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Spatial Analysis of Green Cover Concerning Urban Heat Island Effect in Micro-Climate

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Abstract Urbanization often results in a rise in urban development and a decrease in green cover, which are primary catalysts in increasing urban temperature. The elevated temperature of the microclimate of metropolitan areas, compared to their vicinities, is referred to as Urban Heat Island (UHI). Heat islands cause human discomfort, and life-threatening health issues along with increased energy consumption and aggravated pollution. This paper attempts to comprehend the impact and influence of green cover on the intensity of UHI in the microclimate of Aligarh city areas using the mobile traverse method. Two research objectives formulated to accomplish the study include the evaluation of the impact of green cover on the UHI effect in microclimatic conditions and a proposal of a mitigation strategy to alleviate the UHI impact in the affected area. This study dealt with only ambient D.B.T. and relative humidity- R.H. (%) observations and was confined to only two specific identified locations in Aligarh city. This research determined the presence and extent of UHI's microclimate variation concerning green cover within urban communities of distinct environmental layouts and functionalities. Spatial analysis of the data showed that with the 10% reduction in green cover, there was a rise in temperature by 0.082 ℃ in short distances. These findings are beneficial for reducing the impact in UHI-affected areas and for developing a thermally comfortable environment along with improved urban planning.

Keywords Urban Heat Island, Microclimate, Green Cover, Mobile Traverse Method

1. Introduction

Lack of economic possibilities and poor services have resulted in a constant migration of a significant amount of the population from rural to urban areas. According to a report by the United Nations [1], 55% of the global populace lives in cities, and this figure is projected to grow to 68% by 2050. In India, the urban population accounted for 31.2% in 2011, and it is expected to cross the 40% mark by 2030 [2], [3]. Urbanization has altered natural environments into cities and urban centers, by replacing nature with built structures. To cater to the settlement needs of migrated people, new cities and urban centers are coming up while existing ones are expanding. Such expansions transform the environment and result in unbalanced urban grain and alterations in land use [4]. Modifications in the urban form are anticipated to have a strong correlation with adverse environmental impact and are likely to accelerate with the increasing urban population [5]. Reduction in green cover and agricultural land and aggressive increase in built-up areas result in heating the urban areas when compared to their vicinities or areas with less density. This phenomenon is called Urban Heat Island. It is one of the ecological consequences resulting from the process of urbanization that generates elevated temperatures within cities relative to their vicinities [6].

Luke Howard in 1818, was the first to discover the UHI effect when he studied London's climate and observed that the city had a surplus of artificial heat compared to non-urbanized regions [7]. To understand the phenomenon on a deeper level, several studies were conducted later in different locations of different climatic and environmental conditions with varying scales [5], [8]–[11]. It was observed that the heat island effect varies according to different climatic patterns, topography, and green cover and is also influenced by microclimatic conditions [12], [13]. Each urban area can have distinct UHI effects based on the circumstances found there [14] and sometimes the phenomenon may also result in a reversal effect known as urban cool island [13], [15].

Multiple researchers have extensively scrutinized the effects of greenery and vegetation on UHI; however, the majority of them are based on simulations rather than on-site observations [16]–[21]. This research intends to fill the gap by evaluating the impact of green cover on microclimatic UHI in the existing urban fabric of Aligarh City, India, in terms of reducing air temperature and therefore assuaging UHI effects. The research objectives are formulated as:

1. To evaluate the impact of green cover on the UHI effect in microclimatic conditions.
2. To propose a mitigation strategy to alleviate the UHI impact in the affected area. This study deals with only ambient D.B.T. and the relative humidity- R.H. (%) observations in the canopy layer to analyze the effects of green cover on UHI in microclimate and shall be confined to only two specific identified locations in Aligarh city.

2. Literature Review

2.1. The Terminology

Microclimate is defined as any climatic condition in a relatively small area, within a few meters or less above and below the Earth's surface and within canopies of vegetation" [22]. Surface urban heat island (SUHI) occurs during both diurnal and nocturnal times, but it is observed to be intense in the diurnal period. This happens because the urban surfaces absorb sun rays and increase the surface temperature, i.e. it varies with the sun's intensity [23] and is measured using remote sensing, which depicts thermal images to measure it.

Atmospheric urban heat island (AUHI) is observed to be small during the day but found to be prevailing from predawn to the most intense at night. To measure atmospheric UHI, stationary weather stations and the mobile traverse method can be employed to gather air temperature data. This type of UHI is further divided into two types, based on the height of their occurrence namely, (1)Canopy layer UHI is the most frequently observed form and mainly results from immediate site characteristics [14] and exists in the aerial space where people inhabit or function, extending from ground surface to the highest point of buildings and trees, and (2)Boundary layer UHI exists above the canopy layer, encompassing the space between the top of trees and buildings, reaching approximately to the height of 1.5km. Within this layer of UHI, temperature varies from 7 to 12 ℃ [12], [23], [24].

Gartland [13] defined urban heat island intensity or strength (UHII) as the disparity in air temperature between an urban area and its surroundings and it differs throughout day and night, with the smallest temperature difference observed in the morning. As the day progresses, UHII increases, usually reaching a maximum at night. This happens because urban surfaces continue to release heat at night and decelerate the cooling process within the impacted area, whereas the vicinities experience higher cooling rates [13].

Albedo refers to the proportion of solar radiation that bounces off a surface upon encountering it instead of being absorbed. Materials with high albedo values are typically characterized by being white, light-colored, and reflective, resulting in a greater reflection of solar radiation. Conversely, materials with low albedo values are darker in color, causing them to absorb a larger portion of the solar radiation rather than reflect it. It is measured on a scale of 0 to 1 [25]. Urban materials like concrete, tar, and asphalt have dark colors, which is why they are known to absorb heat and contribute to UHI formation.

2.2. Urban Heat Island: Generation, Causes and Impacts

A significant amount of research has been carried out to investigate the UHI phenomenon, and continuous studies are underway that will increase the understanding of UHI on a more detailed level under different conditions [5], [13], [15], [26]–[28]. Many researchers have investigated the causes of UHI and linked its magnitude to the physical characteristics and activities within a city [29]. The larger the city, the more severe the heat island [30], and the greater the outdoor discomfort and load on air conditioners [29].

Factors such as rapid urbanization, aggressive expansion and introduction of new urban areas, continuous reduction in green cover, and replacement with dry, impervious, and high heat-absorbing urban materials are mainly responsible for UHI generation [6], although, on a detailed level, there are other factors that also foster UHI phenomenon and its intensification. Properties of urban materials broadly influence the microclimatic conditions and comfort of urban dwellers. Surfaces exposed to solar radiations like roofs and pavements generally heat up to 27–50 ℃ more than the air [12], [13], [31]. This absorbed heat is sustained and released into the environment, which slows down the natural cooling process and results in UHI formation [32]. Natural cooling which is highly dominated by trees and vegetation, further experiences decline because of poor green cover [13], [33]–[36]. In addition, the heat generated by human activities contributes to the further escalation of this already elevated temperature, specifically in densely built and populated places where most of the urban activities are clustered [12]. Such conditions make the situation worse by trapping the heat between buildings, reducing long-wave radiation, and forming urban canyons [37], [38]. The influence of meteorological conditions also plays an important role in the creation and intensification of UHI. It has been observed that UHI is the most intense in clear and calm weather, as the solar absorption is more and the heat dispersal is slow [13]. Adding up most of the causes, humidity also influences the UHI effect. Humidity is affected by the amount of moisture and temperature. The relationship between humidity and temperature is inversely proportional, which means that as the temperature increases, relative humidity decreases, rendering air drier, limiting cooling efficiency, and making the environment uncomfortable for users [39]. Declining green cover can be projected as the primary reason for lower humidity levels in urban areas.

Such conditions result in devastating effects, especially during summers. The elevated temperature because of UHI, not only raises the electricity consumption in buildings but also elevates the requirement for portable water for both human use and cooling purposes [40]. This cycle of cooling down buildings and consuming more energy, produces more heat, resulting in further degradation of the air. It also increases the noise pollution generated by the working of air conditioning systems [41]. According to Akbari [42], with each 0.6 ℃ rise in summer temperature, electricity consumption rises by 1.5-2%, and 5-10% of the electricity requirement is utilized to offset the impacts of UHI. Various investigations have indicated that the elevated temperature experienced within urban regions poses potential heat-related problems to urban dwellers. Clarke [43] was probably one of the initial researchers to associate heat-induced fatalities with the microclimatic alterations, resulting from aggressive urbanization and UHI [44]. The excessive heat can cause weakness, heat strokes, cramps, unconsciousness, lack of attention, and irritation and also exacerbate serious illnesses like cardiovascular and respiratory impairments due to prolonged exposure to excessive urban heat, and even death in some cases [41], [44]–[47]. Senior citizens and kids are more susceptible to being affected by this [41], [48]. As per a recent study, rising temperatures reduce human sleep, and insufficient sleep can give rise to serious health complications [49]. At the observed rate of temperature rise, it is highly improbable that human beings will become capable of acclimating to high temperatures in the future [50].

2.3. Relationship between Green Cover and UHI

Trees and vegetation influence the environment at a range of scales, varying from a small area around an individual tree to a microclimate, and later forest cover on a large scale. Water transpiration, wind speed alterations, and changes in energy and heat budget of urban areas are some of the features of trees and vegetation that impact the microclimate. Although trees typically contribute to keeping the air and surface temperature cool, in some instances, their presence and unfavorable locations can increase air temperature by blocking wind and trapping solar radiation [51], [52]. Some of the relationships between the green cover and environmental factors that also influence the UHI effect are discussed below:

- Trees and Energy Consumption

Urban areas usually have dense urban fabric characterized by high built-up areas and poor green cover. Solar energy heats these areas on greater magnitude and contributes in UHI formation. This scenario can be altered with an effective increase in greenery and vegetation.

Trees have a significant impact on solar radiation absorption, leading to the potential to decrease by as much as 90% or possibly higher [53]. If planted effectively, they can minimize heating and cooling demands by offering shade to the structures and surfaces during the summer and by shielding winds in winter. According to a simulation study conducted in Canadian cities by Akbari and Taha [54], increasing the number of trees by 30% could potentially result in a decrease of 10% and 40% in energy consumption for heating and cooling purposes, respectively. The savings from such energy consumption can reach up to 180 dollars annually. The amount of energy savings provided by trees largely depends on the regional climate, the location of trees around buildings, and the size and amount of tree foliage [52]. Trees' evapotranspiration along with the shading factor can lower air temperature up to 5 ℃ [19], [52]. Such a substantial reduction in temperature will lead to a decrease in the usage of heating and cooling systems in cities. Consequently, there will be a reduction in the amount of heat generated by these systems, which will ease the already heat-stressed urban environment and aid in the alleviation of adverse impacts of UHI.

- Trees/ Greenery and Natural Cooling

It is widely acknowledged that the presence of plants and trees keeps the environment cool and mitigates the effects of UHI [17], [55], [56]. The evapotranspiration process used by trees and plants transforms solar energy into vaporized water rather than heat. This allows the temperature of both, trees and surrounding air to remain at a lower level [13], [16]. In simple terms, trees and plants consume water via their roots and transpire it from stems and leaves. This reduces the dry bulb temperature and increases latent cooling by introducing moisture to the air [17]. In addition, the air temperature also gets cooler when the air moves within and on the leeward side of well-vegetated areas. A grown-up tree can absorb approximately 400 liters of water and may eliminate 960 megajoules of heat daily in summer when natural cooling is the most needed [13]. This promotes more comfortable urban communities.

- Green Cover and Albedo

Albedo plays a crucial role in influencing heat energy absorption and its regulation in urban areas [25], [57]. Construction materials like concrete and tar have low albedo, which means they are heat-absorbing materials that increase urban temperature [25]. It is seen that the changes in vegetation are related to the alterations in land cover, which affect the albedo values [58]. The major changes in albedo occur in areas of deforestation [59].

To mitigate this, an increment in green cover can be an effective solution. The existence of vegetation influences and increases the overall albedo value of densely agglomerated areas [60]. Vegetation helps in cooling the surface temperature by increasing albedo along with other factors [61] and it is well established that surface temperature significantly influences near-surface air temperature [62]. The reflective properties of green roofs vary between 0.7 and 0.85 in terms of albedo value. This range is significantly higher than the typical roof's albedo range of 0.1 to 0.2. As a result, green roofs have the potential to reflect 20-30% of incoming solar radiation [63]. Grass which appears a bit dark and has albedo between (0.25-0.30) is a good reflector of infrared radiation [19]. Trees albedo lies between (0.15-0.18) which is higher than most urban surface materials, therefore, vegetation absorbs less solar radiation and helps in keeping the environment cool [25], along with providing aesthetic improvements and environmentally friendly benefits.

- Trees and Pollution

CO_2 is a notorious greenhouse gas that is released from vehicles, factories, power plants, burning, etc., and contributes to global climate change. In the current world order, countries are under pressure to reduce and control their carbon emissions through different strategies. Trees do that naturally. They are well known to absorb CO_2 from air for photosynthesis and produce oxygen in return. A well-grown tree can store approximately 3 metric tons of carbon [52]. They decrease air pollution by assimilating gases and capturing particles through their foliage. This mechanism is known as "dry deposition". It removes nitrogen oxide, ozone, sulfur oxides, and particulate matter (PM10) from air which is known to contribute to UHI formation and its intensification [13].

Apart from the above-mentioned benefits, trees also reduce noise pollution [64]. Several studies have demonstrated that trees can reduce urban noise by up to 15db, which is roughly the same as a standard masonry sound barrier [52].

2.4. Research Context

This research has been conducted in Aligarh city, which is situated in the northern part of the state of Uttar Pradesh, India (Figure 1a). It falls in the central region of Doab, which is positioned amidst the Yamuna and Ganga rivers. Aligarh has a humid subtropical climate [65] and it is approximately 132km southeast of India's capital city, New Delhi. Aligarh is famous for its prestigious educational institution – Aligarh Muslim University (A.M.U). Furthermore, it has also gained recognition for its proficiency in the lock manufacturing industry, earning it the moniker "City of Locks".

Two critical locations were selected in Aligarh city for the data collection. These two areas are opposed in terms of built-up density and micro-climatic characteristics. The first location is Centre Point Chauraha (Square), which is designated as A1. The second location is Staff Club Chauraha (Square), A.M.U campus designated as A2 in this study, as shown in Figure 1b. The distance between these two locations is approximately 3 km. A1 acts as a central business district (CBD) and experiences the majority of the city's footfall with substantial traffic volume. It is located in the core of a high-density area with mixed land use, particularly commercial and residential. The urban grain of the area is unbalanced due to the lack of urban greenery in comparison to the built-up area. A2 is located on the thoroughfare of the university campus and witnesses a significant volume of traffic. The area of A2 has a green cover as compared to A1, with an existing public park in its vicinity.

2.5. Data Collection

The measurements were collected from the canopy layer of study locations for 23 days, between 22nd April and 15th May 2022. However, during the survey period, readings of 4th May 2022 appeared to be outliers and were not considered in the final data due to unexpected adverse weather conditions. Data was collected five times/day i.e. 9:00 hrs, 12:00 hrs, 15:00 hrs, 18:00 hrs, and 21:00 hrs.

A circular peripheral zone of 500m was established at both research areas to capture and comprehend the urban grain, and their built-up to greenery composition (Figure 2). Each examination survey was concluded within 30 minutes to prevent microclimatic variations. This study was conducted based on the methodologies and measures used by earlier researchers [13], [24], [34], [66]. Temperature and humidity data from both locations were analyzed and represented in tables. The data of A1 and A2 were to comprehend the impact of cover on the UHI effect and its intensity, based on different urban settings.

Data was acquired utilizing the mobile traverse method (portable equipment), to capture the evidence of the UHI effect on green cover and vegetation. For measurements, the apparatus was mounted at 1.3 meters height from the surface level on a tripod stand. To prevent the sensor from being exposed to direct sun rays and affecting the readings, hard cardboard was placed over the equipment sensor while taking care to allow proper ventilation. Before taking readings, the apparatus was placed at each designated location for 10 minutes to acclimatize to the environment.

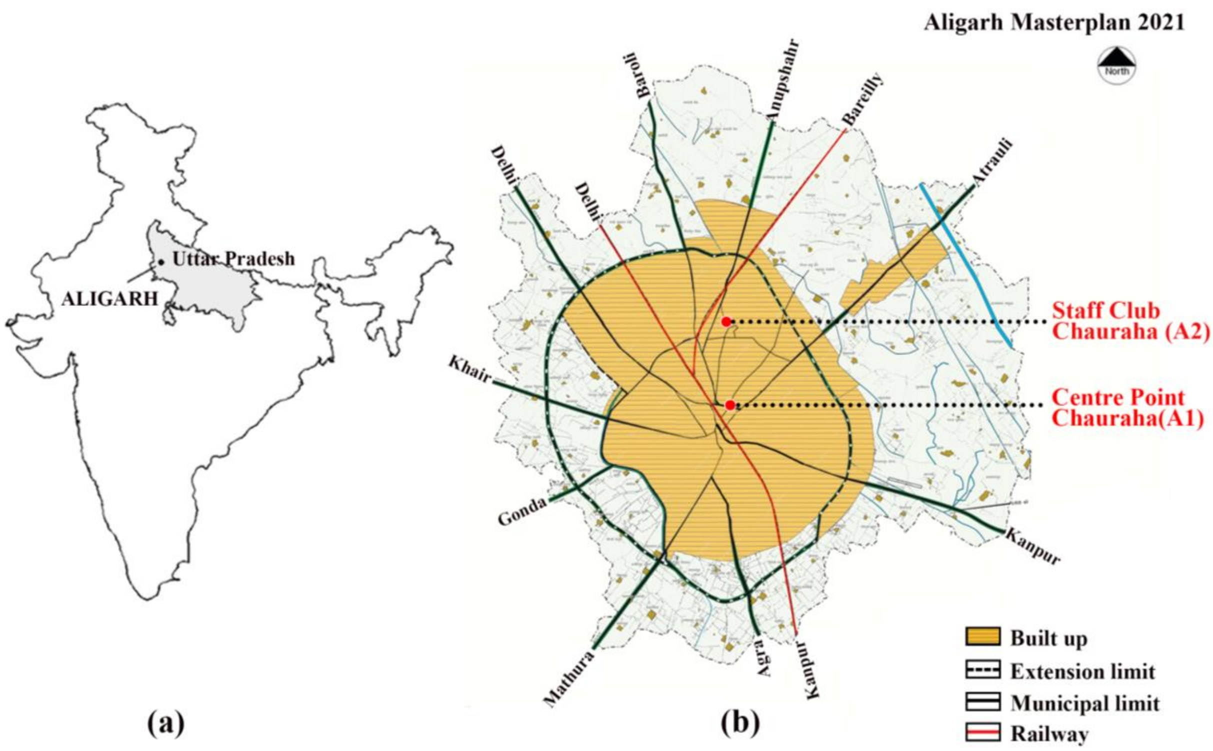

Figure 1. (a) Location of Aligarh city on the map, (b) Image showing the locations of study areas, urban area boundary, and connectivity of Aligarh city (Source: Master Plan Aligarh, 2021)

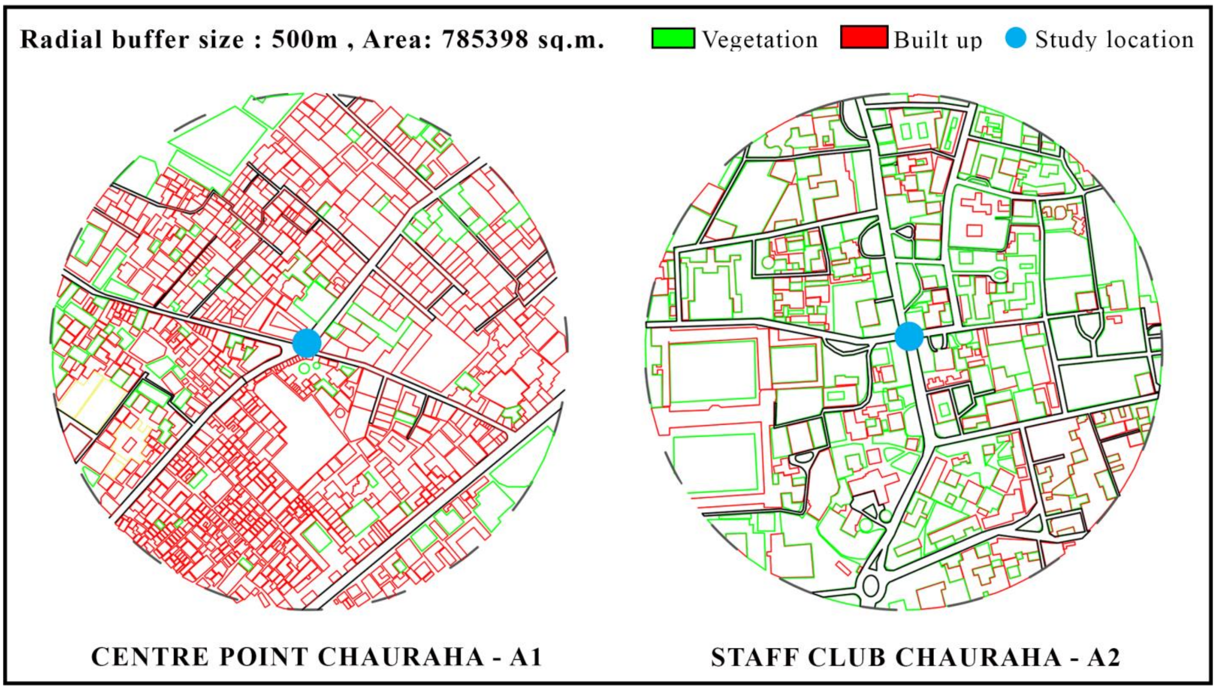

Figure 2. Image showing the circular peripheral zone of a 500m radius at both study locations (Source: Author)

3. Result and Discussion

The shortage of vegetation along with other catalyst factors like artificial impervious surfaces and anthropogenic heat caused an increase in temperature in the microclimate of A1. Based on the assessment of collected data, it was found that A1 witnessed higher temperature compared to A2 in all measurements as shown in Table 1.

This research establishes and demonstrates the fact that the UHI effect varies within short distances about the green cover. It was observed that A1, which has a low green cover (15.78%) and high built-up area (58%), experienced higher temperature, while A2 area, which has a high green cover (46.36%) witnessed consistently lower temperatures in comparison (Figure 3, Table 1). The peak average temperature difference during observation time, was 2.23 ℃ at night (21:00 hrs) while the lowest was in the morning (09:00 hrs) with 0.87 ℃ (Table 1), which justifies the usual pattern of AUHI. The distance between both locations is just around 3km; still, the effect of vegetation on microclimatic UHI is significantly considerable. Due to the lack of trees and greenery at A1, the evapotranspiration must have been reduced, declining the natural cooling along with poor shade to urban surfaces from scorching sun rays. Such conditions are known to favour the formation of UHI and further its intensification [13], [34], [67]. The maximum UHII registered was 3.1 ℃ during the observation time at 21:00 hrs, while the minimum was 0.6 ℃ when observed at 09:00 hrs (Table 2). This is happening because throughout the day, unshaded urban built mass at A1, absorbed more heat and reduced the long wave radiation. In such a scenario with reduced cooling, the heat continues to dominate the microclimate of A1, resulting in intensified UHII by night.

- ***Spatial analysis of the correlation between temperature variation and green cover***

After the scrutiny of green cover at selected locations, it was found that A1 has 65.96% less green cover in comparison to A2 (Figure 3). This notable absence of green cover can be identified as a significant contributing factor to the formation of UHI at A1, as substantiated by comprehensive research findings [13], [34], [35], [62], [68]. It was analyzed that with the reduction of green cover from 46.36% (A2) to 15.78% (A1), the average mean temperature difference of all time slots was 1.59 ℃ (Figure 3, Table 1). Consequently, it can be deduced that a 10% decrease in green cover leads to a temperature increase of 0.082 °Cat A1.

- ***Spatial analysis of the correlation between relative humidity and green cover***

The findings demonstrate that A1 has 65.96% less green cover in comparison to A2 (Figure 3). In concern with relative humidity, it can be inferred that a 10% reduction in green cover leads to a decrease of 0.141% in humidity at A1 (Figure 3, Table 3). This scenario might be taking place, as inadequate green cover reduces the evapotranspiration process, which leads to lower relative humidity [13]. Evapotranspiration plays a crucial role in cooling down temperatures, and lack of it eventually acts as a catalyst in the formation of UHI [13], [34], [35]. Such a scenario makes A1 microclimate difficult to restrain for urban dwellers.

Table 1. Mean temperature (°C) of A1 and A2 and the difference between them at chosen timings in the course of the survey period

MEAN TEMPERATURE DIFFERENCE (℃)			
Time	Mean Temperature Centre Point Chauraha (A1)	Mean Temperature Staff Club Chauraha (A2)	Mean Difference
09:00	36.63	35.76	0.87
12:00	41.80	40.43	1.37
15:00	42.78	41.13	1.65
18:00	37.64	35.80	1.83
21:00	34.00	31.77	2.23
			Average = 1.59

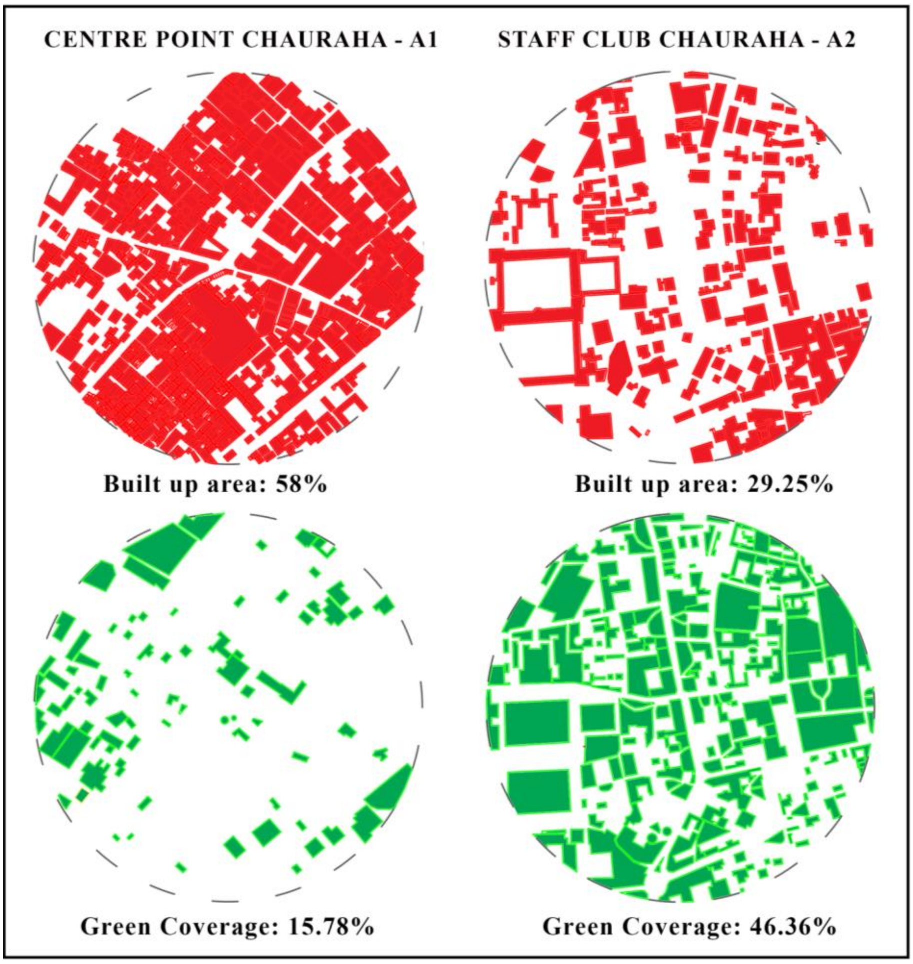

Figure 3. Image depicting the green cover and built-up area within a 500m radius of the study locations (Source: Author)

Table 2. Maximum and minimum UHI intensity at selected timings throughout the survey period

ANALYSIS OF UHI INTENSITY (UHII)		
Time	Maximum UHI	Minimum UHI
09:00	1.4	0.6
12:00	1.8	1.1
15:00	2	1.2
18:00	2.4	1.4
21:00	3.1	1.6

Table 3. Mean relative humidity (%) at A1 and A2 and the difference between them at selected timings during the survey period

MEAN HUMIDITY DATA (%)			
Time	Mean Humidity Centre Point Chauraha (A1)	Mean Humidity Staff Club Chauraha (A2)	Mean Difference
09:00	33.01	34.96	1.95
12:00	25.73	27.21	1.49
15:00	23.58	26.43	2.85
18:00	29.80	32.61	2.82
21:00	36.08	40.70	4.63

3.1. Mitigating UHI through Trees and Vegetation

Increasing urban greenery has the potential to serve as one of the most efficient and inexpensive strategies to mitigate UHI impact [17], [42], [55]. Urban greenery can influence the air temperature through diverse mechanisms. The two prominent aspects are evapotranspiration and shading. Evapotranspiration directly helps in cooling the air temperature near the green areas by 2 to 8 ℃ [11]. Shading, on the other hand, assists in reducing the incoming solar radiation. Consequently, these factors decrease the absorption and conversion of solar energy into heat energy, thereby limiting the impacts of UHI [69].

The size and dispersion of green spaces in urban areas are regarded as the critical drivers influencing thermal comfort [20], [70], [71]. Therefore, it is important to strategically and effectively increase the green cover to fetch maximum results[70]; otherwise, it may have negative consequences like increased temperature, which may accelerate the UHI effect [51]. Trees' good growth and their type are essential considerations. Shade trees, with their expansive canopies, are an appropriate choice as they provide shade to buildings and pedestrians, as well as limit the direct exposure of sunrays on urban surfaces, thereby effectively maintaining a cooler microclimate [16]. The strategic placement of trees is an equally important factor to consider. For optimal shading effects, it is preferable to position trees in the east, southeast, west, and southwest directions [41]. Trees along with street furniture will enhance the visual aesthetics and urban comfort of the cities. A mature tree can release as much as 450 liters of water into the air in a day through evapotranspiration, which is the same amount of work done by a 5-star A.C. in a 20-hour usage per day [41]. The associated saving benefits from a tree can be up to $200, depending on the climatic conditions, and its planting and maintenance costs can range from $10 to $500 [69]. Regarding relative humidity, it was shown that a 10% decrease in green cover causes the humidity at A1 to drop by 0.141%.

The associated studies show how the increase in green cover can help to maintain a better urban microclimate. Temperatures were found to be consistently lower in the A2 region, which has a high percentage of green cover (46.36%), than in A1, which has a low percentage of green cover (15.78%) and a high percentage of built-up area (58%). The increase in green cover can be achieved in two ways– increasing the green cover on the ground and introducing vertical greenery in the A1 region thus lowering the temperatures. Green cover on the ground can be increased by planting trees or introducing urban parks or grassy areas. Trees could potentially hold warm air under their canopies, while a grassy area allows minimal resistance to air movement, which facilitates cooling through convection [6]. A park could be around 1 ℃ cooler compared to an area with no greenery [72].

According to simulation research conducted by Dimoundi and Nikolopoulou [17], a row of trees on a $100m^2$ area of a basic urban setting has the ability to lower air temperature by 1K. Additionally, a $100m^2$ park area has the potential to reduce the temperature on streets by around 4K.

Some of the strategies are discussed below to increase greenery and vegetation:

- Green Roof

Typically, roofs are characterized by their dark color, which possesses poor reflectivity i.e. low albedo. This means that materials with dark colors tend to absorb a greater amount of heat. Roofs and pavements cover 60% of the urban surfaces and consume 80% of sunlight [12]. Converting these heat-absorbing roofs into green roofs can be an effective strategy. A green roof consists of a vegetative layer that grows on rooftops. Research conducted by Pompeii II [73] in Chicago, revealed that the implementation of green roofs can result in an average reduction of 1.77 ℃ in indoor temperature and 0.24 ℃ in outdoor temperature. According to Susca et al. [74], it has been found that green roofs have the potential to enrich the microclimate since they enhance air quality and boost water retention by a margin of 7 to 10%.

Implementing green roofs in buildings in the A1 area could be a highly effective solution without causing significant disruption to urban activities. These buildings' rooftops can be covered with a vegetative layer, placed over a steel framework positioned at an elevation of approximately 1.5m to 1.8m above the roof surface. This approach will not only offer shade to the sun-exposed roof but also facilitate the cooling of air between the roof and the vegetative covering, all while allowing sufficient height for unrestricted movement.

- Vertical Greenery

Areas of high density usually have limited available land. In such conditions, planting can become somewhat challenging. Therefore, the installation of green walls can be contemplated as a viable solution to increase greenery. These walls serve as a vertical ecosystem that generates a microclimate, resulting in a substantial reduction in temperature and an enhancement in the energy efficiency of the buildings they are installed on. This is because these green walls increase the thermal mass of the buildings, which helps to regulate the temperature inside [41], [75]. Typically, green walls experience a maximum temperature of around 30 ℃, whereas conventional walls' temperature can extend up to 60 ℃ [41]. Apart from lowering the urban temperature and energy usage of buildings, they also help to improve the aesthetics of urban areas, making them more attractive and inviting for residents and visitors along with creating more sustainable and livable cities.

- Policies to Promote Vegetation and Greenery

As stated by Imam and Banerjee [76], people’s lack of technological understanding and scientific consciousness has led to a decline in green cover. This can be overcome by government-backed initiatives and awareness programs. Such things can help to dispel misconceptions and encourage people to plant more trees. City authorities can organize programs such as "Tree Census" that will facilitate the identification and help quantify the number of trees within a specific zone or area. This initiative would involve various trees' physical attributes, such as approximate height, age, variety, overall health, etc. The collected data could subsequently be utilized to educate the public regarding the benefits of trees. A similar endeavor named "Right Place, Right Tree" was launched in London to provide technological guidance for the city's intelligent greening [76]. Authorities can organize public events like "Green City-Name", where free trees/plants can be gifted, to instill their environmental responsibilities and accountability in people. In return for receiving free plant saplings, individuals could be encouraged to pledge their participation in their locality's tree census program or to adopt green roofs for their homes. Tree planting programs can be structured to be cost-effective, which will make them more accessible for communities that wish to participate in these programs. Such programs have the potential to teach and motivate youngsters to voluntarily engage in tree planting and their management. However, Imam and Banerjee [76] argued that the successful outcomes of such campaigns rely on public engagement and participation, which is currently missing in India.

4. Conclusions

The spatial analysis of empirical data from the selected locations in this research justifies the fact that the UHI effect and its intensity can occur and vary over small distances in microclimate about the amount of green cover available. The findings of this study align with the outcomes of most of the associated studies [15], [34], [67], [74], [77]. It was found that A1 which has poor green cover experienced high temperature, while A2 which has more vegetation and grassy area witnessed less temperature rise (Table 1, Figure 3). The absorbed urban heat at A2 reduced much more quickly after sunset compared to A1 because of the presence of the high green cover. This scenario resulted in a continuous increase in UHII after sunset and found it maximum during observation time at early night (21:00 hrs). It was found that A1 had consistently higher temperatures compared to A2. This can be attributed to the lack of trees and green cover at A1. Soltani and Sharifi [34] also indicate similar results in their study in which they found that the reduction in tree canopy has a direct correlation with the intensification of the UHI effect. A1 also experienced lower humidity compared to A2 (Table 3). Reduced humidity along with already elevated temperature at A1 can produce uncomfortable microclimatic conditions for urban dwellers.

The results of this research shed some insight related to the thermal effects of trees and vegetation in the urban environment, implying that it may significantly enhance the urban microclimate, and help to attenuate the UHI impact, by lowering the temperature, particularly during summertime in urban centers. Such investigative endeavors can contribute to developing a detailed comprehension of microclimatic UHI, which might become the base for creating a thermally pleasant microclimate. However, there is limited scope to increase vegetation in dense urban areas; therefore, other mitigation methods like adopting high albedo materials along with possible vegetation increase can show a major impact in mitigating UHI. Thus, there is scope for future research to examine the impact of adopting hybrid mitigation strategies for UHI. This study only included measured data from the diurnal period. Additional observation of the nocturnal period can significantly help in understanding the entirety of microclimatic variations of a city, which could be the scope of future studies.

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