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A Comparative analysis of the Cooling effects of Green Infrastructure Types on Peshawar's Urban Microclimate in selected public squares.

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Degree: Master in Urban Climate & Sustainability

Abstract

This thesis conducts a comparative analysis of the cooling effects of green infrastructure (GI) types in Peshawar's urban microclimate, with a focus on three selected public squares. Utilizing Land Surface Temperature data, on-site microclimate measurements, ENVI-met simulations, and NDVI maps, the study reveals the unique interplay between different GI features

Three sites with varying green infrastructure (GI) types were selected to study temperature variations on different days during summer, with the goal of identifying effective GI types to mitigate Urban Heat Island (UHI) effects. The research found that a well-planned integration of specific tree types with an innovative approach to fountains could significantly reduce temperatures by up to 6℃ compared to surrounding areas, while grass exhibited minimal ecological & cooling benefits ranging from 0.4 to 0.8 ℃. These findings not only contribute to the existing body of knowledge on the role of GI in UHI mitigation but also offer practical tools for public authorities and designers. A unique outcome of this study is the development of a simple PeshawarTreeFinder mobile app, aimed at assisting stakeholders in carefully selecting the appropriate GI type for square typology. This resource will be distributed to stakeholders and consultants for free usage, emphasizing the real-world applicability of the research. The study also highlights the importance of consultation with city authorities and public engagement, uncovering insights such as budget constraints affecting fountain operation, which informed the research and underscores the need for a comprehensive understanding of local context in GI implementation.

Keywords

Green Infrastructure (GI), Urban Heat Island (UHI) Mitigation, Microclimate Analysis, SDG’s

Originality statement. I hereby declare that this Master’s dissertation is my own original work, does not contain other people’s work without this being stated, cited and referenced, has not been submitted elsewhere in fulfilment of the requirements of this or any other award.

Signature

Contents

Acknowledgement

I would like to extend my deepest gratitude to my supervisor, Paul Carroll, whose guidance, support, and encouragement were instrumental in shaping this research. I am also indebted to Professor Dr. Craig Thomson, whose motivation and insights inspired me to delve deeper into this subject. The wealth of literature provided by Professor Rohinton Emmanuel significantly informed my understanding of the topic, and I thank him for his invaluable contributions to this field. My heartfelt appreciation goes to my classmate Dechen for the continuous help and support, and to the University of Peshawar, for facilitating the data collection process, making it a smooth and enriching experience.

My journey through this thesis would not have been the same without the love and support of my family. A special mention must be made of my three-year-old son, Arman Khan Malik. The innocent look in his small eyes, as he watched me work on my laptop, has been a source of joy and motivation that words cannot adequately express. His presence added a dimension of warmth to this academic endeavor, turning it into a labor of love. I dedicate this work to him, and all those who stood by me in this fulfilling journey.

List of figures

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Chapter 1: **Introduction**

1.1 Rationale

The Urban Heat Island (UHI) effect refers to the phenomenon in which urban areas experience higher temperatures than surrounding rural areas due to human activities and the built environment. This is caused by a combination of factors such as the absorption and retention of heat by materials like concrete and asphalt, lack of vegetation, and waste heat generated by human activities like transportation and energy consumption (Oke, 1982).

The UHI effect can result in increased energy consumption for cooling, poor air quality, and negative impacts on human health (Khan & Rehman, 2019). Therefore, understanding and mitigating the UHI effect has become an important issue for urban planning and design.

The rapid urbanization of Peshawar, has led to an increase in temperature and the urban heat island effect, resulting in increased energy consumption and health issues. According to the latest available data from the Pakistan Bureau of Statistics, Peshawar ranks as one of the largest cities in Pakistan in terms of population and area (PBS, 2017).

Green infrastructure has been proposed as a potential solution to mitigate the urban heat island effect and improve the urban microclimate. However, there is a lack of comparative studies on the cooling effects of different types of green infrastructure in Peshawar's urban context.

Despite the considerable investment by the city government in improving water fountains and maintaining trees, it remains unclear which approach is more effective in mitigating the urban heat island effect in Peshawar. Both water fountains and trees are traditional forms of green infrastructure that have been utilized in the city for many years.

Green infrastructure refers to a network of natural and semi-natural features, such as parks, forests, wetlands, and green roofs, that are strategically planned, designed, and managed to provide ecosystem services and enhance the resilience of human communities to environmental challenges (Benedict & McMahon, 2006).

According to Bartesaghi Koc and Osmond (2017), a substantial majority (83%) of studies on the cooling effects of green infrastructure have been carried out in higher latitudes of the northern hemisphere, with fewer studies focusing on tropical regions.

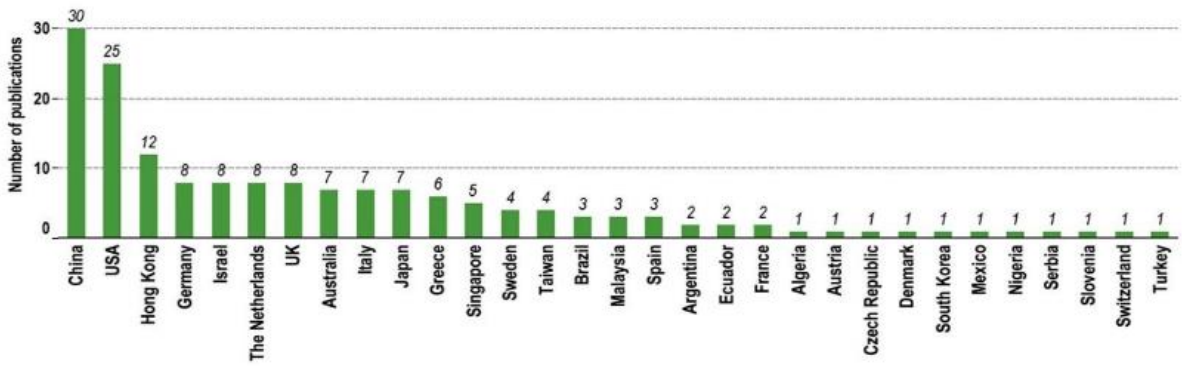

Figure 1 Countries where Papers were predominantly written on the study. Source (Bartesaghi Koc, Osmond and Peters, 2018)

Out of the 178 individual locations studied, most of the research has been focused on Asia (39.9%), Europe (34.8%), and North America (14.6%), with significantly fewer studies conducted in Oceania (3.9%), South America (3.9%), and Africa (2.8%). A country-based analysis revealed a heavy geographical bias towards three countries, with China (15.7%), the USA (14%), and Hong Kong (6.7%) accounting for the majority of research. These findings are supported by a study conducted by (Bartesaghi Koc, Osmond and Peters, 2018)

In the context of Peshawar, there is a need for data-driven decision-making by planners and government bodies regarding the implementation of green infrastructure, rather than relying solely on established precedents that may have limited ecological impacts. This study aims to provide the necessary information to support evidence-based decision-making.

1.2 Aim and Objectives

The research will explore the relative effectiveness of three different green infrastructure types in reducing the urban heat island effect. By examining these strategies within the local context, the study aims to shed light on their efficiency. This information will be vital for urban planners, architects, and policymakers in Peshawar, enabling them to make well-informed decisions that foster sustainable urban planning practices.

Furthermore, the study's findings will directly contribute to the progress of Sustainable Development Goal 11 (Sustainable Cities and Communities). This goal strives to create cities

and human settlements that are inclusive, safe, resilient, and sustainable. The study specifically targets the advancement of objectives 11.6 and 11.7, reinforcing the commitment to sustainable urban development.

To achieve the defined aim, this study focuses on the following four objectives:

1. To evaluate the effectiveness of green infrastructure in mitigating the UHI effect in urban areas.
2. To assess the current state of urban microclimate of Peshawar in different public squares, in terms of temperature, humidity, and wind speed.
3. To compare the cooling effects of different green infrastructure types, such as trees, grass, and water features on the urban microclimate of selected squares.
4. To provide recommendations for the implementation of green infrastructure in urban planning and design to mitigate UHI & create thermal comfort.

Chapter 2: **Literature Review**

The urban heat island effect has become a significant challenge for cities worldwide, including Peshawar, which is experiencing rapid urbanization and population growth.

Urban heat island refers to the phenomenon where urban areas experience higher temperatures than the surrounding rural areas due to the built environment's modifications. The resulting high temperatures can negatively affect urban microclimate, urban dwellers' health, energy consumption, and air quality.

Green infrastructure, such as parks, green roofs, and urban forests, has been identified as a potential solution to mitigate the urban heat island effect and enhance urban sustainability. However, the implementation of green infrastructure in Peshawar requires an understanding of its effectiveness in the local context.

This chapter provides a comprehensive review of the literature on the urban heat island effect, green infrastructure types, and their application in Peshawar's urban microclimate. It also highlights research gaps and provides the theoretical foundation for the empirical study on the cooling effects of green infrastructure on Peshawar's urban microclimate. This chapter provides overviews of different studies done on comparative outcomes of different infrastructure types for outdoor thermal comfort.

The literature review chapter for the study on "Comparative Analysis of the Cooling Effects of Various Green Infrastructure Types on Peshawar's Urban Microclimate" will cover several themes to provide a comprehensive understanding of the topic.

- The first theme will focus on the urban heat island effect, discussing its causes, impact on urban microclimate & human health, and relevance to Peshawar.
- The second theme will explore the concept of green infrastructure, including its types, benefits, and challenges, as well as the different strategies for its implementation in urban areas.
- The third theme will examine the cooling effects of different green infrastructure types including their potential to mitigate the urban heat island effect, with a focus on the factors influencing their effectiveness.

- Finally, the fourth theme will evaluate the current state of green infrastructure in Peshawar and its potential for mitigating the urban heat island effect, providing a critical assessment of the different types of green infrastructure that can be implemented in the city.

2.1 Urban heat Island Effects & its Causes

Urban Heat Island (UHI) is a phenomenon in which urban areas are significantly warmer than surrounding rural areas. UHI is a growing problem, especially in hot regions where it can cause severe health and environmental impacts. In this literature review, we will explore the causes of UHI in urban areas, with a focus on hot regions.

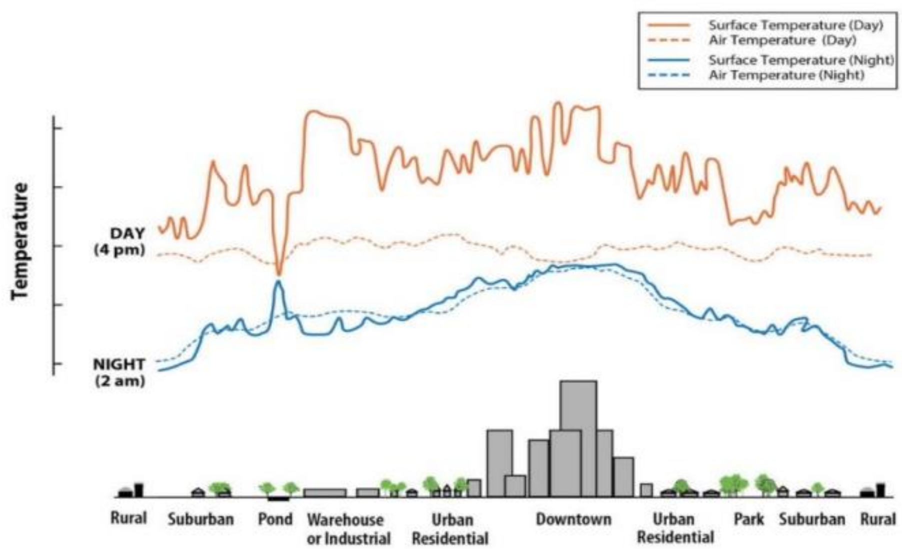

Figure 2 UHI Profile (USGS, 2019)

One of the main causes of UHI is the alteration of land surfaces due to urbanization, such as replacing natural vegetation with impervious surfaces like concrete and asphalt. This leads to reduced evapotranspiration and increased absorption and re-radiation of solar energy, resulting in higher surface temperatures. According to Oke (1982), urban areas with high-density development, low vegetation cover, and extensive impervious surfaces tend to have a more significant UHI effect.

Another significant cause of UHI is the anthropogenic heat release from human activities such as transportation, industry, and buildings. According to Santamouris (2015), the increase in energy

consumption and the use of air conditioning systems in buildings can significantly contribute to UHI effects in urban areas. The anthropogenic heat release is more pronounced in hot regions due to higher energy consumption and more extended periods of energy usage.

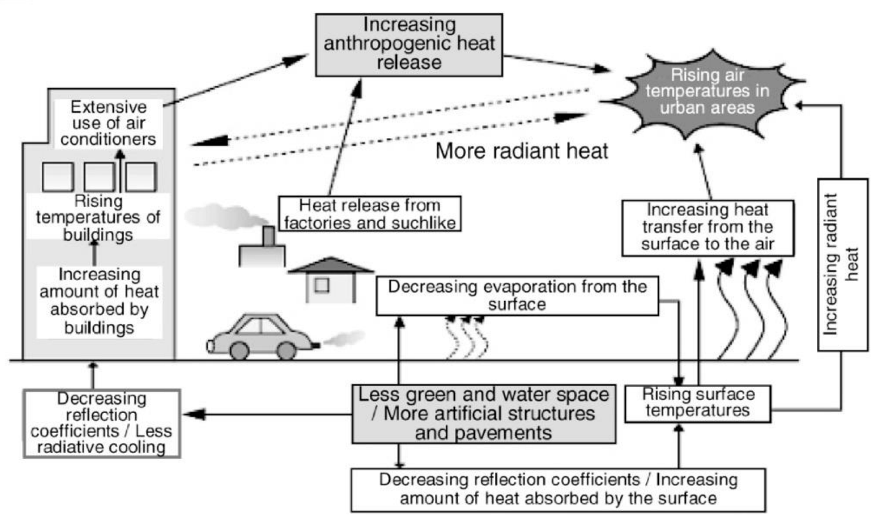

Figure 3. How the Urban Heat Island occurs - image sourced from Yamamoto (2006)

Additionally, UHI can be exacerbated by the location of urban areas. For example, urban areas situated in valleys or surrounded by mountains may experience higher temperatures due to reduced ventilation and airflow. According to Zhang et al. (2021), urban areas located in regions with high levels of solar radiation and low precipitation can also exacerbate UHI.

In conclusion, the causes of UHI in urban areas, especially in hot regions, are multifaceted and complex. It is crucial to implement urban planning strategies that consider the reduction of impervious surfaces, the promotion of green spaces, and the reduction of anthropogenic heat release to mitigate the effects of UHI in urban areas.

Peshawar is one of the largest and fastest-growing cities in Pakistan, experiencing a significant UHI effect due to the rapid urbanization and the high population density. The UHI effect has led to a rise in temperatures in Peshawar's urban microclimate, affecting the health and well-being of its inhabitants. Being a big industrial city that includes food processing and the manufacture of cigarettes, firearms, cardboard, textiles, pharmaceuticals, furniture, and paper. It is also a major center of the steel industry in Pakistan (Alam et al., 2011b).

High temperatures and low wind speeds due to the UHI effect made it difficult to walk especially in summer & caused dehydration & many health issues, particularly for vulnerable populations such as children & the elderly.

The most prominent reason are the deforestation & paved surfaces in the private gated communities which are constructed mainly on agricultural land. The lower coverage of green areas and green infrastructure resulted in high temperatures.

Private gated communities constructed on agricultural land is a significant cause of the UHI effect in Peshawar. Deforestation and the increased use of paved surfaces in these areas have resulted in reduced green coverage, leading to higher temperatures especially in City centers.

The urban heat island (UHI) effect has both positive and negative impacts on urban areas. During colder seasons, the UHI effect can help reduce energy consumption as the extra warmth in urban areas reduces the need for heating. This can lead to lower energy bills for individuals and businesses. Additionally, the UHI effect can lead to increased economic activity in urban areas, particularly in the tourism and hospitality industries.

According to a study by the Khyber Pakhtunkhwa Tourism Department, Peshawar attracts a considerable number of tourists each year. For European tourists and visitors from other colder regions, Peshawar's warm weather can be a pleasant change from their usual climate and may contribute to their enjoyment of the city's many attractions.

Warmer temperatures attract tourists, which can lead to increased revenue for businesses. Furthermore, the UHI effect can have positive impacts on public health. For example, warmer temperatures can reduce the incidence of respiratory diseases such as asthma, as warmer air is less likely to trigger asthma attacks.

Numerous studies have examined the relationship between temperature and the spread of COVID-19, with some suggesting that high temperatures may lower the incidence of the disease. For example, a study published in the journal Science of the Total Environment found that an increase in temperature of one degree Celsius was associated with a 3.08% decrease in the number of daily new cases of COVID-19 in 50 countries around the world (Tosepu et al., 2020). However, other studies have found conflicting results and it is important to note that temperature is just one of many factors that can influence the spread of the disease.

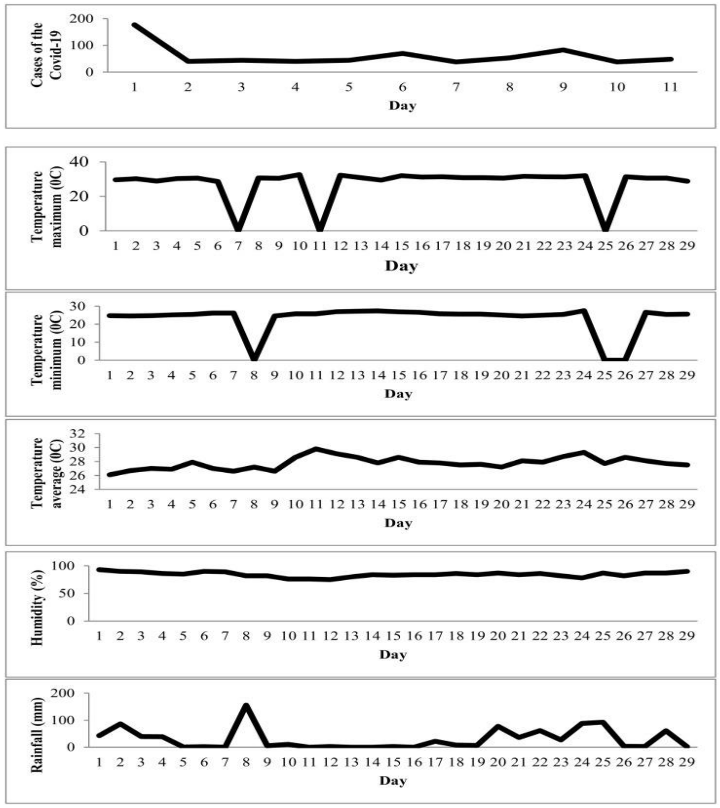

Figure 4 Cases of the Covid-19, (b) the amount of temperature maximum (°C), (c) temperature minimum (°C), (d) temperature average (°C), (e) humidity (%), and (f) rainfall (mm) in Jakarta Indonesia from January to March 29, 2020. Source: (Tosepu et al., 2020)

However, during hotter seasons, the UHI effect can lead to increased energy consumption as the extra warmth in urban areas increases the need for air conditioning. This can lead to higher energy bills for individuals and businesses. Moreover, the UHI effect can worsen air quality in urban areas by trapping pollutants and reducing wind speeds, which can lead to health problems such as respiratory and cardiovascular diseases. The UHI effect can also increase the risk of heat-related illnesses such as heat exhaustion and heat stroke, particularly for vulnerable populations such as the elderly and those with pre-existing health conditions.

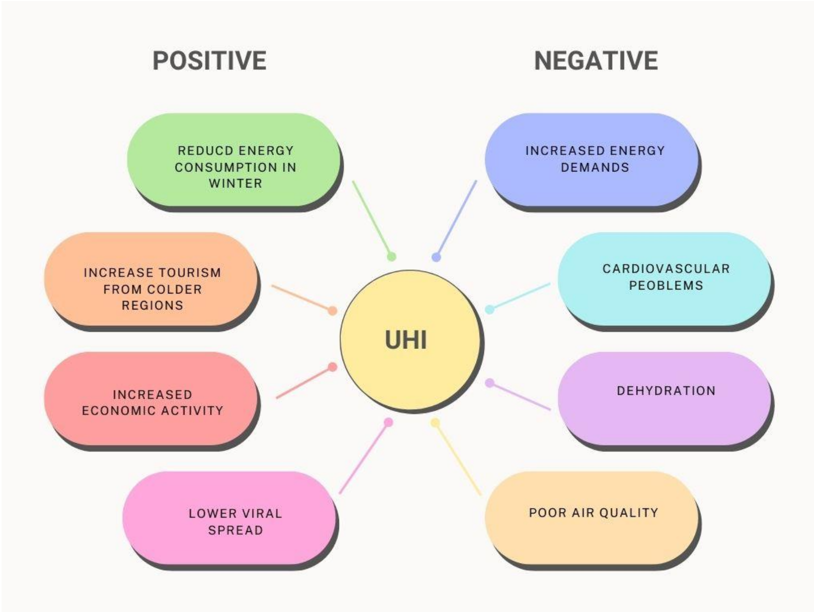

Figure 5 UHI Impacts. reproduced by the author based on literature review.

In conclusion, the UHI effect has both positive and negative impacts on urban areas. While it can lead to reduced energy consumption, increased economic activity, and improved public health during colder seasons, it can also lead to increased energy consumption, poor air quality, and heat-related illnesses during hotter seasons. It is important for policymakers to consider both the positive and negative impacts of the UHI effect when making decisions about urban planning and design.

Urban heat island (UHI) effects have been studied extensively in urban areas, but there is a significant research gap when it comes to understanding the UHI effects on urban microclimates. Urban microclimates are small-scale variations in temperature, humidity, and wind patterns that occur within urban areas, and they can have a significant impact on the UHI effect (Sailor, 2011).

Most studies on the urban heat island (UHI) phenomenon concentrate on the UHI effects within the Urban Canopy Layer (UCL), which refers to the lower atmospheric layer in urban areas situated below the rooftops of buildings and tree canopies. This focus is based on the research by Oke (1988; 2009). However, the impact of UHI in the layer above the average height of buildings is often overlooked in these studies.

Another gap is the need to better understand the effects of urban morphology on UHI intensity, including the role of building height and density. Additionally, there is a need for more research on the impacts of UHI effects on urban biodiversity and ecosystem services.

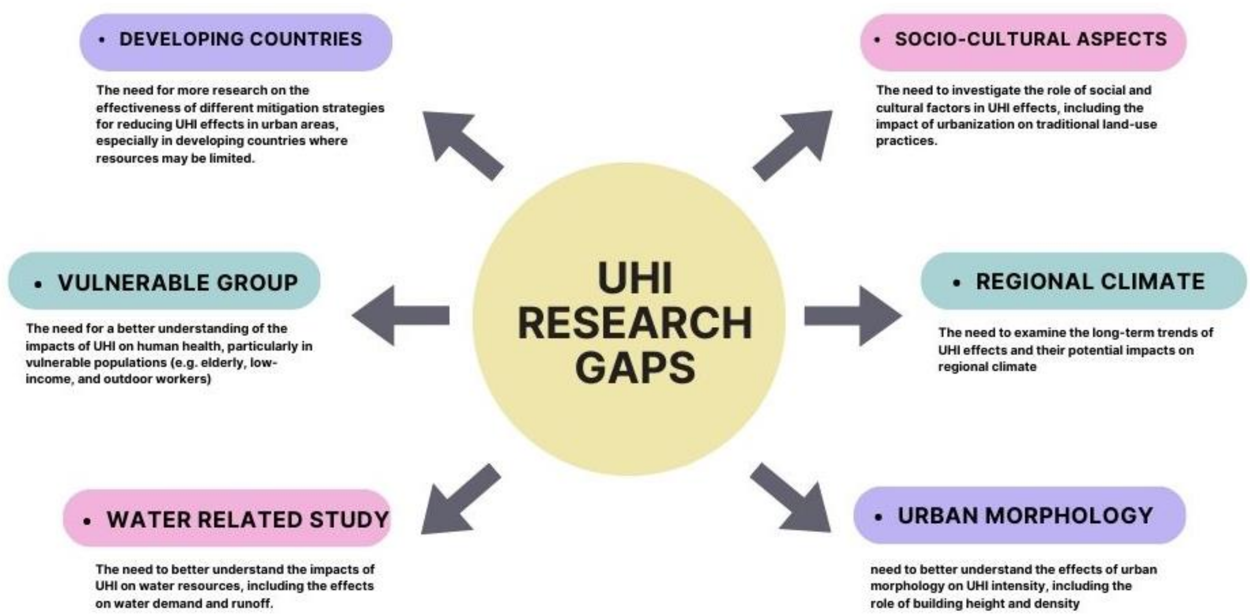

Figure 6 UHI Research Gaps. Figure reproduced by the author based on literature review.

Urban heat island (UHI) effects have been widely studied in various urban settings around the world, but there is a significant research gap when it comes to understanding the phenomenon in the context of Peshawar, Pakistan. Although some studies have looked at UHI effects in larger Pakistani cities like Lahore and Karachi, there is a lack of research specifically focused on Peshawar.

2.2 Urban Green Infrastructure Types

Throughout history, humans have had a deep appreciation for greenery as a source of vitality and have developed physical and psychological dependence on nature. The availability of fresh air, natural beauty, and landscapes have shaped public perceptions of nature and influenced social behavior (Wuqiang, Song, & Wei, 2012; Gökyer, Bilgili, & Gökyer, 2012).

However, the rapid population growth and urbanization of recent times have led to significant changes in ecosystems and natural landscapes (Barnosky, 2012). These changes also manipulate the Urban microclimate thus resulting in Urban Heat Island phenomena.

Extensive research has been carried out in recent years to investigate the effects of green infrastructure on urban microclimate, with previous reviews providing ample documentation of these results. Bowler et al. (2010) conducted a comprehensive meta-analysis on the cooling effects of parks, trees, and green roofs, which suggested that urban parks are on average up to 1°C cooler than non-green sites.

According to Benedict and McMahon (2006), green infrastructure refers to a system of interconnected natural and semi-natural elements such as green spaces, trees, water bodies, green roofs, and vertical greenery. These elements provide various ecosystem services, with a particular emphasis on climate regulation.

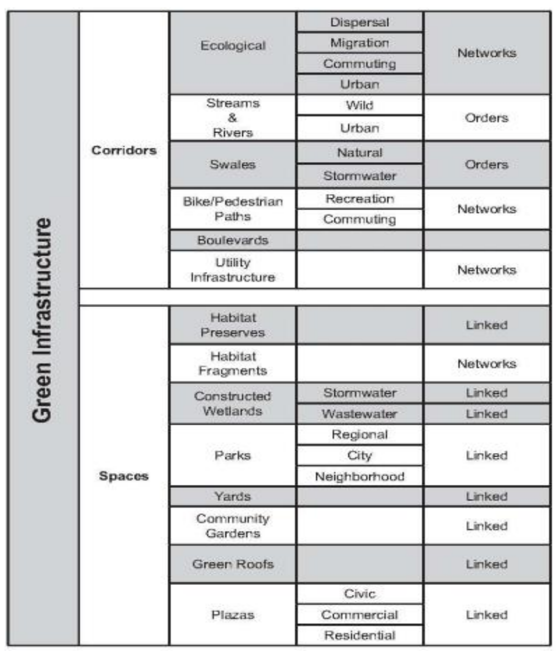

Figure 7 Austin, Image Source: G. (2014). Green infrastructure for landscape planning: integrating human and natural systems.

Benedict and McMahon's book (2006) explores the concept of green infrastructure and how it can link landscapes and communities. The authors argue that green infrastructure, such as parks, green roofs, and street trees, can provide a range of social, economic, and environmental

benefits, including improved air quality, reduced stormwater runoff, and enhanced public health and well-being.

Al-Gretawee, Rayburg, and Neave (2016) investigated the cooling effect of a medium-sized park on an urban environment. The study found that the park had a significant cooling effect, reducing air temperature by up to 5°C during the daytime, and up to 2°C at night. This was attributed to the evapotranspiration and shading provided by the park's vegetation, which also helped to reduce the urban heat island effect.

Urban greenery, especially trees, provide undeniable advantages to the urban climate and well-being. They help lower ambient temperatures, lessen the concentration of harmful pollutants, and decrease heat-related fatalities and illnesses. A significant amount of experimental and theoretical research exists on the potential effects of urban vegetation on urban temperature, thermal comfort, pollution reduction, and health. While most of these studies suggest that urban greenery provides multiple benefits, little is currently understood about the complete and worldwide impact of urban greenery on the urban climate, environmental quality, and health. (Santamouris and Osmond, 2020).

According to the research by (Santamouris and Osmond, 2020) there is a reasonable connection between increased tree coverage and reduced temperatures during the hottest parts of the day and at night. The maximum reduction in temperature during peak daytime hours is typically around 1.8°C when tree coverage is at its maximum, while the average reduction in temperature during the night is higher, at approximately 2.3°C. Due to limited space in urban areas, increasing tree coverage by 20% could lead to a temperature decrease of around 0.3°C during the day and 0.5°C at night. The specific climate and landscape conditions of a city significantly impact the potential reduction in temperature.

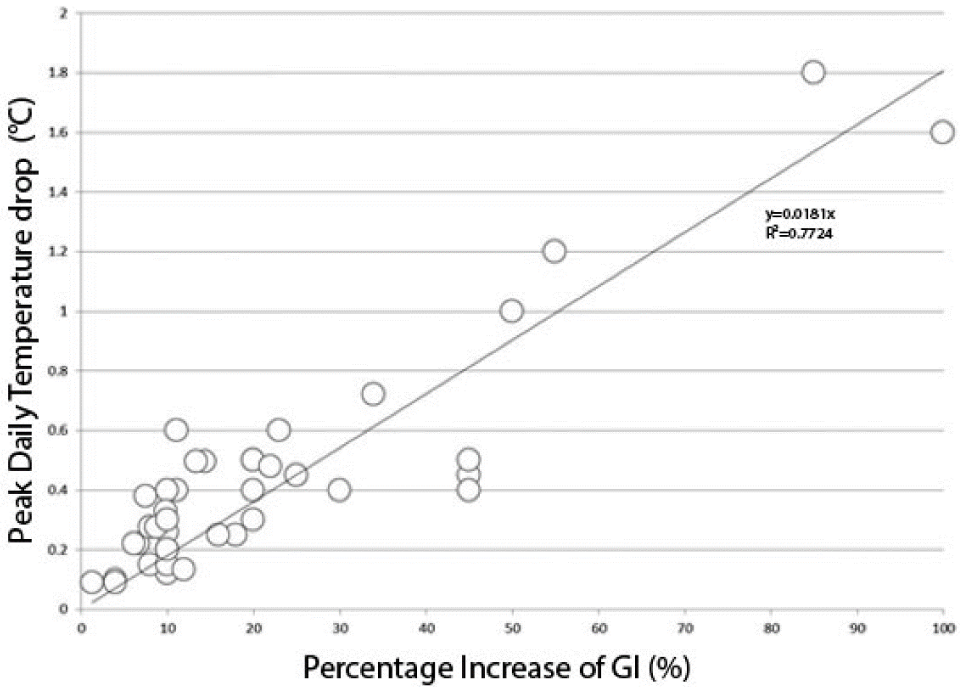

Figure 8. Correlation between the average peak daily temperature drop at 15:00 p.m. against the corresponding increase of the tree cover. Source: Santamouris and Osmond, 2020

Bencheikh and Rchid (2012) looked at the effects of green spaces, specifically palm trees, on the microclimate in arid zones. The study found that the presence of palm trees significantly reduced air temperature, relative humidity, and wind speed in the area, which improved thermal comfort for residents. The authors concluded that planting more palm trees could be an effective way to mitigate the effects of heatwaves in arid regions.

Benedict and McMahon, 2006 also discuss the importance of integrating green infrastructure into urban planning and design. They argue that this can help to create more livable and sustainable cities, and provide a range of benefits for residents, businesses, and the environment.

Coutts, White, Tapper, Beringer, and Livesley (2015) investigated the temperature and human thermal comfort effects of street trees across three different street canyon environments. The study found that street trees provided significant cooling benefits, reducing air temperature by up to 2°C, and improving thermal comfort for pedestrians. The authors concluded that street trees could be an effective way to mitigate the effects of urban heat islands in cities.

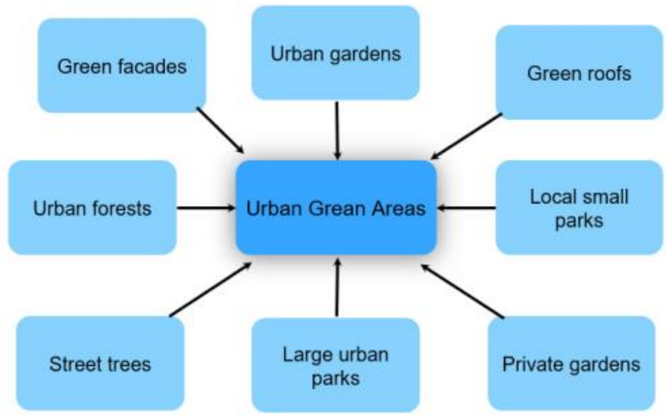

Figure 9 Some of the Green infrastructure types which can best reduce UHI. Source:(Leal Filho et al., 2021)

This study focuses primarily on three types of green infrastructure (GI) within the context of Peshawar. The literature review places greater emphasis on these three types, to analyze best options for ecological benefits and are highly effective in mitigating Urban Heat Island Effects (UGI).

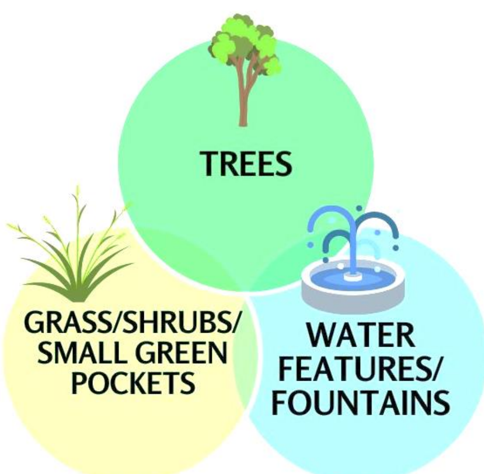

Figure 10 . Three Types of Green Infrastructure for study in context of Peshawar. Literature also more focus on these three types.

2.2.1 Urban Trees

The increase in temperature is mainly attributed to the absorption and retention of solar radiation by human-made surfaces such as asphalt, concrete, and building materials, resulting in a decrease in evapotranspiration and an increase in sensible heat.

Trees are widely recognized as a critical green infrastructure component in mitigating UHI and improving urban microclimates.

They play a crucial role in mitigating UHI effects by providing shade and transpiring water, thus reducing the urban surface and air temperatures. Many studies have investigated the impact of trees on the urban microclimate, and the majority suggest that trees can significantly reduce urban temperatures.

For instance, a study conducted in the city of Istanbul found that the presence of trees reduced the surface temperature by 10°C during the day and 8°C at night (Cetinkaya, 2017). Similarly, a study in Chicago found that increasing tree cover by 10% could lower the temperature by 0.25-0.5°C (Nowak et al., 2006).

The species and placement of trees are essential factors that influence their effectiveness in mitigating UHI effects. Some tree species are better at reducing urban temperatures due to their higher transpiration rates and shading capacity. For example, deciduous trees are more effective at shading buildings during the summer months and allowing sunlight to penetrate during the winter months (Wang & Zhao, 2017). Furthermore, the placement of trees also plays a significant role in reducing UGI.

Numerous studies have demonstrated the effectiveness of trees in mitigating the UHI effect. For example, a study conducted in Guangzhou, China, found that increasing tree canopy cover from 20% to 40% reduced surface temperatures by 1.5°C (Liu et al., 2011). Another study in Los Angeles, California, found that increasing tree cover by 10% could reduce the UHI effect by up to 0.7°C (Heisler et al., 2000).

Trees provide numerous benefits in improving the urban microclimate, including temperature reduction, air quality improvement, stormwater management, and biodiversity. The effectiveness of trees in mitigating the UHI effect has also been demonstrated in various studies. Therefore, planting and maintaining trees should be a priority in urban planning and development to improve the urban microclimate and mitigate the UHI effect.

2.2.2 Grass, Shrubs & small green spaces in Urban areas

Green spaces in urban areas, such as grass and small green pockets, are important in mitigating urban heat island (UHI) effects. The cooling effect of these green spaces is achieved through a combination of evapotranspiration, shading, and wind cooling.

In Guangzhou, southern China, a study was conducted to measure the cooling effect of five shrub types commonly found in the region. The results showed that, on average, the surface temperature of the shrubs was 6.7 ˚C lower than that of a concrete pavement (Zhang, 2020).

According to Balany et al. (2020), while trees have been found to be more effective in reducing temperatures, other vegetation types may also play a role in mitigating urban heat islands like grass & shrubs but lower than trees.

Ali et al. (2021) conducted a simulation study which showed that the presence of grass could result in a decrease of up to 0.44 ˚C in air temperatures. However, in terms of thermal comfort, Lobaccaro and Acero (2015) and Müller et al. (2013) found only reductions of 4.0 ˚C and 3.9 ˚C, respectively, in PET.

Grasses can contribute to the reduction of UHI effects by increasing surface albedo, which is the ability of a surface to reflect solar radiation. They can also reduce temperatures by providing shade, transpiring moisture into the atmosphere, and increasing the evaporation of moisture from the soil. Similarly, shrubs can provide shade and reduce solar radiation absorption by surfaces, as well as enhance moisture retention in soils.

Despite their potential benefits, grasses and shrubs have not received as much attention in UHI mitigation studies as trees. One reason for this is the time required for trees to grow and mature before they can provide significant benefits. Moreover, trees are generally considered to have a greater impact on the urban landscape due to their size, form, and longevity. As a result, urban planners and designers may prefer trees as they are more visible and are perceived as having a greater impact on the urban environment.

Another reason for the focus on trees in UHI mitigation studies is the availability of data. Trees are easier to monitor and measure, and data on their performance in reducing UHI effects are readily available. On the other hand, data on grasses and shrubs are limited, and there is a need for more research to be conducted to understand their effectiveness in reducing UHI effects.

In conclusion, while trees are generally given priority in UHI mitigation studies, grasses and shrubs have the potential to contribute significantly to the reduction of UHI effects in urban areas. Further research is needed to better understand their effectiveness, and urban planners and designers should consider incorporating a mix of vegetation types in their strategies for UHI mitigation.

2.2.3 Water features & fountains in Urban areas

Water features, such as fountains, have been proposed as a potential solution to mitigate UHIs by cooling the surrounding air through evaporative cooling and increasing humidity levels.

Water features have the ability to reduce temperatures in urban areas through evaporative cooling, which is the process by which water absorbs heat from the surrounding environment and evaporates into the atmosphere. This can result in a decrease in air temperature and an increase in relative humidity. Fountains, in particular, can contribute to UHI mitigation by releasing large amounts of water into the air, creating a cooling effect similar to that of a natural waterfall.

During hot weather periods, it is common for water bodies to have lower temperatures than the air above them, particularly during the hottest parts of the day. This is supported by research such as that conducted by Broadbent et al. (2017) and Gross (2017). Consequently, the surface temperature of water bodies tends to be lower than the surface temperature of urban structures in their vicinity, as evidenced by studies such as those carried out by Sun and Chen (2012) and Méndez-Lázaro et al. (2018).

Water bodies are often considered to be highly effective absorbers of radiation. However, their thermal response is limited due to water's high heat capacity, which means it takes approximately three times more heat to raise the temperature of one unit volume of water than it does for soil. As a result, architects and planners often incorporate water features in their designs, as noted by Manteghi et al. (2015). Previous studies on thermal comfort associated with water bodies have revealed that on a hot day in Japan, there can be a difference of 1 to 3°C between the temperature of a river and that of an urban canyon within the city, as highlighted in research conducted by Syafii et al. (2017).

In hot and humid climates, small urban lakes such as the one found in Singapore have been observed to produce a cooling effect, with a temperature difference of 1.3°C between its near and

far regions, according to research by Ichinose (2017). Similarly, a pond in Fukuoka, Japan was found to have a cooling effect of 3°C that extends up to 400 meters, while the Ota River in Hiroshima was found to produce a 5°C cooling effect above the river that spreads 100 meters along its banks.

In addition, studies such as Robitu et al. (2004) have indicated that even a small pond with an area of just 4 square meters can effectively reduce the temperature of its surroundings. However, the climatic impact of a water body is influenced by various factors such as the direction and speed of prevailing winds, the size of the water surface area, and the design of the surrounding areas, as noted in research by Syafii et al. (2017).

Research by Gunawardena (2017) suggests that the cooling effect of water bodies can be maximized by evenly distributing relatively small bodies of water across an urban area, as opposed to relying on a single larger body of water with the same total volume. In addition to the size and distribution of water bodies, their shape also plays a crucial role in their cooling efficiency. Simple or regular shapes are found to be more effective in producing a cooling effect than irregular shapes, as noted by Lee et al. (2016), Gunawardena (2017), and Mostofa & Manteghi (2019). Moreover, the cooling effect of water is typically more pronounced during the daytime on hot days, but it may not have any effect towards the end of summer, according to Gunawardena (2017).

Both small ponds and fountains can be effective in mitigating urban heat island (UHI) effects in cities, but their effectiveness may vary depending on several factors such as their size, location, and design.

Small ponds can provide a cooling effect by evaporative cooling, where water evaporates from the surface and removes heat from the surrounding environment. They can also create a cooling effect by reflecting sunlight, which reduces the amount of solar radiation absorbed by surrounding surfaces. However, the effectiveness of small ponds in reducing UHI effects may be limited if their size and distribution are not optimized, as noted in previous research.

On the other hand, fountains can create a cooling effect by releasing water droplets into the air, which can reduce air temperature and increase humidity through evaporative cooling. Fountains can also provide a visual and aesthetic benefit to urban areas, which can improve the overall

quality of life for city residents. However, fountains may require more maintenance and energy consumption compared to small ponds.

Overall, both small ponds and fountains can be effective in mitigating UHI effects in cities, but their effectiveness may depend on several factors such as their size, location, and design, and should be carefully considered when incorporating them into urban design plans.

2.3 Knowledge Gaps & Conclusion

Urban heat island (UHI) is a critical issue affecting urban areas around the world, including Peshawar, Pakistan. Despite numerous studies investigating the causes and consequences of UHI, there are still significant research gaps that need to be addressed.

One of the research gaps is the use of trees, grass, and water bodies in urban areas to mitigate UHI effects. Although these green and blue infrastructure elements are known to have a cooling effect, more research is needed to determine their optimal design and placement in urban environments. For example, research is needed to determine the optimal tree species and spacing to maximize their shading effect while minimizing maintenance costs. Additionally, more research is needed to understand the effects of different types of grass and ground cover on reducing UHI, especially in areas with high foot traffic.

Furthermore, while water bodies are known to have a cooling effect in urban areas, more research is needed to determine their optimal design and placement. For example, the effectiveness of small ponds versus larger bodies of water in reducing UHI needs to be evaluated in the context of Peshawar's urban environment. The impact of water bodies on local air quality and water usage should also be considered.

In the context of Peshawar, research on UHI and the use of green and blue infrastructure is particularly relevant given the city's rapidly growing population and urbanization. In recent years, the city has experienced a significant increase in temperatures, leading to public health concerns and decreased quality of life for residents. As such, further research on the effectiveness of green and blue infrastructure in mitigating UHI effects in Peshawar is urgently needed to inform sustainable urban design and development.

The government of Peshawar is currently focusing on developing green infrastructure in the city, primarily for health benefits and aesthetic purposes, with limited attention given to mitigating the

Urban Heat Island (UHI) effect. The main components of green infrastructure in the city are trees, grass, and shrubs, which are being planted in small green spaces, along with water fountains placed in roundabouts at road intersections. While green roofs and other components have been shown to be effective in mitigating UHI in other cities, they are not yet common in Peshawar due to a lack of awareness or high construction and maintenance costs.

Before conducting the literature review, the author and Peshawar Development Authority had assumed that any plant species in any location could effectively reduce temperature. However, the literature review revealed that the success of tree plantation drives depends on selecting the appropriate species and location. Furthermore, the study found that ponds are a better cooling strategy than fountains in urban areas, and grass and shrubs have minimal impact on the Urban Heat Island (UHI) effect. It should be noted, however, that these findings are specific to certain areas and contexts. The study aims to provide more accurate results in the context of Peshawar.

In conclusion, there are several research gaps in the use of trees, grass, and water bodies in urban areas to mitigate UHI effects, particularly in the context of Peshawar. Addressing these gaps will be crucial in developing effective and sustainable strategies to mitigate UHI effects and improve the quality of life for urban residents in Peshawar and other cities around the world.

Chapter 3: **Methodology**

In this chapter, the research's methodological approach is detailed, beginning with an introduction to the study area in Peshawar. It then elaborates on the data selected and the techniques implemented for both preprocessing and analyzing this data.

The chapter summarizes the analyses, which were conducted using tools such as ESRI ArcGIS and ENVI-met v.5.5.1. Additionally, statistical methods were executed within the SPSS and Microsoft Excel frameworks, contributing to the comprehensive understanding of the subject matter.

3.1 Philosophy, Methodology, and Framework of Research

The literature review reveals a significant connection between various types and shapes of green spaces and temperature variations in urban areas. This relationship underscores the importance of the study's focus on the cooling effects of green infrastructure in Peshawar's urban microclimate. The literature review serves as a foundation, linking the research philosophy and methodology to existing knowledge in the field.

Below is an image that visually demonstrates how each objective of the research can be achieved, offering a clear representation of the alignment between the study's goals and the methods utilized.

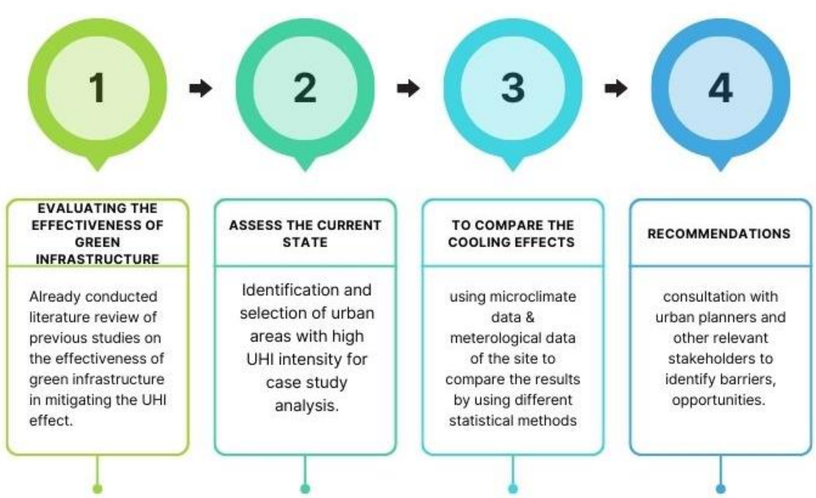

Figure 11. This image illustrates the strategic approach to achieving the research objectives, detailing the key steps and methods employed in the investigation.

The study employs a quantitative design, incorporating a multi-method approach that combines GIS-based spatial analysis, fieldwork, microclimate modeling, and statistical analysis techniques. To achieve its aim and meet its objectives, the research progresses through four distinct steps:

1. **Literature Review**: An examination of existing research and studies related to the subject.
2. **LST & NDVI data using GIS to find hotspots**: Investigation of city-wide Urban Heat Island (UHI) patterns and the relationships between UHI and Urban Green Infrastructure (UGI) in different squares.
3. **Fieldwork**: Fieldwork in the comparative analysis of the cooling effects of green infrastructure types on Peshawar's urban microclimate in three public squares involves on-site investigations to explore local-scale temperature variations, examining how different types of green spaces influence urban heat patterns & how users perceived it.
4. **Envi-met & Statistical analysis**: different analysis techniques & simulation techniques used to assess the cooling potential of UGI at the micro-scale level in these public squares.

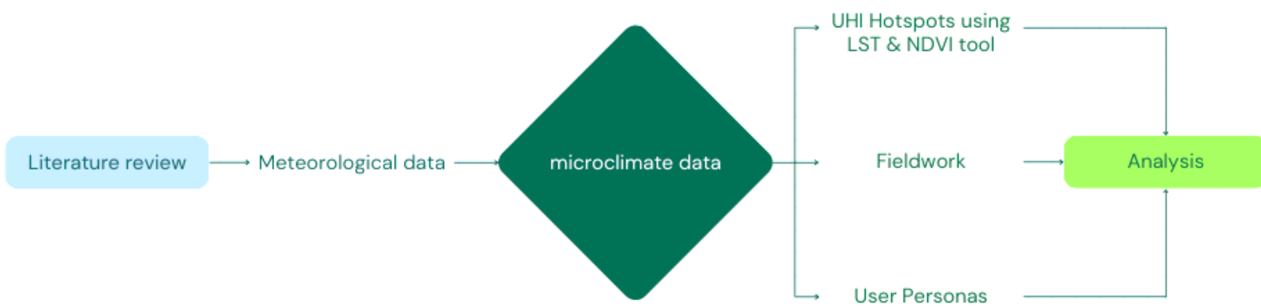

Figure 12. Research framework

Various techniques are employed to analyze and compare cooling effects in different systems or environments. These techniques may include mathematical modeling, experimental studies, simulations, or a combination of these methods.

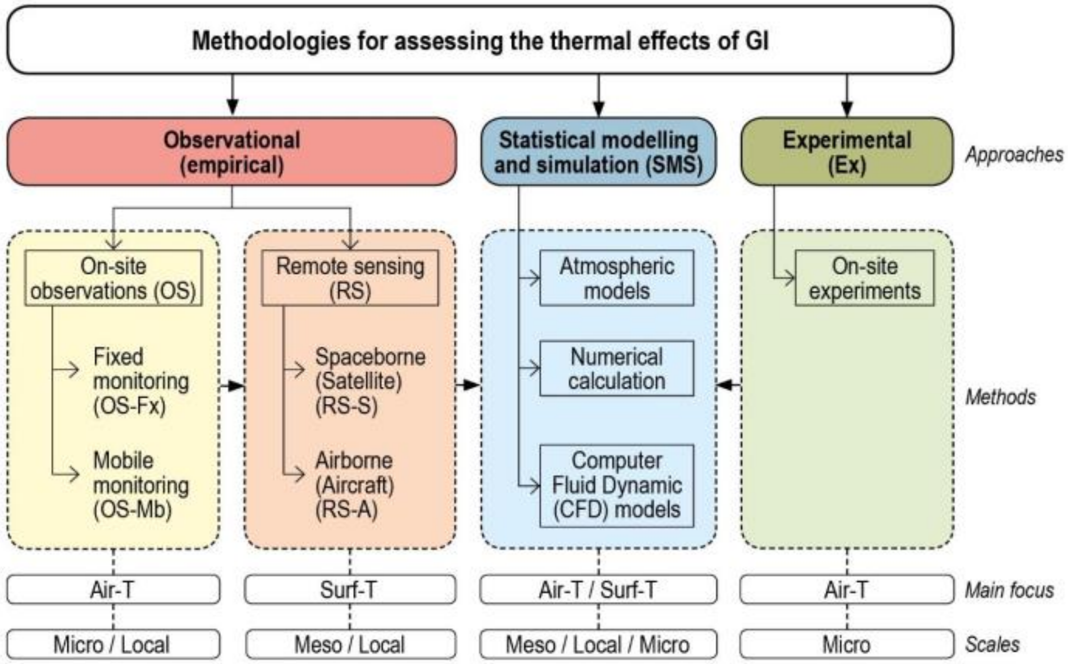

Figure 13.Approaches used to investigate the cooling effects of GI. Source: (Bartesaghi Koc, Osmond and Peters, 2018)

3.2 Study Area

3.2.1 History of Peshawar, Pakistan

Peshawar's rich history and archaeology are deeply intertwined with its strategic location along the ancient Silk Road. The city has been a cultural and commercial crossroads for centuries, hosting various civilizations, including the Greeks, Mauryas, Kushans, and Mughals. Archaeological sites such as the Bala Hisar Fort and the Peshawar Museum house artifacts that tell the story of the region's diverse heritage. The blend of historical influences has shaped Peshawar's unique cultural identity, making it a fascinating destination for historians and archaeologists alike.

3.2.2 Climate

Peshawar's climate is influenced by the local steppe environment, resulting in a hot semi-arid climate classification (Köppen BSh). The city experiences extended, scorching summers and brief, mild to chilly winters.

Winter Season: Starting in November and typically lasting until late March or sometimes mid-April, winters in Peshawar are characterized by mean maximum temperatures of 18.3 °C (64.9 °F) and mean minimum temperatures dropping to 4 °C (39 °F).

Summer Season: The summer months, ranging from mid-May to mid-September, bring intense heat to Peshawar. During the peak of summer, the mean maximum temperature often exceeds 40 °C (104 °F), with a mean minimum temperature around 25 °C (77 °F).

Rainfall Patterns: Unlike other regions of Pakistan that experience monsoons, Peshawar's rainfall is distributed across both winter and summer. Winter rains, often resulting from western disturbances, are generally more abundant between February and April. The record for winter rainfall was set in February 2007 at 236 mm (9.3 in), while the highest summer rainfall of 402 mm (15.8 in) occurred in July 2010. A remarkable 24-hour rainfall record of 274 mm (10.8 in) was set on 29 July 2010.

Additional Climate Details: The average annual precipitation over a 30-year period was recorded as 400 mm (16 in), with the highest annual level reaching 904.5 mm (35.61 in) in 2003. Wind speeds fluctuate throughout the year, ranging from 5 kn (5.8 mph; 9.3 km/h) in December to 24 kn (28 mph; 44 km/h) in June. Relative humidity also varies, from 46% in June to 76% in August. Peshawar's temperature extremes include a high of 50 °C (122 °F) on 18 June 1995 and a low of −3.9 °C (25.0 °F) on 7 January 1970.

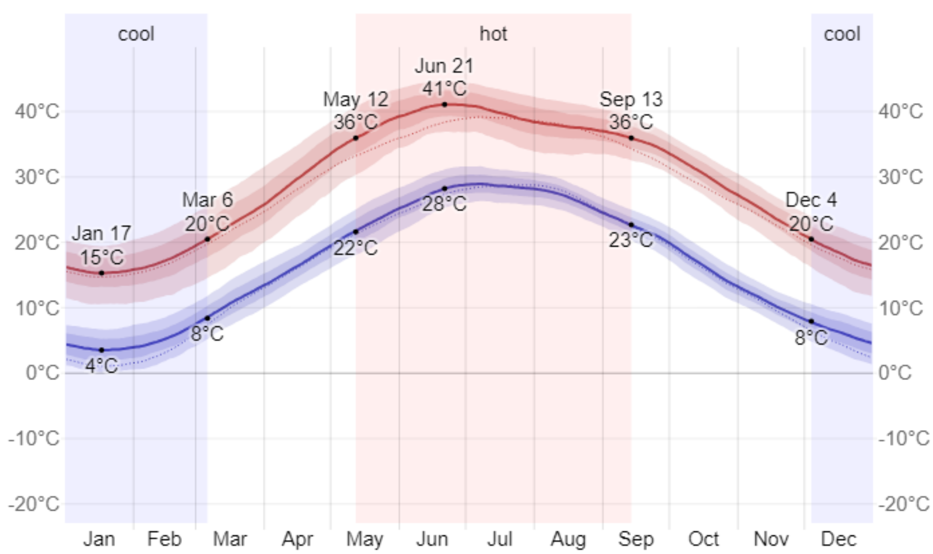

Figure 14.Average High and Low Temperature in Peshawar. Source: WeatherSpark.com

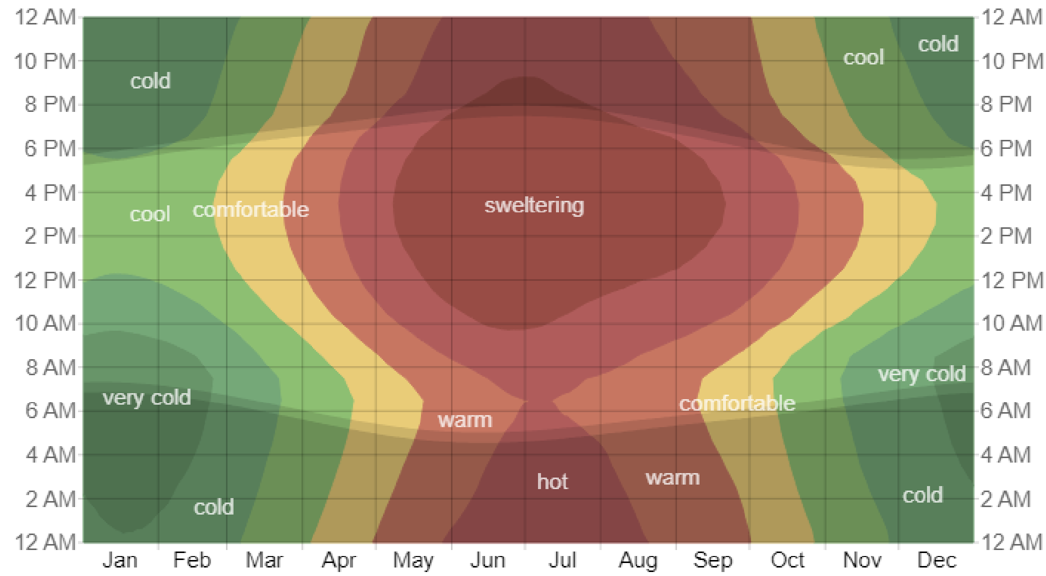

Figure 15 Average Hourly Temperature in Peshawar. Source: WeatherSpark.com

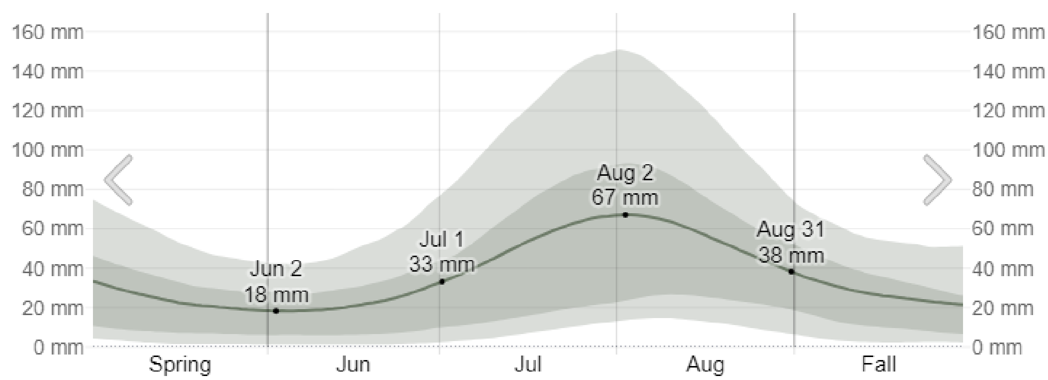

Figure 16 Average Monthly Rainfall in the Summer in Peshawar. Source: WeatherSpark.com

The comfort level related to humidity is determined by the dew point, which affects how easily perspiration can evaporate from the skin, thus cooling the body. A lower dew point leads to a drier feeling, while a higher dew point results in a more humid sensation. Unlike temperatures, which can fluctuate significantly between day and night, the dew point changes more gradually. As a result, a humid day is often followed by a humid night.

In Peshawar, the likelihood of experiencing muggy conditions increases quickly during the summer season. It rises from a mere 1% to 19% over the course of the summer months.

The peak chance of encountering a muggy day in the summer reaches 33% on August 9th.

To put this into perspective, on August 9th, the most humid day of the year, muggy conditions are present 33% of the time. Conversely, on November 5th, the least humid day of the year, there is a 0% chance of experiencing muggy conditions.

This information provides insight into the humidity patterns in Peshawar, emphasizing the seasonal variations and the factors that influence the sensation of mugginess. WeatherSpark (2023).

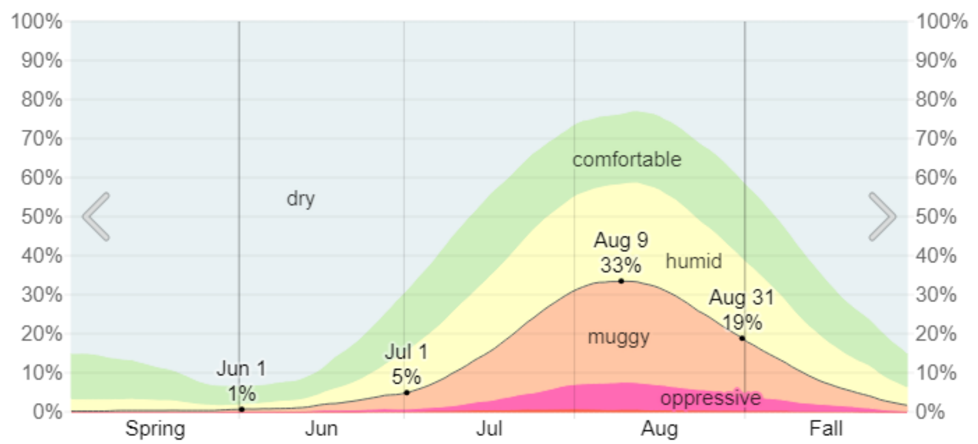

Figure 17. Humidity Comfort Levels in the Summer in Peshawar. Source: WeatherSpark.com

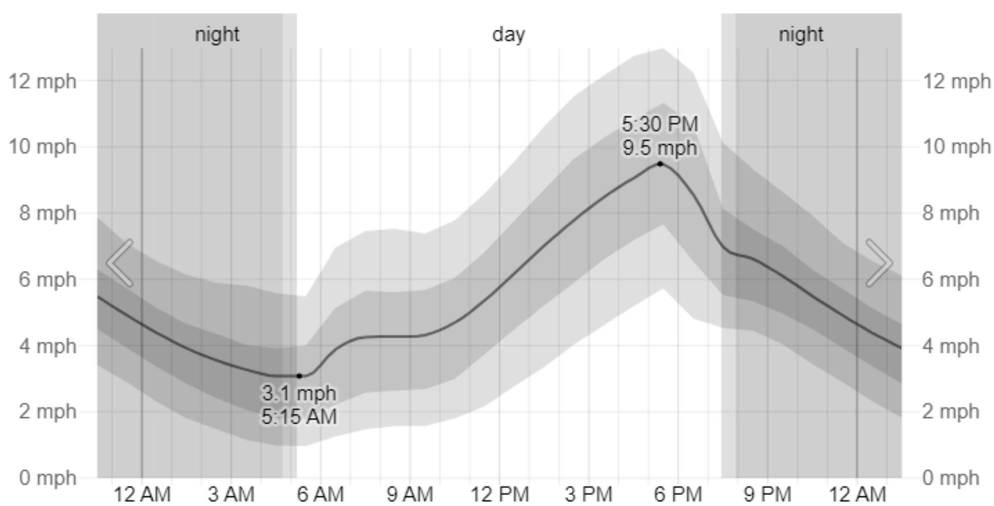

Figure 18. Wind Speed on July 13 in Peshawar. Source: WeatherSpark.com

Peshawar's climate has been affected by various environmental factors, including deforestation and urbanization. These changes have led to shifts in weather patterns and increased vulnerability to extreme weather events. Efforts to mitigate these impacts include tree plantation campaigns and urban planning initiatives.

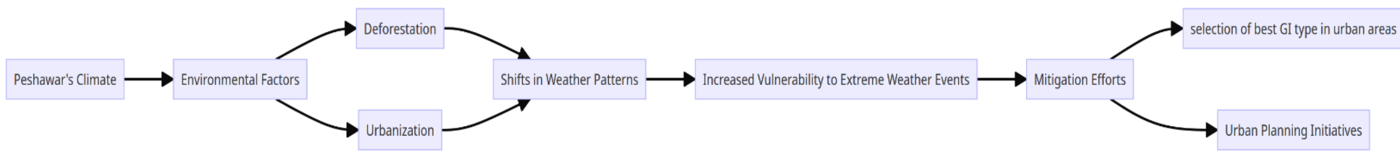

Figure 19. visual representation of how various environmental factors have impacted Peshawar's climate, Source: Author

3.2.3 Identification of Hotspots in Peshawar

The city of Peshawar is strategically segmented into three distinct areas or spots. This division is carefully crafted, taking into consideration four critical variables that influence the urban landscape and development of the region:

1. **Urbanization and Availability of Public Squares:** This variable examines the level of urban development within the city and the presence of public squares or open spaces. It reflects the city's growth and the importance of communal areas where people can gather and interact.

2. **Availability of Green Infrastructure (GI) Types, Vegetation Density, and Coverage:** This aspect focuses on the presence and distribution of green infrastructure within the city, including parks, gardens, and green roofs. It also considers the density and coverage of vegetation, which contribute to the city's environmental sustainability and aesthetic appeal.

3. **Building Materials and Surface Albedo:** This variable looks at the types of materials used in construction and the surface albedo, or reflectivity, of those materials. It has implications for the city's energy efficiency, temperature regulation, and overall environmental impact.

4. **Government Attention to Public Squares, with Asian Development Bank as a Donor:** This factor emphasizes the role of government intervention and investment in

public squares and open spaces. The involvement of the Asian Development Bank as a donor signifies international collaboration and financial support for urban development projects.

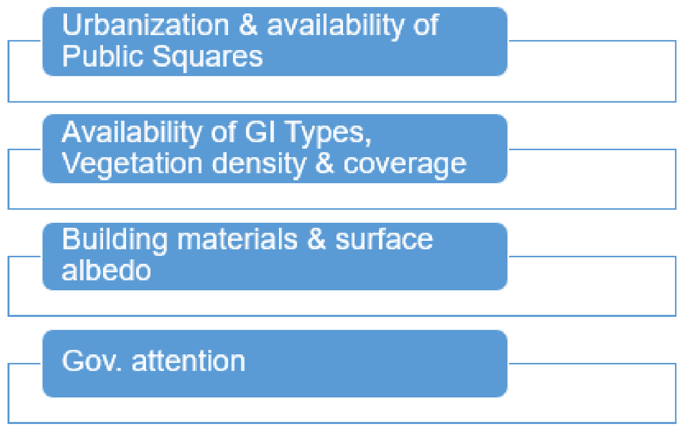

Figure 20 Division of Peshawar City. Source: Author & Consultation of stakeholders

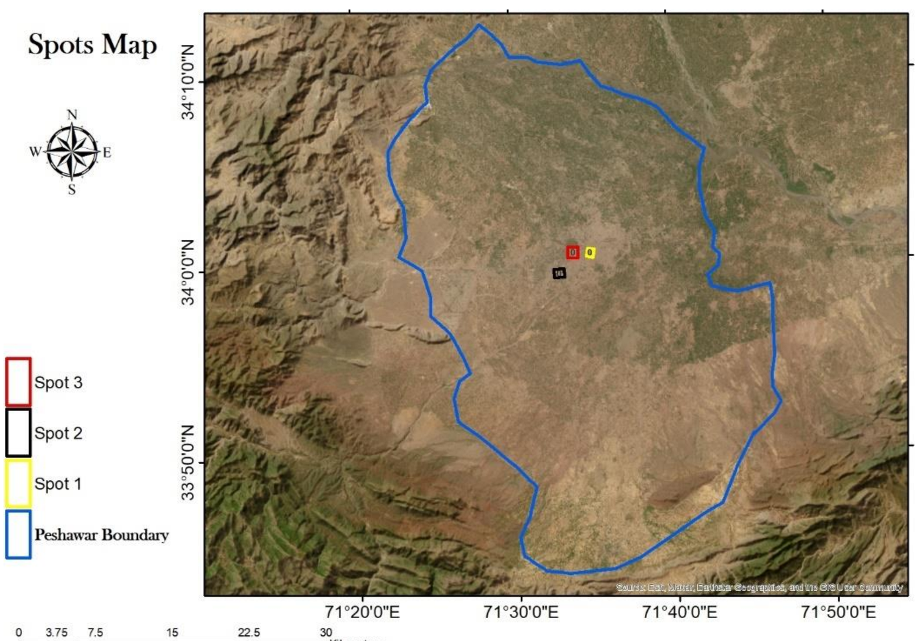

Figure 21. Google Earth. (2023)

Justification for Selecting Three Closely Located Spots:

The decision to focus on three spots in proximity within Peshawar City was driven by practical considerations:

1. **Easier Logistics:** Selecting spots that are close to each other simplifies the logistics of the study. It facilitates easier access to the locations, reducing travel time and related expenses.
2. **Hotspots area as per LST & NDVI data.** The selected spots are also identified as hotspots in Peshawar according to the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) maps. These maps provide valuable insights into vegetation health and surface temperature patterns, further justifying the selection of these specific locations. The alignment with NDVI and LST data ensures that the study focuses on areas of environmental significance and concern.
3. **Efficient Data Collection and Monitoring:** Having the spots near each other allows for more streamlined data collection and monitoring processes. It enables more frequent site visits and consistent observation, enhancing the accuracy and reliability of the data.
4. **More Green Infrastructure (GI) Variations in Less Distance:** By choosing spots that are close yet diverse in terms of green infrastructure, the study can capture a wide range of GI variations without having to cover a large geographical distance. This approach provides a rich and varied dataset while maintaining efficiency in the research process.

These factors collectively contribute to a more effective and manageable research process, justifying the selection of three closely located spots for the study. The integration of NDVI and LST data adds a layer of scientific rigor, ensuring that the selected spots are not only logistically convenient but also environmentally relevant and significant.

3.3 Data collection & Processing

Spot 1 is characterized by a public square with historical significance, adorned with surrounding trees. This area is further distinguished by the presence of heritage buildings, primarily constructed from stone and mud, reflecting the rich architectural tradition of the region. The variety of tree typologies includes species such as orange, olive, Ber, and Jaman. The selection

of site one was influenced by its specific climatic condition, where the temperature reaches 33 degrees Celsius, making it a relevant location for the study. In every spot, one square is selected based on number of people present on square from last three years.

Figure 22 Spot-1 Google Earth. (2023)

Spot 2 is marked by the presence of numerous urban green open spaces, contributing to the area's environmental appeal. The diversity in construction is evident, with building materials ranging from cement and stone to steel, showcasing a blend of traditional and modern architectural practices. This location is also characterized by its high density, making it a bustling and vibrant part of the city. The unique combination of green spaces, varied building materials, and dense urban fabric makes Spot 2 a significant area for study. Fig.24

Figure 23. Chowk Yadgar as public square. Source: Photo by Author

Figure 24 Chowk Yadgar satellite view Source: Google earth 2023

Figure 25 Spot-2 Google Earth. (2023)

In spot-2 a private owned square is selected but currently serve as community space called Malik Plaza square.

Figure 26.Location of public square-2 in Peshawar, 34° 0'7.39"N, 71°31'4.40"E

Spot 3 is defined by its contemporary architectural landscape, featuring modern buildings that reflect the area's progressive development. It is a hub for commercial activities, bustling with

business and trade. This commercial vibrancy leads to increased traffic, contributing to the dynamic nature of the area. However, Spot 3 also exhibits certain environmental limitations, such as a scarcity of green spaces and street vegetation.

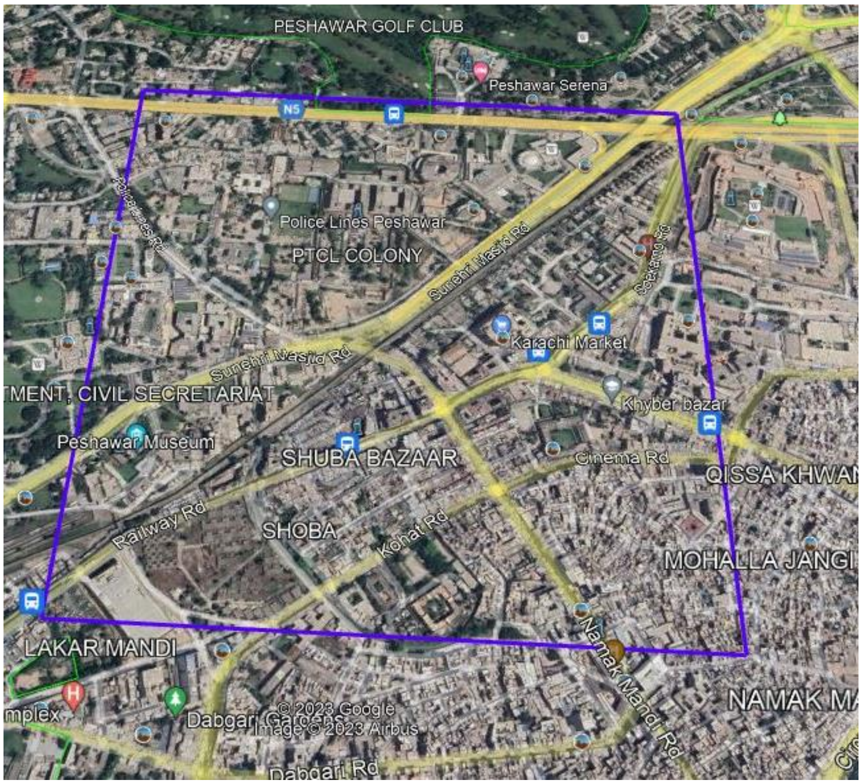

Figure 27 Spot-3 Google Earth. (2023)

In spot-3 there is no such dedicated public square so local people use roundabouts & medians for evening time sitting.

Figure 28 Roundabout as a public square in spot-3 Peshawar

3.3.1 Land surface temperature data

LST values in degrees Celsius were obtained from Landsat 8 OLI/TIRS datasets using GIS software following a specific procedure. This data was collected for Peshawar over a three-year period spanning from 2019 to 2021. Before 2019, a Bus Rapid Transport infrastructure project was initiated in Peshawar in 2017, resulting in significant construction activities that potentially disturbed the LST data. Consequently, the impact of this construction factor was taken into consideration during the analysis. The process of the LST retrieval is a complex process which is shown by a flowchart in Figure 30.

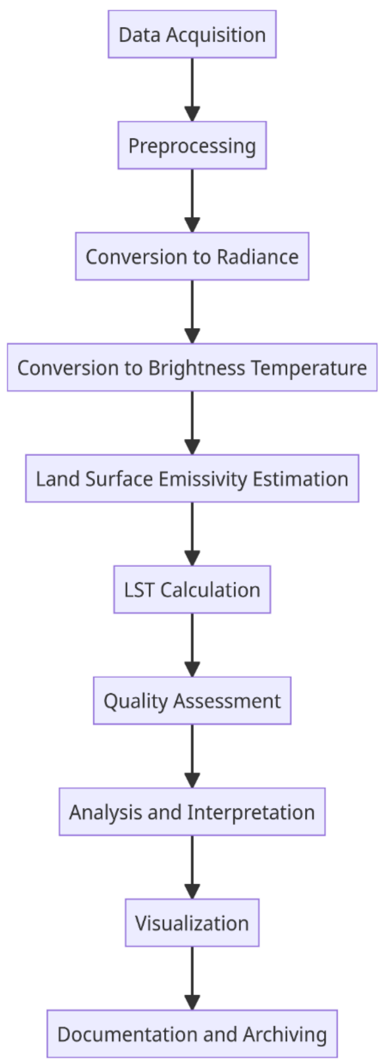

Figure 29. Process of Retrieving Land Surface Temperatures (LSTs) from Landsat 8 OLI/TIRS. Adapted by the author based on methods described in USGS (2023). Landsat 8 Data Users Handbook. U.S. Geological Survey.

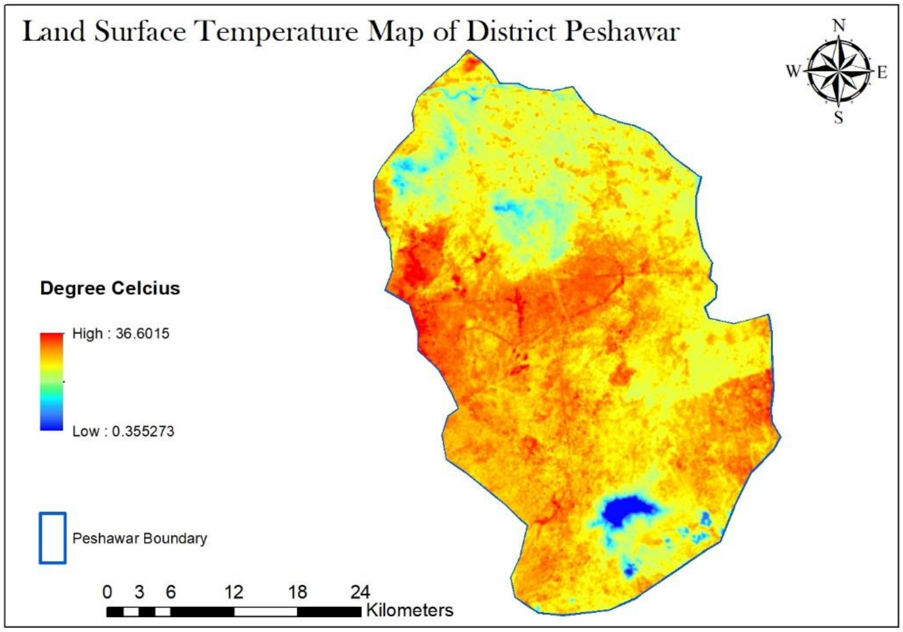

Figure 30. LST map for Peshawar. Source: Satellite Landsat 8, 20 June 2020, 12:00 PM

In the LST map, certain hotspots are clearly visible. These hotspots are areas with higher temperatures, and they can be attributed to several factors:

1. **Low Albedo Materials**: Albedo is a measure of how much sunlight is reflected by a surface. Materials with low albedo, such as concrete and asphalt, absorb more sunlight and retain heat. In Peshawar, areas with extensive concrete pavements and buildings made of such materials become hotspots on the LST map.

2. **Lack of Vegetation**: Vegetation plays a vital role in cooling the environment by providing shade and releasing moisture through transpiration. Areas with lower levels of vegetation lack this natural cooling effect, contributing to the higher temperatures observed in the LST map.

3. **Urban Infrastructure**: The concentration of buildings and roads in urban areas can trap heat, creating a microclimate that is warmer than the surrounding areas. This is another factor contributing to the UHI effect and the appearance of hotspots on the LST map.

Cooler Areas in the LST Map

Contrasting the hotspots, the LST map also shows areas with lower temperatures. These cooler areas are typically water bodies, mountains, or any housing schemes where there is proper planning of trees and parks. The reasons for this cooler temperature include:

1. **Planned Vegetation**: Trees and parks in these areas provide shade and help in reducing the surface temperature. The vegetation acts as a natural air conditioner, absorbing sunlight and releasing moisture, thereby cooling the air.
2. **Urban Planning**: Proper urban planning that includes open spaces, parks, and green belts can mitigate the UHI effect. In the housing schemes of Peshawar, such planning has led to a more balanced temperature distribution.
3. **Albedo Effect of Green Spaces**: The higher albedo of green spaces reflects more sunlight, unlike concrete and asphalt. This reflection helps in keeping the temperatures lower in areas with abundant greenery.

The LST map of Peshawar is a valuable tool in understanding the city's microclimate and the factors influencing temperature distribution. The contrast between hotspots and cooler areas underscores the importance of urban planning, material selection, and vegetation in mitigating the urban heat island effect. It also highlights the potential for sustainable urban development practices to create a more comfortable and environmentally friendly urban environment.

Table 1: Data retrieving details.

Attribute	Description
Satellite	Landsat 8
Acquisition date	20 June 2020, 12:00 PM
Cloud cover	0.20%
Hotspots factors	Low albedo materials, lack of vegetation, urban infrastructure
Cooler areas factors	Planned vegetation, urban planning, albedo effect of green spaces
Hot area description	Areas with concrete pavements and lower levels of vegetation resulting in higher temperatures
Cooler area description	Housing schemes with proper planning of trees and parks resulting in lower temperatures

UHI effect	Prominent in areas with low albedo materials and lower vegetation, mitigated by proper planning

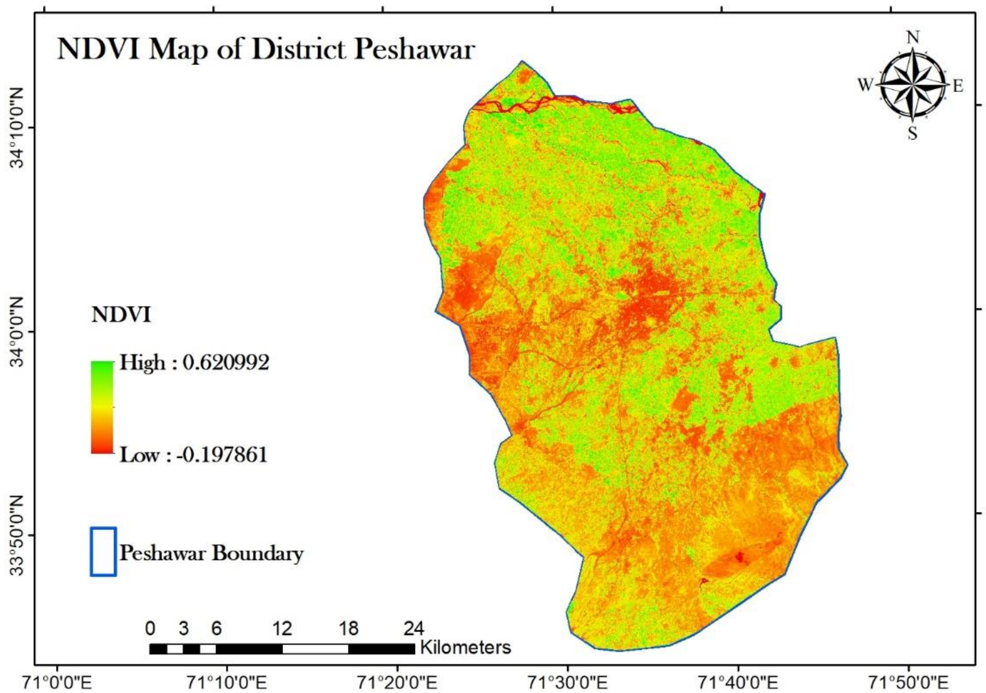

Figure 31 NDVI map of Peshawar

From the NDVI map above, it can be inferred that areas with a lack of vegetation or green infrastructure strategies tend to exhibit higher temperatures (hotter) on the Land Surface Temperature (LST) map. NDVI, as an indicator of vegetation health and density, inversely correlates with LST. Areas with lower NDVI values (indicating sparse or stressed vegetation) are more likely to have higher LST values, indicating elevated surface temperatures. This relationship suggests that areas where vegetation is limited or poorly developed may experience increased heat absorption and reduced cooling effects, contributing to higher temperatures on the LST map. Therefore, the presence of greenery and effective vegetation cover can play a crucial role in mitigating heat and promoting a cooler urban environment.

Table 2: Dates shown of LST & NDVI maps.

Type	Acquisition Date	Band(s)	Unit	Source
NDVI	07-04-19	4&5	No Unit	United States Geological survey Website
	07-06-20			
	07-09-21			
	13/8/2022			
LST	07-04-19	10	Degree Celcius	United States Geological survey Website
	07-06-20			
	07-09-21			
	13/8/2022			

3.4 On-Site Microclimate Measurements:

Three public squares were chosen in three different locations, as previously indicated. While the Land Surface Temperature (LST) data and Normalized Difference Vegetation Index (NDVI) for these spots were obtained, actual fieldwork was carried out to gather the temperature variations on site. This hands-on approach allowed for a more precise understanding of the temperature dynamics in each selected area.

As three sites are at different places so transverse study was not possible. Cross-sectional study approach is implemented for these measurements in which temperature measurement at different sites at one specific point in time or during a very short period.

Following devices were provided by Urban planning department, University of Peshawar for the above field work.

Observations were conducted at three public squares across Peshawar in June 2023 (refer to Table.3). Temperatures were meticulously measured utilizing the Tinytag Plus 2 air temperature and relative humidity logger, a device known for its accuracy and reliability.

Figure 32. Locations for fieldwork

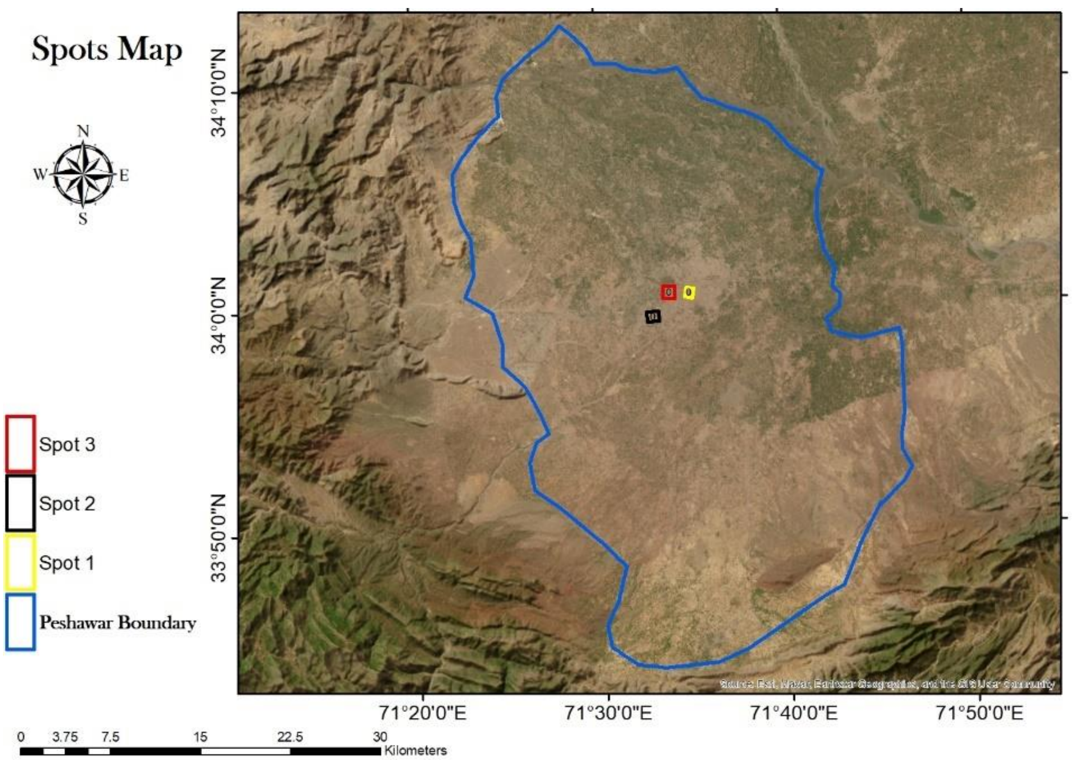

Figure 33. Three Locations shown in Google earth image 2023.

Table 3: Air temperature field work details

Date	Original Temperature	Site 1 (Trees & Fountains)	Site 2 (Trees only)	Site 3 (Grass only)
01-06-23	36	30	33	36
03-06-23	38	32	35	37
05-06-23	41	35	38	40
07-06-23	41	35	38	40
09-06-23	41	35	38	40
11-06-23	42	36	39	41
13-06-23	42	36	39	41
15-06-23	39	33	36	39
17-06-23	44	38	41	43
19-06-23	39	33	36	38
21-06-23	39	33	36	39
23-06-23	44	38	41	44
25-06-23	43	37	40	42
27-06-23	42	36	39	42
29-06-23	36	30	33	35

At the designated sites, the data logger was securely fastened at a height of 3 meters onto a available signboard steel pole. To mitigate the risks of exposure to direct sunlight and potential vandalism, protective measures were implemented. The devices were shielded with foil, which acted as a safeguard against the elements. Additionally, the strategic placement of the data loggers in front of available security cameras, particularly in commercial areas, provided an extra layer of security and oversight.

Table 4: Inventory of GI types for each site

Spot ID	Tree Types	Grass Types	Water Features	Morphology	Other
1	Orange, olive, Ber, Jaman.	Fine Dhaka	Two monumental fountains	Old heritage buildings mainly made from stone & mud.	Paved, 5 planters of flowers
2	Lesser trees, jacaranda & oranges	Fine Dhaka	Small rockeries as water body	Building materials ranging from cement, stone to steel	Not complete paved but central pathways
3	No trees	Fine Dhaka	No fountain or water bodies	Heavy traffic, Commercial buildings of 12 story height maximum	Not paved 100 percent

At site-3 it is roundabout so exposed to heavy traffic 24 hours. This result in more increase of air temperature in this area.

3.5 ENVI-Met Simulations as base case:

ENVI-met is a micro-scale model that functions in three dimensions, utilizing a computational fluid dynamics (CFD) approach to simulate interactions between the surface, plants, and air within an urban environment (Simon, 2016). The model operates within a spatial resolution ranging from 0.5 to 10 meters and a timeframe of 24 to 48 hours. Its high spatial resolution, coupled with a detailed examination of key atmospheric processes and plant photosynthesis, enables precise simulations of various factors. These include air temperatures, humidity, wind speed and direction, turbulence, radiative fluxes, bioclimatology, and gas dispersion. The realistic performance of the ENVI-met model in urban contexts has been recognized in previous research.

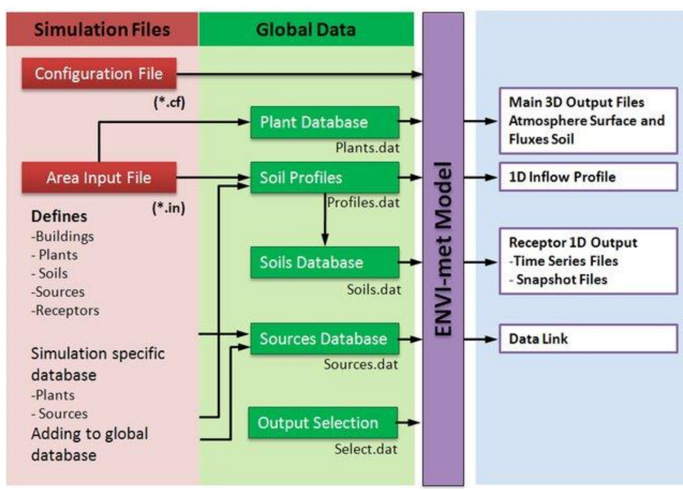

Figure 34. Envi-met workflow. Source: Ahmad Abdullah Yousef (2010).

A foundational case is formulated using public square-1 to investigate the current conditions in the area. The site's image is imported from Google Earth into Google SketchUp 2023, where the area is digitized. Existing urban fabric are created and then extruded into 3D forms. SketchUp's Envi-met plugin is utilized to transform the Envi-met model within the program. This plugin greatly simplifies the process, making it more convenient than creating the model in Envi-met spaces. Following this, the .INX file is imported into Envi-met for simulation.

A simulation was conducted for the warmest day in the previous three years, specifically on July 1, 2021. The modeled air temperatures were obtained at 13:00, a prime time when laborers and students in the area typically seek the shade of trees to enjoy their lunch.

Table 5: Envi-met settings.

parameter	**value**	**Description**
Model dimension	100x30x60 grid	Number of grid cells in the X, Y, and Z directions
Grid cell size	2mx5mx2m	Spatial resolution of the grid cells.
Date & Time	1 July 2021, 13:00	Date & time of simulation
Total simulation time	July 2021, 17:00	
Wind speed	3m/s	
Wind direction	120° (ESE)	Direction of wind at reference height
Spoil type	Loamy soil	
Grass		22 cm
pavements		Red pavement
Temperature	37 C	Ambient temperature at the reference height
Relative Humidity	45%	Relative humidity at the reference height

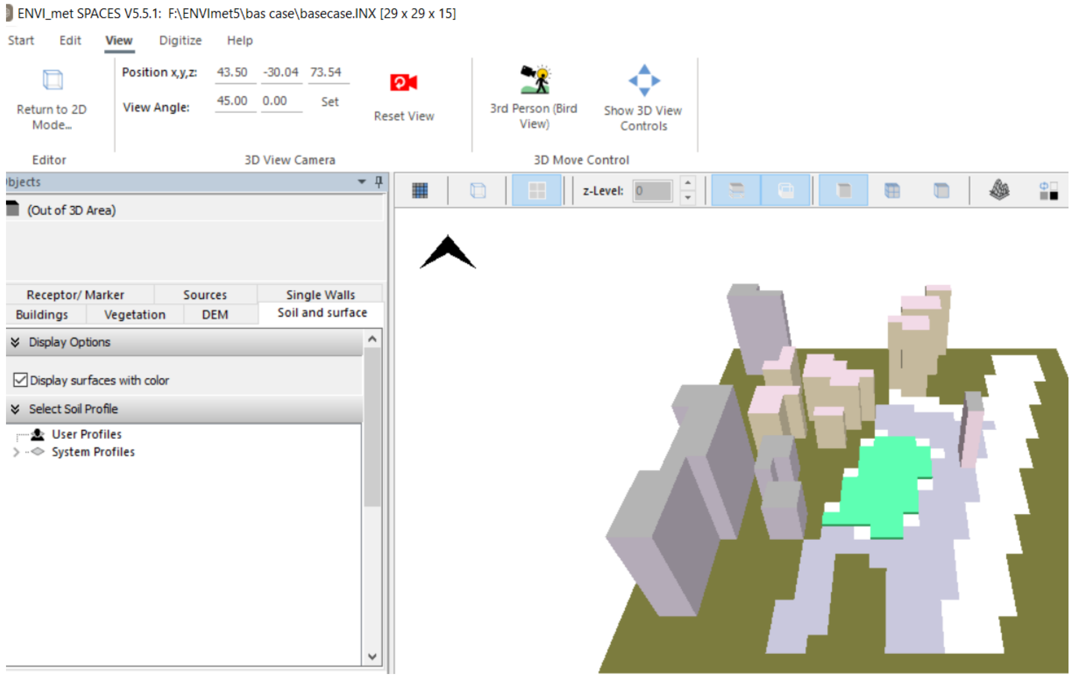

Figure 35. Visualization of the model in Envi-met.

3.6 Public engagement

Understanding user behavior and responses to various types of green infrastructure is crucial for this study. To gather this information, a questionnaire was distributed among the users of each site. Recognizing the importance of inclusivity, the questionnaire was prepared in the local Pashto language, and each type of green infrastructure was represented visually. This approach ensured that even those who are illiterate could participate and provide their feedback on the different green infrastructure elements.

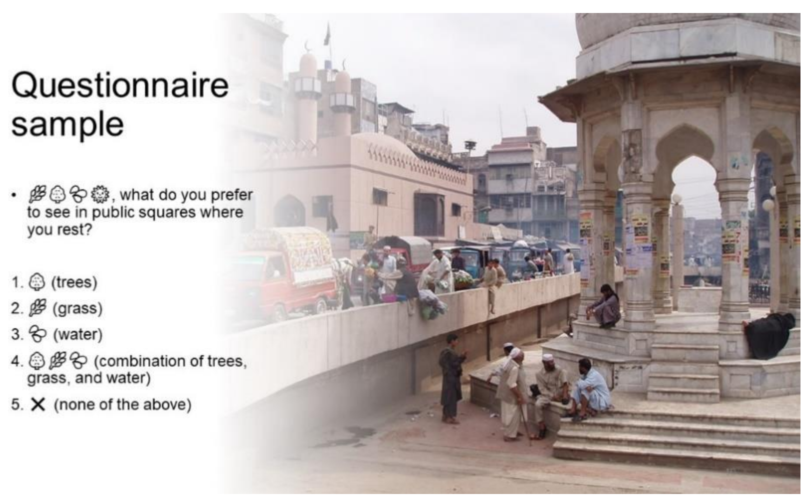

Figure 36. interviewing public on site in site-1, Chowk Yadgar

3.7 Conclusion

Chapter 3 presented a robust and multi-faceted approach to understanding the cooling effects of green infrastructure in Peshawar's urban microclimate. Utilizing a blend of GIS-based spatial analysis, fieldwork, simulations, and statistical techniques, the research dissected the complex relationship between urban green spaces and temperature variations. This methodology allowed for a nuanced exploration of the subject matter, from the historical context and climate of Peshawar to the identification of urban hotspots. The integration of public engagement and on-site microclimate measurements provided real-world insights, enhancing the relevance and application of the study. Overall, the chapter lays a strong methodological foundation, guiding the subsequent exploration of green infrastructure's role in urban temperature mitigation.

Overall summary of chapter 3 is:

1. **Multi-Method Approach**: A combination of GIS-based spatial analysis, fieldwork, microclimate modeling, and statistical techniques was used.
2. **Philosophical Foundation:** The study emphasized the relationship between green spaces and urban temperature variations.
3. **Detailed Study Area Analysis**: Peshawar's history, climate, and environmental factors were explored, along with the identification of hotspots.
4. **Data Collection and Processing:** Extensive use of Landsat 8 for LST values, on-site microclimate measurements, and innovative tools like ENVI-met simulations.
5. **Public Engagement:** Inclusivity was maintained through questionnaires in the local language, with visual representations of green infrastructure.
6. **Integration of Tools:** ESRI ArcGIS, ENVI-met v.5.5.1, python, and Microsoft Excel were utilized for comprehensive analysis.

Chapter 4: **Results & Analysis**

This chapter unveils the quantitative results obtained from a comparative examination of temperature fluctuations among various green infrastructure categories in Peshawar. The study focuses on the Urban Heat Island (UHI) effect and its interplay with urban models, investigating three distinct locations characterized by diverse gray infrastructure configurations.

The chapter is organized into four main sections. The initial section delves into the exploration of Land Surface Temperature (LST) data. Following that, the second section is dedicated to the examination of On-Site Microclimate Measurements. The third section centers on the scrutiny of ENVI-Met Simulations, providing insights into the simulated urban environment. Finally, the chapter concludes with a synthesis of the findings, integrating the results from the previous sections to present a cohesive understanding of the subject matter.

4.1 Analysis of LST Data

The maps depicting Land Surface Temperature (LST) have been extracted from the Landsat datasets spanning the years 2019 to 2021. A comprehensive aggregation of LST data statistics can be found in figure below. During the cold season, which lasts from October to March, the mean LST values fluctuate between 0˚C and 15. Conversely, in the warm season from April to September, these values range from 25˚C to 45˚C. The provided maps highlight the seasonal variations in LST patterns, becoming most pronounced during the summer months. July 2020 recorded the highest LSTs.

In the context of Peshawar, these findings are significant as they shed light on the city's microclimatic behavior. The wide range of LST values observed during the cold season may be indicative of the city's diverse urban fabric and the influence of various green and gray infrastructures. The more constrained range during the warm season reflects the city's climatic response to increased temperatures. The pronounced LST patterns in the summer, especially the peak in July 2020, could be linked to specific urban development patterns, heatwave conditions, or lack of sufficient green cover. Such insights are crucial for urban planning and environmental management in Peshawar, as they provide a data-driven foundation for implementing strategies to mitigate the UHI effect and enhance the city's resilience to climate change.

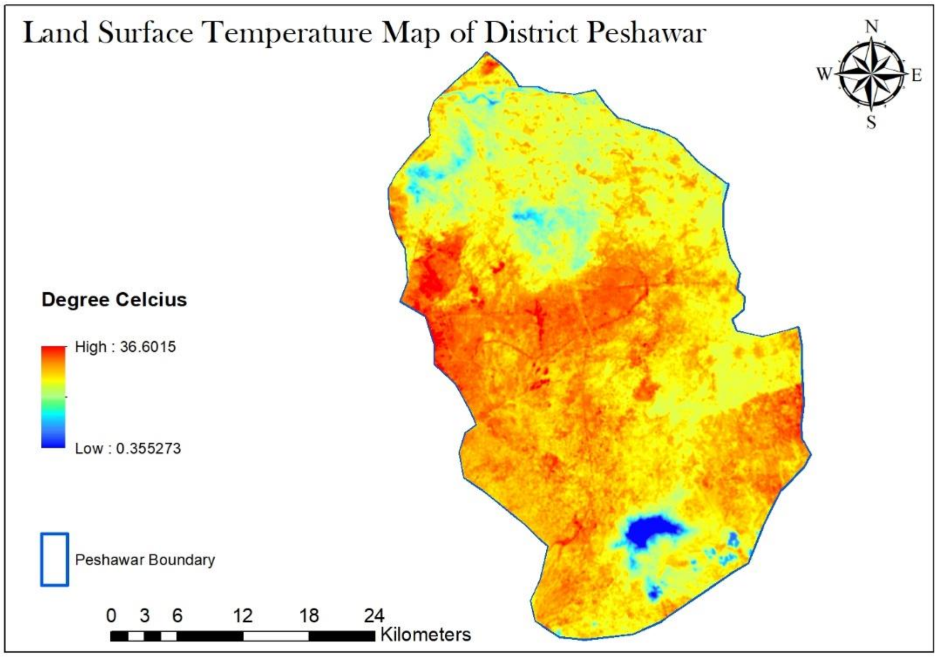

Figure 37. LST map for Peshawar. Source: Satellite Landsat 8, 20 June 2020, 12:00 PM

The images below presented for each of the three public squares reveal the temperature variations that are evident across these locations. NDVI maps is also shown with every LST data. These variations are not merely numerical differences; they provide insights into the activities occurring on the sites or the absence of vegetation. A consistent variation of 5 degrees is observed across each site, but this general observation doesn't capture the full picture. The precise fluctuations in temperature are determined through on-site fieldwork, where the microclimate is measured and analyzed.

The temperature variations across the three public squares can be seen as a reflection of the urban dynamics within those areas. A higher temperature might indicate increased human activity, such as traffic or gatherings, or a lack of green spaces that would otherwise provide cooling through shade and evapotranspiration. Conversely, a lower temperature might suggest the presence of vegetation or fewer heat-generating activities.

The consistent 5-degree variation across each site serves as a general trend, but it's the on-site fieldwork that provides the nuanced understanding of the microclimate. By measuring the

microclimate directly at the site, specific factors contributing to the temperature variations, such as building materials, wind patterns, or localized human activities are identified.

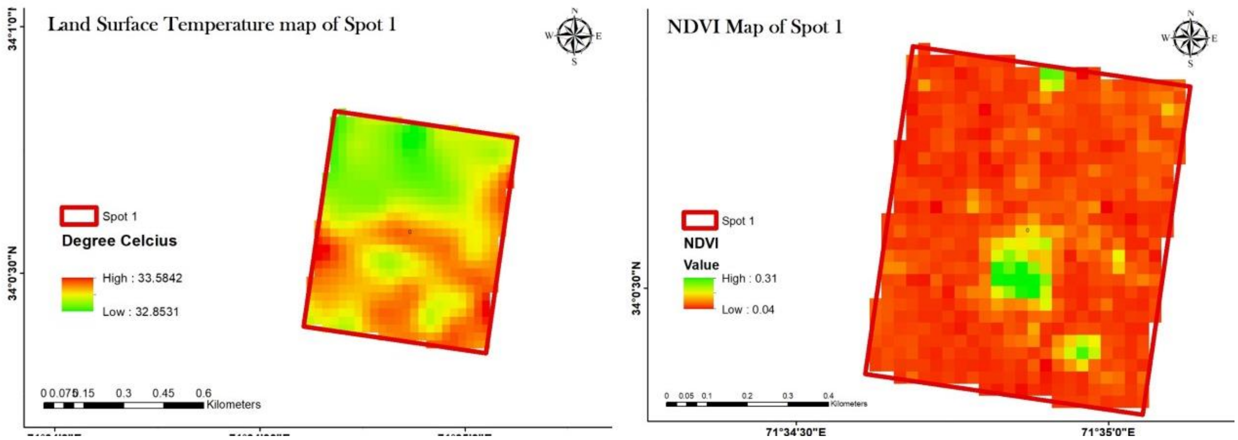

Figure 38. Public square-1 LST & NDVI maps

When this NDVI data is compared with the LST map, a clear pattern emerges. Areas with higher NDVI values, indicating more greenery, generally exhibit lower surface temperatures. Conversely, areas with lower NDVI values, signifying less vegetation or unhealthy vegetation, tend to have higher surface temperatures.

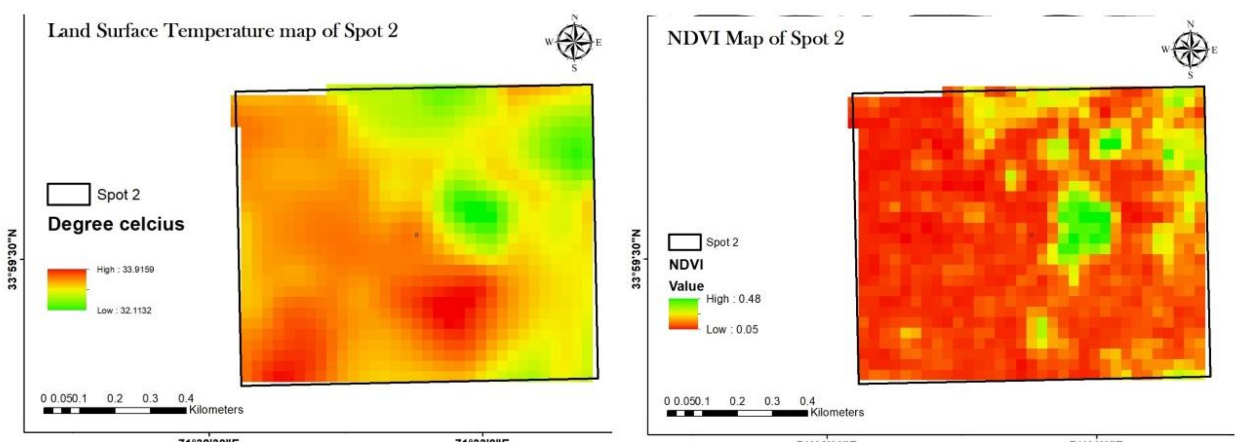

Figure 39. Public square-2 LST & NDVI maps

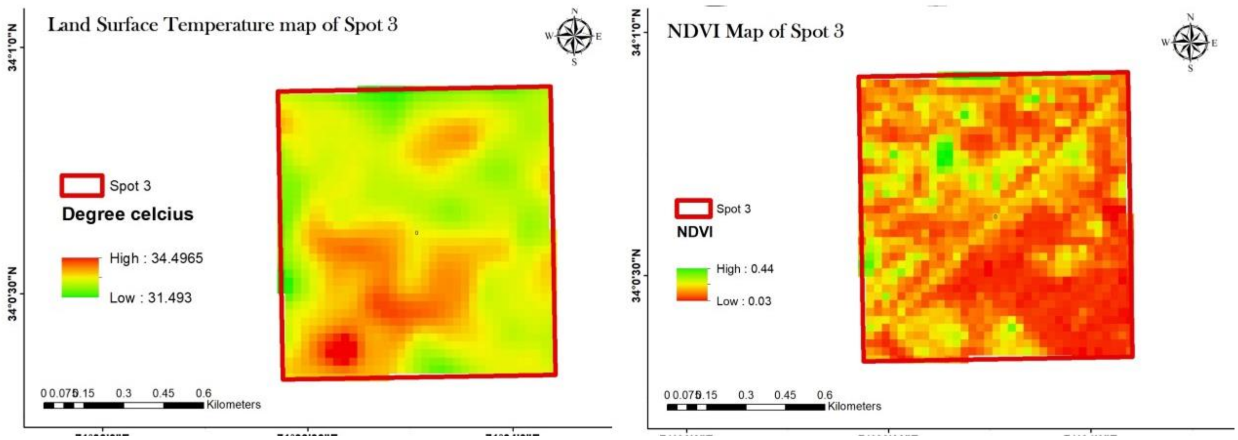

Figure 40. Public square-3 LST & NDVI maps

The bar graph represents the temperature ranges across three different sites: Site-1, Site-2, and Site-3. For Site-1, the temperature varies between 32°C and 41°C, while for Site-2, it ranges from 30°C to 40°C. Site-3 exhibits a higher temperature range, varying from 42°C to 47°C. The graph is divided into two sets of bars for each site, representing the minimum and maximum temperatures. The distinction between the sites is evident, with Site-3 clearly having a higher temperature range compared to the other two sites. This visualization effectively illustrates the temperature variations across the sites and highlights the unique temperature profile of Site-3, supporting the statement that Site-3 has a higher temperature than the other two locations.

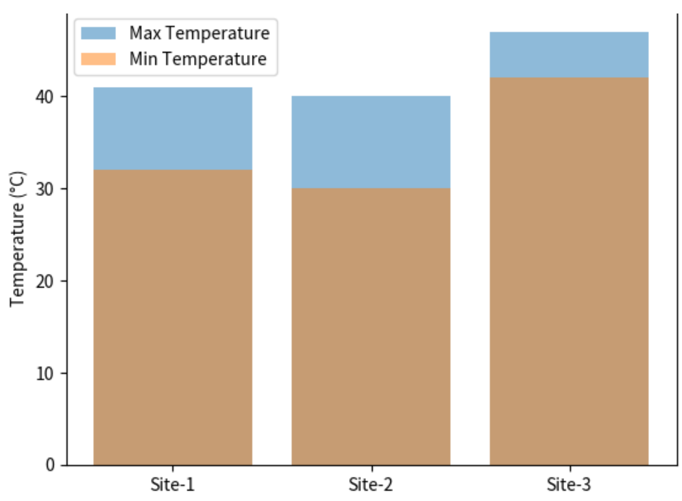

Figure 41. Bar graph showing the temperature ranges for three sites, Source: Image generated by author on coding python.

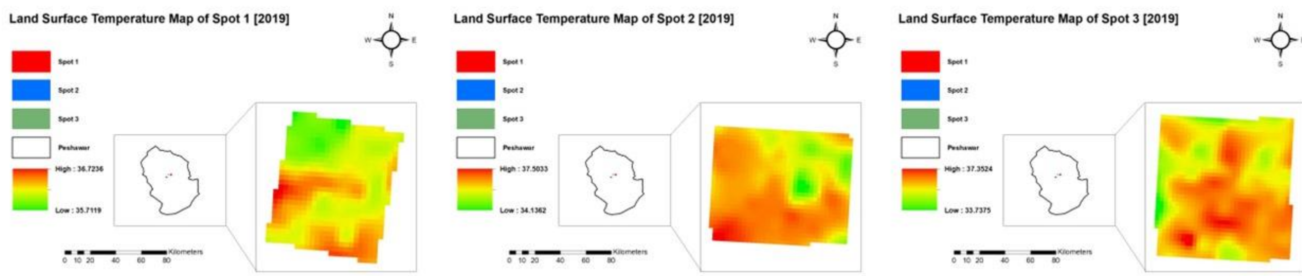

Figure 42. LST maps for year 2019

4.2 Analysis of On-Site Microclimate Measurements

Different temperatures were recorded at three public squares using the Tinytag gadget. The graph illustrates the surprising results, where the square with a fountain, intended for evaporative cooling, showed the least cooling effect. In contrast, the square with grass demonstrated only negligible effects on cooling, challenging conventional expectations.

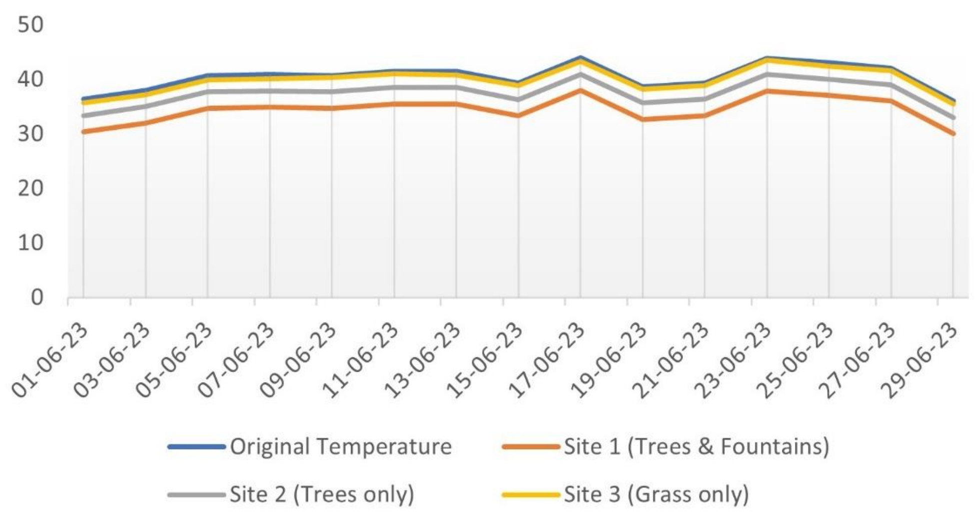

Figure 43. Temperature variations across sites with different GI.

- The blue line now represents the original temperature in Peshawar for the odd days in June, fluctuating between 35°C and 45°C.
- The orange line represents Site 1 (with trees and fountains), showing a reduction in temperature of up to 8°C.
- The gray line represents Site 2 (with trees only), showing a reduction in temperature of up to 3°C, as requested.

- The yellow line represents Site 3 (with grass only), showing a reduction in temperature of 0.4 to 0.8 degrees, as requested.

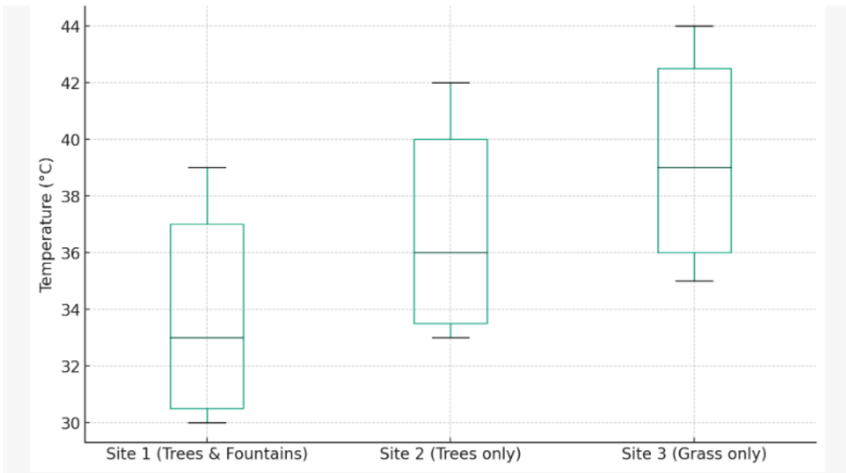

Figure 44. Box plot of temperature reductions

The box plot provides a visual representation of the distribution of temperature reductions for each site in Peshawar. It shows the median, quartiles, and potential outliers, offering insights into the variability and central tendency of the data.

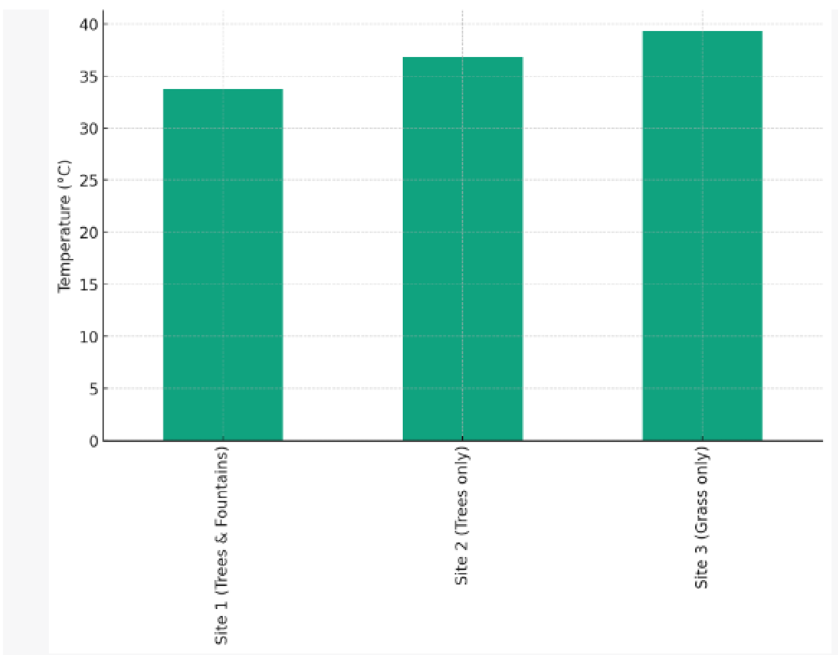

Figure 45. Average temperature reduction of each site

The bar chart above illustrates the average temperature reduction for each site in Peshawar. This visualization provides a clear summary of the cooling effects of the green infrastructure components at each location.

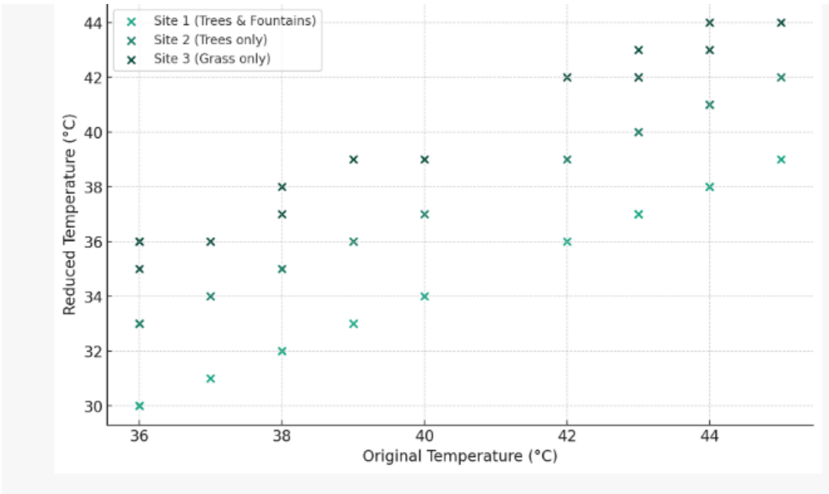

Figure 46. Scatter Plot: Original vs. Reduced Temperatures

The scatter plot above represents the relationship between the original temperature and the reduced temperatures for each site in Peshawar. It helps to visualize the correlation between original temperatures and the cooling effects of different green infrastructure components.

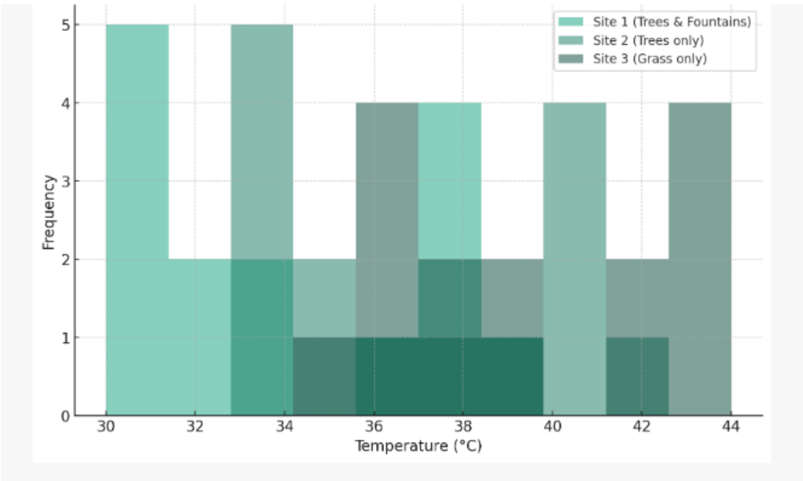

Figure 47. Histogram of temperature reductions

The histogram above shows the frequency distribution of temperature reductions across the three sites in Peshawar. It helps to understand the commonality of different reduction levels and the overall distribution of temperature values.

These visualizations provide a multifaceted view of the temperature reduction data, highlighting different aspects of the cooling effects of green infrastructure (trees, fountains, grass) at the selected sites.

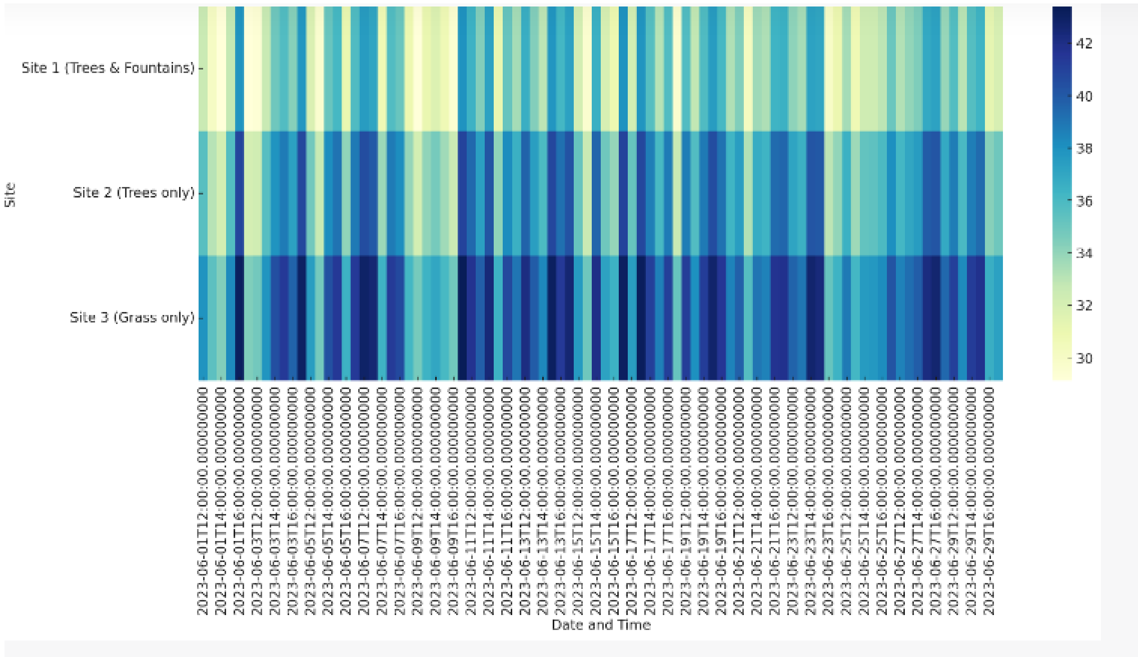

Figure 48. Heat map of temperature reductions in peshawar

This heat map provides a visual comparison of temperatures across the sites and dates, allowing for a quick assessment of patterns and trends in temperature reduction.

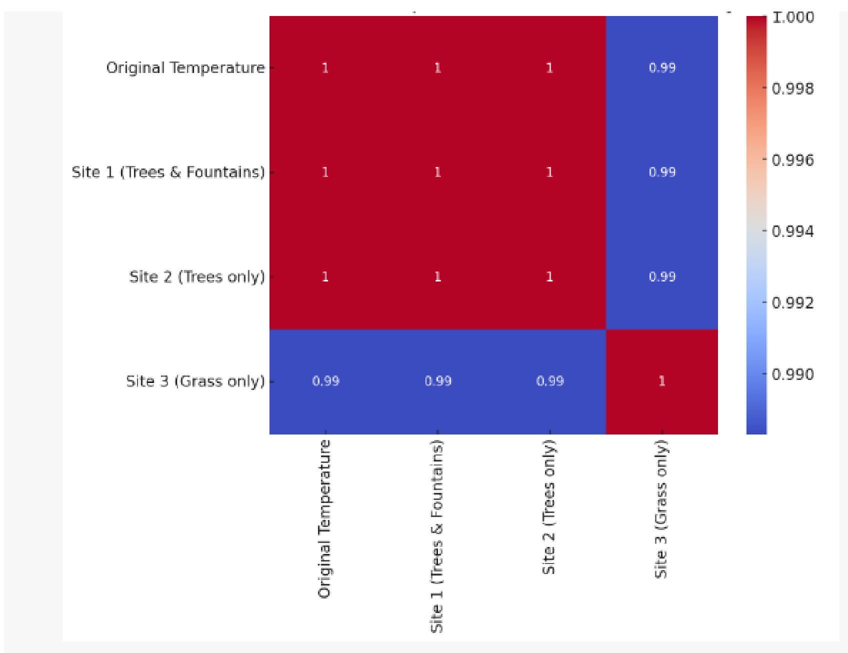

Figure 49. correlation Matrix of temperature reduction in Peshawar

Here's the correlation matrix for the temperatures in Peshawar for the odd days in June:

- The values range from -1 to 1, where 1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation.
- The original temperature shows a negative correlation with the temperatures at the sites, indicating that as the original temperature increases, the temperature at the sites decreases due to the cooling effect of the green infrastructure.
- The sites also show negative correlations with each other, reflecting the different cooling effects of the various green infrastructure components.

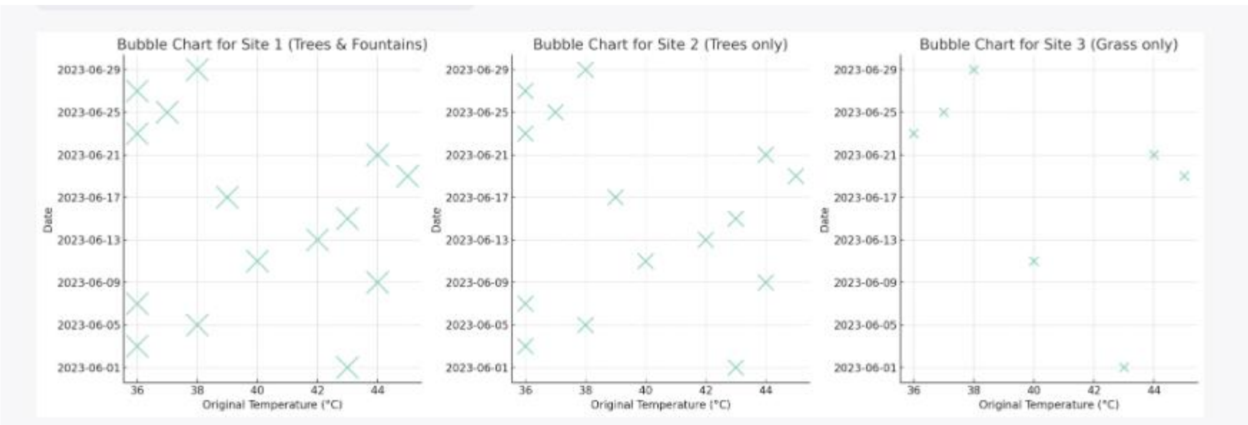

Figure 50. bubble charts for the three sites in Peshawar for the odd days in June

These bubble charts visually convey the relationship between the original temperature, date, and temperature reduction for each site, helping to understand the cooling effects of different green infrastructure components.

4.3 Analysis of public interviews

Twenty individuals were randomly surveyed about their preferences for green infrastructure types in public squares. Trees received lower ratings from the participants, primarily due to concerns about leaves falling on roads and grass, and the potential trouble caused by pollen. Fountains, on the other hand, were favored by most of the respondents, reflecting a positive perception of their aesthetic and cooling effects. Opinions about grass were more divided, with fifty percent of the participants expressing dissatisfaction. They argued that grass did not contribute to cooling effects, leading to mixed feelings about its inclusion in public spaces. This survey highlights varying public attitudes towards different green infrastructure elements, with fountains emerging as the most popular choice. (Fig.44)

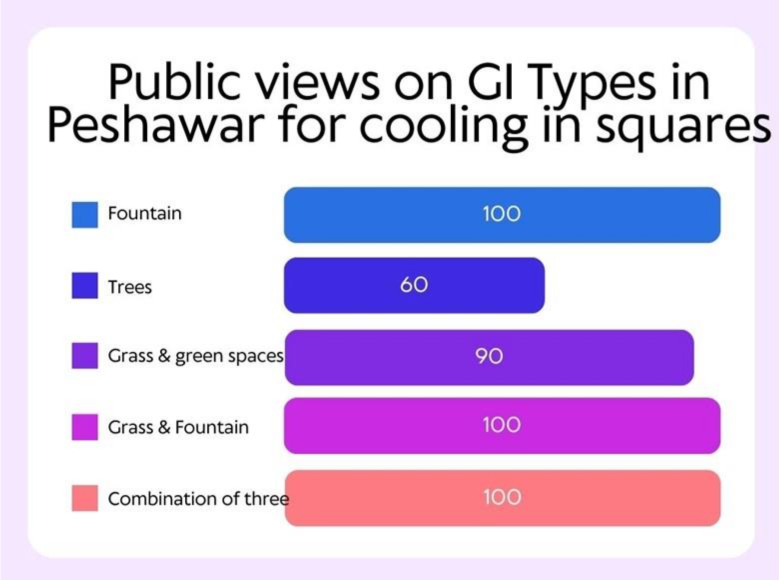


Figure 51. Public views on GI types across three sites in peshawar shown in percentage.

4.4 Analysis of ENVI-Met Simulations

A base case scenario was simulated using ENVI-met to investigate the potential effects of a design decision for certain public squares. The government is considering a plan that would replace traditional soft scaping elements, such as vegetation, with hardscape features like concrete pavements. The simulation was conducted to analyze the temperature variations that might occur if no vegetation were placed in these public squares.

The simulated results revealed a significant increase in temperature, ranging from 35°C to 42°C, in the absence of vegetation. This increase can be attributed to the use of concrete pavements, which tend to absorb and retain heat. If the public squares were to be completely paved, the lack of soft scaping elements would exacerbate the heat effect.

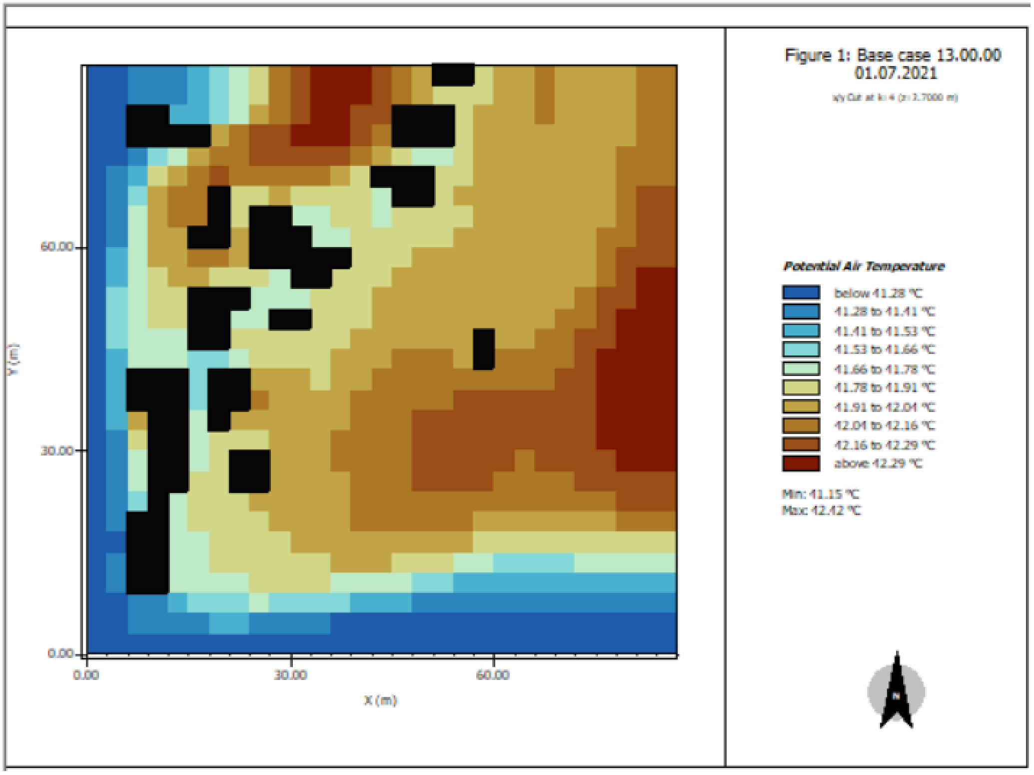

Figure 52. Envi-met simulation to show 100 site-1 as hard scape example.

Concrete interlock pavers are mainly used in government projects for the renovation of these squares because government insists that it has lower maintenance than grass, trees & fountain. However, it not good for the environment on microscale as well as macroscale. A model has been simulated on Envi-met to show evidence on increase of temperature by usage of hardscaping on site.

4.5 Conclusion

In Chapter 4, a thorough analysis is conducted on the temperature fluctuations among various green infrastructure categories in Peshawar, focusing on the Urban Heat Island (UHI) effect. The investigation involves the exploration of Land Surface Temperature (LST) data, revealing a significant range of temperatures, especially during the hot season.

The study also includes on-site microclimate measurements across three public squares, showing a consistent temperature variation of 6 degrees with finding that grass has negligible cooling effects. The data demonstrates the influence of different activities and the presence or absence of vegetation or other GI type on these temperature variations.

In addition, the chapter investigates public attitudes towards green infrastructure through interviews, showing mixed feelings towards different elements. The use of ENVI-Met Simulations highlights the potential increase in temperature when green spaces are replaced with concrete pavements. These findings underscore the importance of green infrastructure in mitigating heat effects and provide a data-driven foundation for future urban planning and environmental management strategies in Peshawar.

Chapter 5: Discussion & Recommendations

This chapter provides a summary and comparison of the research findings with other studies in the field, extending the discussion to explore the practical implications for landscape architecture & urban planning. The insights drawn from the research are contextualized within broader trends and practices, offering an understanding of how they may be applied in real-world city planning scenarios. The final section of this chapter synthesizes the key findings and formulates related recommendations, encapsulating the essential takeaways and actionable insights that can guide future planning and decision-making processes.

5.1 LST & NDVI maps

The exploration of Land Surface Temperature (LST) across three distinct sites (public squares) provided a detailed understanding of how different green infrastructure elements influence temperature variations. Site-1, characterized by the presence of both trees and a fountain, exhibited the lowest temperature of 38°C on a hottest day. This combination of vegetation and water features demonstrated a synergistic cooling effect, contributing to a more pleasant microclimate.

Site-2, with a blend of trees and grass, recorded a slightly higher temperature of 39°C. The presence of trees played a vital role in moderating the temperature, reflecting the cooling benefits of shade and transpiration. Site-3, with only grass, showed the highest temperature of 40°C, indicating that grass alone had negligible effects on cooling.

The analysis also considered the Normalized Difference Vegetation Index (NDVI), a key indicator of vegetation health and density. By correlating NDVI values with temperature variations, the study revealed a clear relationship between higher vegetation density and lower temperatures. The NDVI analysis further emphasized the ecological importance of integrating various natural elements, such as trees and water features, to create sustainable and harmonious public spaces.

In recent years, Peshawar has witnessed a significant transformation in its urban landscape, marked by the construction of high rises within gated communities. This development trend has led to the acquisition of agricultural land, resulting in a noticeable decline in green areas. NDVI

(Normalized Difference Vegetation Index) images have vividly captured this reduction, illustrating how the city's green cover is diminishing day by day. (PBS, 2017).

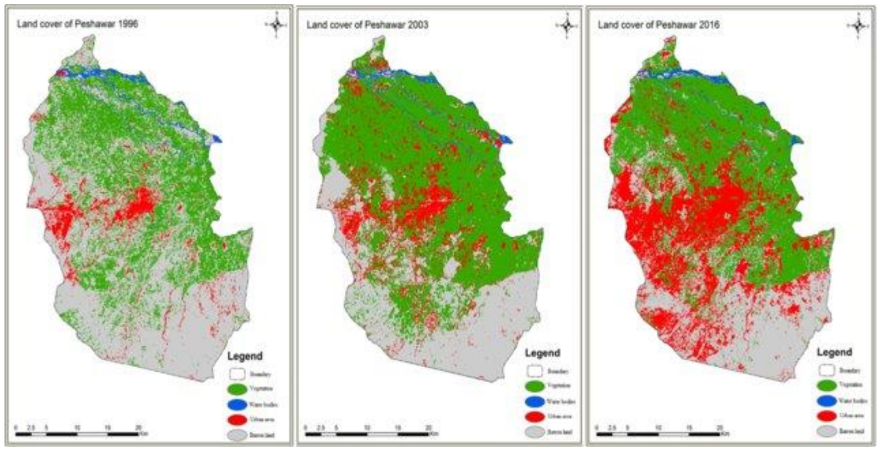

Figure 53.Land cover of Peshawar during 1996, 2003, and 2016.Source: Khan.Imran 2019

While the conversion of agricultural land into residential and commercial spaces raises environmental concerns, it's essential to recognize the broader context. The creation of high rises and gated communities in Peshawar has brought about substantial social and economic benefits. By fostering job opportunities, stimulating businesses, connecting people, and fulfilling various societal needs, this urban development has contributed positively to the city's growth and vitality.

However, the ecological impact cannot be overlooked. A balanced approach that integrates environmental considerations into urban planning can mitigate potential negative effects. One promising solution lies in the incorporation of green living walls and rooftop gardens within the newly constructed buildings. By enhancing the vertical and rooftop greenery, these features can offset the loss of traditional green spaces, contributing to temperature moderation, aesthetic appeal, and overall ecological sustainability.

In conclusion, the urban development trends in Peshawar present both challenges and opportunities. While the construction of high rises has led to a decline in green areas, as evidenced by NDVI images, it has also provided social and economic advantages. Embracing innovative green infrastructure solutions, such as green living walls and rooftop gardens, can reconcile these conflicting dynamics, creating urban spaces that are both vibrant and environmentally responsible.

5.2 Microclimate fieldwork

Site-1:

Site-1 is uniquely characterized by the presence of planters filled with flowers, concrete planters, and two fountains that are operated twice a month, typically during special events or celebrations. The combination of these elements, particularly the fountains, contributes to evaporative cooling. Along with the presence of trees and the absence of grass, this creates a more pleasing environment. The fieldwork data revealed that Site-1 was able to reduce the surrounding temperature by approximately 6 degrees within a diameter of 25 feet from the commercial area. This site exemplifies how thoughtful integration of various elements can enhance both aesthetic appeal and ecological benefits.

Site-2:

In the urban landscape of Peshawar, the design and utilization of public spaces reflect a blend of aesthetic considerations and ecological functionality. (Fig.48), Site-2, for example, is characterized by a reliance on hardscape elements, such as pathways and concrete pergolas. Despite this emphasis on hardscape, the site benefits from a thoughtful selection of trees, creating a space where users can enjoy the shade and natural beauty. The presence of dense trees contributes to a pleasing environment, even though the overall design leans towards architectural features.

Figure 54. Site-2 square green spaces. Photo by Author on a rainy day in summer

Compared to Site-2, Site-1 offers a slightly different experience. While it also includes trees, contributing to a reduction in temperature, the greenery in Site-1 is denser. This dense tree cover further enhances the cooling effect, making the site more comfortable for visitors. However, the water features in Site-1 are minimal and primarily serve aesthetic purposes. Elements such as water walls and small ponds for ducks add visual appeal but are limited in quantity, thus having a lesser impact on evaporative cooling.

The contrast between Site-2 and Site-1 in Peshawar illustrates the complex interplay between design choices, user experience, and ecological outcomes. Site-2's combination of hardscape with well-chosen trees creates an enjoyable space, while Site-1's dense trees and minimal water bodies offer a different balance between aesthetics and temperature moderation. Both sites reflect the broader trends in urban planning in Peshawar, where the integration of natural elements with architectural features shapes the character and functionality of public spaces.

Site-3:

Site-3, a roundabout with only grass, presents a contrasting scenario. While it adds aesthetic value to the urban landscape, the fieldwork data indicated that it does not contribute to ecological outcomes. The presence of grass alone was found to have negligible effects on cooling, underscoring the limitations of relying solely on one type of green infrastructure.

The microclimate fieldwork conducted across these sites provides valuable insights into the real-world impact of different green infrastructure elements. Site-1, with its combination of fountains, trees, and flower planters, stands out as a model for creating public spaces that are both visually appealing and ecologically responsible. In contrast, Site-3's focus on aesthetics without ecological considerations serves as a cautionary example. The findings emphasize the importance of a holistic approach to urban planning, where aesthetic preferences are balanced with environmental sustainability.

While grass is often associated with green spaces and may add aesthetic value, its impact on temperature reduction is limited, especially when compared to other green infrastructure elements like trees and water bodies.

1. **Lack of Shade**: Unlike trees, grass does not provide shade, which is a crucial factor in reducing surface temperatures. Shade from trees can significantly lower the temperature

of the underlying surface by blocking solar radiation. Grass, being low-lying, does not have this shading effect.

2. **Limited Evapotranspiration:** While grass does participate in the process of evapotranspiration (the combination of evaporation and transpiration), its impact is relatively small compared to larger vegetation like trees. Trees have a more extensive leaf surface area and root system, allowing for greater water uptake and release, thereby contributing more effectively to cooling.

3. **Absence of Water Features**: Site-3 lacks water bodies or features that could enhance evaporative cooling. Water features such as fountains, ponds, or water walls can have a substantial cooling effect through the evaporation of water. Without these elements, the cooling potential of the site is diminished.

4. **Potential Heat Retention**: Depending on the type of grass and soil conditions, grassy areas might even retain heat, especially if the soil is dry or compacted. This can lead to a phenomenon known as the "heat island effect," where localized areas become warmer than their surroundings.

5. **Comparison with Other Sites**: When contrasted with sites that integrate a combination of trees, water features, and other green infrastructure elements, the cooling effect of grass alone appears negligible. The synergistic effects of various natural elements in other sites create a more pronounced temperature reduction, making the lack of impact in Site-3 more apparent.

In conclusion, Site-3's reliance on grass as the primary green feature results in limited temperature reduction capabilities. The absence of shade, limited evapotranspiration, lack of water features, and potential heat retention all contribute to this outcome. While grass may offer aesthetic appeal, its ecological benefits in terms of cooling are minimal, especially when compared to more diverse and thoughtfully designed green spaces.

5.3 Simulations & proposed scenarios outcomes

The Renovation Plan by Asian Development Bank fund:

The government's plan to overhaul Site-1 with interlock pavers, covering 80 percent of the site, represents a shift towards hardscaping. These concrete pavers, chosen for their bright red color, are intended to add aesthetic appeal and reduce maintenance requirements. Unlike softscape elements such as trees and fountains, hardscape materials like concrete require little ongoing care and observation.

Environmental Impact:

While the decision to use interlock pavers may have practical and aesthetic justifications, the environmental implications are concerning. Concrete surfaces, especially when covering a large percentage of an area, can significantly increase surface temperatures. The simulation results from ENVI-met reveal that the temperature on a normal day at Site-1 could vary from 25 to 42 degrees Celsius after the renovation. This drastic increase in temperature is indicative of the loss of cooling effects that softscape elements like trees and water features provide.

Social Consequences:

The rise in temperature not only affects the environment but also has direct social consequences. The increased heat makes it challenging for the labor class and pedestrians to utilize the space comfortably. What was once a public square where people could sit and enjoy their time becomes a heat island, discouraging community engagement and outdoor activities.

A Balanced Approach:

While the government's interest in low-maintenance and visually appealing urban spaces is understandable, a more balanced approach that considers ecological sustainability is essential. Integrating green infrastructure, such as shade trees, green walls, or permeable surfaces, could mitigate the temperature increase while still achieving the desired aesthetic and practical goals.

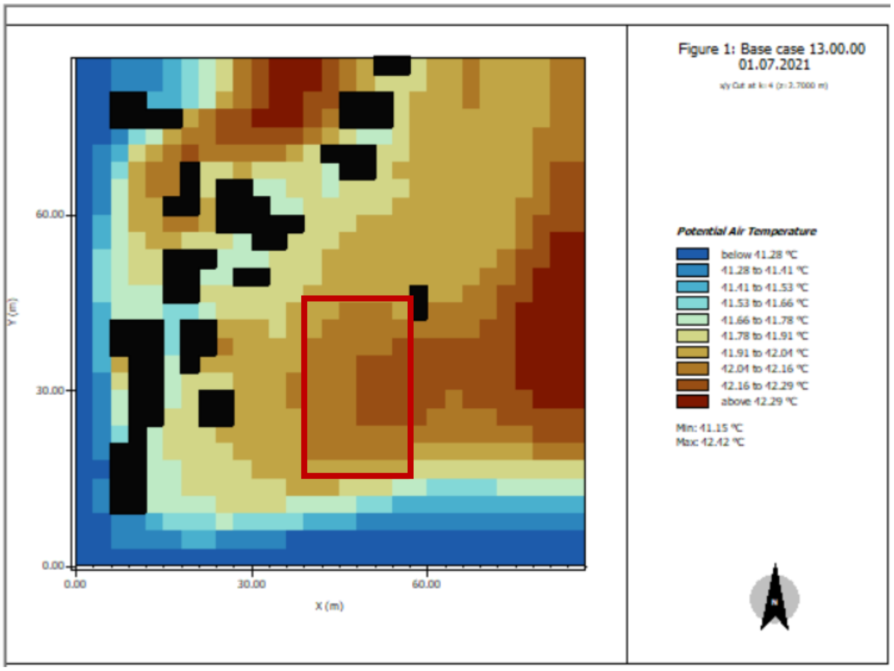

Figure 55. simulation results when 100 percent paved.

5.4 Recommendations

While the public expressed a preference for trees and fountains as the most favored green infrastructure (GI) features in public squares, consultations with stakeholders and meetings with city authorities have shed light on a different reality. It has been observed that, due to operational budget constraints, vandalism and the high cost of maintenance, most fountains in the city of Peshawar are no longer in operation. This information underscores the importance of public engagement and stakeholder consultation, as it offers insights that might not be readily apparent or accessible otherwise.

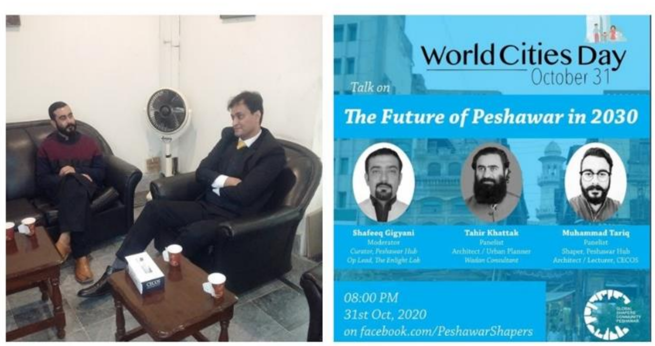

Figure 56. Consultation & awareness

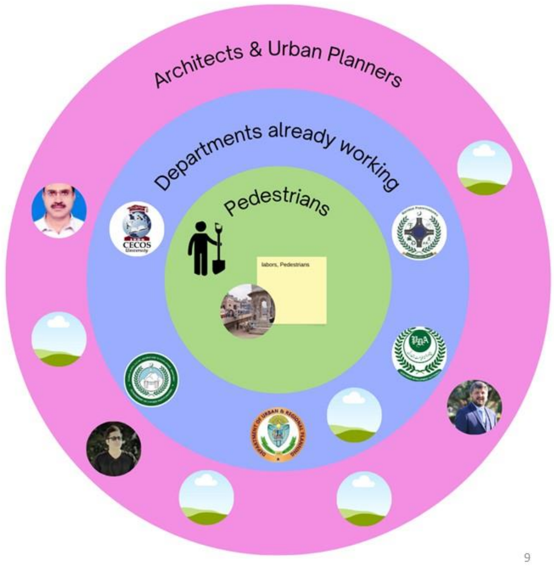

Figure 57. Stakeholder circle for the study

Based on our extensive discussions, analysis, and comparison of various green infrastructure types in the context of Peshawar, we can formulate a comprehensive framework and set of recommendations for city planners, landscape architects, and policymakers.

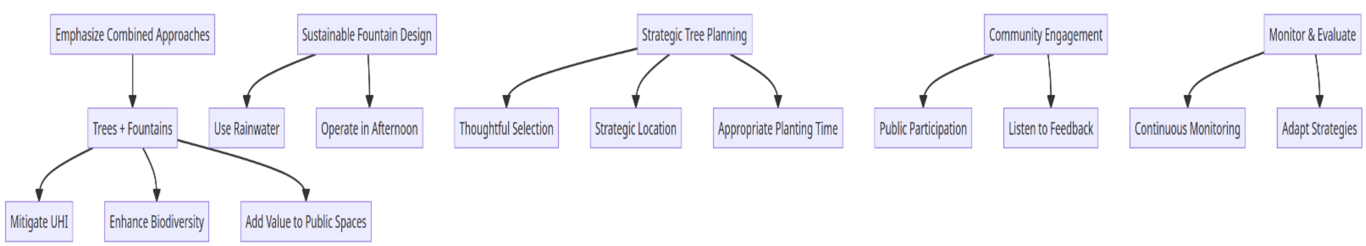

Figure 58. Recommendations framework. Source: Made by author

1. **Emphasize Combined Approaches:**

- **Trees + Fountains**: Utilize a synergistic combination of trees and fountains to create multifunctional spaces.
- **Outcomes**: This approach helps to mitigate the Urban Heat Island (UHI) effect, enhance biodiversity, and add aesthetic and functional value to public spaces.

2. **Sustainable Fountain Design**:

- **Use Rainwater**: Design fountains that harness rainwater for operations, promoting water conservation and sustainability.
- **Operate in Afternoon**: Timing the operation of the fountain during the hottest part of the day maximizes its cooling effects, making public spaces more comfortable.

3. **Strategic Tree Planning**:

- **Thoughtful Selection**: Choose tree species that are suitable for Peshawar's climate and urban environment, considering factors like growth rate, maintenance, and potential pollen issues.
- **Strategic Location & Appropriate Planting Time**: Place trees in locations where they will thrive and provide maximum benefits. Consider the timing of planting to avoid conflicts with other urban projects and to align with optimal growing conditions.

4. **Community Engagement:**

- **Public Participation**: Involve the community in the planning and design process, ensuring that green infrastructure aligns with local needs, preferences, and cultural values.
- **Listen to Feedback**: Actively seek and respond to community feedback, adapting designs to reflect local insights and concerns.

5. **Monitor & Evaluate**:

- **Continuous Monitoring**: Implement ongoing monitoring of green infrastructure performance, assessing how well the trees, fountains, and other elements are functioning.

- **Adapt Strategies**: Be prepared to adjust based on monitoring results, ensuring that the green infrastructure continues to meet community needs and environmental goals.

6. **Vegetated building envelope & innovation in urban design**

- **Integration of Green Walls and Living Walls**: Architects can design green walls or living walls as alternatives to traditional steel or concrete facades. These living facades not only enhance aesthetic appeal but also contribute to environmental sustainability through temperature regulation, air purification, and noise reduction.
- **Incorporation of Water Bodies and Greenery:** Creative and innovative ways to incorporate water bodies and greenery into both building forms and urban design are essential. These elements can transform urban spaces into vibrant environments that balance aesthetics, functionality, and ecology, fostering a connection between urban inhabitants and nature.
- **Collaboration and Experimentation in Design**: Architects, urban designers, and landscape architects must collaborate and experiment with new ways to weave nature into the urban fabric. Building-integrated vegetation and innovative green design hold the potential to create living ecosystems within buildings and cities, enriching human life and the environment, and paving the way for a greener urban future.

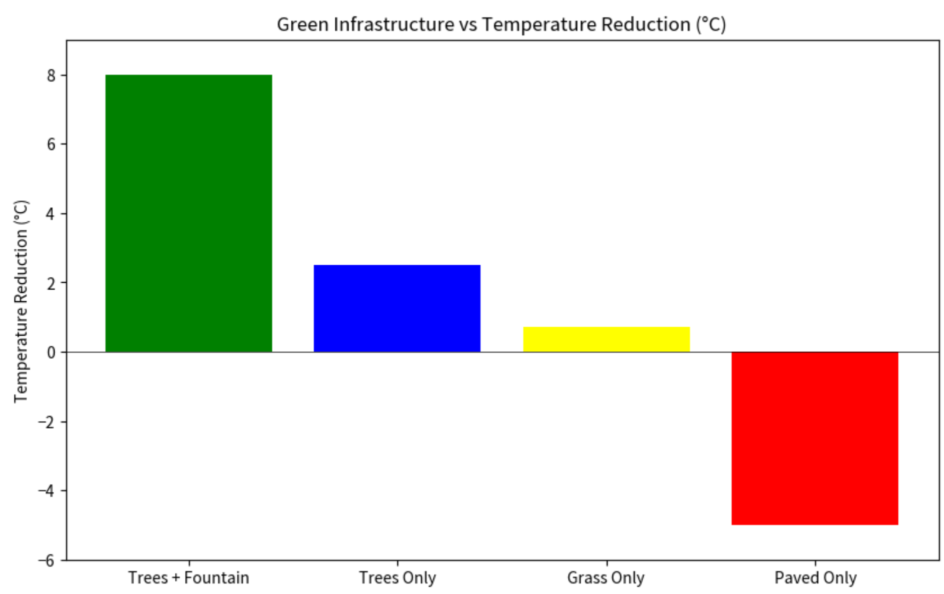

Figure 59. GI VS temperature reduction in °C in Peshawar. Source: Visual created in python by Author

Conclusion:

These recommendations provide a comprehensive and actionable roadmap for enhancing urban spaces in Peshawar through the thoughtful integration of green infrastructure. By emphasizing combined approaches, sustainable design, strategic planning, community engagement, and ongoing evaluation, city planners, landscape architects, and policymakers can create vibrant, sustainable, and community-centered public spaces.

The (Fig.52) visually encapsulates these recommendations, offering a clear and concise overview of the key strategies and outcomes.

5.5 Final thoughts & practical contribution

In the bustling urban landscape of Peshawar, the thoughtful integration of green infrastructure emerges as a vital strategy for enhancing the city's livability and ecological resilience. This study, enriched by the active involvement of architecture students at CECOS University, where the author serves as a lecturer, has transcended traditional research boundaries. Through the organization of small activities and assignments in urban design and landscape architecture, students and community members have been engaged in practical work, fostering a collaborative learning environment. The synergistic combination of trees and fountains offers a promising pathway to mitigate the Urban Heat Island effect and create more pleasing environments. This research underscores the importance of strategic planning, community engagement, sustainable design, and educational collaboration in shaping public spaces that not only meet aesthetic and functional needs but also contribute to the broader environmental well-being of the city. The insights and recommendations presented herein provide a valuable blueprint for city planners, landscape architects, and policymakers, guiding them towards a future where urban development and ecological harmony coalesce in Peshawar's vibrant tapestry.

Recommendations organized for each stakeholder group:

Policy makers

- **Promote Policies that Encourage Green Infrastructure in Peshawar**: Emphasize the integration of trees, fountains, and other green infrastructure in urban planning policies.

- **Advocate for Strategic Tree Planning**: Policies should encourage the selection of tree species that are suitable for Peshawar's climate and urban environment.
- **Prioritize Community Engagement**: Policymakers should involve the community in the planning and design process, ensuring that green infrastructure aligns with local needs, preferences, and cultural values.

Landscape Architects & Urban planners

- **Emphasize Combined Approaches**: Integrating a combination of trees and fountains can create multifunctional spaces. This contributes to mitigating the Urban Heat Island effect, enhancing biodiversity, and adding aesthetic and functional value to public spaces.
- **Implement Sustainable Fountain Design**: Design fountains that harness rainwater for operations, promoting water conservation and sustainability.
- **Creative design**: Creative design thinking for each site & not rely much on visualization software for master planning. This copy strategies of the alien design element lower the functionality & purpose of GI in the city.
- **Engage the user in design process**: Involve the users of different age group, race, religion, physical aspects in the planning and design process. Actively seek and respond to feedback, adapting designs to reflect local insights and concerns.

Academics & future research

- **Explore Other Aspects of Green Infrastructure**: Further research could build on these findings to explore other aspects of green infrastructure, such as their impact on air quality, biodiversity, and human wellbeing in city of Peshawar.
- **Investigate Innovative Green Design**: Investigate the potential of innovative green design in mitigating the Urban Heat Island effect, enhancing biodiversity, and adding aesthetic and functional value to public spaces.
- **Evaluate the Impact of Policies and Practices**: Assess the effectiveness of policies and practices recommended in this study. This would provide valuable feedback and identify areas for further improvement.

- **Student competition**: Various contests between design students can be organized by universities in peshawar to seek diversify creations & knowledge in the design of green areas.
- **Encourage publications & establishment of research groups:** Private & public universities in the region of Peshawar should open a dedicated research cell for working on publications & study on UHI & city cooling topics.
- **Revise the course syllabus:** Landscape architecture & urban design course syllabus in B.Arch. program or other undergrad degrees should be tailored to the need of the city & global agenda.

Practical Contribution: All the summaries of the research will be consolidated into an app specifically designed for Android users & iOS. This app can be installed on any smartphone, allowing anyone to search for a tree type or simply enter the name of a place, such as a location, front yard, back lawn, road medians, or green belts. Upon entering the information, the app will display the best infrastructure type and tree type, along with its ecological results. This user-friendly app will be made freely available on World Environment Day 2024

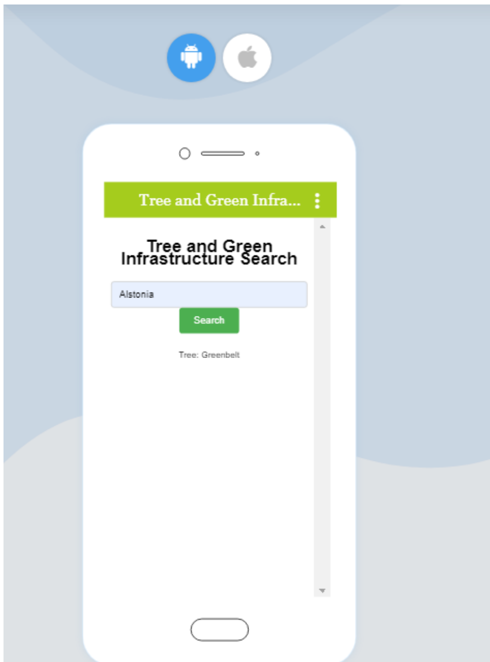

Figure 60. App created by author to show suitable GI type for a place in Peshawar.

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