Quantifying the Extent of the Cooling Effect of Pocket Green Spaces: A Case Study of the Kathmandu Valley

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EXECUTIVE SUMMARY

This report delves into the significant cooling effect of Pocket Green Spaces (PGS) in the Kathmandu Valley and its multifaceted implications for environmental sustainability, urban planning, public health, and social well-being. Notably, the size of PGS plays a pivotal role in their cooling impact. Increasing the size of these green spaces can effectively enhance urban local climate, thereby reducing the adverse impacts of urban heat islands. However, a key revelation is the existence of a threshold size, beyond which cooling efficiency does not increase significantly. This insight can guide the economical use of green space in high-density urban areas. The study also emphasizes the importance of tree-dominated vegetation within PGS, as it exhibits superior cooling effects compared to non-tree vegetation. Moreover, the cooling effect of PGS is significantly influenced by the surrounding landscape patterns, making the synergistic effect of green space and surrounding landscape crucial for optimizing urban surface heat islands. These findings have extensive implications.

From an environmental sustainability perspective, the recommendations, such as expanding PGS and promoting tree-dominated vegetation, directly contribute to mitigating urban heat islands and improving air quality. These insights underscore the significance of well-designed and connected green spaces as integral components of green infrastructure. The study also guides urban planning and design by informing decisions about land use, emphasizing community engagement in PGS development and maintenance, and fostering a sense of belonging within the community. This approach facilitates the creation of community spaces that enhance social interactions, mental well-being, and the overall quality of life. In the context of public health, the cooling effects of PGS can reduce heat-related health risks, particularly in regions where the frequency of heatwaves is rising.

In conclusion, this research highlights the vital role of PGS in mitigating the urban heat island effect, offering a range of benefits for urban communities. By expanding these spaces, optimizing their features, and engaging communities in their development and maintenance, urban areas can become healthier, more sustainable, and more socially connected environments. These findings, along with recommendations, have the potential to significantly influence the sense of belonging and social connectedness within urban communities, fostering stronger bonds among residents of the Kathmandu Valley.

GLOSSARY

Anisotropic Characteristics: A material that is anisotropic exhibits properties that are different depending upon the directionality, location considered on the material, or where and how force is applied to the material. Anisotropic materials have properties of the material that are considered directionally dependent, such as in the case of wood.[1]

Evapotranspiration: "Evapotranspiration is the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration."[2]

Pocket Green Space: "An urban green space that is smaller than 0.5 ha and established at the city center with limited free space. A pocket park is highly accessible to urban inhabitants through walking."[3]

Shapes of Urban Green Parks: Regular shaped parks typically refer to parks that have a well-defined, consistent, and easily recognizable geometric shape, such as squares, rectangles, circles, or other symmetrical configurations. These shapes are typically more uniform and geometrically precise compared to irregular or asymmetric shapes, like those found in many natural settings. An irregular park may have sides and angles of any length and size. Usually, parks are deliberately designed in a regular shape for ease of planning, maintenance, and aesthetic purposes.

Spatial Configuration: "The spatial configuration is one of the properties of a green area, which is defined by the shape, arrangement and layout of green areas (Wilmers, 1990)."[4]

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[1] Nichole Miller, "Isotropic vs. Anisotropic Materials | Definition & Examples," Study.com, accessed September 2023.

[2] Water Science School, "Evapotranspiration and the Water Cycle," U.S. Geological Survey, accessed September 2023.

[3] Hasnat G N Tanjina et al., "Urban Forestry in Sabah, Malaysia: A Perspective Review," chapter, in *Examining International Land Use Policies, Changes, and Conflicts* (IGI Global Publisher of Timely Knowledge, 2021), 252–71.

[4] Sahar Sodoudi et al., "The Influence of Spatial Configuration of Green Areas on Microclimate and Thermal Comfort," *Urban Forestry & Urban Greening* 34 (August 2018): 85–96.

1. INTRODUCTION

1.1 Background

Urban areas experience higher temperatures compared to surrounding non-urban or green areas due to the urban heat island (UHI) effect, which results from modifications in land surfaces during urbanization.[5] The UHI effect increases heat stress in urban organisms and presents substantial health hazards, such as heat-related illnesses and casualties. Furthermore, it drives up energy and water usage. Effectively addressing the UHI effect is essential for urban public health and the promotion of sustainable development.

Urban green spaces, such as parks and gardens, have been recognized as potential UHI mitigators by providing shade, evaporative cooling, and improved air circulation.[6] Numerous studies have examined temperature variations within and around urban green spaces to quantify their cooling effects. For instance, Lu et al. examined microclimatic variations in a public garden within a densely built city and discovered significantly lower temperatures inside the garden compared to the surrounding built-up areas.[7] These variations were attributed to factors such as

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[5] Sharon L. Harlan et al., “Neighborhood Microclimates and Vulnerability to Heat Stress,” *Social Science & Medicine* 63, no. 11 (2006): 2847–63.; Jianguo Tan, Youfei Zheng, Xu Tang, Changyi Guo, Liping Li, Guixiang Song, Xinrong Zhen et al., "The urban heat island and its impact on heat waves and human health in Shanghai," *International journal of biometeorology* 54 (2010): 75-84.; Katharina MA Gabriel, and Wilfried R. Endlicher, "Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany," *Environmental Pollution* 159, no. 8-9 (2011): 2044-2050.; Sharon L. Harlan, and Darren M. Ruddell, "Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation," *Current Opinion in Environmental Sustainability* 3, no. 3 (2011): 126-134; H. S. Chan, M. H. Kok, and T. C. Lee, "Temperature trends in Hong Kong from a seasonal perspective," *Climate Research* 55, no. 1 (2012): 53-63.; Jing Dong, Meixia Lin, Jin Zuo, Tao Lin, Jiakun Liu, Caige Sun, and Jiancheng Luo, "Quantitative study on the cooling effect of green roofs in a high-density urban Area—A case study of Xiamen, China." *Journal of Cleaner Production* 255 (2020): 120152.

[6] Hashem Akbari and Dionysia Kolokotsa, “Three Decades of Urban Heat Islands and Mitigation Technologies Research,” *Energy and Buildings* 133 (2016): 834–42.

[7] Jun Lu et al., "A micro-climatic study on the cooling effect of an urban park in a hot and humid climate," *Sustainable cities and society* 32 (2017): 513-522.

vegetation cover, shading, and evaporative cooling. Similarly, Tan et al. analyzed thermal characteristics of various urban green spaces and identified substantial temperature reductions and cooling effects within these areas.[8]

Among several heat mitigation strategies proposed to mitigate the UHI effect, urban green space has been widely used due to their cooling effects via evapotranspiration and shading.[9] Urban green space has been regarded as a nature-based solution for enhancing climate change adaptation and sustainable land management.[10]

This study investigates temperature variations within and around a pocket green space (PGS) to determine its maximum cooling distance and area. PGS has become a significant component of open spaces in high-density urban areas, providing various ecosystem services such as pollination, carbon sequestration, air quality improvement, biodiversity support, and so on.[11] There is a lack of agreement regarding the definition of PGS, however, it is commonly defined based on its size, with green spaces measuring less than 2 hectares in urban and suburban areas considered as PGS.[12]

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[8] Xingyu Tan et al., "Comparison of cooling effect between green space and water body," *Sustainable Cities and Society* 67 (2021): 102711.

[9] Fanhua Kong et al., "Retrieval of three-dimensional tree canopy and shade using terrestrial laser scanning (TLS) data to analyze the cooling effect of vegetation." *Agricultural and forest meteorology* 217 (2016): 22-34.

[10] Dagmar Haase, "Integrating Ecosystem Services, Green Infrastructure and Nature-Based Solutions—New Perspectives in Sustainable Urban Land Management: Combining Knowledge About Urban Nature for Action," *Sustainable Land Management in a European Context: A Co-design Approach* (2021): 305-318.

[11] Karin K. Peschardt, Ulrika K. Stigsdotter, and Jasper Schipperrijn, "Identifying features of pocket parks that may be related to health promoting use," *Landscape Research* 41, no. 1 (2016): 79-94; Pingying Lin, Stephen Siu Yu Lau, Hao Qin, and Zhonghua Gou, "Effects of urban planning indicators on urban heat island: a case study of pocket parks in high-rise high-density environment," *Landscape and Urban Planning* 168 (2017): 48-60.

[12] Melissa Anne Currie, "A design framework for small parks in ultra-urban, metropolitan, suburban and small town settings," *Journal of Urban Design* 22, no. 1 (2017): 76-95.; Juan David Amaya-Espinel et al., "The influence of building density on Neotropical bird communities found in small urban parks," *Landscape and Urban Planning* 190 (2019): 103578.

1.2 Literature Review

a. Overview of the Urban Heat Island (UHI) Effect and its Implications

Although the UHI phenomenon was documented over a century ago, focused research into its effects on the urban climate and environment, particularly during the summer, has only taken place in the past three decades.[13] The volume of research pertaining to UHI studies has experienced a substantial surge since the year 2000.[14] A variety of land cover types, including densely vegetated areas, barren land, industrial zones, densely built-up spaces, and water bodies, collectively contribute to temperature variations, leading to the formation of urban micro heat islands.[15] Industrialization and urbanization are two pivotal factors that act as triggers for increased occurrences of heat waves within urban areas. The formation of heat islands in the urban areas of Hyderabad, India and their environmental impact becomes evident when analyzing nighttime data, as the central urban regions consistently show significantly increased temperatures.[16] The increased construction associated with urbanization primarily increases the absorption of thermal energy in cities, consequently impacting climate change, with variations in urban design elements such as building heights, transportation routes, open spaces, and public infrastructure responding uniquely to environmental factors within the urban areas, thereby influencing the intensity of the urban heat island effect.[17] Recently,

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[13] Hashem Akbari and Dionysia Kolokotsa, "Three Decades of Urban Heat Islands and Mitigation Technologies Research," *Energy and Buildings* 133 (2016): 834–42.
[14] Rajashree Kotharkar, Aparna Ramesh, and Anurag Bagade, "Urban Heat Island Studies in South Asia: A Critical Review," *Urban Climate* 24 (2018): 1011–26.
[15] Lilly Rose Amirtham, Monsingh David Devadas, and Mohana Perumal, "Mapping of Micro-Urban Heat Islands and Land Cover Changes: A Case in Chennai City, India," *The International Journal of Climate Change: Impacts and Responses* 1, no. 2 (2009): 71–84.
[16] K. V. Badarinath et al., "Studies on Urban Heat Islands Using ENVISAT AATSR Data," *Journal of the Indian Society of Remote Sensing* 33, no. 4 (2005): 495–501.
[17] Zanyar Abdi et al., "Analysis of Urban Form Typology Using Urban Heat Island Indicators: Case Study of Ferdous Neighborhood of Tabriz," *Frontiers in Ecology and Evolution* 10 (2023).

advancements in remote sensing (RS) and geographic information system (GIS) have accelerated the evaluation of the urban heat island effect, making it a faster, more cost-efficient, and accurate process.[18]

The significant growth of urban development has increased the urban heat island effect, thereby negatively impacting the well-being and overall quality of life for urban residents.[19] For example, the noticeable urban heat island phenomenon in Guangzhou, China is notably prominent in the central and southern regions of the city, where the spatial arrangement and developmental changes in land use patterns and population density are directly correlated with the level of intensity observed in the heat island effect.[20] In the Depok subdistrict, the distribution area of urban heat island decreased between 2014 and 2019 (from 49% to 30%). Meanwhile, the land surface temperature (LST) increased from 29.78^{0}C to 31.10^{0}C. Population density had no impact on the UHI value, while surface cover characteristics notably influence the UHI index value.[21]

1.3 The Role of Green Spaces in Mitigating the UHI Effect

There is a widespread agreement that increasing the density of vegetation is a simple and effective strategy to mitigate the urban heat island effect and increase

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[18] H. B. Akdeniz, "Spatio-Temporal Analysis of the Effects of Urban Growth on Urban Heat Island: Case of Konya, Turkiye," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLVIII-M-1–2023 (August 15, 2023): 441–48.
[19] Zhengtong Yin et al., "Urban Heat Islands and Their Effects on Thermal Comfort in the US: New York and New Jersey," *Ecological Indicators* 154 (2023): 110765.
[20] Chi Fong Tang, "A Study of the Urban Heat Island Effect in Guangzhou," *IOP Conference Series: Earth and Environmental Science* 1087, no. 1 (2022): 012015.
[21] D Irawati, R Noviani, and M G Rindarjono, "Effect Urban Development on Urban Heat Island in Depok Subdistrict, Sleman Regency, Yogyakarta," *IOP Conference Series: Earth and Environmental Science 1180*, no. 1 (2023): 012021.

the adverse consequences of urban climate change.[22] A series of strategic interventions have been proposed, including initiatives such as expanding green spaces, improving access to water bodies, and incorporating water-sensitive design principles into urban planning. These measures are intended to enhance cooling effects, mitigate the urban heat island effect, and promote the development of a more sustainable and resilient urban environment.[23] Increasing the density of vegetation in urban planning is a popular method for addressing the urban thermal environment, and it is even more effective when combined with the incorporation of high-evapotranspiration broadleaf forests and shaded areas, which can further reduce environmental temperatures.[24]

Urban parks, lakes, and mountains with unique surface or block patterns also demonstrated noticeable cooling benefits. Scenario simulation underscored that green spaces were more efficient in mitigating heat, while blue spaces played a critical role in the spatial fragmentation of the UHI effect.[25] The strategic formulation and execution of multifunctional green roofs hold the potential to effectively mitigate UHI effects.[26] Scientific studies on the mitigating effects of vegetation on the UHI phenomenon have shown that various types of green spaces, including parks, street

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[22] H. B. Akdeniz, “Spatio-Temporal Analysis of the Effects of Urban Growth on Urban Heat Island: Case of Konya, Turkiye,” *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLVIII-M-1–2023 (August 15, 2023): 441–48.
[23] Pritipadmaja, Rahul Dev Garg, and Ashok K. Sharma, “Assessing the Cooling Effect of Blue-Green Spaces: Implications for Urban Heat Island Mitigation,” *Water* 15, no. 16 (2023): 2983.
[24] Yue Chang et al., “Monitoring Diurnal Dynamics of Surface Urban Heat Island for Urban Agglomerations Using ECOSTRESS Land Surface Temperature Observations,” *Sustainable Cities and Society* 98 (2023): 104833.
[25] Yanxia Hu, Changqing Wang, and Jingjing Li, “Assessment of Heat Mitigation Services Provided by Blue and Green Spaces: An Application of the Invest Urban Cooling Model with Scenario Analysis in Wuhan, China,” *Land* 12, no. 5 (2023): 963.
[26] Jana Brenner, Stefan Schmidt, and Christian Albert, “Localizing and Prioritizing Roof Greening Opportunities for Urban Heat Island Mitigation: Insights from the City of Krefeld, Germany,” *Landscape Ecology* 38, no. 7 (April 6, 2023): 1697–1712.

trees, and green roofs, contribute to urban areas adapting to UHI effects.[27] The spatial configuration and composition of green spaces have a significant impact on lowering the land surface temperature, thereby mitigating the urban heat island effect.[28] A study by Ghosh and Das (2018) found that green spaces could decrease temperatures by about 1 degree Celsius within a 150 to 180-meter distance from their edges. Elongated green spaces are particularly good at spreading this cooling effect over a wider area compared to circular or irregularly shaped ones, while water bodies are even more effective than regularly shaped green spaces at countering the urban heat island effect.

The cooling reach of an urban green space, which helps reduce the urban heat island effect, is not solely determined by its size, the extent of vegetation, and its layout, but also displays anisotropic characteristics.[29] In densely populated urban settings, where space is constrained, urban planning should incorporate a strategic distribution of scattered green spaces to ensure fair coverage and maximize cooling benefits.[30] Materials with high thermal resistivity like fiberglass, mineral wool, aerogel and polystyrene foam may not directly combat and mitigate the urban heat island effect, but when used in construction, they grant inherent cooling benefits to buildings, resulting in a decrease in the artificial heat released by structures, thereby

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[27] Nastaran Shishegar, "The Impacts of Green Areas on Mitigating Urban Heat Island Effect," *The International Journal of Environmental Sustainability* 9, no. 1 (2014): 119–30.
[28] Sasanka Ghosh and Arijit Das, "Modelling Urban Cooling Island Impact of Green Space and Water Bodies on Surface Urban Heat Island in a Continuously Developing Urban Area," *Modeling Earth Systems and Environment* 4, no. 2 (2018): 501–15.
[29] Tongliga Bao et al., "Assessing the Distribution of Urban Green Spaces and Its Anisotropic Cooling Distance on Urban Heat Island Pattern in Baotou, China," *ISPRS International Journal of Geo-Information* 5, no. 2 (February 6, 2016): 12.
[30] Ibid.

aiding in the mitigation of the UHI phenomenon.[31] Major findings from previous studies on the effects of urban green space on urban heat islands (UHI) can be summarized as follows: the majority of urban green spaces contribute to cooling their immediate surroundings,[32] helping to alleviate the UHI effect. However, some green areas exhibited higher temperatures than their surroundings. Researchers identified linear relationships between land surface temperature and biophysical factors, like the normalized difference vegetation index (NDVI) and vegetation coverage, at the city scales.[33] Nonlinear associations were observed between the size of urban green spaces and their cooling effect, particularly concerning local cool island intensity at patch and class scales.[34] Additionally, the arrangement and layout of urban green spaces had a discernible impact on urban land surface temperature,[35] with the surrounding landscape patterns significantly enhancing their cooling effect.[36]

1.4 Role of PGS in Mitigating the UHI Effect

Recent research has focused on the diverse ecosystem services provided by PGS, including wildlife habitat, community interaction and recreation, and health benefits, which are particularly valuable in light of their compact size, making them

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[31] Anurag Kandya and Manju Mohan, "Mitigating the Urban Heat Island Effect through Building Envelope Modifications," *Energy and Buildings* 164 (2018): 266–77.
[32] Xiaoyun Cheng et al., "Influence of Park Size and Its Surrounding Urban Landscape Patterns on the Park Cooling Effect," *Journal of Urban Planning and Development* 141, no. 3 (2015).
[33] Junxiang Li et al., "Impacts of Landscape Structure on Surface Urban Heat Islands: A Case Study of Shanghai, China," *Remote Sensing of Environment* 115, no. 12 (2011): 3249–63.
[34] Ibid.
[35] Junxiang Li et al., "Impacts of Landscape Structure on Surface Urban Heat Islands: A Case Study of Shanghai, China," Remote Sensing of Environment 115, no. 12 (2011): 3249–63.
[36] Xin Cao et al., "Quantifying the Cool Island Intensity of Urban Parks Using Aster and Ikonos Data," *Landscape and Urban Planning* 96, no. 4 (June 30, 2010): 224–31.; Xiaoyun Cheng et al., "Influence of Park Size and Its Surrounding Urban Landscape Patterns on the Park Cooling Effect," *Journal of Urban Planning and Development* 141, no. 3 (October 2014).

well-suited for implementation in urban areas. Despite the growing importance of PGS in urban planning and design, limited attention has been given to its cooling effect. A study by Lin et al. in Hong Kong showed that urban pocket parks could help mitigate the UHI intensity at the microscale in high-rise, high-density urban environments.[37] However, more research is needed to quantify the cooling effect of PGS and identify the key factors that determine its effectiveness.

1.5 Importance of Public Engagement in Urban Planning and Climate Resilience

The 1992 Rio Declaration at the UN Conference on Environment and Development (UNCED) introduced Principle 10, emphasizing public participation in climate actions, with nation states entrusted to enable access to information and decision-making opportunities, thereby highlighting the enduring significance of public engagement in climate action initiatives.[38] Enhanced public involvement and engagement are regarded as essential elements within the formulation of any adaptation strategy and the process of policy development.[39] Public participation enables the sharing of resources and expertise, fosters creative thinking to go beyond traditional viewpoints, and supports continuous professional development and training for effective urban planning.[40]

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[37] Pingying Lin, Stephen Siu Yu Lau, Hao Qin, and Zhonghua Gou, "Effects of urban planning indicators on urban heat island: a case study of pocket parks in high-rise high-density environment," *Landscape and Urban Planning* 168 (2017): 48-60.
[38] Stephan Hügel, and Anna R. Davies, "Public participation, engagement, and climate change adaptation: A review of the research literature," *Wiley Interdisciplinary Reviews: Climate Change* 11, no. 4 (2020): e645.
[39] Paul Burton and Johanna Mustelin, “Planning for Climate Change: Is Greater Public Participation the Key to Success?,” *Urban Policy and Research* 31, no. 4 (May 23, 2013): 399–415.
[40] Mark Scott et al., Report, “Research 418: Built Environment Climate Resilience and Adaptation,” Wexford, Ireland: *University College Dublin*, 2022.

Studies find that urban areas susceptible to climate vulnerabilities should employ participatory approaches to incorporate community preferences into the creation of climate adaptation strategies.[41] While urban cities are progressively engaging in climate change adaptation planning, the scope and significance of public participation within these initiatives remain insufficiently theorized and underexplored.[42] The prevailing approach to public engagement has been constrained by its inability to account for the diverse experiences people have with climate change and their distinct responses to its impacts and implications.[43] Public engagement has a more pronounced impact on improving the ability to adapt to climate change than on mitigation efforts, positively influencing both aspects.[44] Climate-vulnerable communities require adaptive measures to enhance resilience. According to Khatibi *et. al.,* robust government policies are pivotal, but community awareness, informed choices, and empowerment are also vital, underscoring the role of effective public engagement in successful climate change planning.[45]

2. METHODOLOGY

The methodology section outlines the approach followed to carry out the study, including data preparation, temporal range selection, pocket green space (PGS) definition and selection criteria, along with the overall flow of the study.

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[41] Ella Jisun Kim, "Frames and games: testing a public health orientation to climate adaptation planning." PhD diss., *Massachusetts Institute of Technology*, 2018.
[42] Andrea Sarzynski, "Public participation, civic capacity, and climate change adaptation in cities," *Urban Climate* 14 (2015): 52-67.
[43] Debashish Munshi et al., "Centering Culture in Public Engagement on Climate Change," *Environmental Communication* 14, no. 5 (2020): 573–81.
[44] Massimo Cattino and Diana Reckien, "Does Public Participation Lead to More Ambitious and Transformative Local Climate Change Planning?," *Current Opinion in Environmental Sustainability* 52 (October 2021): 100–110.
[45] Farzaneh Shaikh Khatibi, Aysin Dedekorkut-Howes, Michael Howes, and Elnaz Torabi. "Can public awareness, knowledge and engagement improve climate change adaptation policies?." *Discover Sustainability* 2 (2021): 1-24.

2.1 Study Area

Our research centers on the Kathmandu Valley, situated between latitudes 27° 32’ 13” N and 27° 49' 10” N and longitudes 85° 11’ 31" E and 85° 31' 38" E. This valley, located at an elevation of 1300 meters above sea level, spans approximately 665 square kilometers and includes three districts: Kathmandu, Bhaktapur, and a part of Lalitpur (Figure 1).

Figure 1: Map of Kathmandu Valley

Kathmandu stands out as Nepal's most densely populated urban area, inhabited by 29% of the nation's urban population. Kathmandu is also one of the fastest-growing urban clusters in South Asia, with a growth rate of 3.94%, according to the United Nations Department of Economic and Social Affairs (UN DESA).[46] Over the past four decades, there has been significant transformation in the land use of Kathmandu Valley, with a 412% expansion of the city, largely at the expense of agricultural land. This transformation has substantially altered the valley's landscape.[47]

Research conducted by Bijesh Mishra on the Urban Heat Island (UHI) effect in Kathmandu indicates an average temperature difference of 5°C between forested areas and developed land within the valley.[48] Additionally, an annual temperature

[46] Elisa Muzzini, and Gabriela Aparicio. “Urban Growth and Spatial Transition in Nepal.” *Directions in Development*. Washington, DC: World Bank (2013).
[47] Asif Ishtiaque, Milan Shrestha, and Netra Chhetri, “Rapid Urban Growth in the Kathmandu Valley, Nepal: Monitoring Land Use Land Cover Dynamics of a Himalayan City with Landsat Imageries,” *Environments* 4, no. 4 (2017): 72.
[48] Bijesh Mishra, Jeremy Sandifer, and Buddhi Raj Gyawali. "Urban heat island in Kathmandu, Nepal: Evaluating relationship between NDVI and LST from 2000 to 2018." *International Journal of Environment* 8, no. 1 (2019): 17-29.

increase of 0-2°C has been observed over an 18-year period. Consequently, the valley has experienced shifts in its weather patterns, resulting in adverse effects on human health. The frequency of these temperature-related fluctuations have been on the rise throughout the 21st century.

Given these circumstances, there is growing interest among urban residents, as well as urban planners and designers, to effectively utilize urban green spaces as nature-based solutions to mitigate the UHI effect, and improve the urban thermal environment. Our research focuses specifically on the central urban area within the metropolitan wards of Kathmandu Valley, making it an ideal location to investigate the cooling impact of Pocket Green Spaces (PGS) in a densely populated metropolitan setting.

2.2 Data Collection and Sources

The study utilizes various datasets (Table 1) to analyze temperature variations within and around Pocket Green Spaces (PGS) in the Kathmandu Valley. These datasets include remote sensing data, geographic information system (GIS) data, and climate data.

Table 1: Datasets collected from the Kathmandu Valley along with their sources

Dataset	Sources
Kathmandu Valley Admin Boundary	Survey Department (2022)
Kathmandu Valley Rivers	ICIMOD (2008)
Land Cover	ICIMOD (2019)
Population Data	CBS (2021)
Income Data	CBS (2021)
Open Spaces Data	OSM (2023)
Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI)	LANDSAT 8

2.2 Pocket Green Space's Definition and Selection

There are more than three thousand green/open spaces in the Kathmandu Valley, downloaded from 17 labels in OSM, 2023 (*label list provided in Annex*). In the context of this research, a Pocket Green Space (PGS) is operationally defined as an urban public green space encompassing a minimum area equivalent to more than one pixel within Land Surface Temperature (LST) data. Peng et al. (2021) demonstrated that the cooling effect of urban parks could overlap each other.[49] Thus, to identify the cooling effect of individual green spaces, it is necessary to select green spaces which are not overwhelmed by the other green or blue spaces.[50]

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[49] Jian Peng et al., "How to Quantify the Cooling Effect of Urban Parks? Linking Maximum and Accumulation Perspectives," Remote Sensing of Environment 252 (2021): 112135.
[50] Caiyan Wu et al., "Estimating the Cooling Effect of Pocket Green Space in High Density Urban Areas in Shanghai, China," *Frontiers in Environmental Science* 9 (2021).

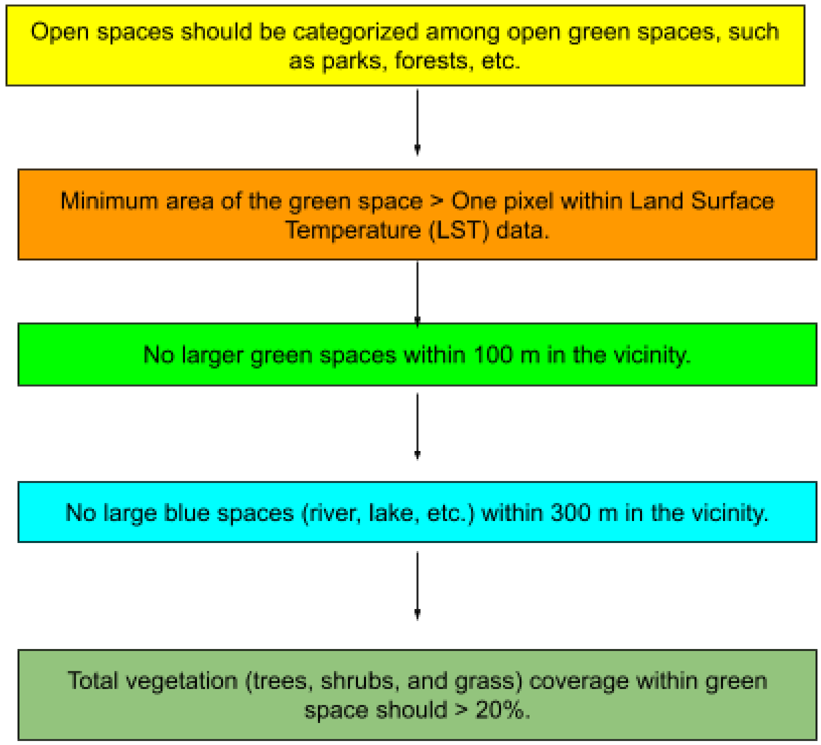

Figure 2: Criteria for selection/defining Pocket Green Spaces for this study

For this study purpose, considering the availability of datasets and size of the green spaces in the Valley, we defined following criteria for the selection of Pocket Green Spaces (PGS) in the Kathmandu Valley (Figure 2): first, only the open spaces obtained from the OpenStreetMap (OSM) database that fell under open green spaces were considered, with the definitive labels provided in the Annex I. Second, only the green spaces with a minimum size equivalent to more than one pixel in the Land Surface Temperature (LST) data were filtered for further considerations to ensure their visibility in Landsat Thermal images. Additionally, smaller green spaces clustered together were merged and larger green spaces like National Parks were not considered for this study. Furthermore, pocket green spaces within the proximity of substantial blue spaces, such as rivers or lakes, were avoided within a 300-meter radius. Lastly, the collective vegetation cover, encompassing trees, shrubs, and grass, within the green space surpassed an 0.2 threshold. Finally, a total number of 252 PGS were selected (Figure 3). The areas of selected PGS range from around 398 square meters to around 511,596 square meters.

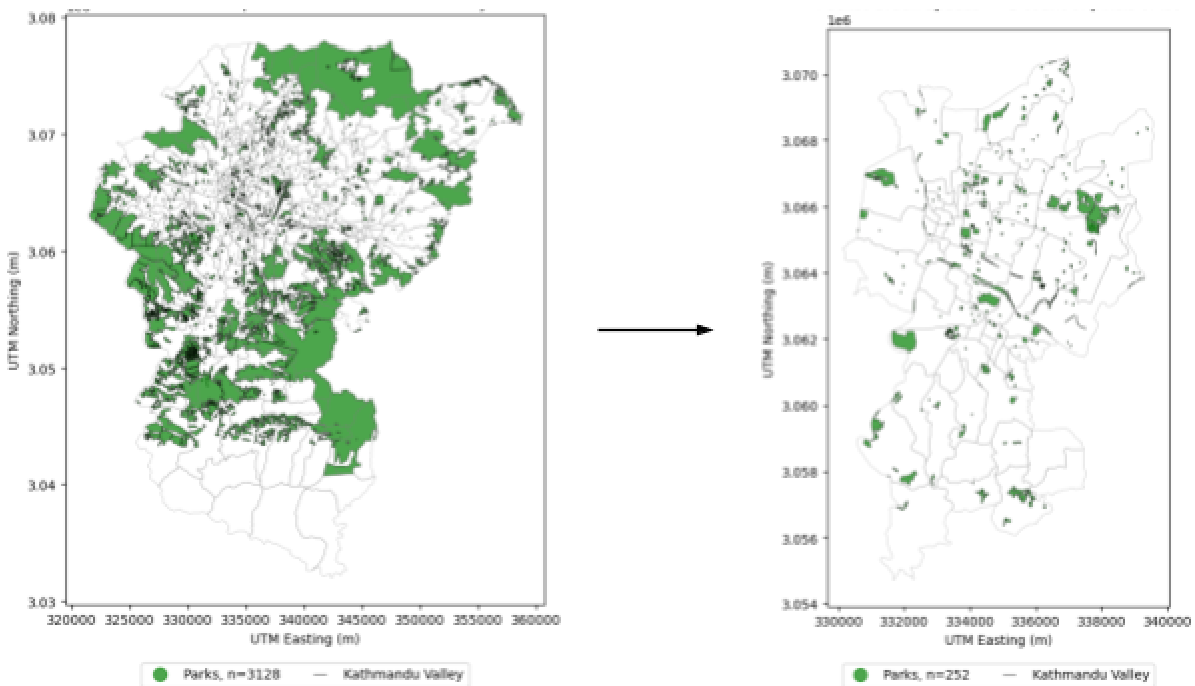

Figure 3: Selected Pocket Green Spaces (n = 252) for further analysis in this study

2.4 Data Analysis

a. Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) Calculations

The land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI) was retrieved from Landsat 8 image. The original spatial resolution of the Landsat 8 thermal band is 100 m. The image acquired was of August, 2022.

Firstly, the at-sensor spectral radiance was converted to effective at-sensor brightness temperature using the following equation:[51]

$$T_B = \frac{K2}{In(\frac{K1}{L\lambda} + 1)} \text{ ....(1)}$$

Where T_B, the effective at-sensor brightness temperature in Kelvin, is determined from the spectral radiance (L_λ) using the formula outlined in Wu et al.'s work from 2019.[52] In the context of Landsat 8 TIRS band_10, the calibration constants K_1 and K_2 are specific values, being 774.89 $W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$ and 1,321.08°K, respectively. It's important to note that the brightness temperature computed using Equation 1 pertains to a theoretical black body. The emissivity-corrected land surface temperature (T_s) is computed as in the following:[53]

$$T_s = \frac{TB}{1 + (\lambda * \frac{TB}{\alpha})\ ln\varepsilon} \text{ .... (2)}$$

Where, λ represents the wavelength of emitted radiance, specifically set at 10.90 μm, which corresponds to the center of the spectral bandwidth for Landsat 8 TIRS band_10; and α = hc/b, where h stands for Planck's constant (h = 6.626 × 10–34 Js), b stands for Boltzmann constant (b = 1.38 × 10^{-23} J/K), and c is the speed of light (c = 2.998 × 108 m/s); and the surface emissivity (ε) = 0.02644F_v + 0.96356 [54], which is estimated using Li et al.'s equation from 2011. Here, F_v represents the

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[51] Gyanesh Chander, Brian L. Markham, and Dennis L. Helder, "Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 Ali Sensors," *Remote Sensing of Environment* 113, no. 5 (May 15, 2009): 893–903.
[52] Caiyan Wu et al., "Understanding the Relationship between Urban Blue Infrastructure and Land Surface Temperature," *Science of The Total Environment* 694 (2019): 133742.
[53] David A Artis and Walter H Carnahan, "Survey of Emissivity Variability in Thermography of Urban Areas," *Remote Sensing of Environment* 12, no. 4 (1982): 313–29.
[54] Junxiang Li et al., "Impacts of Landscape Structure on Surface Urban Heat Islands: A Case Study of Shanghai, China," *Remote Sensing of Environment* 115, no. 12 (2011): 3249–63.

vegetation fraction, and its estimation is based on the NDVI (Normalized Difference Vegetation Index) following the methodology outlined by Yu et al. in 2014.[55] NDVI is traditionally computed as the ratio between the red (R) and near-infrared (NIR) values, following the standard approach:

NDVI = $\frac{(NIR - R)}{NIR + R}$ ……………………………..(3)[56]

Using Landsat 8, for our study, NDVI = $\frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$

2.5 Workshop

We conducted a two day workshop, 4 hours each, where we discussed citizens' understanding of climate commitments of the city. We started with a survey for general understanding of climate change and climate commitments in the first half of the workshop. In the second half, we distributed the 1-pager containing Nepal's climate commitments, and engaged in a more verbal discussion of their sentiments and attitude towards the commitments.

Figure 4: Workshop conducted to assess citizen's understanding of climate commitments of Nepal

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[55] Xiaolei Yu, Xulin Guo, and Zhaocong Wu, "Land Surface Temperature Retrieval from Landsat 8 TIRS—Comparison between Radiative Transfer Equation-Based Method, Split Window Algorithm and Single Channel Method," *Remote Sensing* 6, no. 10 (2014): 9829–52.

[56] "Landsat Normalized Difference Vegetation Index," Landsat Normalized Difference Vegetation Index | U.S. Geological Survey, accessed October 20, 2023.

3. ISSUE, EVIDENCE, AND KEY FINDINGS

(a) Relationship between LST and PGS

The mean Land Surface Temperature (LST) of the selected Pocket Green Spaces ranged from 296.18 Kelvin to 322.34 Kelvin, while the Normalized Difference Vegetation Index (NDVI) ranged from 0.12 to 0.832. It can be seen that the mean LST varied with the PGS's land use type (Figure 5). The forest type PGS had the lowest mean LST.

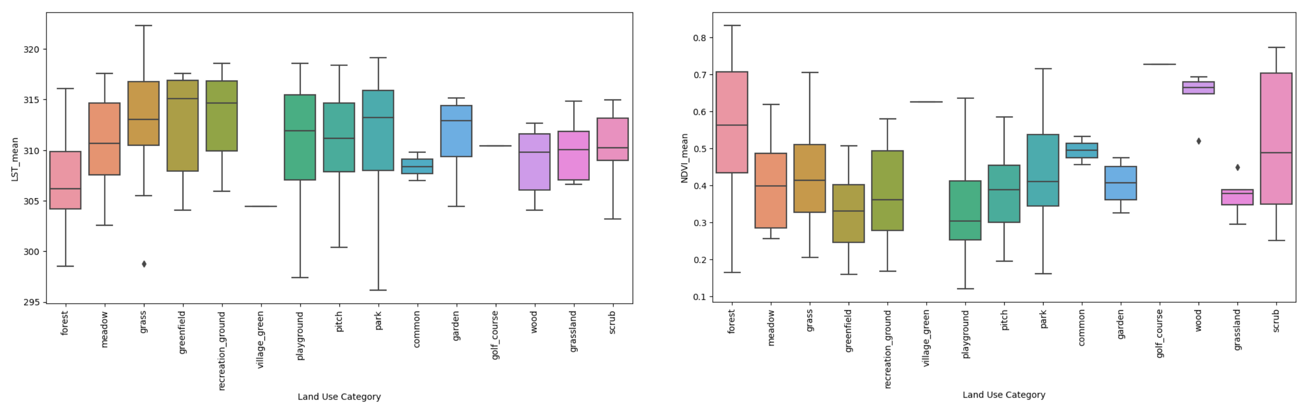

Figure 5: Distribution of mean LST and mean NDVI in the pocket green spaces (n=252) of the Kathmandu Valley selected for this study

Among the 252 PGS, the lowest mean land surface temperature (LST) of pocket green space (PGS) was 296 K with an area of approximately 1632.69 square meters, while the highest mean land surface temperature of PGS was 322 K with the size of 602.43 square meters. The average of the mean land surface temperature of all PGS was 311 K. There is a statistically significant relationship between the land surface temperature of PGS and its area (due to low p-value, i.e. 0.0114, but the model's goodness of fit is relatively low (as indicated by the low R-squared value, i.e.

0.03). This suggests that area might have some impact on the land surface temperature but it doesn't explain much of the variability, and there are likely other factors influencing that might not have been accounted for in the model (Figure 6).

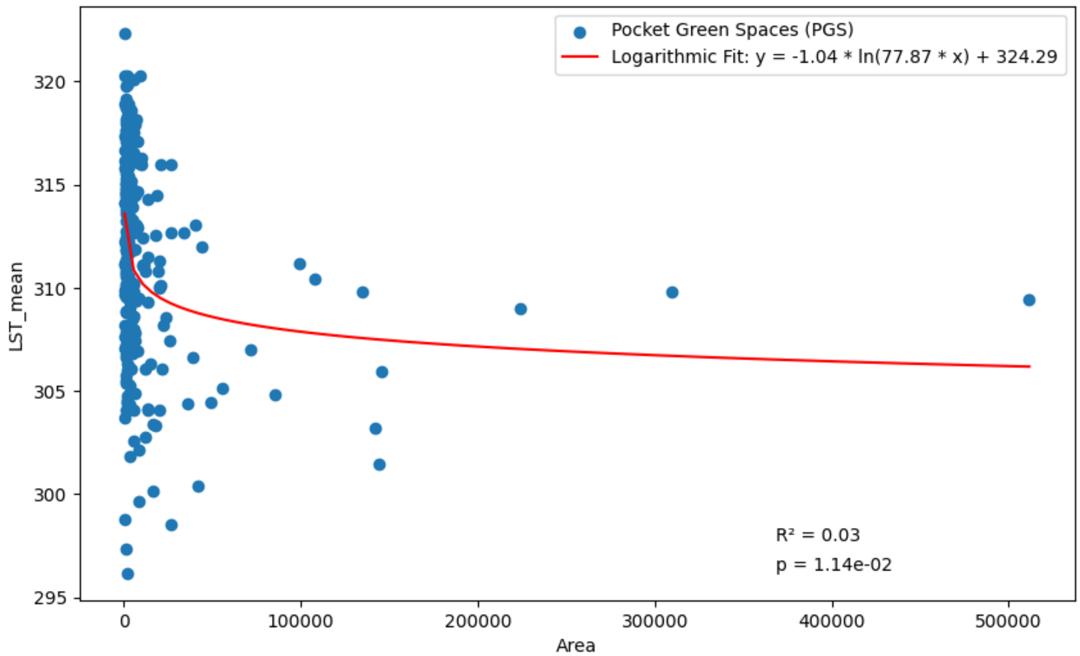

Figure 6: Relationship between the mean LST and the area of PGS (in square meters).

The data reveals a distinctive inverse correlation between the land surface temperature (LST) of Pocket Green Spaces (PGS) and the characteristics of their surrounding landscape (Figure 7). This relationship demonstrates that as one moves farther away from the park, the LST consistently rises, indicating a progressive increase in temperature with increasing distance from the PGS.

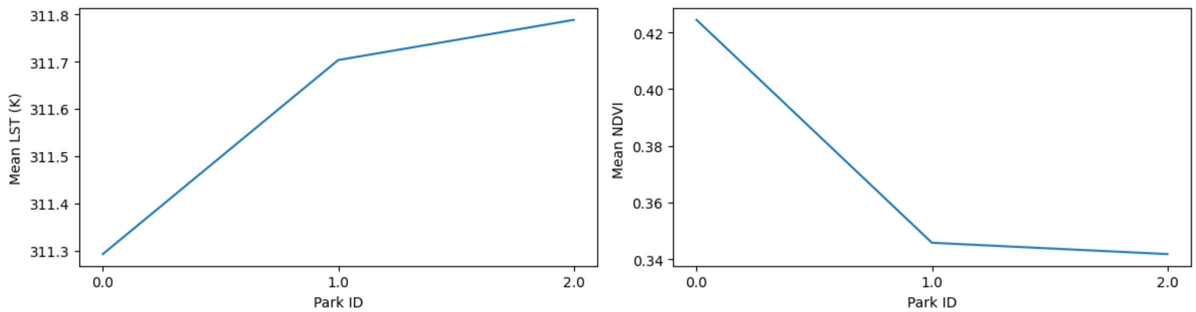

Figure 7: Relationship between pocket green spaces and its surrounding area with LST and NDVI (here, Park ID 1 represents original pocket green space polygon, Park ID 1 represents 1st buffer of 100 meters and Park ID 2 represents 2nd buffer of 100 meters.

(b) Workshop Findings

Out of 14 respondents, 41% of respondents were aware of Nepal's climate commitments before reading about them in the workshop, while the rest were either unaware of Nepal's climate commitments or were somewhat aware of the issue.(Figure 8). However, after reading the handouts provided in the workshop, 31% of the respondents felt more informed, and 39% of the respondents felt encouraged towards meeting Nepal's climate commitments (Figure 9). 75% of respondents felt a stronger sense of ownership and responsibility towards climate action after the workshop (Figure 10), and almost 17% of respondents suggested that a regular awareness program would encourage citizens to take ownership of climate commitments and actively contribute in their implementation. More importantly, 81%

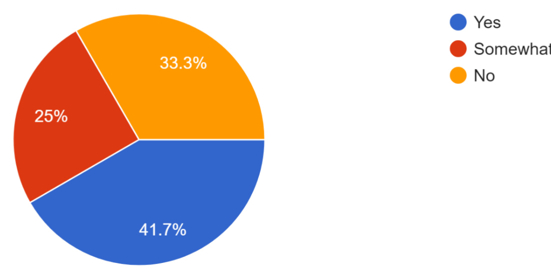

Figure 8: The understanding of respondents before reading about Nepal's climate commitments in the workshop

of respondents felt that regular feedback sessions or mechanisms should be established to ensure continuous improvement of these climate commitments.

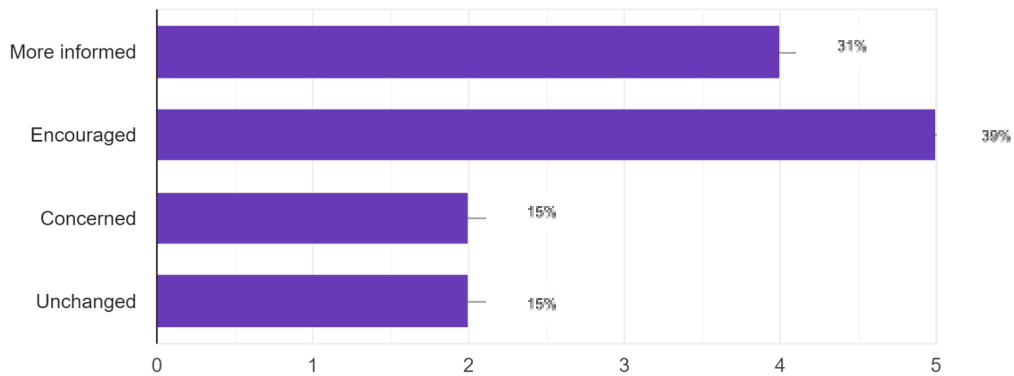

Figure 9: Respondents sentiments for Nepal's climate commitments

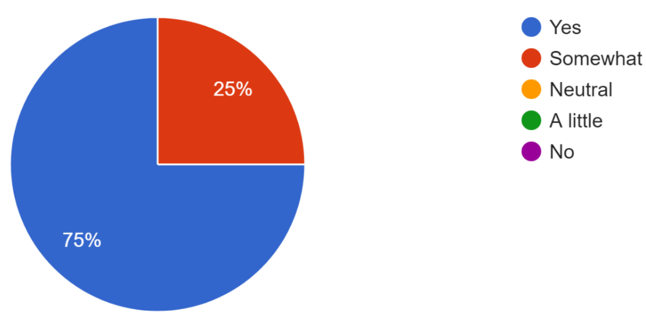

Figure 10: Respondent's sentiment (for question did they feel empowered ?) after reading about the climate commitments of Nepal

4. IMPACT

This section discusses the findings and implications of our study, as well as other studies (literature review) in relation to the Urban Heat Island (UHI) effect and the role of Pocket Green Spaces (PGS) in mitigating this phenomenon in the Kathmandu Valley. It also addresses the significance of public engagement and awareness in meeting climate commitments and driving climate action. In the realm of environmental sustainability, innovative approaches such as nature-based solutions have gained prominence for addressing the consequences of human activities on the environment. These solutions, including natural systems agriculture, ecosystem-based approaches, and green infrastructures, provide a promising path towards mitigating long-term environmental challenges.[57] Notably, these approaches encompass the strategic use of urban green spaces, making them a pivotal element in sustainable urban development. Urban green spaces have emerged as essential contributors to sustainable urban development. These spaces hold the potential to significantly enhance the local urban climate and outdoor thermal comfort, making them valuable assets in addressing environmental concerns, particularly in densely populated urban areas.[58] Consequently, optimizing the composition of vegetation in these green spaces is a critical consideration in effectively mitigating the urban thermal environment.[59]

In this context, the role of Pocket Green Spaces (PGS) becomes especially noteworthy. PGS, with their compact nature, offer a unique opportunity to foster sustainable urban development while simultaneously mitigating the adverse effects

[57] Hilde Eggermont et al., "Nature-Based Solutions: New Influence for Environmental Management and Research in Europe," *GAIA - Ecological Perspectives for Science and Society* 24, no. 4 (September 2015): 243–48.
[58] Evyatar Erell, "Urban Greening and Microclimate Modification," Advances in 21st Century Human Settlements, 2017, 73–93.; Erik Andersson et al., "Neighbourhood Character Affects the Spatial Extent and Magnitude of the Functional Footprint of Urban Green Infrastructure," *Landscape Ecology* 35, no. 7 (2020): 1605–18.; Stephan Pauleit et al., "Urban Green Infrastructure – Connecting People and Nature for Sustainable Cities," Urban *Forestry & Urban Greening* 40 (2019): 1–3.
[59] Caiyan Wu et al., "Estimating the Cooling Effect of Pocket Green Space in High Density Urban Areas in Shanghai, China," Frontiers in Environmental Science 9 (2021).

of the urban heat island (UHI) phenomenon. Our study, conducted in the Kathmandu Valley, emphasizes the importance of strategically utilizing PGS to counter the UHI effect and enhance thermal comfort in densely populated metropolitan settings. A study by Wu et al., (2021) in Shanghai found that increasing the size of PGS enhances their cooling impact. Larger green spaces have a more pronounced cooling effect on their surroundings, contributing to the mitigation of the UHI effect. Similarly, the author suggested the existence of a threshold value, beyond which further increases in PGS size might not lead to significantly enhanced cooling efficiency. As such, urban planners and designers should focus on optimizing the use of limited green space while considering the diminishing returns in cooling efficiency with excessive size. Additionally the authors recommended the impact of vegetation composition within PGS and encouraged urban planners to prioritize and promote tree-dominated compositions within PGS to maximize their cooling potential and enhance the urban thermal environment. Further insights from studies conducted by Hamada and Ohta (2010)[60] and Doick et al. (2014)[61] reveal seasonal and daily reductions in Land Surface Temperature (LST) brought about by urban parks. Furthermore, other findings suggest small green areas can significantly enhance cooling effects within urban blocks, where the configuration of green space, particularly the presence of polygonal and mixed types, emerges as a more critical factor in maximizing cooling effects.[62]

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[60] Shuko Hamada and Takeshi Ohta, “Seasonal Variations in the Cooling Effect of Urban Green Areas on Surrounding Urban Areas,” Urban Forestry & Urban Greening 9, no. 1 (2010): 15–24.
[61] Kieron J. Doick, Andrew Peace, and Tony R. Hutchings, “The Role of One Large Greenspace in Mitigating London’s Nocturnal Urban Heat Island,” Science of The Total Environment 493 (2014): 662–71.
[62] Jonghoon Park et al., “The Influence of Small Green Space Type and Structure at the Street Level on Urban Heat Island Mitigation,” Urban Forestry & Urban Greening 21 (2017): 203–12.

5. LIMITATIONS

There were several limitations in our study that should require attention in the future. One primary limitation was the use of land surface temperature derived from the Landsat 8 thermal band, as opposed to the conventional air temperature measurements. This choice resulted in a relatively coarse spatial resolution of 100 meters. Consequently, our study could not precisely identify and evaluate the thermal performance of Pocket Green Spaces (PGS) within a spatial and temporal (night-time) context. To mitigate this limitation, future research may benefit from employing advanced technology, such as Unmanned Aerial Vehicles (UAV) equipped with high spatial resolution, hyperspectral, and thermal sensors.[63] These tools can offer more detailed, diurnal, and real-time canopy and thermal information, enabling a comprehensive assessment of PGS cooling effects.

In our study, we employed a series of buffer widths to investigate the cooling effect of urban green space. However, the delineation of 100-meter width buffer rings around the PGS was necessitated by the coarser resolution of our land surface temperature data. This approach introduced inherent limitations in capturing the nuanced cooling effects, particularly in areas where PGS overlapped. In future studies, it is imperative to address this issue by adjusting or excluding the temperature data from overlapping buffer rings. This adjustment would enable a more accurate assessment of the cooling effects associated with distinct PGS.

[63] P.J. Zarco-Tejada, V. González-Dugo, and J.A.J. Berni, “Fluorescence, Temperature and Narrow-Band Indices Acquired from a UAV Platform for Water Stress Detection Using a Micro-Hyperspectral Imager and a Thermal Camera,” *Remote Sensing of Environment* 117 (February 2012): 322–37.; Xiaoxue Feng and Peijun Li, “A Tree Species Mapping Method from UAV Images over Urban Area Using Similarity in Tree-Crown Object Histograms,” Remote Sensing 11, no. 17 (2019): 1982.; Felix Schiefer et al., “Mapping Forest Tree Species in High Resolution UAV-Based RGB-Imagery by Means of Convolutional Neural Networks,” ISPRS Journal of Photogrammetry and Remote Sensing 170 (2020): 205–15.

Another challenge we encountered relates to the difficulty of isolating the interference of residential green spaces from the cooling effects of PGS. Future investigations should explore methods to disentangle these influences to provide a more precise understanding of the unique contributions of PGS to urban cooling.

An additional noteworthy constraint was the relatively short duration of our study, spanning only four months. This limited time frame allowed only for a preliminary examination of the cooling effects of PGS in the Kathmandu Valley. To conduct a more comprehensive and detailed study, an extended research period is essential.

The emergence of innovative technologies, such as UAV remote sensing, offers promising avenues for future research. By leveraging the capabilities of UAVs equipped with advanced sensors, researchers can conduct detailed, high-resolution assessments of PGS in various spatial and temporal contexts. Additionally, investigating the diurnal and real-time thermal dynamics of PGS can provide valuable insights into their cooling potential.

6. RECOMMENDATIONS

The findings and recommendations of this research aim to increase people's understanding of pocket green spaces and the positive impact they can have across various urban spaces. These potential impacts span across various critical domains, including environmental sustainability, urban planning and design, public health, and social well-being, collectively contributing to the overall resilience and quality of life within the community.

5.1 Environmental Sustainability

1. **Mitigating Urban Heat Islands:** The research recommendations, which include expanding Pocket Green Spaces (PGS), promoting tree-dominated vegetation, and optimizing surrounding landscape patterns, directly address the mitigation of urban heat islands. By implementing these measures, policy & decision makers actively contribute to reducing the adverse impacts of elevated temperatures and extreme heat events in the Kathmandu Valley, thus enhancing the environmental sustainability of the urban ecosystem.

2. **Enhancing Green Infrastructure:** This study underscores the importance of well-designed and connected green spaces as integral components of green infrastructure. These findings offer a strategic blueprint for planning and expanding urban green infrastructure to improve air quality, reduce pollution, and conserve biodiversity..

5.2 Urban Planning and Design

1. **Optimizing Land Use:** The research elucidates the intricate relationship between PGS size and cooling efficiency, informing land-use decisions in high-density urban areas. By considering threshold values for PGS size, urban planners can optimize land use, ensuring that green spaces are leveraged effectively to enhance thermal comfort and overall urban quality. SCSC is concerned primarily with building a world where everyone has space to belong. Recognizing the importance of building and preserving community

space for people to congregate and crucially, cool down, PGS offer low-cost, environmentally significant spaces to invest in.

2. **Community Engagement:** In the workshop during this study period, 75 % of the respondents felt a stronger sense of ownership and responsibility towards climate action after they were made aware about the climate commitments of Nepal. Hence, to enhance community engagement and promote a sense of ownership in climate action, it is essential to continue organizing awareness workshops, feedback sessions and develop a mechanism to be engaged in understanding and being kept up to date with Nepal's ongoing climate commitments. These workshops can be a valuable tool for inspiring individuals to take responsibility and contribute to climate-related initiatives.

5.3 Public Health

1. **Heat-Related Health Risks:** In a context where the frequency of heatwaves is rising in the Kathmandu Valley, the cooling effects of PGS assume paramount importance for public health. By actively promoting and expanding PGS in accordance with the research findings, key decision-makers can contribute to reducing heat-related health risks, encompassing heat-related illnesses like heat exhaustion and heatstroke. This translates to an improvement in overall well-being, particularly among vulnerable populations.

2. **Quality of Life:** Access to green spaces holds a direct impact on the quality of life for urban residents. By creating and maintaining PGS with optimal cooling effects, decision makers can enhance the outdoor thermal comfort of

the community, encouraging outdoor activities and social interactions. PGS improves mental-health and wellbeing of urban-residents, including those who may be economically marginalized. They are a free place to be with family and friends, and connect with nature. Social connectedness, according to SCSC, encompasses the ability to connect with place and people, among other facets of belonging.[64] It is clear that PGS are optimal, environmentally impactful spaces to build belonging.

5.4 Dissemination and Collaboration

1. **Knowledge-Sharing:** To maximize the impact of this research, key stakeholders working in urban management can actively disseminate the findings and recommendations through workshops, seminars, and publications targeting urban planners, policymakers, and local communities. Sharing this knowledge empowers stakeholders to make informed decisions and implement practical solutions.

5.5 Impact on Belonging and Social Connectedness

In addition to the aforementioned impacts, this research and its recommendations have the potential to significantly influence overall sense of belonging and social connectedness within the community. These social dimensions are vital components of urban well-being and resilience, and the research findings have direct implications:

[64] "About Social Connectedness," Samuel Centre For Social Connectedness, April 19, 2023, https://www.socialconnectedness.org/about-us/about-social-connectedness/.

1. **Creating Community Spaces:** Accessible and well-maintained Pocket Green Spaces (PGS) serve as local community spaces, fostering a sense of belonging whereby residents can gather and engage in activities. Implementing the recommendations to expand PGS and promote tree-dominated vegetation can actively create environments conducive to social connectedness, enhancing social bonds and community ties.

2. **Community Engagement and Participation:** Involving the community in the planning, development, and maintenance of PGS empowers residents to take ownership, fostering attachment and responsibility that strengthens belonging. SCSC can facilitate collaborative initiatives, such as community tree-planting events and volunteer-driven maintenance projects, which enhance not only the physical environment, but also social cohesion and connectedness among residents.

3. **Improving Quality of Life:** Access to green spaces have a beneficial effect on mental health by reducing stress and promoting positive mental health, leading to a greater sense of belonging within the community. Implementing the suggested recommendations ensures inclusive and accessible green spaces for all community members, regardless of age, ability, or socioeconomic status. This inclusivity promotes a sense of belonging among diverse groups within the urban population.

6. CONCLUSION

In this study, based on both primary and secondary sources, we delved into the cooling potential of Pocket Green Spaces (PGS) and their associated influencing factors in the Kathmandu Valley. The investigation revealed several crucial findings that can significantly impact urban planning, design, and sustainable development in metropolitan settings. Our research unveiled that the overwhelming majority of PGS exerted a cooling effect on their immediate surroundings. The area and composition of vegetation within PGS emerged as prominent factors influencing their cooling effects.

The significance of configuration in green spaces is another critical aspect that emerged from our research. We have learned that even small green areas can bring positive benefits by increasing cooling effects within urban blocks. Furthermore, our study aligns with the study done by Wu et al., that the size of PGS plays a substantial role in enhancing their cooling effect.[65] Furthermore, our research aligns with the significance of vegetation composition within PGS.

Beyond the technical aspects of PGS and their role in mitigating the UHI effect, our study underscores the significance of public engagement and awareness. The engagement of urban residents, as well as urban planners and designers, is instrumental in shaping climate commitments and driving climate action. As witnessed in the workshop conducted during our research, public participation fosters a sense of ownership and responsibility towards climate action. This

[65] Caiyan Wu et al., "Estimating the Cooling Effect of Pocket Green Space in High Density Urban Areas in Shanghai, China," Frontiers in Environmental Science 9 (2021).

sentiment is essential for the successful implementation of climate commitments and the development of resilient urban environments.

It is essential to acknowledge the limitations of our study, such as spatial resolution, buffer width, overlapping effects, and the study's relatively short duration of four months. These limitations can guide future research directions, prompting a focus on advanced technologies like Unmanned Aerial Vehicles (UAV) equipped with high-resolution sensors to provide more detailed insights into PGS performance. Additionally, the need for extended research periods to explore seasonal variations and the long-term impact of PGS on the UHI effect is imperative.

In conclusion, our study in the Kathmandu Valley highlights the vital role of Pocket Green Spaces as nature-based solutions in mitigating the UHI effect and fostering sustainable urban development. By optimizing the size, composition, and configuration of PGS and engaging the public in climate commitments, urban areas can effectively combat the adverse consequences of urbanization and create environmentally resilient and thermally comfortable cities. Continued research and innovative approaches are essential to refine our understanding of how Pocket Green Spaces can contribute to long-term urban sustainability.

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APPENDIX

Table 1: List of labels used in downloading open spaces from the Kathmandu Valley

Features	Legend	Status
leisure	park	Considered
leisure	garden	Considered
leisure	nature_reserve	Removed
landuse	grass	Considered
landuse	forest	Considered
landuse	greenfield	Considered
landuse	meadow	Considered
leisure	golf_course	Considered
natural	grassland	Considered
leisure	playground	Considered
natural	wood	Considered
landuse	recreation_ground	Considered
landuse	brownfield	Considered
landuse	farmland	Removed
leisure	pitch	Considered
amenity	parking	Removed