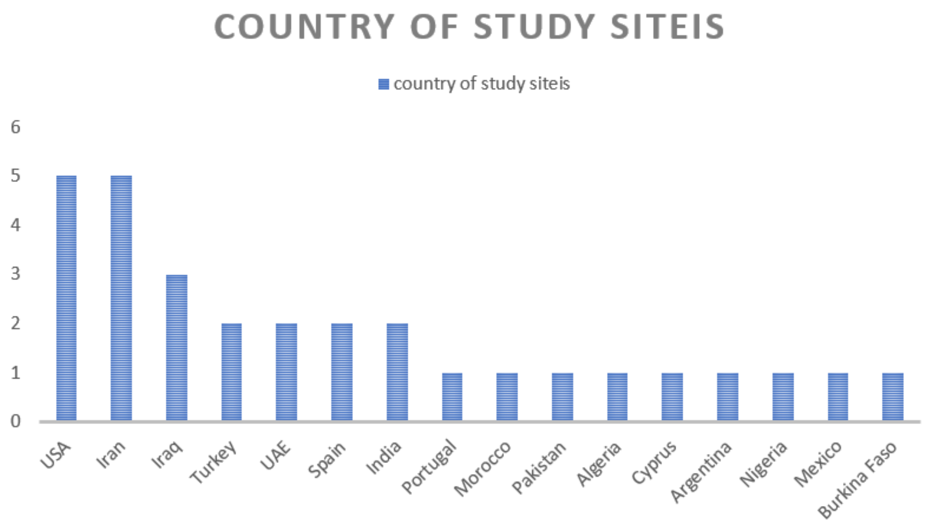

Figure 3. Country pattern of the studies.

because they often struggle with social and economic problems in addition to problems such as climate warming and drought.)

2.2 Classification based on the thematic focus of the research

Generally, researchers have studied the thermal performance of green infrastructure by analyzing the magnitude and intensity of its thermal effects on different UHIs [53]. Based on this, research is generally focused on these three areas: a) reducing the temperature of urban surfaces, which is related to surface urban heat islands (SUHI) and surface urban cool islands (SUCI) (19.35%); b) analysis of the relationship It is concentrated between the reduction of air and surface temperature (54.83%), c) physiological equivalent temperature (PET) (12.90%). Also, studies focused on specific sub-topics such as thermal comfort (9.67%), Precipitation Concentration Index (PCI) (6.45%), and one article (3.22%) focused on evaporation and transpiration. Some articles only mentioned one of the mentioned factors, and some examined two or more fields.

2.3 Classification of studies based on study scale

The studies were divided into three categories based on the studied scale. As shown in Fig. 4 the first category, studies that examined the cooling effect of green infrastructure in the whole city (41.94%), studies that examined the effect of green infrastructure on several parts of the city (35.48%), the effect of green infrastructure on one part Checked from the city (22.58%). The articles of each section were compared in terms of quantitative and qualitative data and findings, including the type of coverage under analysis, size (if it is mentioned in the article), and the purpose and result of the research. Next, we will describe each category.

2.3.1 The cooling effect of green infrastructure in the whole city

In this section, we looked closely at studies exploring how green infrastructure affects whole cities (Table 1). The idea is understanding how green infrastructure cools down urban areas and reduces heat islands, especially in dry and semi-dry regions. Because these studies covered a large area, they relied on satellite images and maps like LST MAP, MODIS LST, MODIS/ASTER Airborne, MODIS/TERRA,

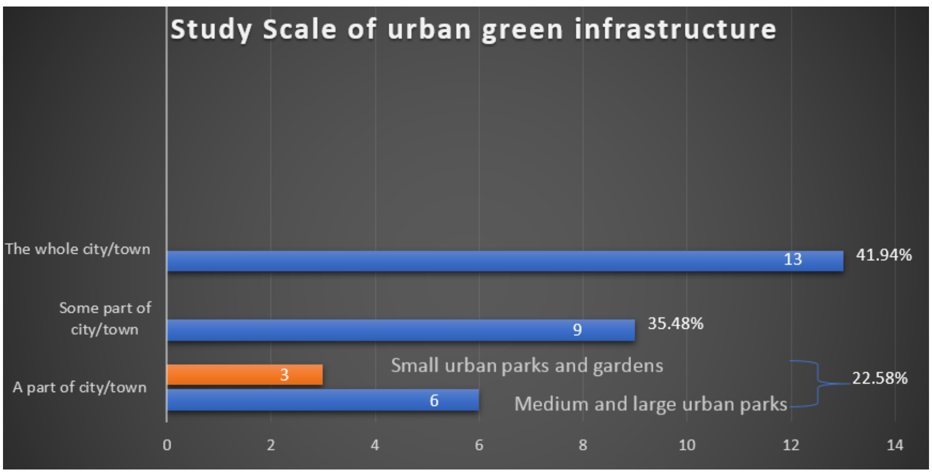

Figure 4. Study scale of urban green infrastructure .

Table 1. Studies related to the cooling effect of green infrastructure in the whole city.

Ref	Location	Green site & comparator	Features of green site	Purpose	Methods/ Instruments	Size	Conclusion
[25]	**Shiraz City , Iran**	Total OF Shiraz city	1. Orchard areas are regions with tree cover, such as pomegranate and pine trees. 2. Vegetation-covered areas are defined as farmland and grass-covered regions	Examining the effect of urbanization on the surface of urban green infrastructure (UGI) and urban heat islands (UHI)	_LST map _machine learning algorithms -NDVI and NDBI index	145 km^2	The mean LST over the entire study domain increased considerably due to urbanization, a decrease in green areas, and an increase in industrial areas
[20]	**Bobo-Dioulasso, Burkina Faso**	Total of Bobo-Dioulasso	Different land use/cover classes in the urban and peri-urban study areas (for example, agricultural areas, natural areas, forest plantations, orchards, etc.)	Analyze the role of urbanization and green infrastructure on urban surface temperatures	Remote sensing, LST map Spatial regressions between each LST image and the NDVI image	136,78 km^2	To maximize the benefits of temperature reduction, seasonal phenological differences due to rainfall patterns and site limitations should be accounted for.
[43]	**Hyderabad City, India**	All urban areas of Hyderabad City	Grassland vegetation	Investigate the urban growth and consequent changes in surface UHI (SUHI) intensity over this period using Landsat LULC and Moderate Resolution Imaging Spectroradiometer (MODIS)	-MODIS LST -MODIS NDVI Instrument -MODIS-Terra -ASTER	Not mentioned	Extensive vegetation cover and the presence of water bodies have been linked to reduced land surface temperatures (LSTs) and should be integrated into city planning efforts to manage urban growth.
[44]	**Karachi, Pakistan**	All urban areas of Karachi City	Vegetation area	Explore changes in land use/land cover (LULC) and their influence on the urban thermal environment in Karachi, Pakistan, a tropical megacity	-vector machine (SVM) -LST values -GWR analysis in Arc GIS -Pearson's correlation	Not mentioned	Parks with large areas of medium and high-density vegetation play a significant role in regulating the thermal environment
[45]	**Marrakech, Morocco**	All urban areas of Morocco City	Evergreen trees grassland Agriculture	Analyze the urban heat island (UHI) across the cityscape and estimate how vegetation contributes to reducing UHI and local energy consumption	-Landsat Thematic Mapper -MODIS NDVI data -SiB2 model	Not mentioned	The mix and amount of vegetation in an urban area are essential modulators of surface temperature and help reduce excess urban heating.
[46]	**Las Vegas, Nevada USA**	All urban areas of Las Vegas	-shrub/scrub, -open water -grassland/herbaceous -woody wetlands	Use multi-temporal remote sensing data to analyze spatiotemporal variations in surface urban heat island intensity in Las Vegas, Nevada, from 2001 to 2016.	Geographically weighted regression (GWR) -Remotely sensed LST data -ENVI	Not mentioned	That vegetation and water bodies are essential factors for SUHI mitigation in Las Vegas
[47]	**Dohuk City, Kurdistan Region ,Iraq**	All urban areas of Dohuk City	Built-up areas, water, barren land, and vegetation lands are the four selected LULC types	Investigate the impact of land use changes on land surface temperature (LST)	-LST maps (Mono-window algorithm was used) -NDVI, NDBI, NDBAI and NDWI index - Linear regression analysis	Not mentioned	The study's findings confirm that alterations in land use/cover significantly increase land surface temperatures.
[48]	**Tabriz City, Iran**	Total of Tabriz areas	Green Lands	Derive LST to identify urban heat islands (UHI) and explore their correlations with land use/land cover (LULC)	-Remotely sensed ASTER LST data -Normalized difference spectral indices (NDSI) -CORRELATION COEFFICIENTS	Not mentioned	The findings suggest that land surface temperature (LST) is strongly impacted by land use/land cover (LULC), and urban heat islands (UHIs) are closely associated with both LST and LULC.
[49]	**Jaipur, India**	All urban and pre-urban areas of Jaipur	Urban forest	Identify differences in LSTs across demi-decadal, seasonal, and zonal variations in a semiarid region within the city of Jaipur	_LST map -Kruskal's algorithm -Wallis ANOVA test in R-statistical software -QGIS analyses	29 km^2	Upon obtaining land surface temperatures (LSTs) from remote sensing data, we observed a notable variation across the zones.
[34]	**Dubai, UAE**	All urban areas of Dubai	Vegetation areas: -Deciduous broadleaf forest -Deciduous needle leaf -Evergreen broadleaf -Evergreen needle -leaf forest -Shrub and Grasslands	Numerically assess the impact of incremental increases in urban green infrastructure (GI) on urban cooling potential and regional urban climate in Dubai	-WRF model -(SVM) method in Arc GIS	35 km^2	Although green infrastructure (GI) cooling is crucial in delaying sea breezes and managing humidity, it could potentially increase the risk of heat discomfort within indoor building spaces.

Continued on next page

Table 1. Studies related to the cooling effect of green infrastructure in the whole city. (Continued)

Ref	Location	Green site & comparator	Features of green site	Purpose	Methods/ Instruments	Size	Conclusion
[50]	**Seville, Spain**	All urban areas of Seville	-Agricultural, semi -natural and wetland areas -Green urban areas -Water bodies Compared with other land use	Use remote sensing and GIS to analyze the LST and NDVI correlation in Seville, Spain, across different LULC types.	-ESRI Arc GIS -Remotely sensed LST and NDVI data	73 km^2	The study has revealed a significant correlation between LULC types and their surface characteristics with LSTs, thereby impacting the broader pattern of the urban heat island (UHI).
[51]	**Los Angeles, California, USA**	All zone of Los Angeles metropolitan	Vegetation cover	Explore how vegetation-based surface cooling services vary across the coastal-to-desert climate gradient of Los Angeles	-MODIS/ASTER -remotely sensed data -linear regression -structural equation modeling (SEM) -ENVI	88000 km^2	The enhanced cooling impact of vegetation moving farther from the coastline within Los Angeles is comparable to variations observed between different cities.
[52]	**Portland, Oregon, USA**	Almost the total of Portland areas (seven clusters in 100 m grid size)	Trees and Grass: 1&2-High and medium canopy Neighborhood 3-Urban districts and corridors 4-Hardscaped industrial 5-vegetated Urban 6-Semei-rural	Determine which characteristics of the built environment are most strongly linked to high temperatures and which design elements contribute to reducing ambient temperature	-ENVI-met microclimate modeling -Pearson's correlation coefficients	Not mentioned	The outcomes varied between different landscapes, indicating that relying solely on one mitigation solution would not effectively reduce extreme heat.

and MODIS NDVI to measure things like land surface temperature, atmospheric conditions, and land cover.

Numerous studies have highlighted the crucial role of vegetation in enhancing thermal conditions and mitigating heat islands. For instance, a study titled "Characterizing Spatiotemporal Variations in the Urban Thermal Environment Related to Land Cover Changes in Karachi, Pakistan, from 2000 to 2020," which investigated land use/land cover (LULC) changes and their impact on Karachi's urban thermal environment, found that parks with extensive medium and high-density vegetation significantly regulate the thermal environment. Conversely, dispersed vegetation patches in the urban core do not notably affect the land surface temperature (LST) [44]. Many studies have pointed out that vegetation is vital in improving thermal conditions and reducing heat islands. For example, a study conducted by Baqa et al. to investigate the LULC changes and its impacts on the urban thermal environment of Karachi from 2000 to 2020 pointed out that parks having large medium and high-density vegetated areas are majorly regulating the thermal environment. On the other hand, the dispersed vegetation patches found in the urban core have no significant impacts on the land surface temperature [44].

Additionally, several studies emphasized urbanization as a critical factor in land use changes, leading to reduced vegetation and increased urban temperatures. A study in Hyderabad, India, highlighted how urban expansion and significant changes in land cover over the past two decades have increased city temperatures compared to surrounding areas. Large vegetation cover and water bodies were associated with lower LSTs and should be considered in urban planning [43].

Other research has also supported urbanization as a driver for the land use changes mentioned earlier, which result in reducing vegetation and increasing urban temperatures. For instance, in Hyderabad, India, the exponential growth of the city combined with considerable land cover changes in the last two decades, which have increased the city temperature relative to its periphery, indicates that large vegetation cover and water bodies mean lower LST and hence should be factored in urban planning [43].

Some studies also discussed the varying role of vegetation in different urban areas with varying humidity levels and its importance in improving dry and semiarid conditions. For example, a study in Los Angeles emphasized that the cooling effect of vegetation varies across coastal to inland areas. The study suggested that inland rather than coastal areas are more effective for using vegetation as an adaptation strategy [51].

Some studies have also mentioned the different effects of vegetation in different urban areas with different humidity levels and its role in ameliorating dry and semiarid conditions. For example, a study in Los Angeles indicated that the cooling effect of vegetation differs between the coastal and inland regions. The study suggested that inland rather than coastal areas are more effective for using vegetation as an adaptation strategy [51].

2.3.2 The impact of green infrastructure on several parts of the city

This section focuses on assessing the cumulative impact of green infrastructure in specific city neighborhoods (Table 2). These studies do not typically evaluate green infrastructure for an entire city but often make a comparison on the cooling effect of green infrastructures in two or more neighborhoods of a city and/or different types of parks and or open spaces with distinct uses in addition to comparing the neighborhoods of a city or the suburban and urban fabric. This comparison often highlights variations in the characteristics, types, or extents of green infrastructure, contributing to differences in their cooling efficacy across various parts of the city or its surroundings. Additionally, some studies delve into the distinct characteristics of land use and types, and they introduce factors such as land cover type or disparities between urban and peri-urban textures as significant contributors to the cooling effectiveness of green infrastruc-

Table 2. Studies related to the impact of green infrastructure on several parts of the city.

Ref	Location	Green site & comparator	Features of green site	Purpose	Methods/ Instruments	Size	Conclusion
[54]	**Tehran, Iran**	Districts 6 and 22 of Tehran	Not mentioned	Assessing the role of parks as part of urban green infrastructure in regulating surface temperatures in Tehran, a semiarid city.	-SCP plugin in QGIS NVDI index	District 6:21.4 km^2 District 22:58.5 km^2	While both area and vegetation cover impact parks of all sizes, the shape of parks becomes particularly significant for those larger than 1 hectare in open-built zones.
[55]	**Abu Dhabi, UAE**	Downtown, Mussafah, Khalifa City A and a sandy surface	Vegetation area	Exploring the correlation between land cover and trends in land surface temperature (LST) in the desert environment of the United Arab Emirates.	NVDI index MODIS data ASTER data	Not mentioned	Temperatures downtown are typically 5–6 Kelvin lower on average compared to suburban areas, particularly during peak heat.
[56]	**Erbil city in Iraq**	Several parts of city have different land uses and land cover	-Dense Trees -Scattered trees Grass	Analyzing the formation of the daytime Surface Urban Cool Island (SUCI) effect in Erbil city.	-ENVI software -LST map -Correlation analyses	Not mentioned	In certain cities such as Erbil, surface wetness primarily dictates the Urban Cool Island (UCI) effect during the dry season rather than vegetation cover.
[57]	**Isfahan, Iran**	Several areas of the city have different land uses and land cover	The five stations: -a city park: -residential, agricultural area, -sparsely forested park, -residential area, -commercial residential area	Examining the impact of urban land use on changes in air temperature in an arid city.	-Local Climate Zone -SPSS (IBM Corp. released 2010, Version 19) -Correlation analyses	75 ha sparse forest park + 8.2 ha garden area	Changes in land cover/ use in arid cities can either increase or decrease canopy-level air temperatures.
[58]	**Hermosillo**	Randomly selected 48 AGEBs or 10.9% of the Hermosillo area	Vegetation Cover	Investigating the relationship between unpaved surfaces and total suspended particles (TSP), daily temperature oscillation (DTO), and vegetation cover.	-ArcGIS 10.1 -T-tests -multiple linear regression analyses	Not mentioned (10.9% of the Hermosillo Area)	Increased vegetation cover reduces temperature fluctuations and air temperatures during summer at the neighborhood level in Hermosillo.
[59]	**Lake Valley (SLV), northern Utah, USA**	Five different urban parks (Hunter et al. Ridge and Sugar House)	(1) green turf grass (2) trees (3) roofs, dead/brown turf grass, bare soil, and impervious surfaces	Assessing the influence of turf grass cover compared to tree shading on spatial and temporal variations in microclimate in a semiarid urban area.	-Relative humidity (RH) sensor -Estimate sky -View factor (SVF) -Handheld infrared thermometer -FLIR Tools and **R** software -Linear regression	Five urban park : 135+110+90 +161+500 (whole zone area:17.5 km by 15.4 km)	The conversion of vegetation to impervious surfaces contributes to microclimatic uniformity.
[60]	**Ankara, Turkey**	Four city parks	Vegetation Cover	This study aims to assess the effect of four city parks in Ankara on the urban heat island phenomenon.	-NVDI index -LST map -Linear regressions -ArcGIS	Four urban park with: -606,591 m^2 -278,487 m^2 -120,506 m^2 -65,000 m^2	Urban parks have been observed to decrease temperatures in the surrounding areas locally.
[61]	**Abuja, Nigeria**	Three urban parks	Not mentioned	Evaluate the cooling impact of green parks on the urban microclimate of Abuja by applying geospatial methods.	-NVDI index -LST map -Park cooling intensity (PCI) -linear regression	3urban park: 143.0ha + 2.09ha + 6.37 ha	The shape of urban parks had a strong negative correlation with PCI intensity, indicating that as the complexity of the park shape increases, PCI intensity decreases.
[62]	**Ankara, Turkey**	Three types of green areas urban park and one green space in Ankara University	-Trees and shadows of trees -Grass	Highlight the impact of various types of green areas on the climate of Ankara.	-Air temperature and humidity and point measurements -A one-way variance analysis -F Test	Urban parks: -642000 m^2 -100 000 m^2 Green space in the University: -10 400 m^2	When appropriately designed and positioned, green areas within residential zones can create distinct microclimates in terms of temperature and humidity values, regardless of their size.
[63]	**Mendoza, Argentina**	Three representative squares	Not mentioned	Suggest combinations of variables (such as vegetation, materials, green-sealed ratio, and layout of pathways and spaces) to design squares effectively.	T-HR sensors -Mobile measurements -Sky view factor (SVF) -COMFA method	11699 m^2 + 11995.28 m^2 +7358.51 m^2	Although green spaces are crucial for the sustainable development of cities in arid regions, the design criteria for squares must be carefully considered to ensure and maximize their benefits.
[64]	**Phoenix, Arizona, USA**	Seven urban residential parks	Six landscape tree taxa and constructed ramadas	Evaluate the ability of natural and artificial shade to enhance outdoor human comfort during typically hot summer midday conditions in desert environments (from 1200 to 1400 hours).	-Portable Kestrel meters -Handheld infrared thermometer -Rayman model -Sky-view factor -Linear regression	Seven urban residential parks ranged in size from 3.7 ha to 47.5 ha	Choosing trees that most effectively block solar radiation is the best urban design strategy for reducing PET (physiological equivalent temperature) during typically hot summer midday conditions in desert environments.

ture. For instance, in an article titled "Seasonal Effect of Urban Parks on Land Surface Temperature (LST) in the Semiarid City of Tehran," various parks in districts 6 and 22 of Tehran were examined. These parks ranged in size from 0.04 hectares (the smallest) to 27.04 hectares (the largest) in district 6 and from 0.14 hectares to 979.58 hectares in district 22. The study finds that due to the larger average area of parks in region 22 compared to region 6, a greater cooling capacity is observed in region 22. Consequently, with the increase in cooling effect during spring, the maximum cooling of parks larger than 10 hectares in region 6 is 4.6 ℃, which is 1.9 ℃ higher than in region 22 (2.7 ℃). In contrast, the maximum cooling distance in region 22 is 270 meters, compared to 210 meters in region 6. These results highlight a correlation between park areas and the cover of vegetation cover within the parks, which becomes more significant during the spring and summer seasons, with a statistically significant linear relationship observed in both districts [54]. This correlates with the results from similar studies on the relationship between the NDVI of parks and the LST in semiarid regions like California (Dronova et al., 2018). Seasonal correlations have been significant as the overall level of vegetation cover increases in warmer seasons, resulting in more significant cooling effects because of shading and transpiration, among others. As a result, the study concludes that while both park area and vegetation cover influence their impact across all sizes, the shape of parks becomes particularly important in parks larger than 1 hectare in open-built zones [54].

A separate study conducted in Abu Dhabi, United Arab Emirates, compared four areas: Downtown, Mussafah, Khalifa City A, and a sandy surface using satellite and meteorological data to analyze the interactions between land cover and temperature in the city from 2000 to 2010. Another study in the city of Abu Dhabi in the United Arab Emirates compared four areas: Downtown, Mussafah, Khalifa City A, and a sandy surface of satellite data and meteorological data to investigate the land cover and temperature interactions of the city of Abu Dhabi (United Emarat) for the period 2000 – 2010 is analyzed Land surface temperature data from MODIS analysis revealed that the temperature in the city center was 5 – 6 degrees Kelvin lower on average than in the suburbs, especially during the hottest months. Normally, the central part of the city is expected to have higher temperatures due to the urban heat island effect. However, this reverse case is usually noticed in desert environments, just like this study tends to determine. Some of the major apparent reasons for this are that, in urban areas, particularly these arid cities, the vegetation coverage is often higher than that in the rural areas, which consist mainly of bare land and sand [55]. This finding opposes the typical expectation of higher temperatures in the central part of the city resulting from the urban heat island effect. In desert environments, such as Abu Dhabi, this phenomenon is often reversed, as shown in this study. The primary reason for this turnaround is that the vegetation cover in these urban centers is usually more than in the rural land, which is bare land and sand [55].

Another investigation was carried out in Erbil, Iraq. It focused on the spatial dynamics of the daytime Surface Urban Cool Island (SUCI) effect in Erbil city. This study serves as a representative case study for semiarid climate cities. The findings reveal that densely populated areas, including the central districts of the city's green spaces and water bodies, exhibited lower Land Surface Temperature (LST). These areas functioned as cool islands in contrast to the non-urbanized periphery surrounding the city.

Conversely, areas such as the airport, open spaces, and newly developed low-density housing on the outskirts displayed higher LST. This indicates an Urban Heat Island (UHI) effect. The study highlights a robust inverse correlation between surface temperature and wetness index. It suggests that the average surface temperature within the city's built-up areas is lower during summer daytime, particularly in the morning. This is compared to the mean surface temperature in a 10 km non-urban reference zone surrounding the city. Similarly, in dry seasons, such as in Erbil, surface wetness emerges as the primary determinant of the Urban Cool Island (UCI) effect superseding vegetation cover [56].

2.3.3 The impact of green infrastructure on a specific part of the city

In this type of study, instead of collecting climate data through satellite images, many of these studies focus on collecting climate data such as heat through meteorological stations, portable tools, other field collection tools, or Envi-tools. In Envi-Met, this information is simulated (However, in most cases, the information input to Envi-met is already collected by meteorological data collection devices or weather stations) (Table 3).

Some of these studies were done on a large scale (more than 10 hectares) and medium (1 to 10 hectares) and others on a small scale (below 1 hectare):

(A) Large Scale (more than 10 hectares) and Medium Scale (between 1 and 10 hectares)

These studies usually focus on large, medium-sized urban parks in a city region or district. For example, in Madrid, Spain, the cooling benefit of a central urban park was analyzed about the adjacent thermal comfort. Measurements made over hot summer days indicated that this 125-ha park can lower air temperatures by 0.63 ℃ at 150 meters distance and by 1.28 ℃ at 380 meters and 665 meters. Additionally, the physiologically equivalent temperature (PET) index at 150 meters was, on average, 2 ℃ PET lower than 380 meters and 2.3 ℃ PET lower than 665 meters. The study found an inverse correlation between distance from the park and the occupant's perceived thermal comfort (PTC); as distance increased, PET rose, and PTC decreased [65].

In another study in Phoenix, Arizona, by integrating geographic information systems, remote sensing, spatial statistics, and spatial optimization, a framework was developed to identify the best locations and configure new green spaces regarding cooling benefits. Adding green spaces could reduce land surface temperature by 1–2 ℃ locally and 0.5 ℃ regionally. The study concluded that clustered green spaces enhance local cooling due to the agglomeration ef-

Table 3. Studies related to the impact of green infrastructure on a specific part of the city.

Ref	Location	Green site & comparator	Features of green site	Purpose	Methods/ Instruments	Size	Conclusion
[65]	**Madrid, capital of Spain**	An urban park	Not mentioned	Examine the cooling effects of a large urban park on the thermal comfort of people near the main central park in Madrid, Spain.	-Questionnaire -Ray Man 1.2 software -SPSS software -Aram MMA software	125 ha	As the distance from the park increases, physiological equivalent temperature (PET) rises while perceived thermal comfort (PTC) decreases.
[66]	**Baghdad, Iraq**	Risafa, a municipality located at the center of Baghdad city	3 types of UGI: green horizontal surfaces of open urban spaces, green roofs, and green walls	This study aims to evaluate the effectiveness of urban green infrastructure (UGI) in mitigating the urban heat island (UHI) effect in Baghdad.	ENVI-met	0.09 km^2	The study shows that urban green infrastructure (UGI) effectively reduces Baghdad's urban heat island (UHI) effect, with cooling efficiency depending on surface conditions and the type and intensity of UGI assets.
[67]	**Phoenix, Arizona, USA**	An area of the city of Phoenix that consists of several low-income neighborhoods	-Tree -Grass	Develop a framework to identify optimal locations and configurations for new green spaces to maximize cooling benefits.	-ASTER imagery -Arc Gis -Correlation Analyses -Multiple regression	8,800 ha	Clustered green spaces enhance local cooling due to the agglomeration effect, whereas dispersed green spaces provide greater overall regional cooling.
[68]	**Tehran, Iran**	An urban park	-Pine and plane trees -Shrubs	Analyze the factors determining the thermal environment and explore strategies related to albedo and greenery in a medium-sized park.	-ENVI-met software -SVF -Ray Man software -Thermal cameras	2 ha	Field investigations and simulations reveal that vegetation coverage has a greater impact on thermal comfort than albedo.
[15]	**Lisbon, Portugal**	The Garden Teófilo de Braga is located in the city district	Not mentioned	Investigate the thermal performance of a small green space (0.24 ha) and its influence on the weather parameters of the surrounding atmosphere environment of a densely urbanized area in Lisbon	-Itinerant measurements -The meteorological station -Ray man software (PET analysis)	5795 m^2	The garden was found to be cooler than surrounding areas, both in the sun and shade, with temperature differences being more pronounced on hotter days.
[69]	**Nicosia, Cyprus**	An urban block	Trees	Assess how specific urban bioclimatic design concepts and strategies influence urban heat island intensity in Mediterranean semiarid environments classified as subtropical.	-ENVI-met -PV GIS	200 m 200 m	In semiarid conditions, using extensive vegetation in an urban block of 200 by 200 meters and reducing built-up areas by about 10% resulted in an air temperature decrease of 1.5 ºC during the summer.
[70]	**City of Baskar, Algeria**	A City Square (Revolution's plaza)	-Trees -grass	Evaluate the impact of vegetation on the urban microclimate at "Revolution Plaza" by measuring the local climate and comparing it with weather station data.	-ENVI-met -Testo 480 measuring device -Meteorological station -ArcMap	Not mentioned	The results indicate that trees and natural surfaces significantly reduce heat transfer and lower temperatures.

fect, whereas dispersed patterns result in greater overall regional cooling. This framework can guide planning decisions for green space allocation to mitigate excessive heat [69].

(B) Small Scale (below 1 hectare)

This category focuses on small green infrastructures such as parks, gardens, and urban squares, each covering less than 1 hectare.

One project in Lisbon, Portugal, assessed the thermal performance of a small green space (0.24 ha) and its influence on the surrounding atmospheric environment in a strongly urbanized context. Point microclimatic parameters such as temperature, relative humidity, wind speed, and solar and infrared radiation were measured from inside the green area and along a path to the surrounding streets. The results suggest that the garden is cooler than its surrounding street, both in the sun and shade. The largest differences occur on the warmer days and are particularly large for the mean radiant temperature (Tmrt). The largest differences between shaded sites inside the garden and sunny spots on east-west-oriented streets in the southern part of the study area are 6.9 ºC for air temperature and 39.2 ºC [15].

Another study in the same area in Kaimakli, an urban district in Nicosia, Cyprus, with very high intensities of urban heat island, investigated urban density, vegetation, soil sealing, building age and materials, land coverage ratio, and orientation. The study focused on assessing the effect of urban bioclimatic design concepts on the intensity of the urban heat island under Mediterranean semiarid conditions. This research claims that extensive vegetation in an urban block measuring 200 m by 200 m and measures in reducing built area by up to 10% reduce air temperature amid summer by 1.5 ºC during the summer solstice at 15 h. This paper shows that specific urban bioclimatic design strategies have great potential in reducing the UHI, especially at nighttime.

2.4 Types of green infrastructure studied at different scales

The analysis of the studies that focused on the scale of the whole city showed that, in general, these studies included 11 categories of green infrastructure, studies that focused on several parts of the city, 5 categories of green infrastructure, and studies that focused on one the parts of the city were focused on 6 categories of green infrastructure. Fig. 5 shows this category along with the number of reviews of each one.

3. Analysis and discussion

In our research, we examined the impact of green infrastructure on climate resilience and thermal comfort in arid and semiarid climates. Given the intense heat in these regions, natural cooling methods like green and blue infrastructures are particularly crucial.

However, studies on the impact of green infrastructure in arid and semi-arid cities are less compared to cities with different climates, the number of cities with this climate is less than cities with other climates, and therefore it was necessary to categorize them.

Initially, we categorized these studies by geographical region, followed by their thematic focus, and finally grouped them into three main categories based on the scale: 1) city-wide green infrastructure studies, 2) studies examining green infrastructure in multiple city areas, and 3) studies focused on specific city sections. These were further divided into large (over 10 hectares), medium (1 to 10 hectares), and small (under 1 hectare) scales. Studies addressing city-wide or multi-area green infrastructure predominantly used remote sensing and satellite data. At the same time, those focusing on specific parts of the city primarily relied on climate data collected via meteorological stations, mobile devices, or other field tools, with a few utilizing ENVI computer simulations.

Overall, the research on green infrastructure's impact on thermal conditions in arid and semiarid cities prioritizes city-wide or large-scale studies, followed by multi-area

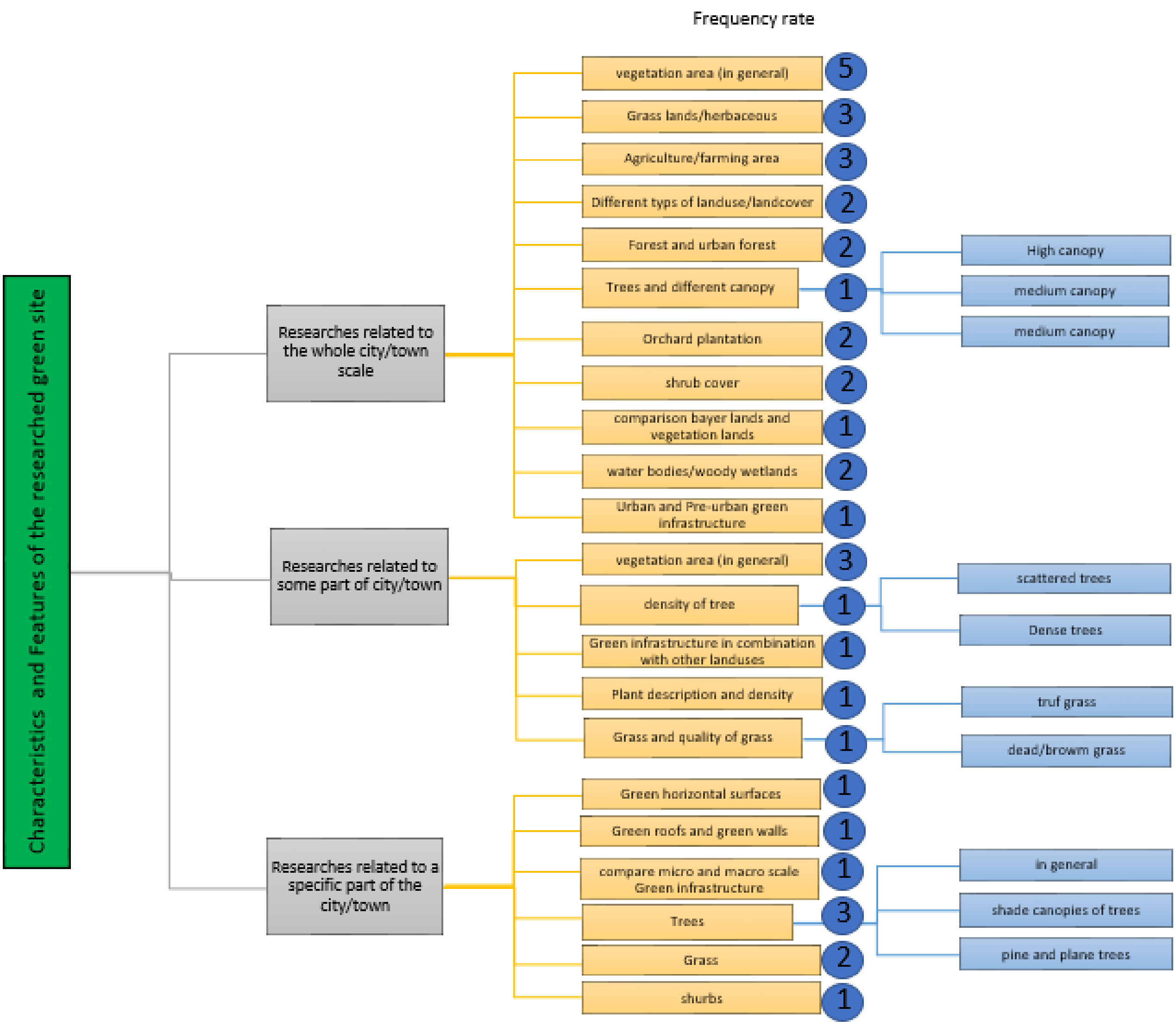

Figure 5. Types of green infrastructure studied at different scales.

studies, and finally, studies on specific city parts. Many of these studies have been conducted in developing or less developed countries, which face greater vulnerability to extreme climatic conditions. This vulnerability is expected to increase with global warming and climate change.

Developing green infrastructures, particularly over large areas, can significantly improve environmental conditions and enhance thermal resilience in arid and semiarid cities. Nonetheless, medium- and small-scale green infrastructures should be considered. Even small parks, with their limited size and low construction costs, can significantly improve local thermal conditions. For instance, in Kaimakli, Cyprus, a study found that reducing built-up areas by about 10% in a 200-square-meter urban block led to a 1.5 ºC decrease in air temperature during summer, highlighting the vital role of small green infrastructures [69].

Studies on green infrastructures about improving the environmental temperature conditions in medium and small areas are less than large infrastructures in arid and semiarid areas, and there is a lack of such studies, especially on small infrastructures such as parks is well felt. Some of studies have been done in small and medium-sized infrastructures in cities with arid and semiarid climates with the ENVI-met tool, which is a climate simulation tool, and they are less reliable without the use of validation tools such as climate data measuring devices and weather stations. Also, since in semiarid and dry regions, the development of green infrastructure is limited due to climatic conditions and lack of water resources, the role of these infrastructures in creating environmental cooling should be calculated and measured more precisely. However, studies at large levels, such as the city, are often done without considering the type and characteristics of the vegetation cover, and therefore, the role of green infrastructures in this thermal resilience has yet to be accurately calculated.

One of the other factors that affect the performance of green infrastructure in dry and semiarid areas is the lower humidity of these cities. This characteristic makes the role of green infrastructure in creating better temperature conditions in semiarid and arid regions more than in other climatic regions. The lower the air humidity, the greater the effect of these infrastructures in reducing the environmental temperature. For example, research conducted in Los Angeles metropolitan areas showed that across the coastal to urban climate gradient, the cooling capacities of vegetation increased, and the importance of vegetation availability peaked in inland areas. This suggests that the most effective areas for using vegetation as an adaptation strategy are inland areas of cities compared to coastal areas [51].

Conversely, in areas with extremely low air humidity, such as dry and desert regions, the temperature in the city center is lower than in the surrounding desert areas. In desert environments, the typical heating phenomenon is often reversed. For instance, a case study in Abu Dhabi, UAE, demonstrated that the temperature in the city center is generally $5-6$ K lower than in the suburbs, particularly during the hottest months. Normally, the central part of a city is anticipated to have higher temperatures due to the urban heat island effect. However, in this context, more vegetation and higher humidity levels in urban areas than the surrounding desert areas leads to a different approach to green infrastructure planning for these cities [73]. Fig. 6 illustrates the differ-

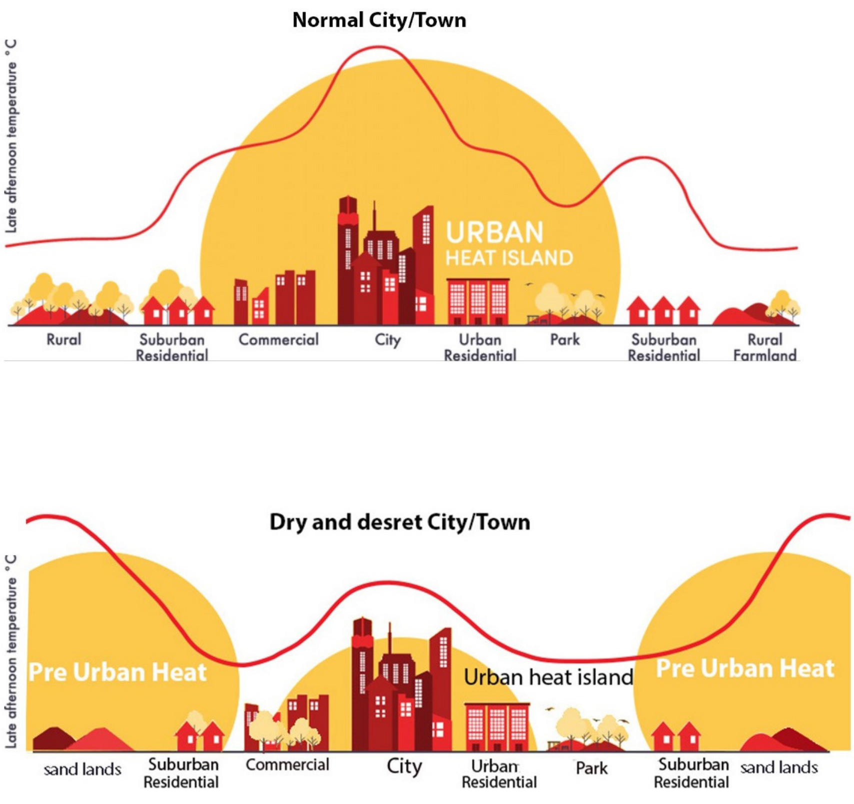

Figure 6. Differences Normal City and Desert City in Urban heat spatial pattern
Top image: ([71], [72]), Down image: Authors.

ences in urban heat patterns between a normal and desert city.

Considering the role and importance of humidity performance in dry and semiarid cities, it is necessary to consider levels of vegetation and water levels together to achieve the best performance as the best cooling strategy for such cities. One of the big caps of research in the studies of green infrastructures in creating better temperature conditions in dry and semiarid cities is that in most studies, the role of infrastructures has been evaluated independently of water bodies and water infrastructures. On the other hand, the health of the vegetation, the amount of transpiration based on the type and material of the cover cover cover and the humidity level of the green infrastructure have a very decisive role in the cooling rate of the green infrastructure in dry and semiarid cities, which were not addressed in any of the studies reviewed in this research. The summary of the analysis of studies is shown in Fig. 7.

4. Conclusions

Nowadays, many cities are facing various environmental challenges, including global warming [74]. Green infrastructure is recognized as an effective solution to mitigate urban heat. However, despite its benefits, research on the cooling effects of green infrastructure in semi-arid and arid cities worldwide is scattered. Much existing research has focused on broad aspects of green infrastructures, such as vegetation or large-scale landscaping, neglecting the specific attributes and integration of green infrastructures with diverse urban environments. In addition, due to the lower humidity in these cities, the cooling capacity of green infrastructures in these cities is greater than that of cities with moderate and humid climates and hot and humid ones. Despite such advantages, the research conducted in semiarid and arid cities of the world is limited. Most of this limited research has also investigated the generalities of green infrastructures such as vegetation or trees and lawns on a large scale and has less focused on the specific features and details of green infrastructures, as well as the combination of urban green infrastructures with different urban forms. Without considering such important factors, it is impossible to calculate urban green infrastructure's cooling capacity accurately. The importance of more accuracy in such a calculation is greater because dry and semiarid cities in many cases, due to the lack of water resources due to climatic conditions, also face the development of green infrastructures, and the cooling capacity of green infrastructure in these cities should be used to the maximum.

What is certain is that for better performance in planning and managing urban green infrastructure (UGI) in arid and semiarid cities, any development regarding these infrastructures should be based on how they improve the environmental temperature conditions of cities and the climatic comfort of citizens. Also, although large green infrastructures significantly improve the temperature conditions of cities, the contribution of small and medium infrastructures, such as urban parks in dry and semi-dry cities, should not be neglected because the development of such spaces is often faced with less intervention and cost.

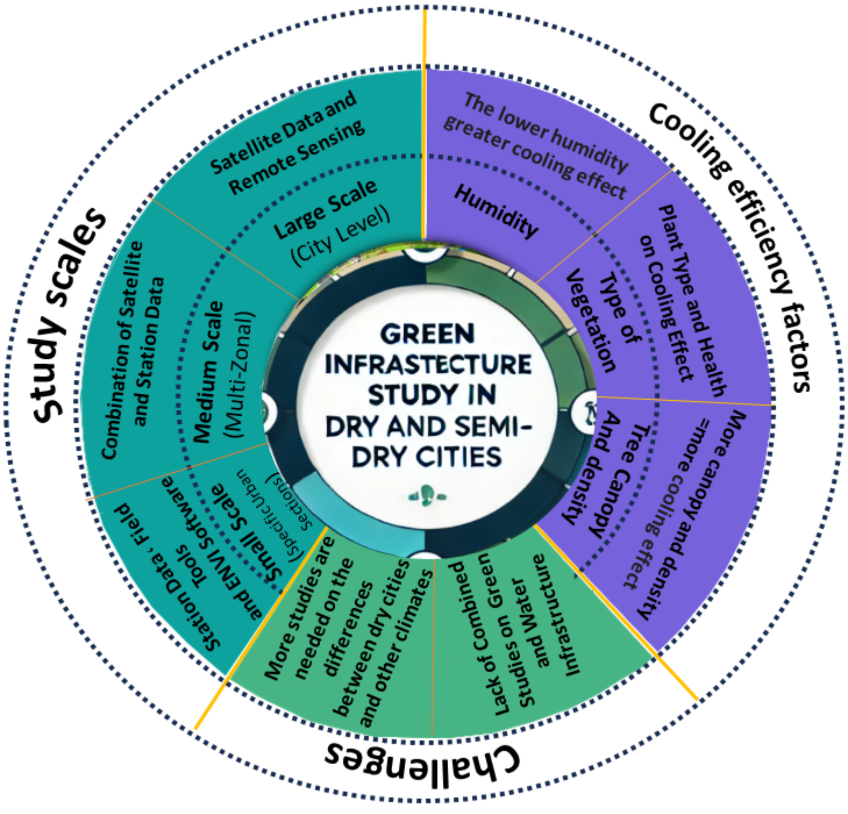

Figure 7. Summary graph of analysis studies ON green infrastructure impact in arid and semi-arid cities.

As was shown in the study in Algeria, the combination of trees and their shade causes the temperature to decrease by more than 3 degrees in a small green space like a small city square [70].
Along with the development of such infrastructures, the cooling capacity of existing green infrastructures in dry and semiarid cities increased by changing the type of cover and structural features of plants and tree canopy. Of course, all these things should be based on the available facilities and potential and the type of climate of the area. In addition to all these cases, the urban green infrastructure program, based on its cooling capability, should be considered part of urban land use planning in dry and semi-dry cities to achieve the most optimal result.

Authors contributions
Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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