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RESEARCH PAPER

Optimizing Urban Cooling: A Comparative Analysis of Green Infrastructure in Peshawar

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ABSTRACT

Current research analyzes the efficacy of several green infrastructure components in reducing the urban heat island effect in Peshawar city, KPK. It focuses on three public squares that have different forms of GI. Lack of planning for urban open and green spaces have negatively impacted cities and resulted in poor life quality, hence these must be evaluated for intervention planning. By integrating Land Surface Temperature information with on-site observations, simulations, and vegetation maps, overall research direction was established. Research highlighted intricate interactions among many GI characteristics. The study enlightened that while grass alone provides only marginal cooling effects (0.4–0.8°C), strategically combining trees with creative fountain design may dramatically lower urban temperatures (up to 6°C) relative to neighboring regions. GI's contribution to UHI mitigation is enhanced by these research findings, which offer useful resources for urban planners and designers. Simulations and further evaluations are proposed.

KEYWORDS Green Infrastructure, Green Spaces, Land Surface Temperature, Landscape Design, Urban Centers

Introduction

The Urban Heat Island (UHI) effect, characterized by significantly higher temperatures in urban areas compared to rural surroundings, presents a growing challenge, particularly in hot regions (Oke, 1982). This phenomenon arises from factors like reduced vegetation cover and increased absorption of solar energy by impervious surfaces, leading to detrimental consequences for public health and air quality (Khan & Rehman, 2019).

Peshawar, Pakistan's urbanization boom has exacerbated its UHI effect, making it one of the country's hottest cities (PBS, 2017). While traditional green infrastructure elements like parks and trees have been deployed, their effectiveness in mitigating UHI within this hot, arid context remains unclear (Benedict & McMahon, 2006). This lack of clarity is further emphasized by the geographic bias in existing UHI research, with 83% of studies originating from the northern hemisphere, leaving areas like Peshawar understudied (Bartesaghi Koc & Osmond, 2017).

Data analysis reveals that most UHI research (79.6%) has focused on Asia, Europe, and North America, with significantly less attention paid to Oceania, South America, and Africa (Bartesaghi Koc & Osmond, 2017). This geographical imbalance highlights the need for research aimed at understanding and tackling UHI in understudied regions like Peshawar.

Therefore, this study seeks to address the specific challenges posed by UHI in Peshawar by:

- Assessing the effectiveness of traditional green infrastructure elements like parks and fountains in mitigating local UHI effects, as documented by Benedict & McMahon (2006).
- Considering the unique climatic and urban characteristics of Peshawar, including its hot, arid climate and rapid urbanization, as described by PBS (2017).
- Bridging the gap in UHI research regarding tropical regions, as identified by Bartesaghi Koc & Osmond (2017), to provide evidence-based strategies for sustainable urban development in Peshawar and similar cities.

Literature Review

Urban heat island effect has become a major problem for cities all over the world, especially for Peshawar, whose population is growing and its urbanization is happening very quickly. The term "urban heat island" describes the phenomena wherein urban regions, as a result of built environment alterations, suffer greater temperatures than the surrounding rural areas. The ensuing high temperatures may have a detrimental impact on the air quality, energy use, urban microclimate, and the health of city people. Parks, green roofs, and urban forests are examples of green infrastructure that has been highlighted as a potential way to improve urban sustainability and lessen the impact of the urban heat island effect (Khan & Rehman, 2019).

The phenomenon known as a "urban heat island" (UHI) occurs when nearby rural regions are noticeably colder than metropolitan areas. UHI is becoming a bigger issue, particularly in hotter areas where it can have detrimental effects on the environment and human health. Urbanization-related changes to land surfaces, such as the replacement of natural vegetation with impermeable surfaces like concrete and asphalt, are a major contributor to urban heat island (UHI) effects. Surface temperatures rise as a result of decreased evapo-transpiration and greater solar energy absorption and re-radiation. Oke (1982) asserts that metropolitan areas with high construction densities, little plant cover, and large amounts of impermeable surfaces often have a greater impact on urban heat island effects. Anthropogenic heat emission from human activities including industry, buildings, and transportation is another important source of UHI (PBS, 2017).

One of Pakistan's biggest and fastest-growing cities, Peshawar is rapidly urbanizing and has a high population density, which contributes to a notable UHI impact. The urban microclimate of Peshawar has warmed up due to the UHI effect, which has an impact on the residents' health and well-being. being a large industrial metropolis whose industries include the processing of food and the production of paper, cardboard, cardboard, textiles, cigarettes, and weapons. Additionally, it is a significant hub for Pakistan's steel sector (Alam et al., 2011b).

A survey conducted by the tourism department of Khyber Pakhtunkhwa states that Peshawar sees a sizable influx of visitors annually. The mild weather in Peshawar may be a welcome departure from the regular climate for travelers from colder countries, especially those from Europe, and may enhance their appreciation of the city's numerous attractions. Warmer weather draws more tourists, which can boost a company's earnings. Additionally, there may be advantages to public health from the UHI effect. For example, since warmer air is less likely to cause asthma episodes, higher temperatures can lower the incidence of respiratory conditions like asthma (Bartesaghi Koc & Osmond, 2017).

The association between temperature and the spread of COVID-19 has been the subject of several research, some of which have shown that high temperatures may reduce the disease's occurrence. For instance, a research that was published in the journal Science of the Total Environment discovered that a one-degree Celsius increase in temperature was linked to a 3.08% drop in the number of new COVID-19 cases reported each day in 50 different countries worldwide (Tosepu et al., 2020). But other research has produced contradictory findings, and it's crucial to remember that there are other variables that might affect how quickly the illness spreads, including temperature (Benedict & McMahon, 2006).

In a nutshell urban areas are impacted by the UHI effect in both good and bad ways. In the winter months, it can result in lower energy use, more economic activity, and better public health; but, in the warmer months, it can also cause higher energy use, worse air quality, and diseases linked to heat. Policymakers should take into account the UHI effect's advantages and disadvantages when deciding how to develop and construct metropolitan areas. Although the impacts of urban heat islands (UHIs) have been thoroughly investigated, much more study is needed to fully comprehend how UHIs affect urban microclimates. Small-scale changes in humidity, temperature, and wind patterns that take place in metropolitan environments are known as urban microclimates (Sailor, 2011).

Material and Methods

To comprehensively assess the effectiveness of trees, grass, and water fountains as urban heat mitigation strategies in Peshawar, this study employed a multi-pronged quantitative approach. GIS- based spatial analysis, utilizing Land Surface Temperature (LST) visuals and Normalized Difference Vegetation Index (NDVI) data, pinpointed urban heat hotspots and explored potential relationships between temperature and vegetation cover. Fieldwork in select public squares, meticulously measuring temperature, wind patterns, humidity levels, urban morphology, and vegetation types, further enriched the dataset. Envi-Met microclimate modeling software then took center stage, simulating various scenarios with different green infrastructure configurations to virtually assess their cooling effectiveness. This robust methodological trinity – geospatial analysis, field data collection, and microclimate simulation – provided a multifaceted lens through which to evaluate the urban heat mitigation potential of the three green infrastructure options in Peshawar.

Study Area

One of the largest metropolitan areas in Pakistan in terms of both people and size, Peshawar as a city, has rapidly become more urbanized, which has raised temperatures and created the effects of an urban heat island. The steppe nature in the area influences Peshawar's climate, which is classified as hot and semi-arid (Köppen BSh). Long, hot summers and short, warm-to-cold winters are common in the city.

The summer months, which start in mid-May and last in mid-September, are quite hot in Peshawar. The mean maximum temperature in the height of summer is frequently more than 40 °C (104 °F), while the mean minimum temperature is about 25 °C (77 °F).

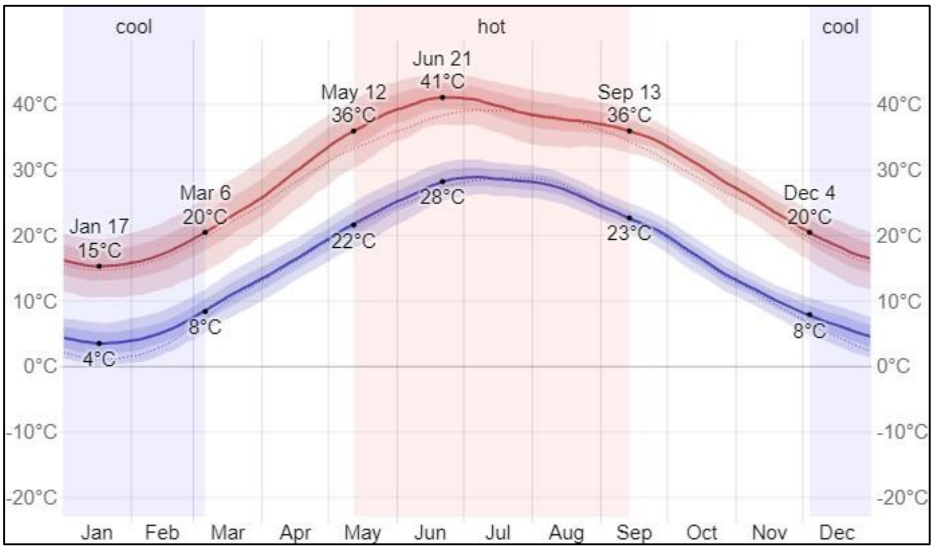

Figure 01 Average High and Low Temperature in Peshawar. Source: WeatherSpark.com

Three public squares are selected in Peshawar based on user's numbers, Availability of Green Infrastructure (GI) Types, buildings materials on sites, Peshawar city government intention of development under city improvement & beautification scheme. Public squares were selected not very far from each other due to easy logistics & more GI variations in less distance.

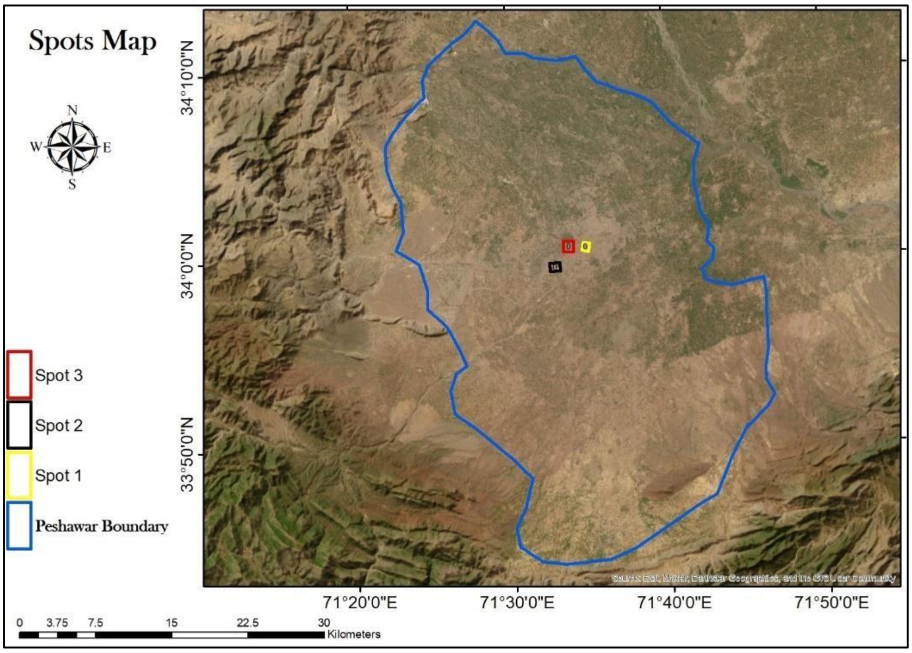

Figure 2. Sites for study, Google Earth. (2023)

Site 1 is distinguished by a historically significant public square that is planted with trees. The presence of historic elements, which are mostly made of stone and lime and represent the rich architectural legacy of the area, further distinguishes this area. Given that site one has a unique climate with temperatures reaching 45 degrees Celsius, it was chosen as a suitable location for the study.

Figure 3. Chowk Yadgar a historical public square

An urban green open space distinguishes **Site 2**, adding to the area's allure from an environmental standpoint. With building materials ranging from steel to cement and stone, the diversity in construction is clear and demonstrates a fusion of classic and modern architectural techniques. The high density of this area contributes to its lively and busy status as a city neighborhood. Site 2 is a notable region for research because of its unusual blend of dense urban fabric, various construction materials, and natural areas.

Figure 4. Location of public Site-2 in Peshawar, 34° 0'7.39"N, 71°31'4.40"E

Site-3 is a roundabout surrounded by traffic & commercial activities. Residents of the area use the site as public square in evening. Lesser number of small trees are on this site, all the area is covered by grass.

Figure 5. Roundabout as a public square in Site-3 Peshawar

Data Collection

LST & NDVI data: LST values in degrees Celsius were extracted. Engaged tools included GIS software and Landsat 8 OLI/TIRS files, adhering to a prescribed protocol based on the review of literature. Between 2019 and 2021 i.e. an overall of three-year period, this data was gathered for Peshawar. Prior to 2019, there was a Bus Rapid Transport infrastructure project in Peshawar city as a major large scale project in development sector that was initiated in 2017. As a result, there were major engineering, design and planning based activities which culminated into construction activities impacting and hence affected the LST data. As such, during the study, the effect of this construction component was considered as a major aspects and thus was taken into account.

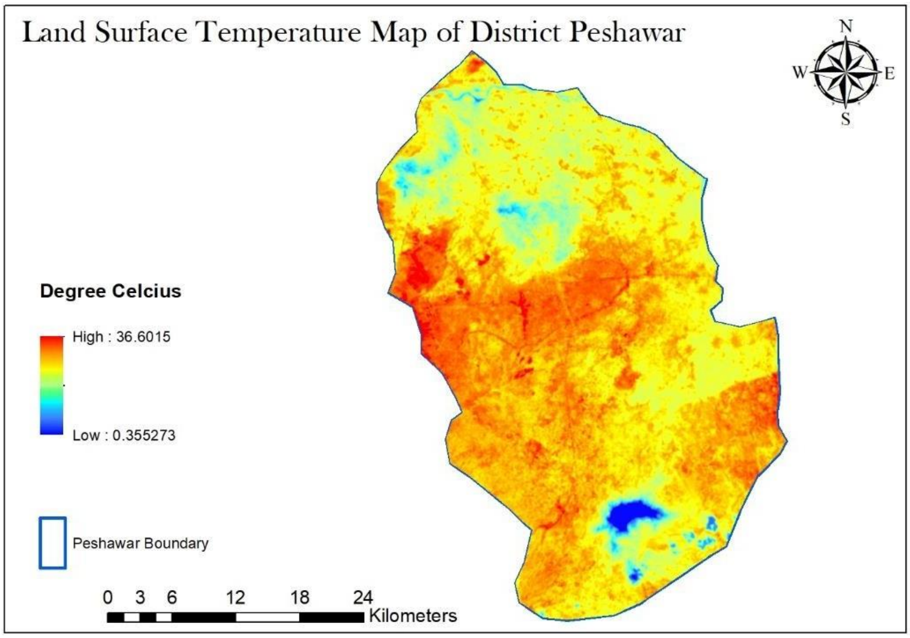

Figure 6. LST map for Peshawar. Source: Satellite Landsat 8, 20 June 2020, 12:00 PM

Several of the hotspots are easily evident on the LST map. Higher temperatures prevail in these hotspots, which can be attributed by a number of variables including deprived albedo materials, an absence of flora, and urban infrastructure. The LST map also displays areas with lower temperatures in contrast to the hotspots. These greener spaces typically exist near mountains, bodies of water, or any housing developments with well-planned designed parks and trees.

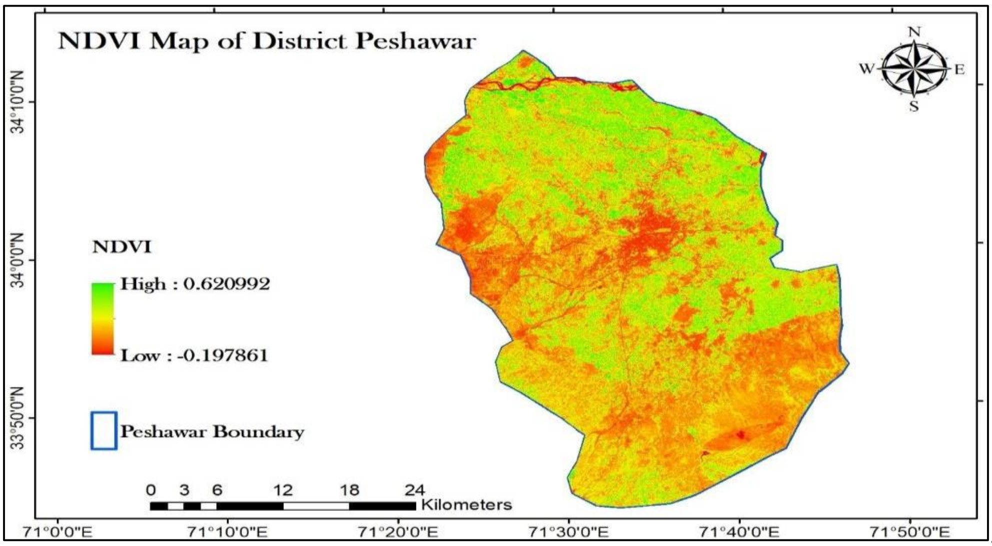

Figure 7. NDVI map of Peshawar

It may be deduced from the above NDVI map that regions devoid of green infrastructure or vegetation typically show higher temperatures (hotter) on the Land Surface Temperature (LST) map. There is an inverse correlation between NDVI and LST as indicators of vegetative health and density. Higher LST values, which indicate higher surface temperatures, are more common in areas with lower NDVI values, which show sparse or stressed vegetation. According to this connection, regions with sparse or underdeveloped vegetation may absorb more heat and have less of a cooling impact, which would raise the temperature on the LST map. As a result, having enough greenery and vegetation cover may be extremely important for reducing heat and fostering a cooler urban atmosphere.

On-Site Microclimate Measurements: In June 2023, observations were made in three public squares located around Peshawar (see figure 09). The Tinytag Plus 2 air temperature and relative humidity recorder, which is renowned for its precision and dependability, was used to keep track of temperatures with meticulousness.

Figure 8. Locations for fieldwork

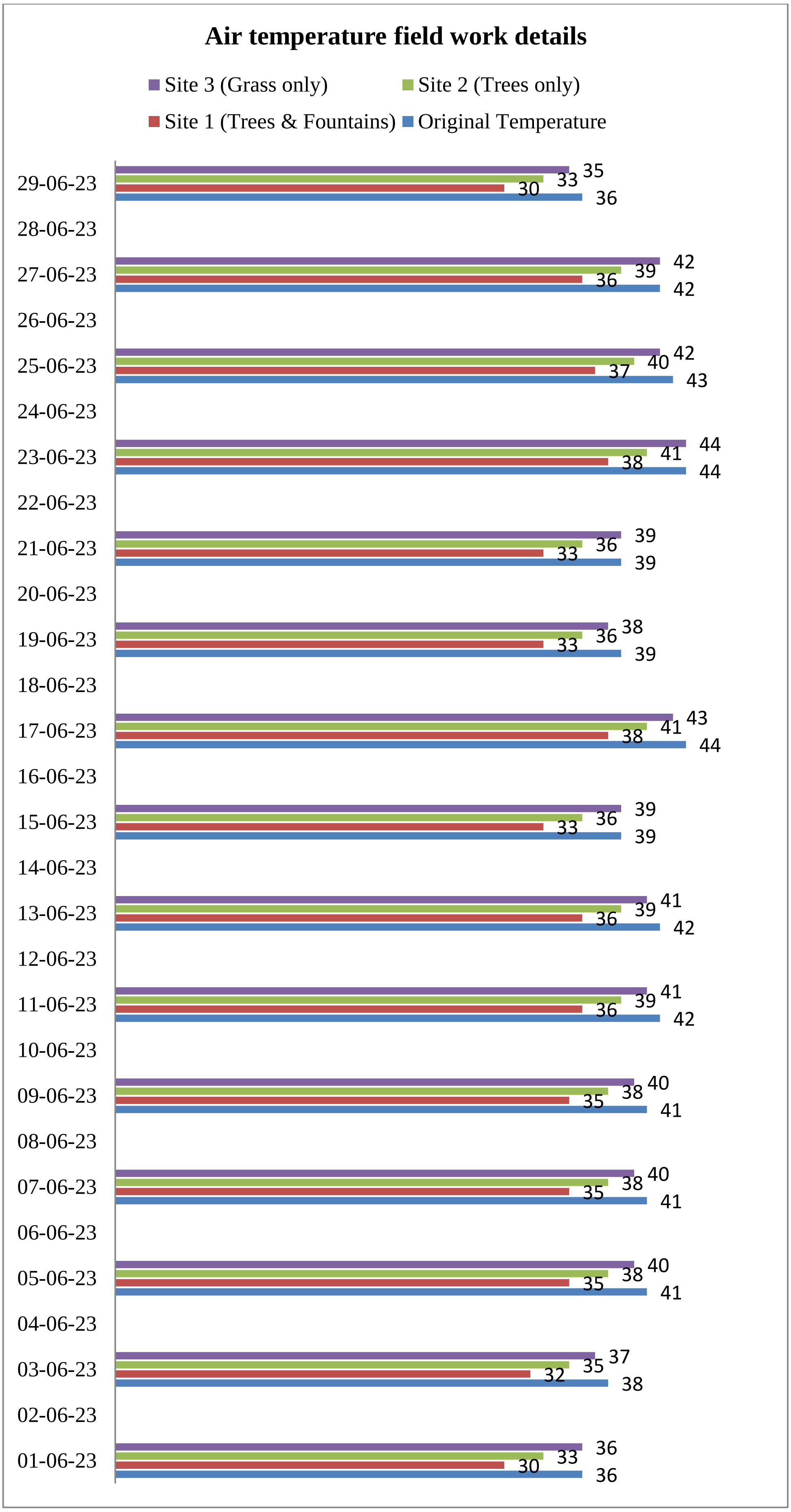

Figure 09: Air temperature field work details

The data recording device was safely installed at the specified locations on a steel signboard pole that was available, three meters above the ground. Protective measures were put into effect to lessen the hazards of exposure to direct sunlight and possible damage. The foil shielding the electronics served as a protective barrier against the weather. An additional degree of protection and supervision was added by carefully positioning the data recorders in front of accessible security cameras, especially in commercial environments.

Analysis

Three public squares had different temperatures measured using the Tinytag device. The fountain-designed square, which was supposed to provide evaporative cooling, had the least amount of cooling impact, as the graph demonstrates the unexpected findings. On the other hand, the square with grass had very little impact on cooling, defying expectations.

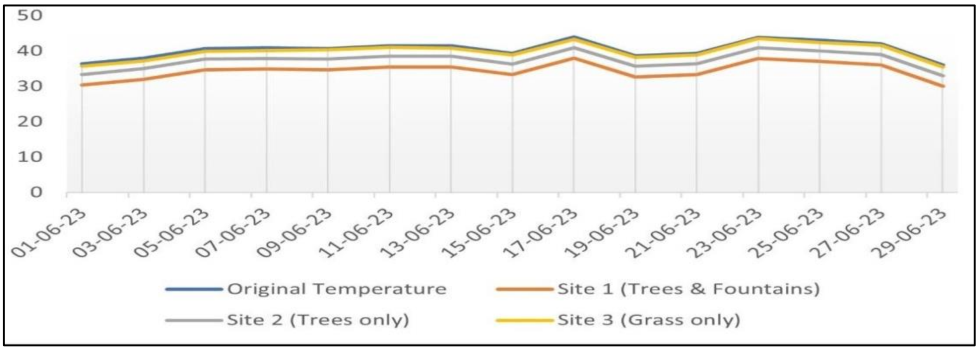

Figure 10. Temperature variations across sites with different GI.

As of present time, the blue line depicts Peshawar's initial temperature, which ranged from 35°C to 45°C on odd days in June. Site 1 (trees and fountains) is represented by the orange line, which indicates a drop in temperature of up to 8°C. Site 3 (grass only) shows a drop in temperature of 0.4 to 0.8 degrees; the gray line indicates Site 2 (trees only), demonstrating a reduction in temperature of up to 3°C, as required.

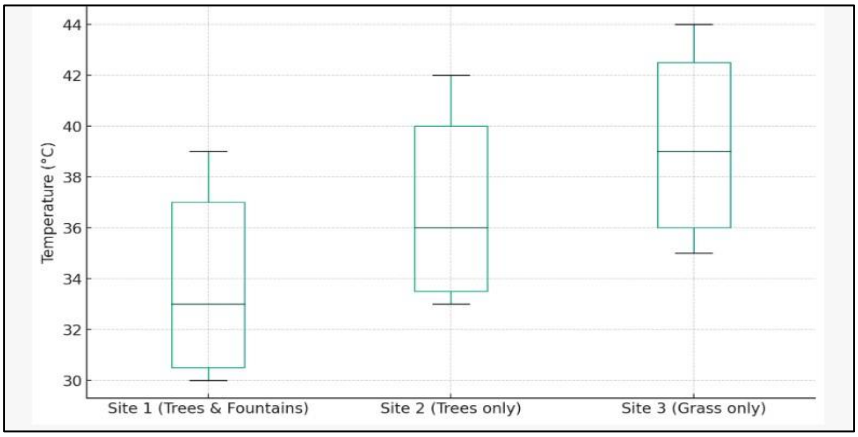

Figure 11. Box plot of temperature reductions

The box plot displays each location in Peshawar a visual depiction of the distribution of temperature drops. It provides information about the central tendency and variability of the data by displaying the median, quartiles, and possible outliers.

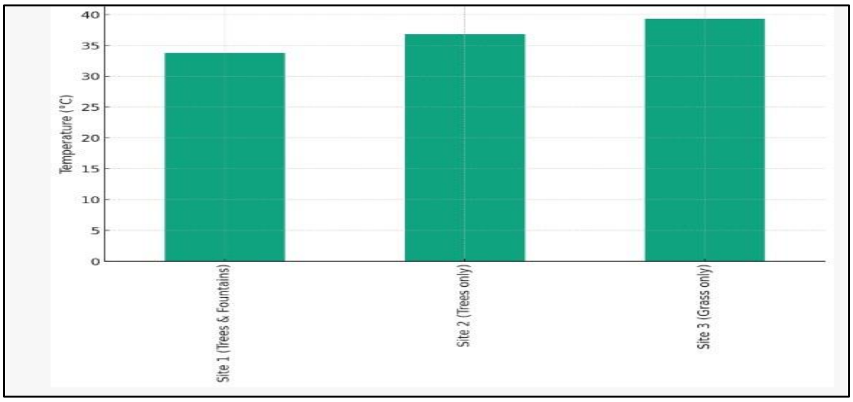

Figure 12. Average temperature reduction of each site

Analysis of ENVI-Met Simulations:

ENVI-met simulations were conducted to assess the potential thermal implications of replacing traditional landscaping elements (soft scaping) with hardscape features (concrete pavements) in public squares. This scenario represents a potential design decision currently under consideration by the government. The simulations aimed to quantify the temperature variations that might occur in the absence of vegetation within these squares.

Results indicate a significant rise in temperature (35°C to 42°C) when vegetation is absent. This increase is primarily attributed to the inherent properties of concrete pavements, which readily absorb and retain heat. The widespread implementation of hardscape, as envisaged in the proposed plan, is likely to exacerbate this effect, leading to microclimatic alterations within the public squares.

The absence of soft landscaping elements not only elevates temperatures but also eliminates the moderating effects of vegetation. Transpiration processes and shading provided by trees and shrubs contribute to temperature regulation, creating a more comfortable microclimate for pedestrian activities within the squares.

This thermal analysis highlights potential concerns associated with the proposed design decision, emphasizing the importance of balancing aesthetics with thermal comfort in public spaces. Further considerations should include exploring vegetation-inclusive hardscape designs or alternative materials with lower heat absorption coefficients to mitigate the predicted temperature increases.

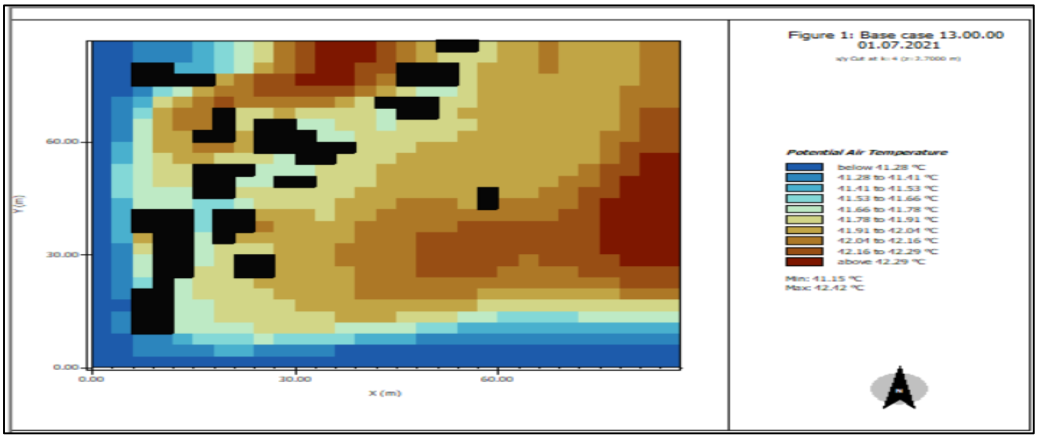

Figure 13. Envi-met simulation to show site-1 as hard scape example.

Conclusion:

Site-1: Multifaceted Design and Enhanced Cooling

- Characterized by flower planters, concrete planters, and bi-monthly operated fountains, creating evaporative cooling.
- Denser tree cover compared to Site-2 further enhances cooling, reducing surrounding temperature by 6°C within a 25-foot radius.
- Fieldwork data demonstrate the effectiveness of diverse elements in achieving both aesthetic and ecological objectives.

Site-2: Similarities with Differentiating Tree Density

- Similar to Site-1 in having trees, contributing to temperature reduction.
- Denser tree cover in Site-1 translates to a more pronounced cooling effect compared to Site- 2.

Site-3: Limited Ecological Impact Despite Aesthetic Value

- Roundabout featuring solely grass, primarily serving aesthetic purposes.
- Fieldwork data reveal negligible impact on cooling due to the absence of shade, limited evapo-transpiration, and lack of water features.
- This example underscores the limitations of relying solely on grass for microclimate improvement

Recommendations

Combating urban heat and fostering sustainable development requires a multifaceted approach, where strategic green infrastructure plays a pivotal role. By integrating trees and fountains within urban environments, we can create multifunctional spaces that tackle the Urban Heat Island (UHI) effect, nurture biodiversity, and enhance public spaces.

This holistic strategy cools urban areas, improving comfort for residents while conserving water and promoting sustainability through rainwater-powered fountains. Timed operation during peak heat amplifies their cooling effect, crafting urban oases.

To ensure success, community involvement is crucial. Green infrastructure must align with local needs and values, adapting to feedback and continuously monitored to fulfill evolving community and environmental goals.

Urban design innovation is crucial, going beyond park fountains and avenues lined with trees. Green walls and living facades are useful architectural features that provide aesthetic appeal as well as environmental advantages including noise reduction, air purification, and temperature control. Building forms and urban landscapes may create dynamic, ecological habitats that connect ecology, utility, and aesthetics by including vegetation and water features.

For nature to be smoothly incorporated into the urban fabric, architects, urban designers, and landscape architects must work together and experiment. The ability to create living ecosystems within buildings and cities through building-integrated vegetation and inventive green design holds great promise for improving human well-being and fostering a more sustainable urban future.

- Diverse green infrastructure elements, such as trees, fountains, and planters, can collectively enhance cooling and public comfort.
- Site-1 exemplifies a successful integration of aesthetics and ecological functionality, serving as a model for future urban design.
- Site-3 highlights the need to move beyond purely aesthetic considerations and prioritize elements with tangible environmental benefits.
- Urban planning should adopt a holistic approach, balancing visual appeal with microclimatic and ecological factors for sustainable and resilient urban environments.

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