Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Nature Based Solution to Counter Urban Heat Island Effect: A Case of Kathmandu Valley

Bipin Bhusal [a], Inu Pradhan Salike [b]

[a, b] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] bipinbhusal55@gmail.com, [b] inupradhan@gmail.com

Abstract
Urbanization leading to the dense population on the city core has enhanced heat effect of urban spaces. UHI enhance climatic and biophysical risks which are governed by rising anthropogenic CO2 and other greenhouse gas emissions and also has potential to change the intensity, temporal pattern and spatial extent of UHI. It has been revealed that temperature in Kathmandu increased by 0℃ to 2℃ between 2000 and 2018. With this effect and the presence of Urban Heat Island in Kathmandu Valley, a natural solution is required. These solutions involve maintaining biodiversity and enhancing human well-being while also protecting, restoring, and sustainably managing ecosystems in ways that strengthen their resilience and capacity to solve those societal concerns. The green, blue and grey infrastructure to guide the Nature Based Solution to counter UHI in Kathmandu valley helps to understands their attributes and suitable NBS which could be integrated for Kathmandu Valley. The post-positivist paradigm was used to perform the research. For this, two case study area i.e., Kuleshwor Site and Service Area to evaluate the effect of green and grey infrastructure and Harisiddhi area for old settlement and new settlement. The temperature is recorded in hourly interval to examine the urban heat island effect. These two are completely different set of sites and are not interconnected. The study shows the role of green space and material with high albedo value in cooling the urban areas.

Keywords
Nature Based Solutions, Urban Heat Island, Kathmandu Valley, Albedo value

1. Introduction

Urban heat islands (UHIs) are meteorological effects of urbanization in which the air temperature in urban areas is greater than in non-urban areas. Urbanization is the main driver of UHIs, as it leads to massive land-use land-cover (LULC) change, transforming natural urban landscapes from green into grey areas to accommodate housing and public infrastructure [1].Natural features such as urban green space are replaced with high thermal admittance materials as cities grow, allowing more solar energy to be stored and re-emitted, resulting in an increase in the surrounding air temperature.UHI has an indirect effect on health since heat interferences impair daily activities like working, sleeping, and overall health and well-being.Climate change is the steady alteration of the earth's climatic that is caused by human activity that modifies the composition of the global atmosphere, in addition to the natural climate variability that has been documented during comparable time periods[2].

The growing effect of Urban Heat Island (UHI) need to be addressed by the natural methods.Nature-based solutions are considered as having a lot of potential for helping cities make the transition to sustainability.They have the ability to mitigate the effects of climate change, increase biodiversity, and improve environmental quality while also supporting economic and social activities.For the European Commission, nature-based solutions are defined as: "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience.Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions"[3].

The urban population growth rate in Nepal almost doubled from 3.6per in 1991 to 6.5per in 2001, and the number of urban centers increased from 58 in 2013 to 293 in 2017[4].State reorganization after 2015 is the main element promoting urban expansion in Nepal.Unplanned land use, shrinking open areas, haphazard development, and poor services have all become prominent urban elements in Nepal, mirroring the rise of the Kathmandu Valley.The Kathmandu Valley is the most populated urban region and one of the fastest-growing urban agglomerations in South Asia [5].Kathmandu Valley accounts for 24 per cent of the total urban population, with Kathmandu Metropolitan City alone accounting for 9.7 per cent (MoUD, 2015).Kathmandu Valley continues to be the "hub" of urban development in Nepal.In Nepal, urbanization is dominated by a few major and midsize cities, with a disproportionately high population density in the Kathmandu Valley.The urbanization process reduces greenery and increase the number of impervious surfaces.These lead to change in land use, land cover, and land surface.Consequently, Heat trapping leads to temperature difference between urban and surrounding rural areas i.e., temperature in urban areas higher than rural areas.The UHI phenomenon is important to study because it affects many aspects of life, such as infrastructure, health, energy consumption, environmental stress, and discomfort, and leads to additional costs in building infrastructure [6].

To enable a greater use of nature-based solutions, four key concerns must be addressed [7].The first point to consider is assessment techniques. We have a poor understanding of how ecosystem services work in an urban context, despite the expanding body of evidence.Many of our assessment systems emphasize nature's ecological benefits, overlooking its economic, social, and cultural values.Business models are the second difficulty.The advantages of technologies or changes in behavior that promote sustainability are reasonably straightforward to calculate.Governance strategies are the third point to consider.Municipal governments play a critical role in urban sustainability.Pathways to innovation are the fourth concern.Understanding the primary obstacles and opportunities confronting projects on the ground is necessary for mainstreaming nature-based solutions.Any invention must travel a path from conception to implementation in policy, industry, and society.

2. Research Objectives

The main objective of this thesis is to study prospect of implementing Nature based solutions inside Kathmandu valley with regard to urban heat island effect. The research objectives for this thesis is:

- To understand Nature-based solutions and urban heat island effect and its attributes.

3. Literature Review

3.1 Nature Based Solutions

For the European Commission, nature-based solutions are defined as: "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience.Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions".

For the International Union for the Conservation of Nature, a non-governmental organization that promotes nature conservation, nature-based solutions are: "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits".The concept of NBS need to be mainstreamed within urban planning, policy and development.Enabling wider uptake of NBS means tackling four key issues (McCormick, 2020).The first is assessment methods, second issue is business models, third issue is governance strategies and the final one is innovation pathways.

The most commonly used Nature Based Solutions for heat adaptation in urban areas can be classified into Green, Blue and Grey infrastructure (Magotra et al., 2018).Green Infrastructure i.e., Use of greenery can be tree canopy/increase in the afforestation cover, vertical Greenery and Green Roofs which helps in temperature reductions.Likewise, blue Infrastructure include use of water bodies. Several studies have observed that the areas closer to water body are cooler than the areas far from them [8].Similarly, Grey Infrastructure i.e use of built architecture should be incorporated as heat-adaptive planning which allows for the natural airflow around built infrastructures.

The intervention guide for the probable areas can be seen in the table below with the major three types solutions.

Table 1: Choice of NBS

Solutions	Intervention Guide	Probable intervention areas
Type 1	Improving existing natural or protected ecosystems	Mainly sprawl semi urban areas where a large part of the existing natural ecosystem is still intact like: lake catchment areas the hill areas some agricultural areas
Type 2	Developing sustainable management protocols and procedures for managed or restored ecosystems	Mainly peripheral urban areas within the administrative limits where some part of the existing natural ecosystem can still be partly restored and managed; Lake edges Parts of river the greens of hill the large-scale city level greens large roadside greens
Type 3	Creating new ecosystems	Mainly congested city core where the over urbanized areas need to create a new ecosystem mainly based on a large-scale engineering intervention Parks and Green cover Community level open spaces Green roof and Green walls for new community buildings Bamboo housing projects in highly vulnerable slum regions Small sized Parks and Green cover in unutilized landscapes within the city Air Ventilation Friendly Urban Planning for the newly developing areas on the boundaries of the cities

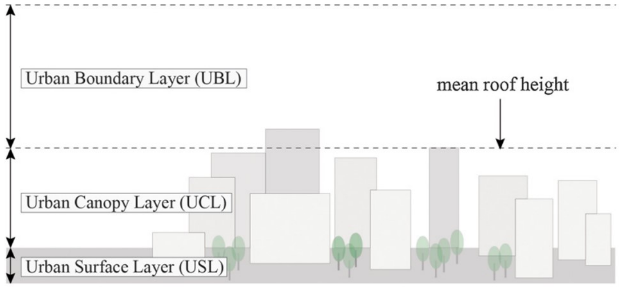

Figure 1: Different Layer of UHI (Kim et al., 2018)

3.2 Urban Heat Island Effect

Urban areas with greater temperatures than their surroundings are said to have the urban heat island effect (UHI). The scientific foundation for examining the Heat Island Effect is represented by Luke Howard's investigation of the local climate in and around London. When he contrasted the air temperature in his rural area with the temperatures recorded by the Royal Society in the heart of London, he was describing an urban heat island (UHI).

Plotting these data revealed that the near-surface atmosphere was warmer in the metropolitan region. The average temperature in London, according to Howard, is roughly 48.50 degrees Fahrenheit. However, in the city's more populated areas, where there are more fires, the temperature can reach 50.50 degrees[9].This was the beginning of the study regarding UHI effect on atmosphere.

Heat islands are categorized mainly as surface and atmospheric heat islands on the basis of the different processes in the underlying mechanisms for their formation, the methods employed to measure them, their impacts and the methods available to mitigate them[10].In our research we measured the temperature and humidity of canopy layer, which is the layer of air closest to the surface in cities and extends approximately to a building height.

3.2.1 Causes Of UHI

1. **Constituents of Urban Infrastructure** In the urban environment, artificial and impervious built-up surfaces, such as roads, roofs, and pavements, with components including bricks, concrete, asphalt, steel, and glass, replace natural and vegetated surfaces. The thermal properties of urban infrastructure materials (heat capacity and thermal conductivity) are different from that of rural natural surfaces [11].

2. **Less Evapo-transpiration** Evapo-transpiration, a cooling process that plants use to keep the environment cold even during the warmest part of the day, involves the absorption of water by the roots and transpiration through the leaves. Urban environments lack Evapo-transpiration since there is a dearth of flora and natural surfaces.

3. **Urban Geometry** Due to canyon like topography and tall buildings, the urban areas are usually characterized by reduced sky view factor and low wind speed.

4. **Anthropogenic heat** An additional substantial contributor to the rise in temperature in metropolitan areas is the anthropogenic heat that is released from air conditioners, power plants, automobiles, and other heat sources.

Attributes and Indicators of Urban Heat Island are shown in fig 3;

4. Study Area

4.1 Introduction to Kathmandu Valley

The Kathmandu Valley contains three major cities of Bhaktapur, Lalitpur, and Kathmandu.The capital of

Table 2: Attributes and indicators of UHI

Urban Heat Island	
Attributes	**Indicators**
Vehicular Emissions	CO2, GHGs
Materials	Albedo Value
Wind Speed	speed and direction, humidity, cloud cover, city design such as built-up areas , aspect ratio, sky view factor (SVF), construction material
Anthropogenic Heat Sources	Heating and Cooling Devices
Urban Geometry	Height to width ratio (H/W), microclimate conditions

Nepal is Kathmandu.It is evident that the urban development planning for rapidly changing land patterns in urban areas of the valley is lagging behind.Due to lack of successful planning, there is haphazard infill development as well as urban sprawl.Significant decrease in open space can be observed because of encroachment of any available land in the valley as well as the surrounding agricultural land by buildings and roads.Lack of green areas has made the bowl-like valley with its low velocity wind to be warmer compared to previous years.

The climate of Kathmandu Valley is sub-tropical cool temperate with maximum of 35.6°C in April and minimum of –3°C in January and 75per annual average humidity.The temperature in general is 19°C to 27°C in summer and 2°C to 20°C in winter.The average rainfall is 1400 millimeters, most of which falls during June to August [12] .

4.2 Site Selection

The two different locations for the experiment are selected within Kathmandu and Lalitpur Metropolitan City. Two stations are set at 'Kuleshwor site and service area' and another two stations are set at Harisiddhi in Lalitpur Metropolitan. The site is selected in such a way that each location represents a unique combination of green and grey environment, further old and new settlements. To eliminate variation in weather, urban character, wind speed and direction, the distance and elevations of the two different location are almost the same.

Depending on the parameters following area has been chosen.

- Pavement Area – Kuleshwor Station A
- Green Area- Kuleshwor Station B
- Old Traditional Settlement – Harisiddhi Station C
- New Settlement- Harisiddhi Station D

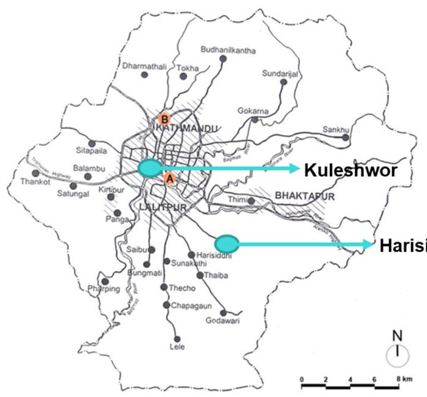

Figure 2: Map of Kathmandu Valley

Kuleshwor Site and Service Area The area selected for the research is "Kuleshwor Site and Services," one of the earliest planned residential communities and a representative of the modern urban settlement of the Kathmandu Valley.It is located on Kuleshwor height ward no: 14.It was started to plan in 2036 BS for 26.56 ha of land and was distributed to government worker from 2039 B.S.It has total number of 817 plots of lands.Open spaces were provided in 26 spaces which is almost 4per of total Kuleshwor Awash.Also, community school area 4578.63 sq. m. were provided on the high contour land [13].Open Space was created with residences on three of its sides and a road that separated it by 5 to 7 meters.Total area of open space 1.29 ha, which is 4.85 percent of total planned area.Open space density is 3678.84 ppha. Street length is 8401 m, with the area of 3.47 ha[13]

Harisiddhi Area On the route to Godawari, Lalitpur, there is a historically renowned village called Harisiddhi, where the Temple of Harisiddhi is situated. It is situated around 8 km south-east of Kathmandu, Nepal's capital. The height of the temple is roughly 4,400 feet from the sea level, whose latitude is 270°38' north and longitude is 850°21' east. The Karmanasha River is located around 800 meters west of the temple. This location has a typical climate with hot summers and freezing winters. The residential neighborhood encircles the shrine. To the south-east of the temple lies a pond that is thought to be Kunda, one of the significant holy pools. Harisiddhi, also known as "Jala" in Newari, is renowned for its antiquated historical and cultural landmarks. The village is actually called ”Hara siddhi,” but residents call it ”Harisiddhi” because that is what they call it. This village is home to a sizable population of Newari people. Harisiddhi is known for its historic festivals and rituals, traditional homes, taps, wells, temples, and ponds.

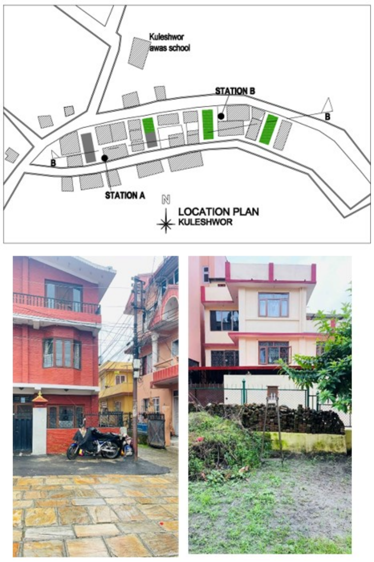

Figure 3: Station A and B at Kuleshwor

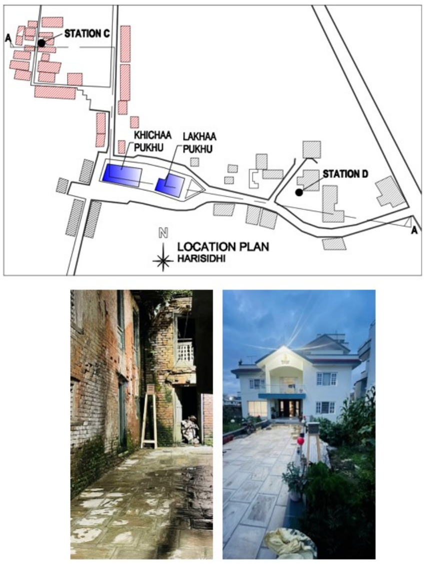

Figure 4: Station C and D at Harisiddhi

5. Methodology

The post-positivist paradigm was used to perform the research. My research focuses on investigating several nature-based solutions for reducing the urban heat island effect in the Kathmandu valley. As a result, the theory of nature-based solutions generates a hypothesis that can mitigate the Urban Heat Island effect, as evidenced by observations of many relevant practices. Last but not least, primary data could be used to validate or authenticate the solutions.

To measure the effect of UHI, the device recording temperature is placed at 4 different areas. The device “HTC data logger” was calibrated at Department of Hydrology and Meteorology (DHM). To eliminate the variables such as weather changes, site is selected at near distance to have the same environment.The canopy layer temperature is recorded i.e. the vertical surface has been acknowledged. The thermometer

Figure 5: Calibration of Thermometers at DHM

needs to be positioned in shade and out of direct sunlight in accordance with rules for taking outdoor temperature readings.In order to protect it from the weather, it should be kept in a covered place. As a result, the device has been stored in a wooden box that measures 1’ x 1’ x 1’-3’ and has louvered ventilation on all sides. As seen in Figure 4, the box has been attached to a 5 foot tall wooden stand. To ensure that surface temperature has no impact on air temperature, thermometers should be positioned 4-6 feet above the ground while measuring outside temperatures. To provide a more accurate reading of the air temperature, a sound height of 5 feet has been maintained from the ground.

The temperature is taken daily at 14:00 LST during the day, 19:00 LST in the evening and 23:00 LST at night from 28 July 28 to 7 August 2022, a total of 10 days. The temperature rises dramatically over the day, peaks at 14:00 LST, and then gradually lowers after that. The temperature will therefore be measured at 14:00 LST. The impact of canyon level UHI is most pronounced after sunset, which occurs around 18:00 LST. The impact of canyon level UHI will therefore be studied at 19:00 LST.

6. Finding and Analysis

Due to the limitation of time, temperature has been recorded for 11 days in total from 28 july to 8 August at 2 PM, 7 PM and 11 PM. Observing the data in two different set of locations we can find that the temperature difference in pavement surface and green area in the Kuleshwor Site and Service Area is 0.52°C. The difference between these stations i.e station A and B is only 50m. There we can see the maximum difference of temperature within short distance in similar environment and orientation of the stations.Within this distance of only 50m in Kuleshwor site and service area, the transformation of green parks into the pavement for the parking has given rise to the temperature as seen through the observations. The temperature difference is maximum at day time making pavement area hotter. Further, the maximum temperature difference of 2.08°C is seen on 4th of August.

Similarly, Harisiddhi area being selected for the old and new settlements effect on temperature. We can observe that new settlement (Station D) has significantly high temperature at day time but has low temperature at night time. The average difference in temperature is 1.11 °C. The maximum temperature difference is seen on 6th August of 6.88 °C. This is the huge difference of temperature in the similar environment and at a distance of only 200 m.The new settlement has higher temperature than old settlement due to road pavement and new construction technique like colored paint on the building which has low albedo value than exposed bricks. The old settlement however has the stone or brick paved pavement, exposed brick on the buildings.

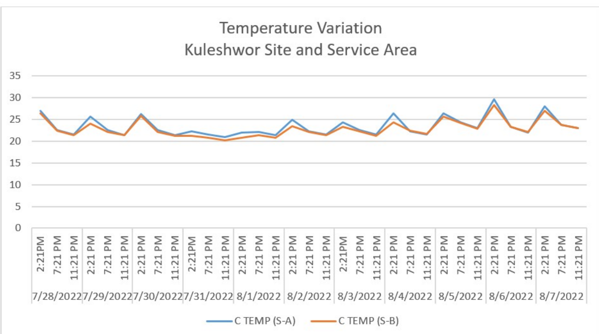

Figure 6: Temperature variation at Kuleshwor

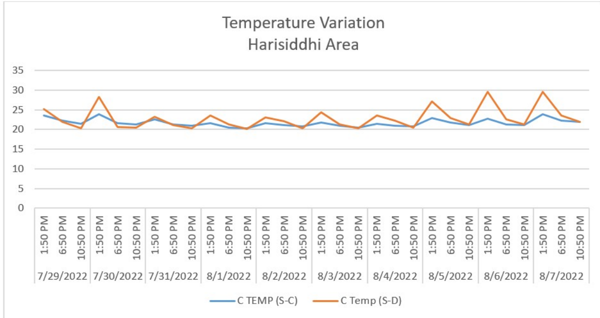

Figure 7: Temperature variation at Harisidhi

7. Conclusion

Kuleshwor site and service has the temperature difference of 0.52°C within the short distance of 50m due to conversion of green space to the pavement for parking. The change in use of open space to make the settlement warm has affected the mico-climate of the area.

Similarly, the materials used in old settlement with high albedo value has made the day's temperature less which is suitable. Bricks posses a low thermal conductivity making the inside environment of house colder in day time. These bricks act like thermal insulator as they restrict the movement of heat passing through them. Hence, high difference of temperature is at day time making old settlement viable for the resident. In night time the heat transfer process making place hot in old settlement has no effect on the settlement. Hence, old settlement has comfortable and easy temperature as compared to new settlement.

Acknowledgments

The authors express sincere thanks to Ms. Anuja Rajkarnikar, Ms. Suwani Pradhanang , Urban Planner, for technical support and guidance; and Ms. Padma Aryal, Mr. Yuvraj Bhusal for their support for placing the station and during data collection.

References

[1] Dikman Maheng, Ishara Ducton, Dirk Lauwaet, Chris Zevenbergen, and Assela Pathirana. The sensitivity of urban heat island to urban green space—a model-based study of city of colombo, sri lanka. *Atmosphere*, 10(3):151, 2019.

[2] MoEF. The Environment Protection Act, 2019 (2076). *Ministry of Environment and Forests, Government of Nepal*, 2019(9):1–24, 2019.

[3] Rocío Pineda-Martos and Cristina SC Calheiros. Nature-based solutions in cities—contribution of the portuguese national association of green roofs to urban circularity. *Circular Economy and Sustainability*, 1(3):1019–1035, 2021.

[4] Netra Prasad Timsina, Anushiya Shrestha, Dilli Prasad Poudel, and Rachana Upadhyaya. Trend of urban growth in nepal with a focus in kathmandu valley: A review of processes and drivers of change. 2020.

[5] Elisa Muzzini and Gabriela Aparicio. *Urban growth and spatial transition in Nepal: An initial assessment*. World Bank Publications, 2013.

[6] Juliana Antunes Azevedo, Lee Chapman, and Catherine L Muller. Quantifying the daytime and night-time urban heat island in birmingham, uk: A comparison of satellite derived land surface temperature and high resolution air temperature observations. *Remote Sensing*, 8(2):153, 2016.

[7] Clara Amado. Unravelling the urban heat island phenomenon in the netherlands. a multicity spatial analysis on the distributive component of environmental justice, analysing the urban green infrastructure, and the urban heat island effect. *A Multicity Spatial Analysis on the Distributive component of Environmental Justice, analysing the Urban Green Infrastructure, and the Urban Heat Island Effect.(January 12, 2022)*, 2022.

[8] Suwani Pradhanang and Inu Pradhan Salike. A study of influence of blue landscapes in outdoor air temperature: Case of traditional ponds of kathmandu valley. 2021.

[9] Gerald Mills, LUKE HOWARD, CLIMATE OF LONDON, John Heilprin, and OZONE-FRIENDLY CHEMICALS LEAD TO WARMING. Eurasap newsletter 61 august 2006.

[10] Wolfgang Tress, Mozhgan Yavari, Konrad Domanski, Pankaj Yadav, Bjoern Niesen, Juan Pablo Correa Baena, Anders Hagfeldt, and Michael Graetzel. Interpretation and evolution of open-circuit voltage, recombination, ideality factor and subgap defect states during reversible light-soaking and irreversible degradation of perovskite solar cells. *Energy & Environmental Science*, 11(1):151–165, 2018.

[11] Hashem Akbari, Melvin Pomerantz, and Haider Taha. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar energy*, 70(3):295–310, 2001.

[12] Pradip Raj Pant and D Dangol. Kathmandu valley profile. *Briefing Paper, Governance and Infrastructure Development Challenges in Kathmandu Valley*, 18(3):1–13, 2009.

[13] Praveen Maharjan. *Activating Public Space: Rethinking and Reforming of Public Spaces in Kuleshwor Site and Services Area*. PhD thesis, Pulchowk Campus, 2020.