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INSTITUTE OF ENGINEERING
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NATURE-BASED SOLUTION TO COUNTER URBAN HEAT ISLAND EFFECT; A CASE OF KATHMANDU VALLEY

By

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CERTIFICATE OF THESIS APPROVAL

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DECLARATION

I hereby declare that the thesis entitled "**Nature-Based Solution to Counter Urban Heat Island Effect; A Case of Kathmandu Valley**", submitted to the Department of Architecture in partial fulfillment of the requirement for the degree of Master of Science in Urban Planning, is a record of an original work done under the guidance of Dr. Inu Pradhan Salike, Institute of Engineering, Pulchowk Campus, Lalitpur. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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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°C to 2°C 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 Harsiddhi area for old settlement and new settlement. The temperature and humidity are 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.

Keyword: Nature Based Solutions, Urban Heat Island, Kathmandu Valley, albedo value

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LIST OF ABBREVIATIONS

UHI: Urban Heat Island

NBS: Nature Based Solutions

CBS: Central Bureau of Statistics

DoR: Department of Roads

DHM: Department of Hydrology and Meteorology

LST: Land Surface Temperature

LULC: Land Use Land Cover

NAPA: National Adaptation Programme of Action

LAPA: Local Adaptation Plan of Action

NDVI: Natural Difference in Vegetation Index

SDG: Sustainable Development Goals

UCL: urban canopy layer

UBL: Urban Boundary Layer

SRI: solar reflectance index

CHAPTER 1: INTRODUCTION

1.1 Background

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 UHI, 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 (Maheng et al., 2019). 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, increasing 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, which is caused by increased anthropogenic emission of carbon dioxide and other greenhouse gases, is a long-term effect with the potential to alter the intensity, temporal pattern, and spatial extent of UHI in metropolitan regions (EPA, 2012). The UHI phenomenon occurs primarily at night because roads and other surfaces that absorb solar radiation during the day release heat at night.

The urban population growth rate in Nepal almost doubled from 3.6% in 1991 to 6.5% in 2001, and the number of urban centers increased from 58 in 2013 to 293 in 2017 (Timsina, 2020). The key factor driving urban growth in Nepal is rural-to-urban migration. 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 (Elisa Muzzini, 2013). Kathmandu Valley accounts for 24% of the total urban population, with Kathmandu Metropolitan City alone accounting for 9.7% (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 increases the number of impervious surfaces. These lead to changes in land use, land cover, and land surface. Consequently, Heat trapping leads to the temperature difference between urban and surrounding rural areas i.e., the temperature in urban areas is higher than in rural areas. The UHI phenomenon is important to be addressed 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 (Azevedo et al., 2016).

The growing effect of Urban Heat Island (UHI) needs to be addressed by natural methods. Nature-based solutions are considered as having a lot of potential for helping cities make the transition to sustainability. NBS can 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” (Commission, 2022).

Different study on the Urban heat island effect in Kathmandu valley indicates the temperature of the valley has been rising. The amount of forest land dropped although the cover of agricultural land rose beyond the valley, according to Mishra's analysis. It roughly implies that once-forested area has been converted to farmland. According to Mishra, "the urban heat island effect continues to spread" since in the future agricultural area will also be developed.

1.2 Problem Statement

Rapid and haphazard urbanization in Kathmandu metropolis has resulted in the increased use of grey infrastructures which results in increasing urban temperatures due to the urban heat island effect. As stated by Mishra, et al., 2019, the temperature of Kathmandu has increased by 0-2℃ in the past 18 years. The generation of urban microclimate has impacts on the life of city dwellers and existing infrastructures. This has resulted in higher energy usage for cooling devices in metropolitan areas, causing discomfort for city people. Various research has shown that Nature Based Solutions has promising results in tackling the increasing urban temperature and planning towards climate resilient cities.

1.3 Need of Research

The number of new settlements has expanded as a result of the country's restructuring into new municipalities. The necessity for new settlement policies and plans has arisen as a result of population shifts in metropolitan areas. In urban contexts, UHI circumstances enhance the risk of climatic and biophysical risks, such as heat stress, as well as acute and chronic air pollution exposure. Climate change, which is driven by rising anthropogenic CO2 and other greenhouse gas emissions, is a long-term influence that has the potential to change the intensity, temporal pattern, and spatial extent of UHI in metropolitan areas (EPA, 2012). As a result, the UHI effect leads to higher energy costs for cooling buildings, health difficulties owing to heat stress, an increase in mortality rate, and increased air pollution.

The average trend of rising mean annual maximum temperature over Nepal is 0.04C/year whereas the minimum temperature trend is only 0.01°C/year (Department of hydrology and meteorology, 2015). Based on data collected from five weather stations between 1971 and 2011, temperature trends in the Kathmandu Valley show a continuous mean warming rate of 0.033°C per year, with the average maximum temperature increasing at 0.043°C per year and the average minimum temperature increasing at 0.02°Cper year (Salike et. al.,2015). UHI value of the Kathmandu district ranges from -2.21286 °C to 2.19264 °C, positive and higher values correspond to the nearby densely built-up areas and central zone of the Kathmandu district, whereas vegetative and forest areas are experiencing negative UHI (Chaudhary et al., 2021). The study of Regmi et al.(2021) shows that the difference within the built-up scheme is around 2-4 °C whereas the difference between Building and Land cover types in the comparison is around 5-10 °C. The difference between the Building and Land cover types in comparison suggests that there is the presence of the UHI effect in Kathmandu valley (Regmi et al., 2021). The study by Mishra et. al. (2018) also revealed that the temperature in Kathmandu increased from 0°C to 2°C between 2000 and 2018.

1.4 Importance of Research

UHI in urban areas is a global challenge that demands immediate attention and research to mitigate its impacts. There has been little research or response in the case of Kathmandu Valley to the growing urban temperature, notably with the usage of Nature-Based Solutions. This study will assist urban planners, ecologists, and policymakers in adopting Nature Based Solutions and formulating the appropriate policy measures to combat the urban heat island effect. In the case of urban regions, mainstreaming nature-based solutions holds several challenges that this research paper aims to study.

1.5 Research Objective

1. To understand Nature-based solutions and the urban heat island effect and its attributes.
2. To identify suitable nature-based solutions for Kathmandu Valley.
3. To understand different policies concerning Urban Heat Island and Nature-based solutions.

1.6 Research Question

The main objective of this thesis is to study the prospect of implementing Nature-based solutions inside Kathmandu valley concerning the urban heat island effect.

The research question for this thesis can be:

1. What are the factors of Urban Heat Island?
2. What are the Nature Based Solution responding to Urban Heat Island Effect?
3. Which Nature Based Solution is appropriate for Kathmandu Valley?
4. How can Nature based Solution approaches be incorporated in policies to address Urban Heat Island Effect?

1.7 Validity of Research

The valley is the epicenter of urbanization, drawing people from all over the Nation. The urban area is expanding at an unprecedented rate as a result of migration. The Valley is vulnerable to the effects of urban heat islands due to the loss of surrounding green spaces and rapid land change. There have been few studies dedicated to the study of the urban heat island effect and even fewer studies on Nature Based Solutions as an adaptive measure for this issue from a planning perspective.

CHAPTER 2: LITERATURE REVIEW

The research was an approach to study the attributes of urban heat island and nature-based solutions. The literature review on the relevant topics of the research has been studied and discussed on this section. Further, from the literature the attribute table for the urban heat island and nature-based solution has been generated.

2.1 Urban Heat Island Effect

The urban heat island effect (UHI) is an urban area with a higher temperature than the temperature of its surroundings. The ability of the surfaces in each environment to absorb and store heat is what determines the temperature differential between metropolitan and less developed rural locations. There are several causes of UHIs. A UHI can be produced when homes, businesses, and industrial structures are built near to one another. Generally speaking, building materials are excellent heat insulators. The regions next to buildings become warmer due to this insulation. Population centers tend to alter larger regions of land as they expand, which causes a rise in the global mean temperature.

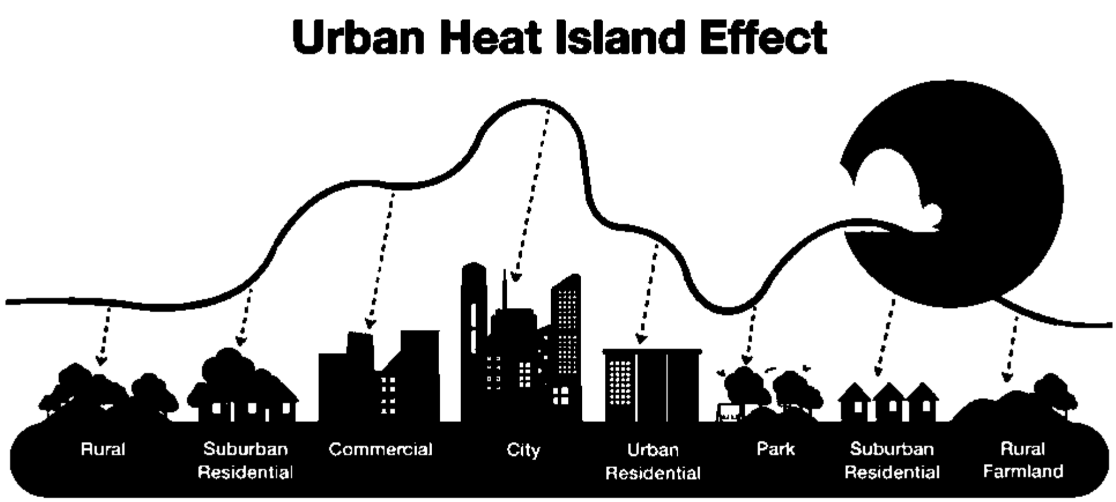

Figure 1: Urban Heat Island Effect

The first research into the Heat Island Effect was conducted scientifically by Luke Howard, who examined the local climate in and around London. When he contrasts the air temperature with the "rural" temperatures kept by the Royal Society (the recognized scientific organization) in the heart of London, Howard in this study defined an urban heat island (UHI). Plotting these data demonstrated 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 may reach 50.50 degrees (Mills, 2006). This marked the start of the investigation into the impact of UHI on the atmosphere.

2.2.1. Radiation balance and heat fluxes in an urban or suburban area

Urban heat islands are the outcome of surface and atmospheric changes brought on by human activities in urban settings. All energy transfers are accounted for by the surface energy balance. The energy changes in land and atmospheric systems should thus be measured and studied. The sun's radiation is the primary source of energy for the earth-atmosphere system. After entering the earth's atmosphere, solar radiation gets altered by three processes: scattering, absorption, and reflection. Four aspects of the incoming and outgoing radiation may be used to determine radiation balance on the ground: incoming shortwave radiation, outgoing shortwave radiation, entering longwave radiation, and the quantity of longwave radiation given off by the surfaces. The incoming ones are independent of surface conditions (vegetation, bare soil, etc.). However, outgoing terms are highly dependent on surface conditions.

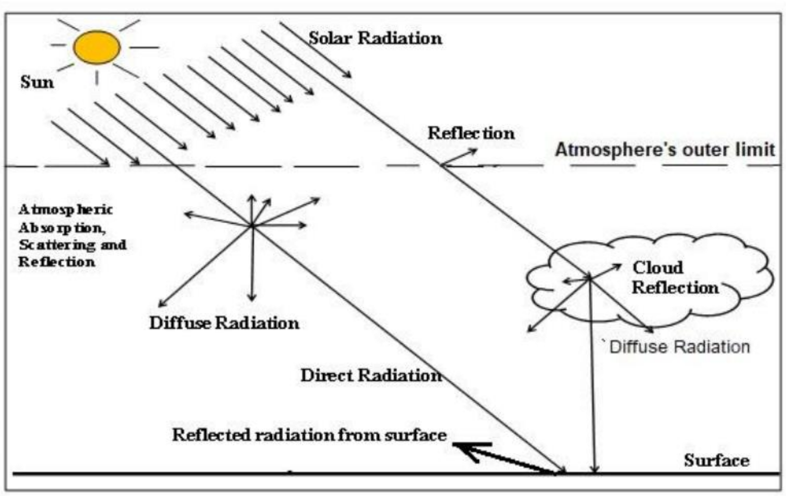

Figure 2: Dynamics of solar radiation in atmosphere and earth's surface

2.2.2. Major Contributors to Urban Heat Island effect

There are many contributors that contributes to rise in temperature of urban areas. The Key Causes of the Urban Heat Island are:

1.7.1.1 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 (Akbari et al., 2001). Most of the shortwave radiation that strikes these surfaces is absorbed, and very little is reflected, due to their high heat capacity and low albedo. Long wave radiation is the sole form of radiation that the absorbed energy emits at night. As a result, urban areas cool more slowly at night than rural ones.

For instance, we can observe that cars and other vehicles contribute to heat emissions in metropolitan areas when it comes to transportation. In urban canyons with inadequate ventilation, the whole quantity of heat emitted by autos may be trapped, reducing the thermal comfort of city dwellers. Additionally, vehicle emissions have a role in the development of urban pollution and global warming (Wang et al., 2004; Watkins et al., 2007; Younger et al., 2008).

1.7.1.2 Less Evapotranspiration

Evapotranspiration, 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 Evapotranspiration since there is a dearth of flora and natural surfaces. The impermeable built-up surface makes it easier for precipitation to quickly drain into drains. The majority of the solar energy that is received on the ground in metropolitan areas is used to warm the atmosphere. Urban regions are warmer at night than rural ones, which raises the air temperature. Heat is easily transferred into concrete during the day, retained during the day, and released at night.

1.7.1.3 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. The sky view factor, or "openness of a location," specifies the proportion of the sky that is visible to a particular viewer. The factor ranges from 1 to 0, with 1 representing a perfectly clear view of the sky and 0 representing an obstruction.

1.7.1.4 Anthropogenic heat

Another important source of urban heating is anthropogenic heat released from vehicles, power plants, air conditioners, industrial activity, and other heat sources which significantly contribute to the increase in temperatures in urban areas. A study done by (Akil, 2013) showed that electricity demand in Japan is 10–25% higher in summer as compared to winter because of air conditioning.

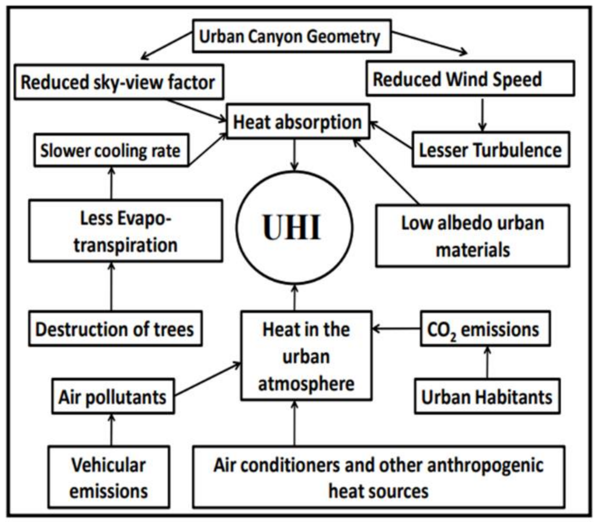

Figure 3: Cause of urban heat island (UHI) formation

2.2.3. Types of Urban Heat Island

Heat islands are categorized mainly as surface and atmospheric heat islands based on 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 (Yadav, 2018).

2.2.3.1. Atmospheric urban heat islands

This kind of heat island relates to how warm urban air is contrasted to air in adjoining rural areas. Atmospheric heat islands may be measured as observations taken from fixed station networks or by using mobile traverses using a vehicle. Due to the differences between the rate of nocturnal cooling in urban and rural surroundings they are best expressed under calm and clear weather conditions(Magee et al., 1999). Atmospheric heat islands may be categorized depending upon their occurrence in atmospheric layers such as the urban canopy and urban boundary layer.

2.2.3.2. Canopy layer UHI

The urban canopy layer, which roughly reaches a building's height, is the layer of air closest to the ground in urban areas. Temperature sensors positioned on ground stations are used to measure air temperature in the canopy layer and to identify UHIs. These sensors can be put on stationary stations or sites as well as the roofs of moving vehicles. It is an expression of the surface energy balance in an urban area primarily through sensible heat transfer from the surface into the urban canyon to change the temperature in the canopy layer (Oke, 1976).

2.2.3.3. Boundary Layer UHI

The urban boundary layer, which lies above the canopy layer, can have a thickness of up to 1 km or more during the day and only a few hundred meters or less at night. Urban boundary heat island observations are made from temperature sensors equipped with tall towers, radiosonde, airplanes, helicopters, and tethered balloon flights.

2.2.3.4. Surface UHI

Unlike atmospheric heat islands, surface urban heat islands are seen by thermal remote sensors by collecting the thermal fingerprints of various land cover patterns on the surface of the planet. Sensors onboard the satellite measure the amount of upwelling thermal radiance emitted by each surface. This is called an indirect measurement of temperature as the thermal behavior of urban surfaces would be different than that of their sub-urban or rural surroundings (Voogt & Oke, 2003).

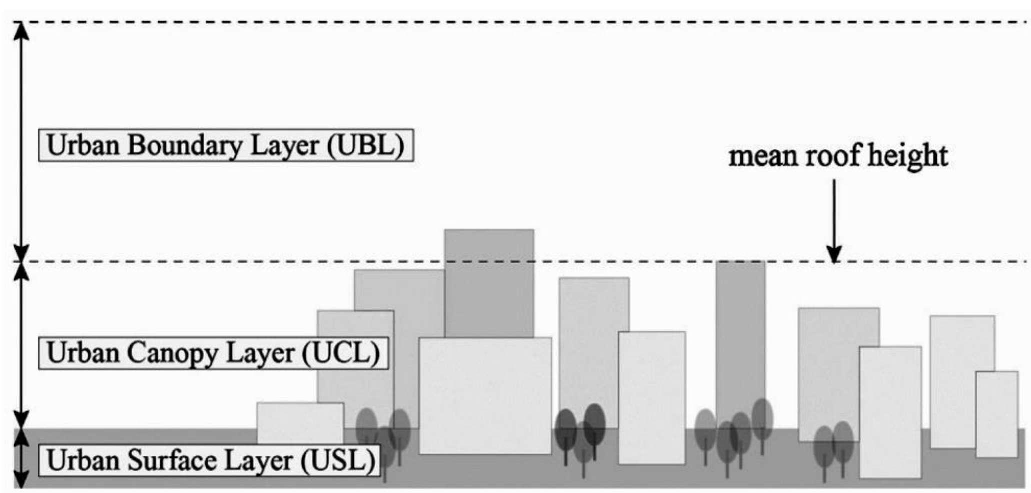

Figure 4:Different layers of Urban Heat Island

The "urban canopy layer," which is the layer of air between the ground and the tops of trees or rooftops, is where most people feel the climate and high temperatures (UCL) (Norton et al., 2013). The nearby surroundings have an impact on the microclimate that is experienced (eg. street environment), the local-scale climate (e.g. neighborhood environment), and the city-wide (mesoscale) climate (e.g. synoptic influences and the UHI).

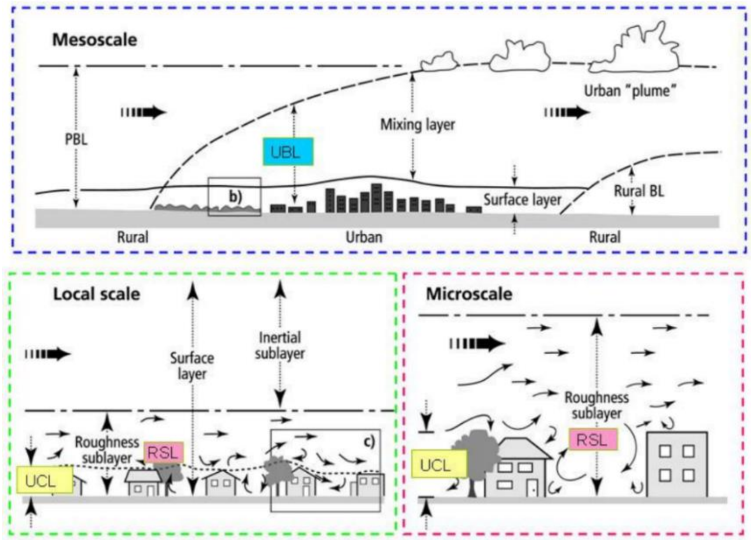

Figure 5: The different scales of urban heat retention and the urban heat island effects

2.2.4. Regional atmospheric and geographic conditions

The UHI impact and its severity in cities are significantly influenced by the local atmospheric and topographical factors. The geographic characteristics, climatic conditions, and seasonal fluctuations of a city's specific location have a considerable impact on the UHI effect. Even the time of day has a significant impact on UHI severity. Considering the night, when the emissivity of pavement and heat radiation into the atmosphere have the greatest effects on the temperature of the surface and lower atmosphere within an urban canyon (Santamouris, 2013).

According to Oke (1982), Taesler (1981), and Oke (1976), the urban canopy layer (UCL) and the urban boundary layer are two connected layers that make up the atmosphere in modern cities (UBL). The UCL influences the UBL's evaporation, heating, and cooling, while the UBL influences the UBL's more severe mesoscale weather conditions (Oke, 1982). Wind speed is the climatic variable that has the greatest impact on the intensity of UHI, followed by cloud cover, according to Oke's research from 1982. The availability of moisture and rainfall, the geometrical characteristics of a site, and the thermal characteristics of a surface are just a few more elements in the local atmosphere that directly affect the intensity of the heat island and its presence within a metropolis. The built environment of an urban region, a site's geometric characteristics, a surface's thermal characteristics, and building materials all have an impact on the UHI intensity.

2.2.5. Consequences of the urban heat island

The consequences of the urban heat island may be looked for in the summer as well as winter seasons. During the summer season, there is discomfort to the people, an increase in energy demand, and fuel burning. Likewise, the winter season also has to face discomfort. Some consequences can be highlighted as follows (Mohajerani et al., 2017);

1. Higher cooling energy costs and consumption.
2. Considerable rises in peak energy demand.
3. The development of significant levels of smog and other air pollutants, which leads to a decline in air quality.
4. Greater thermal stress on locals and the general populace.
5. Impact on urban environments is significant.
6. A considerably degraded living environment, and
7. A significantly higher degree and risk of heat-related morbidity or sickness.

2.2.6. Classification of building materials for mitigation of the UHI

The heat produced by solar and infrared radiation absorption by urban area materials is then discharged into the atmosphere. Two guiding concepts are used to support the numerous solutions developed across the world to minimize the urban heat island: increase the quantity of green space and concentrate on the thermo-physical attributes, such as albedo, emissivity, rugosity, etc. of the materials used to resolve urban areas (Alchapar et al., 2014). The solar reflectance index (SRI) measures the amount of heat that would build up in a substance when exposed to a white or black pattern surface in a typical environment. The index allows for direct comparison of various urban façade materials with various optical qualities (solar reflectance and emissivity). Equations based on the values of solar emittance and reflectance are used to compute it. Either a value (0.0–1.0) or a percentage (0–100%) is used to express it.

High Albedo Pavements and Roofs

The heat/solar radiation reflectance factor of a substance is called albedo. Its value is between 0 and 1. A fully white surface with an albedo of 1 will reflect 100% of light, whereas an absolutely black surface with an albedo of 0 will not reflect any light at all. Higher the value, the greater the ability of the material to reflect heat.

Nuruzzaman, (2015) states that white roofing has an albedo factor greater than 0.60 as compared to black roofing material which has an albedo of 0.05 to 0.10, thus absorbing less heat compared to black roofing. By employing roofing materials with different albedos ranging from 0.20 to 0.60, Bretz et al. (1998), Akbari et al. (1998), and Konopacki et al. (1997) investigated the efficiency of albedo. They discovered that the temperature of the roof decreased by 5°C for 0.60 albedos compared to 0.20 albedo. (Nuruzzaman, 2015) Taha (1997) also showed that lowering the albedo by 0.15 can lower summertime high temperatures in Los Angeles' metropolitan districts by up to 1.5°C. Additionally, black surfaces can get up to 21°C hotter than white surfaces when exposed to the sun (Louiza et al., 2015).

Table 1:Typical albedos for urban surface (Source: US EPA, 1992)

Material	**Albedo**
Highly reflective roof	0.60-0.70
White Paint	0.50-0.90
Grass	0.25-0.30
Brick and Stone	0.20-.040
Trees	0.15-0.18
Red or Brown Tile	0.10-0.35
Concrete	0.10-0.13
Corrugated Roof	0.10-0.16
Tar and Gravel	0.08-0.20
Asphalt	0.05-0.20

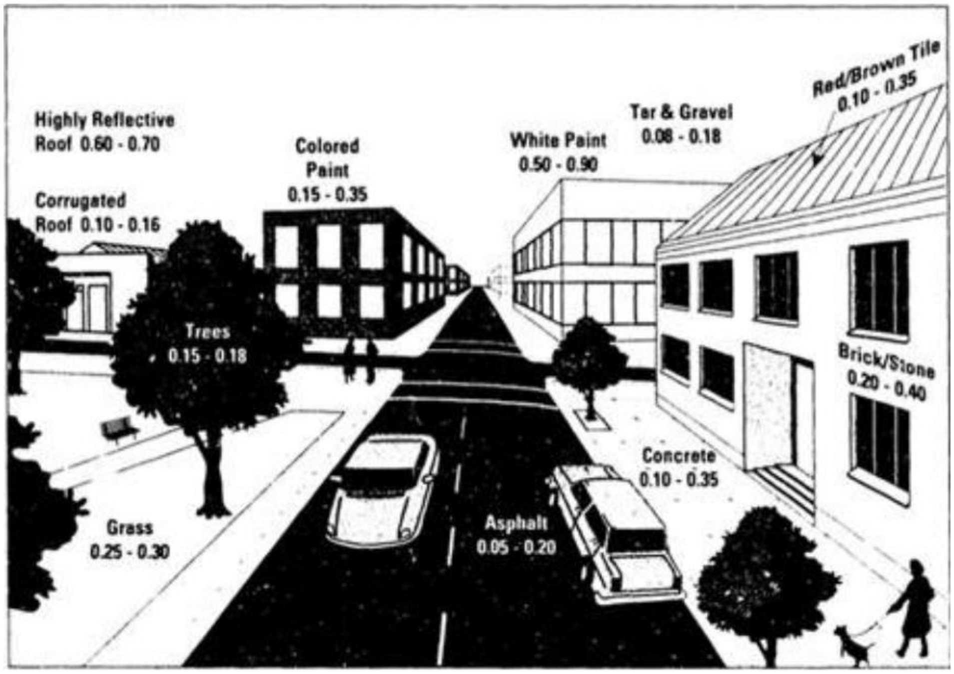

Figure 6:Albedo Value of an Urban Area (Louiza et al., 2015)

2.2 Nature Based Solution

The term "nature-based solutions," which was first used in the European Union, is an umbrella term for a variety of strategies that make use of nature to enhance urban sustainability. These strategies include the creation of green infrastructure, green space, river restoration, ecosystem services, and ecosystem-based adaptation.

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”.

Although these two definitions are different, they both regard nature-based solutions as intentional interventions that aim to harness aspects of nature to tackle societal problems. And in both cases, it is the potential to provide multiple benefits that are seen to be key to the value of nature-based solutions. A growing number of sustainability issues are being addressed using nature-based solutions. It is necessary to integrate the NBS idea into urban planning, policy, and development. Taking on four major concerns will enable NBS adoption to be more widespread (McCormick, 2020).

The evaluation methodologies, business models, governance techniques, and lastly the innovation route that would direct the nature-based solution as the adoption measures, are the major concerns. We seek to contribute to the creation of sustainable cities for the future by comprehending the circumstances that allow nature-based solutions to flourish in our cities and towns and how society may profit from them.

2.2.1 Types of Nature-Based Solutions

Green, Blue, and Grey infrastructure make up the majority of the Nature Based Solutions for Heat Adaptation in Urban Areas (Magotra et al., 2018).

2.2.1.1 Green Infrastructure (Use of greenery)

Increase in the amount of afforestation: It is frequently observed that less than 5% of the area of many cities is now covered by trees. Cities may increase their green cover by planting urban parks, bushes, and bio-retention cells in the streets. Urban trees can alter air quality, air humidity, wind speed, and temperature. Small green spaces of 300 m2 in Seoul were found to reduce temperatures by 1 °C, and those of 650 m2 by up to 2 °C. (Aram et al 2019, Park et al 2017).

a) **Vertical Greenery:** Vertical vegetation systems were quite successful at lowering the exterior wall surface temperature by 1.61 °C to 1.72 °C.
b) **Green roofs:** When tropical temperatures were at their highest, green roofs were shown to lower the temperature by around 1.70 °C. When installed on private dwellings, cool roofs can lower neighborhood air temperatures by 0.3 °C. Rooftop temperatures can be decreased by 5 to 9 °C using a hybrid green-blue roof.

City of Milan, Italy: The City of Milan, Italy, recognized "green Infrastructure" as the most effective means of achieving environmental goals, fostering social development, and enhancing social welfare. The plan details the funding channels and offers recommendations to the various municipalities for managing and establishing ecosystems. The city has incorporated two important

NBS strategies: vertical gardens and green urban areas. According to studies, the urban parks significantly cooled the areas around the urban green zones. Additionally, it demonstrated how the vertical garden in the two towers might lower particle pollution.

Glasgow, Scotland: Glasgow has added 20% more green space. As a result, by 2050, the city will have reduced its urban heat island effect by half.

2.2.1.2 Blue Infrastructure (Use of water bodies)

Urban blue infrastructure (UBI) can reduce surface urban heat islands by as much as 8.0 °C during the summer in urban lakes. Rooftop ponds can lessen the amount of heat that enters upper-floor interior spaces. The finest cooling is found in a pond with wet towels floating in it that is shady. According to studies, the presence of a water body can reduce the UHI effect on metropolitan areas, providing a cooling island effect around the water body (Ghosh and Das, 2018 cited Costanza et al.1998; Chang et al. 2007; Cao et al. 2010). Several studies have observed that the areas closer to the water body are cooler than the areas far from them (Pradhanang, 2021).

2.2.1.3 Grey Infrastructure (Use of Built architecture)

To mitigate UHI without incurring additional costs, city planning organizations should implement heat-adaptive planning that allows for natural airflow around constructed infrastructures. A wind speed of 1.1 to 1.5 m/s has a cooling impact in tropical areas like Singapore that is comparable to a 2 °C reduction in temperature. In addition to providing respite from heat exhaustion, wind also lowers carbon dioxide emissions and improves the dependability of mechanical air conditioners.

For instance, air ventilation corridors have been developed for Stuttgart, Germany, with the purpose of improving the city's UHI. It led to the maintenance and improvement of cool air flows and air exchange in the city. Theoretically, a well-designed ventilation corridor system encourages proper wind movement, improves local circulation, aids in the dispersion of pollutants, and reduces local pollution (DU et al., 2017). Stuttgart has not only safeguarded its environment with winds that prevent overheating but has also used green ventilation corridors and development limits at key locations. Additionally, it has boosted resistance to global warming and air quality.

2.2.2 Framework for Implementing NBS

There are different frameworks for implementing Nature-Based Solutions. In this section, we will discuss the appropriate frameworks that could be applicable.

2.2.2.1 DPSIR model:

DPSIR model is the Driving force, Pressure, State, Impact and Response model. It is frequently used to research how they affect urban dynamics. The adaptive and mitigating services provided by the various NBS choices may be assessed using the DPSIR model. The Model suggests a seven-stage procedure for integrating co-benefit analysis into the execution of projects and policies.

The seven phases consist of:

1) identify an issue or opportunity;

2) choosing, evaluating, and acting accordingly using NBS;

3) designing NBS implementation procedures;

4) implementing NBS;

5) periodically involving stakeholders and providing advantages;

6) transferring and scaling NBS; and

7) co-benefits should be tracked and assessed at every level.

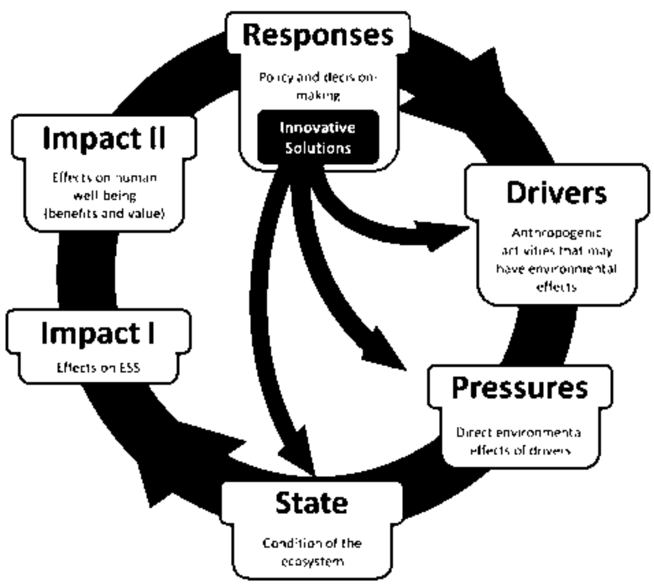

Figure 7: DPSIR Model

2.2.3 Ecosystem-based Approach for NBS Implementation:

As a possible model for NBS application in other Indian cities, a research conducted in Nagpur city investigated the applicability of the Ecosystem-based approach to NBS deployment in the city. The study's use of the NBS umbrella in Indian cities led to the categorization of five ecosystem-based approach groups (ABC area-based conservation, EBM ecosystem-based management, ER ecological restoration, EE ecological engineering, EbA ecosystem-based adaptation, CAS climate adaptation services, Eco-DRR ecosystem-based disaster risk reduction, GI green infrastructure). A similar approach would be utilized for the selection and implementation of NBS in Delhi, Rajkot, and Bhubaneswar.

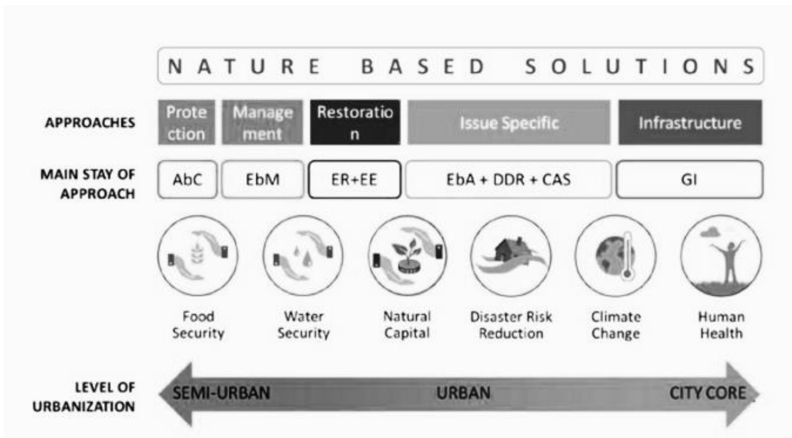

Figure 8:NBS for Mitigation and Adaptation to Heat waves

2.2.4 Conceptual framework for planning nature-based solutions

2.2.4.1 Key NBS criteria:

a) The first of three requirements that we believe are necessary for NBS is a challenge-orientation (Albert et al. 2019). It makes reference to an NBS's help in alleviating a specifically stated social problem that is frequently mentioned in the literature.
b) Utilizing ecosystem processes entails making use of ecological behaviors and occurrences that connect organisms with their surroundings (Albert et al. 2019).
c) Practical viability, the third criteria, pertains to the integration of NBS into governance and commercial frameworks for implementation.

Six steps of planning nature-based solutions:

The co-define setting, the first step, clarifies the project's context, underlying social concerns, goals, and methods. It also involves the project launch. This action prepares the ground for the NBS's practical feasibility. Typically, the planning team will work closely with important decision-makers and stakeholders to complete it (cf. Raymond et al. 2017; Izydorczyk et al. 2019).

Understanding challenges is the second phase, and it has to do with the many NBS definitional criteria. The unique socioeconomic concerns defining the project must be evaluated in this planning stage in terms of issues or opportunities across spatial and temporal levels (cf. Raymond et al.2017).The identification and spatial localization of potential NBS siting choices within a certain landscape environment entail the creation of visions and scenarios. Finding proper answers is the essential component of planning (Sarabi et al. 2019).

Considering possible effects entails doing a multifaceted analysis of the advantages and costs of implementing the NBS in its current or future forms as well as other options (cf. Raymond et al. 2017). Following the multidimensional valuation principles (Pascual et al. 2017), this evaluation should at the very least take into account the requirement to recognize and—to the extent practicable—apply social and ecological valuations of decision-alternatives.

Developing solution strategies entails creating workable governance and commercial models for putting the desired NBS scenarios into action, as well as fairly balancing the benefits and drawbacks of various implementation options. Targeting the local context and addressing the numerous implementation hurdles like insufficient funding and regulations, institutional fragmentation, uncertainty about implementation and effectiveness, and a lack of available land and time are all things that need to be addressed by the solution strategies (Sarabi et al. 2019).

Last but not least, realizing and monitoring means putting the first NBS actions into practice and critically observing how they have an impact. Consequently, the process of designing a plan or specification for implementation and monitoring may operate as a link between the cycles of scientific inquiry and real landscape change (Nassauer and Opdam 2008).

Five principles of planning nature-based solutions

a. Place-specificity,
b. Evidence base,
c. Integration,
d. Equity
e. Trans-disciplinarily

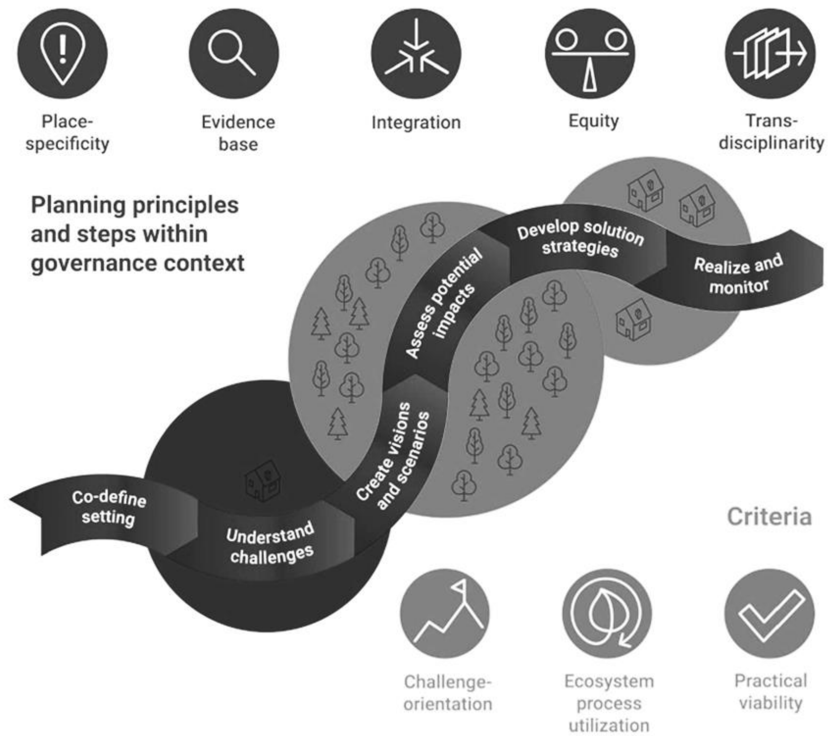

Figure 9: Conceptual framework for planning nature-based solutions: concepts and procedures (NBS) (Albert et al., 2021)

2.2.5 Types Of Innovations (McCormick, 2020)

2.2.5.1 Ecological Innovations

a. The construction of new parks and other green or blue natural areas, such as green roofs.
b. Managing current green and blue spaces and
c. Ecosystems' functioning and repair in order to provide a larger variety of ecosystem services and advantages.

2.2.5.2 Social Innovations

It refers to fresh or major adjustments made to governmental policies, cultural norms, economic structures, or strategies for discovering the natural world in urban settings.

2.2.5.3 Technological Innovations

This includes the product, process, and infrastructure innovations.

2.2.5.4 System Innovations

a. System innovations can facilitate ecological, social, and technical advances as well as the interactions between them by causing systemic changes.
b. Change in Municipal Working Practices/ Organizational Structures.

Drivers for Nature-Based Innovations

a. Agency,
b. Discourse and vision,
c. Policies,
d. Governance structures,
e. Collaborative arrangements,
f. Learning,
g. Resources and
h. Place-based factors.

2.2.6 Choice of NBS

The various choices of Nature Based Solution are listed below with the possible solutions of three types:

Table 2:Choice of NBS

Solutions	**Intervention Guide**	**Probable intervention areas**
Type 1	Improving existing natural or protected ecosystems	Mostly sprawling semi-urban regions with remnants of the natural ecology, such as lake catchment areas, hilly terrain, and some agricultural districts.
Type 2	Developing sustainable management protocols and procedures for managing or restoring ecosystems	The majority of the remaining natural ecosystem can still be partially restored and managed inside the administrative boundaries of peripheral urban regions, such as lake borders, portions of rivers, hillside greens, and expansive city-level and roadside greenspaces.

Type 3	Creating new ecosystems	Congested city cores where overpopulated regions seek to establish new ecosystems rely mostly on extensive technical interventions: Parks and vegetation Public areas at the local level Green walls and a green roof for new community structures Housing developments made of bamboo in vulnerable slum areas Small parks and greenery in urban areas that aren't being used Air ventilation friendly Urban planning that is accommodating for freshly emerging regions around city borders

2.2.7 Old Newari Settlement and attributes of Nature-Based Solutions

Row houses that are four to five stories high are located on both sides of the streets in the historic Newari settlement. Compact settlements allow for the more agricultural area, emphasizing the value of vegetation in green spaces. The central areas of all Newar settlements were distinguished by the square-shaped open spaces where practically all of the major streets met. These included the temples and other monuments, the rest houses (sataa), shops, and a water feature or spring (Shrestha, 1981). The public area is frequently utilized by individuals for personal activities including going to temples, playing with children, or working.

The construction materials used are mud, wood, sun-dried or fire-burnt bricks, tiles, and other building materials. The Kathmandu Valley's traditional villages stretch back to the prehistoric era, and the majority of the city's roads serve as walkways. These streets are covered with brick or stone. The three palaces in each of the three principal cities—Kathmandu, Bhaktapur, and Lalitpur—along with the surrounding squares, temples, and towns give the valley its distinct personality.

Houses are grouped along the streets or in courtyards. Public amenities may be found in every neighborhood's community plaza. The Newari settlement has a Pati (public rest house), a water well and Dhungedhara (stone water spouts), a Stupa and Chaitya (Buddhist shrines), and a Dabali (an elevated platform). The open courtyards inside the houses vary in size as well. Some of them can hold up to 100 homes, while others may only hold a few homes. Open areas in the shape of squares made up the heart of Newar villages, where all of the major arteries came together (Dhungel, 2017).

To accommodate extended families in communal social spaces and to preserve the land for agriculture, the buildings were arranged in rows and around courtyards. These once-cultivable fields are now mostly being developed as building sites.

Figure 10: Street for walking and selling things

Hence, from the literature we can conclude the attributes of nature based solutions and urban heat island and also the relationship and possibilities associated with them. The tabular form of attributes are indicated below:

Table 3:Attributes and indicator of UHI with NBS

Urban Heat Island		**NBS**
Attributes	**Indicators**	
Vehicular Emissions	CO2, GHGs	Walking, Bicycling, micro-mobility such as e-scooters, Electric vehicles, Improving public transportation
Urban Habitats	Mortality	
	Diseases	Public Parks, Open spaces, Fountains, wetlands
	Comfort	
Materials	Albedo Value	lighter colors on major buildings and urban surfaces
Wind Speed	speed and direction, humidity, cloud cover, city design such as built-up areas, aspect ratio, sky view factor (SVF), construction material	ventilation corridor, planting trees in walkways
Anthropogenic Heat Sources	Heating and Cooling Devices	Cool roofs and walls, efficient lighting, heating, ventilation and AC, Solar shading
Urban Geometry	Height to width ratio (H/W), microclimate conditions	Street and Building Orientation, Building with less wall and roof area, Ratio of building height to street width, Provision of shade, Cool Pavement

2.3 Policy

2.3.1. National Urban Development Strategy (NUDS, 2017)

In NUDS 2017, (MoUD, 2017)there is a strategy for urban safety and resilience. In accordance with Strategy 50, coping with calamities such as climate change requires a multi-hazard strategy. This activity further stimulates the collection of knowledge about climate change in urban areas of various ecological zones.

NUDS has a plan to adhere to established pollution criteria in all metropolitan areas with regard to contamination of the land, air, water, and visual environment. This might be accomplished through the study, implementation, and upgrading of the 2011 Urban Environment Management Guidelines (UEMG) and Planning norms and standards. Additionally, the action may be to assist and motivate regional organizations to create ward-level pilot programs to deploy UEMG across all municipalities.

Urban Environment Management Guideline (UEMG), 2011, and Planning Norms and Standards with a focus on urban forests are being reviewed, updated, and implemented as part of a plan to promote and maintain a minimum forest cover in urban areas. The selection of appropriate locations for enhancing forest cover in urban settings is also necessary. In terms of open space, NUDS stipulates that an existing urban area should contain 2.5% of the land at the ward level and a new urban area should contain 5% of the land at the ward level.

2.3.2. By-laws of Kathmandu Valley

Any area of 0.25 hectares or more in a community is set aside as open space for the community's benefit. For the intended residential zone, current bylaws contain the following provision for communal open space (M. O. U. Development, 2017): The local bodies shall preserve the open spaces in their area and declare public land as open spaces and convert them into parks.

5% should be allocated for open space for any land pooling, house pooling, or integrated settlement development programs. The area of the open space should be less than 80 sq. m. and width not less than 8m, the open space should not be adjacent to the neighboring plot or boundary of the development area.

According to the DUDBC's (2013) Planning Norms and Standards, the minimum amount of designated open space should account for 2.5% of Sub-metropolitan cities and 5% of Metropolitan cities, respectively. `

2.3.3. Local Governance Operation Act, 2074(GoN, 2017)

In section 3, Rural Municipality and Municipality Function, Duty and Power, under the environment conservation, there is provision for environmental and biodiversity protection through acts, regulations, and policies, and its monitoring and evaluation are also stated. Furthermore, a low carbon footprint and environment-friendly development are to be adopted.

2.3.4. Environmental Policy 1993 (GON, 1993)

The United Nations Conference on Environment and Development in 1992 marked the culmination of a growing global awareness about the significance of maintaining a balance between economic development and environmental conservation, prompting the development of the National Environment Policy and Action Plan (NEPAP).

The following are the five primary objectives of environmental policy:

- To manage natural and physical resources effectively and sustainably is one of environmental policy's five basic objectives.
- To strike a balance between environmental protection and development initiatives in order to sustainably meet people's fundamental needs.
- To protect national heritage
- To lessen the damaging effects of development initiatives and human activity on the environment.
- To combine ecology with development through the right institutions, sufficient public funding, proper legislation, and financial incentives.

Some of the objectives of the policy that support control measures of UHI are:

- Sustainable management of natural resources
- Safeguarding national heritage
- Mitigating adverse environmental impacts

Some notable actions proposed are:

- Reduce the level of vehicular air pollution by continuing to review pricing policies for petroleum products.
- Improving data availability on air pollution by setting up pollution monitoring stations.

- Involve NGOs, private sectors, and donors in urban development and environmental protection by preparing and implementing Environmental Action Plan for Kathmandu valley addressing the problem of degradation.
- Investigate the possibilities for more broad application of the "green roads" strategy to promote the adoption of environmentally friendly road construction techniques.
- Strengthen the Environmental Management Unit at DOR to enable it to oversee road contractors to ensure essential environmental measures are taken and produce EIA sector standards for road construction. This would increase DOR's capacity to carry out environmental assessments of roads projects.

2.3.5. The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24)

The goal is to increase environmental services while preserving, restoring, and using forests, biodiversity, and watershed resources sustainably. A vision for a clean, green, and healthy environment exists in the environmental field (National Planning Commission, 2019).The stated objective is to encourage planned integrated river management and vegetation in urban areas.

In the climate change section, the strategy is:

• To strengthen and expand the institutional frameworks and federal, provincial, and municipal policies that are essential for managing climate change.

• Adopting the idea of sustainable development and supporting renewable energy to slow down global warming.

But there are no clear indications of Nature-based solution measures.

2.3.6. National Climate Change Policy, 2019

With the aim of providing policy advice at various levels and thematic areas toward building a resilient society by lowering the risk of climate change impacts, the National Climate Change Policy, 2019 has been launched.

The objectives of this policy are to: promote a green economy by adopting the concept of low carbon emission development; increase the capacity of individuals, families, groups, and communities to adapt to climate change; build the resilience of ecosystems that are at risk of adverse effects from climate change; and contribute to the socioeconomic prosperity of the country. To conduct research, develop technology effectively, and provide information services related to climate change; To mainstream or integrate climate change issues into policies, strategies, plans, and programs at all levels of the State and sectoral areas; To mobilize national and international financial resources for climate change mitigation and adaptation in a just manner; to incorporate social inclusion and gender equality into initiatives for mitigating and adapting to climate change.

To achieve the aforementioned goal and objectives, the sectoral and intersectoral policies, strategies, and working policies listed below will be used. Improvements in agriculture and food security will result from implementing climate-friendly agricultural practices; protection of forests, biodiversity, and watersheds will result from creating ecosystems that are climate resilient; and protection of water resources and energy will result from encouraging multiple uses of water resources and the production of low-carbon energy. By creating resilient, safe, and sustainable infrastructures, rural and urban ecosystems will be constructed; Development of dependable, sustainable, and low-carbon technologies for industry, transportation, and physical infrastructure will be implemented; By making the tourist industry climate-friendly, natural and cultural heritage will be preserved and developed; By lessening the negative consequences of climate-related catastrophes on human health, disaster risk reduction and management will be improved, and awareness-raising and capacity-building will be boosted by raising awareness of the effects and danger of climate change.

The National Planning Commission and several line agencies will work with the Ministry of Forests and Environment to monitor and evaluate this Policy's implementation on a regular basis.

2.3.7. Other Policies

In the report on inclusive cities: resilient communities (Habitat III) under the environment and urbanization chapter there is the point for addressing climate change. Through the creation and execution of programs, the strengthening of institutional frameworks, and the formation of policies, Nepal has made major efforts to mitigate the effects of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) and the Sustainable Development Goals (SDGs) that address climate change are among the international agreements and pledges on climate change that the Government of Nepal has given the appropriate importance.

National Adaptation Programme of Action (NAPA)

According to decision 29/CP.7, every Least Developed Country that has signed the UNFCCC Kyoto Protocol is required to create a National Adaptation Programme of Action (NAPA). To address immediate and urgent adaptation needs, Nepal created the National Adaptation Programme of Action (NAPA) in September 2010. The NAPA document was created with the following goals in mind: evaluating and ranking climate change vulnerabilities, identifying adaptation strategies, developing proposals for priority activities, preparing, reviewing, and finalizing NAPA focus areas, creating and maintaining a knowledge management and learning platform, and creating a multi-stakeholder framework of climate change action.

Despite a number of shortcomings, NAPA has provided local communities with the chance to implement the following local projects. The NAPA anticipates nine prioritized activities, four of which are community-focused. These four pursuits consist of:

Activity 1: Using Integrated Management of Agriculture, Water, Forests, And Biodiversity sectors to promote Community-Based Adaptation

Activity 2: Improving the System and Access to Agricultural Development Services to Build and Improve the Adaptive Capacity of Vulnerable Communities

Activity 8: Empowering Vulnerable Communities through Sustainable Management of Water Resources and Clean Energy Supply and

Activity 3: Community-Based Disaster Management for Facilitating Climate Change.

Several NAPA follow-up initiatives are now being carried out, including the Strategic Program for Climate Resilience (SPCR), the Nepal Climate Change Support Program (NCCSP), and ecosystem-based adaptation (EbA).

Local Adaptation Plan of Action (LAPA)

In terms of the planning and execution of local-level adaptation efforts, the Local Adaptation Plan of Action (LAPA) is anticipated to be more precise and effective. LAPA is being created in contrast to previous policy papers in response to needs mentioned by attendees of the NAPA Inception Workshop.

The Climate Adaptation Design and Piloting-Nepal Project created and tested the LAPA framework in 2010 in nine districts around Nepal: Achham, Ilam, Udayapur, Dhading, Kaski, Kapilvastu, Pyuthan, Rukum, and Kalikot (CADP-N). Several entry points were used to evaluate the viability of incorporating climate change resilience into local-to-national planning, including agriculture, forestry, health, water and sanitation, watersheds, and microfinance. The bottom-up, inclusive, responsive, and flexible nature of the integration of climate change resilience into local-to-national planning is guaranteed by the LAPA framework. It is especially crucial when it comes to policy texts that deal with dynamic, ever-evolving concerns like climate change and direct community engagement.

Updates have been made to the Forestry Sector Policy, 2014. One house, one tree, one village, one forest, and one town, numerous parks are the themes of the government of Nepal's Forest Decade (2014–2023).

Likewise, the Environment-Friendly Local Governance (EFLG) Framework, 2013 (L. Development & Development, 2013) was launched with the goals of incorporating environmental considerations, disaster preparedness, and climate change adaptation into local planning procedures. In chapter 3, Indicators for municipal environment-friendly Local Governance, under greenery and urban beautification promotion it is stated that “at least two perennial trees planted in the premises of house or at least two small perennial shrubs planted on the rooftop in case of no space around one’s land or house.” Additionally, it is said that inside the boundaries of the house's enclosure, at least one-third of the land shall remain vacant. This framework also describes tree plantation and garden management in the open and fallow land. At least one nursery established in the ward area is another framework for the environment-friendly government as stated in the EFLG framework. The Tole Improvement Committee is actively involved in the planting of numerous flower varieties in vases in front of the home (In case of no such space, the vases are placed safely on the rooftop or veranda or suitable place visible from the road outside).

The National Biodiversity Action Plan (2014-2020) (Ministry of forests and soil conservation, 2014) offers a wide framework for creating an extensive work plan for forests, protected area systems, wetlands, mountains, and agriculture.

CHAPTER 3: RESEARCH METHODOLOGY

This section outlines the broad ideas and philosophical underpinnings of how the inquiry will be conducted in the specific setting of this study and how the information obtained will be validated. The epistemological perspective, which is determined by identifying the ontological assumption associated to the study itself and is based on the paradigm under which the research falls, informs the research technique. The various approaches and data sources are then reviewed.

3.1 Research Paradigm

A research paradigm is the philosophical foundation around which the study is built. It provides a framework of ideas and perceptions upon which the research project's theories and methods might be based. A paradigm as the dictionary states is "a typical example or pattern of something".

It is a theoretical concept that affects how information is researched and perceived. (Mackenzie & Knipe, 2006). Without nominating a paradigm as the first step, there is no basis for subsequent choices regarding methodology, methods, literature, or research design. (Mackenzie & Knipe, 2006). Positivists, Post-positivists, Interpretivists, Transformative, and Pragmatics are the most common paradigm classifications. Only "factual" knowledge acquired by observation, including measurement, is considered reliable by positivists. The positivist approach is defined as scientific research, the "systematic, controlled, empirical and critical investigation of natural phenomena guided by theory and hypothesis about the presumed relations among such phenomena" (Fred N. Kerlinger). In positivist studies, the researcher's only responsibility is to gather data and objectively analyze it. This paradigm is not appropriate for my research because the factors in my study cannot be adequately controlled and studied.

Positivism was replaced after World War II (Mertens, 2005) by post-positivism. Post-positivists argue that the ideas, and even the particular identity, of a researcher influence what they observe and therefore impact what they conclude. The post-positivist perspective is that not everything is completely knowable (Krauss, 2005). "Post-positivists support the idea that social scientists and natural scientists share the same goals for research and employ similar methods of investigation." (Chilisia, 2017). The most prevalent approach to data collecting and analysis used by positivists and post-positivists is quantitative methods. This post-positivist paradigm is well suited for my research objective.

Interpretivism is a philosophy that requires the researcher to learn from people to discover information. The analysis is context-based, with the interpretation of different ideas about conservation and growth problems synthesized to arrive at a justifiable conclusion. Ontology, epistemology, and methodology are all based on the interpretive model. This paradigm is more likely to rely on qualitative data and analysis. The research approach for the Interpretivism paradigm includes an interview, questionnaire, and observations.

The pragmatic paradigm, according to Creswell (2003), is concerned with the what and how of the research challenge. It is not devoted to any one philosophy or conception of reality (Mackenzie & Knipe, 2006). The pragmatic paradigm treats "the research problem" as its focal point and considers all methods of comprehending it (Creswell, 2003, p.11). The pragmatic paradigm is a simple mix of qualitative and quantitative research logic. “Pragmatism is not committed to any one system of philosophy or reality.” (Mackenzie & Knipe, 2006). It can combine both positivist and Interpretivism paradigms and can integrate more than one research strategy within the same study.

Positivists and post-positivist usually adopt a deductive approach. A deductive approach can also be called “Top-Down” research. A deductive approach is concerned with “developing a hypothesis based on existing theory and then designing a research strategy to test the hypothesis” (Wilson, 2010) Deductive approach can explain the causal relationship between concepts and variables. 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.

3.2 Research Methodology

Every research has three parts: Ontology, Epistemology, and Methodology. What defines reality, or what is, is what ontological assumptions are concerned with. Researchers must give their opinions on how they see the world and how it operates (Scotland, 2012). The ontological claim for the research is that Urban Heat Island effect in urban area can be mitigated through Nature-Based Solutions.

The nature and sources of knowledge are addressed by epistemology (Cohen et al., 2007, p. 7). Epistemological presumptions are concerned with what it means to know, or how knowledge may be produced, gained, and conveyed (Scotland, 2012). The epistemological claim for my research is that the Nature-Based Solution can be validly found as solutions in the real-world scenario through a comparative study of the relation between natural spaces and heat island effects.

The study of UHI and NBS characteristics is conducted in the following order, starting with the calibration of the device used to detect temperature and humidity by the department of hydrology and meteorology.

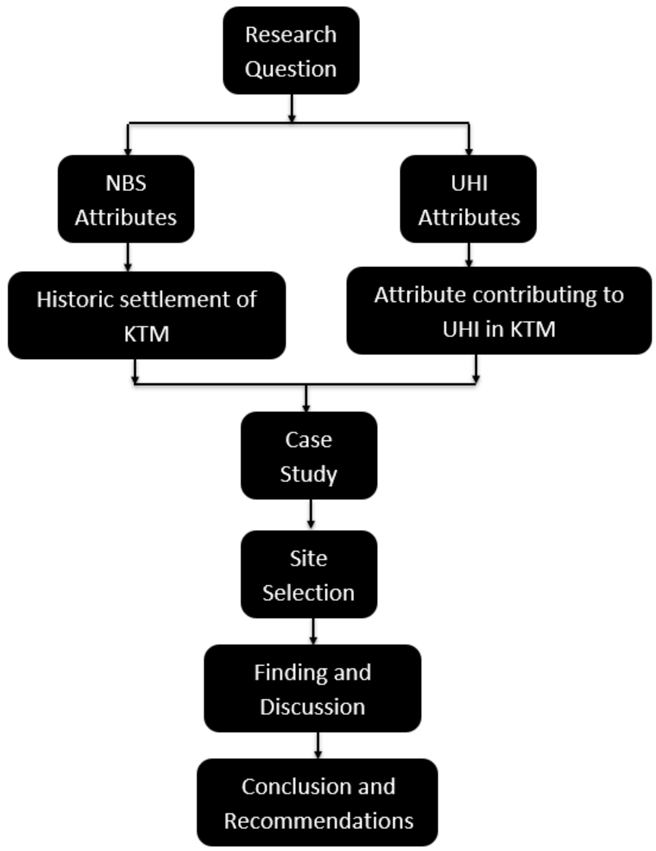

Figure 11: Research Methodology

3.2.1 Literature Review

The critical study of a section of a body of published information known as a literature review involves summarizing, categorizing, and comparing earlier research projects as well as reviewing relevant literature and theoretical pieces. The initial steps in any research project for a literature review will be the collecting of relevant material that will aid in understanding the fundamental ideas behind that research. The primary literature sources for this study will be taken from publications that have already been published. The causes of UHI and NBS will be investigated in articles and research papers. Different studies that have been published on the same topic in comparable settings will also be examined. A thorough discussion of common nature-based solutions in practice ought to also be included.

3.2.2 Quasi-Experiment

Although it is desirable to conduct experiments in a totally controlled setting, this is sometimes not feasible or practicable. Consequently, the use of a quasi-experimental study design becomes required. Even if not all of the variables can be controlled, the researcher must make every effort to statistically control for as many as feasible in a quasi-experiment.

In that an independent variable is manipulated, quasi-experimental research is comparable to experimental research. Because there is either no control group, no random selection, no random assignment, or no active manipulation, it varies from experimental research (Abraham, 2011).

The study's goal is to measure the temperature and humidity in two distinct places to investigate the urban heat island effect. For this, the temperature and humidity are recorded for a predetermined period of time. The study will ascertain the impact of urban heat islands on humidity in urban settings. The locations for this experiment should be as close together as possible so that the meteorological conditions, such as wind, rain, and cloud patterns, are the same everywhere.

3.2.3 Field Measurement

The machine used for the measurement of temperature and humidity in four different sites are HTC digital temperature humidity data logger; easy log. It can record 32,700 reading with a measurement cycle from 1 sec to 24 hours.

The thermometer needs to be positioned in shade and out of direct sunlight by the guidelines for taking outdoor temperature readings. To protect it from the weather, it should be kept in a covered place. To provide airflow in all directions, the equipment has been stored in a wooden box. It will ensure proper airflow and correct temperature and humidity readings. This is also a measure to ensure the safety of the device from rain, external environment, and theft. As seen in the Figure, the box has been mounted to a 5 feet high wooden stand.

Since the device used is the data logger can generate the data of varying intervals, the interval is set for 1 hour in all four stations.

Figure 12:Device used to measure temperature and Humidity

Figure 13: Calibration of thermometer at DHM

All the used devices have been calibrated with the thermometer in the Department of Hydrology and Metrology as shown in table below:

Time	DHM		HTC easy logger(A)				HTC easy logger(B)			
	Temp (℃)	Humidity (%)	Temp (℃)		Humidity (%)		Temp (℃)		Humidity (%)	
			Reading	Correction	Reading	Correction	Reading	Correction	Reading	Correction
3:00 PM	27	40.13	28.3	-1.3	43.9	-3.77	28.3	-1.3	44.1	-3.97
3:05 PM	27	40.18	28	-1	43.4	-3.22	28.1	-1.1	43.5	-3.32
3:10 PM	27	39.93	27.8	-0.8	42.9	-2.97	27.9	-0.9	43.2	-3.27
3:15 PM	26.98	40.02	27.7	-0.72	42.7	-2.68	27.8	-0.82	42.7	-2.68
3:20 PM	26.67	40.5	27.6	-0.93	42.3	-1.8	27.7	-1.03	42.4	-1.9
Correction (Avg)				-0.95		-2.888		-1.03		-3.028

HTC easy logger(C)				HTC easy logger(D)			
Temp (℃)		Humidity (%)		Temp (℃)		Humidity (%)	
Reading	Correction	Reading	Correction	Reading	Correction	Reading	Correction
28.4	-1.4	44.2	-4.07	28.2	-1.2	43.1	-2.97
28	-1	43.7	-3.52	28.2	-1.2	43.1	-2.92
27.8	-0.8	43.1	-3.17	28.2	-1.2	43.1	-3.17
27.7	-0.72	42.9	-2.88	28.2	-1.22	43.1	-3.08
27.5	-0.83	42.4	-1.9	28.2	-1.53	43.1	-2.6
	-0.95		-3.108		-1.27		-2.948

Table 4:Caliberation of thermometer

3.2.4 Investigation methods of urban heat island

Most commonly, characterization of UHI intensity is conducted through statistical analysis of temperature data measured from fixed weather stations or mobile surveys or by using modeling or computer simulation (Zoboki, 2001).

In the case of weather stations or meteorological observatories, ambient air temperatures (screen level temperature) of two areas having different temperature conditions are compared to compute urban heat island intensity. This method of investigation is called fixed station network. In our research this method is used.

Some other ways of investigation could be mobile transverse measurement in which temperature sensors are typically connected to the roofs of moving objects, and this method for examining UHI involves calculating the fundamental temperature difference between the metropolitan region and any nearby suburban or rural areas. Finally, thermal mapping & NDVI for mapping of thermal data is useful in retrieving land surface temperature from satellite images. This is also used as per the need of the research.

3.3 Conceptual Framework

Urbanization and climate change are two different causes that have an impact on the urban heat island. Urbanization takes into account air pollution, anthropogenic heat, fabric thermal characteristics, and urban geometry. Similarly, temperature, humidity, wind, and sunlight all have an impact on climate change. For the study of urban geometry and the thermal characteristics of materials, temperature and humidity measurements are made. Nature Based Solutions must address these urban heat island characteristics. The all-encompassing solutions for nature-based solutions are green, grey, and blue infrastructure. Finally, the report recommends a strategy for laws and a plan for using natural remedies to combat urban heat islands.

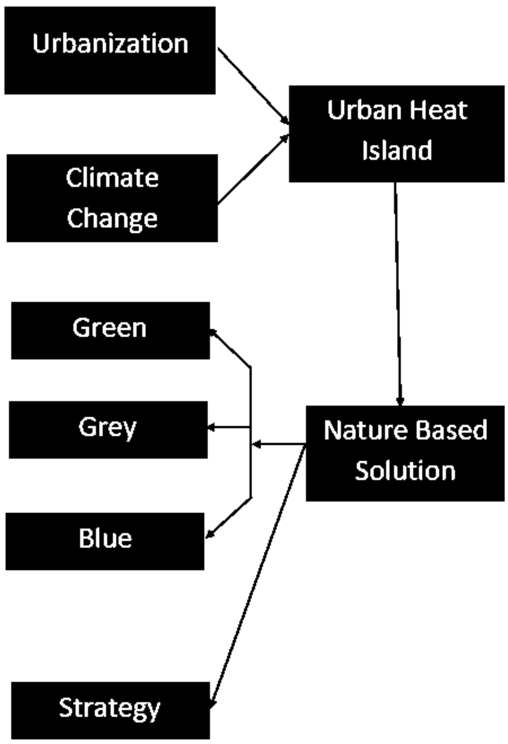

Figure 14: Conceptual Framework

CHAPTER 4: CASE STUDY

4.1 Phoenix: struggles to withstand the heat in one of the hottest American cities

With a population increase from 106,818 in 1950 to 1.68 million in 2020, the City of Phoenix has been one of the fastest growing cities in the United States for a significant portion of the previous century. The fifth-largest city in the nation is now Phoenix (U.S. Census Bureau 2020).

Phoenix's severe heat has a genuine impact on people's health and well-being since it may become up to 8.3°C hotter in urban areas than in the nearby natural regions on the warmest days. Heat-related fatalities in the metropolitan region climbed by 62.3 percent, from 199 in 2019 to 323 in 2020 (Maricopa County Department of Public Health 2021).

Long aware of the dangers of severe heat, the City of Phoenix has put a number of heat management and mitigation measures into place. Given that the city's overall projected cover for all vegetation is just 13%, the city established a Tree and Shade Master Plan in 2010, which sets a lofty objective of increasing tree canopy cover to 25% (Phoenix, 2010). The city and Arizona State University collaborated in 2020 to assess a cool pavement treatment to lessen the heat trapped by road infrastructure; as a result, the city currently has more miles of cool pavement treatment than any other city in the United States. According to preliminary findings, the typical pavement increased pedestrian heat exposure by 5.5°F (3.1°C) from noon to the afternoon, whereas the cool pavement increased it by up to 12°F (6.7°C) (Phoenix 2021a).

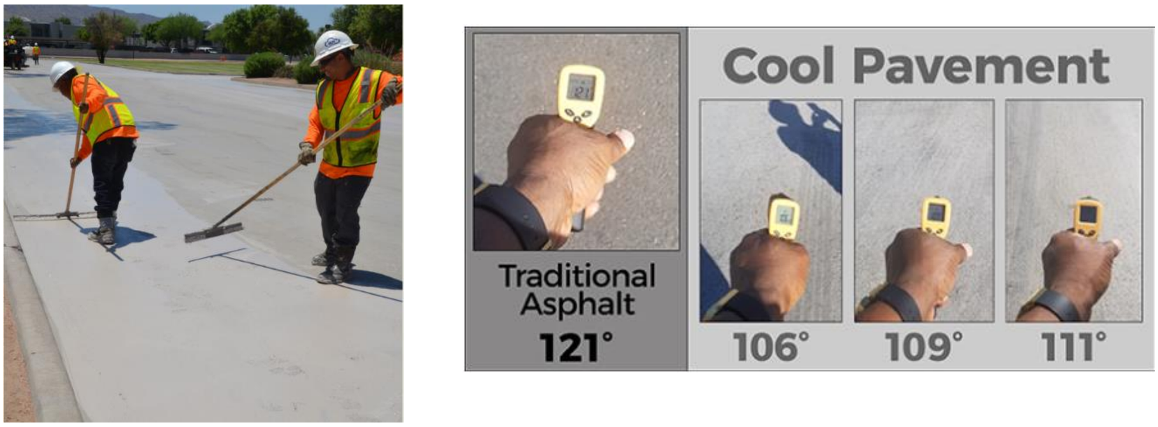

Figure 15: Phoenix city workers are covering streets with a cool surface as part of a pilot project that Arizona State University is evaluating

On top of the current asphalt surface, a water-based asphalt treatment is used. Asphalt, water, soap as an emulsifier, mineral fillers, polymers, and recyclable materials are used to make it. It is compatible with conventional asphalt and doesn't include any dangerous compounds. Utilizing cool pavement technology could help to lessen the city's temperature increase due to the heat island effect. Additionally, it helps to keep neighborhood streets that receive little sun shade cool.

In order to better manage these continuing initiatives, which span several levels of government and departments, the City of Phoenix established the Office of Heat Response and Mitigation in 2021. The office in question was the nation's first of its type to be publicly financed. The office will also contain built environment and urban forestry professionals to assist minimize urban heat, and it is charged with developing a strategic action plan to help coordinate existing and new actions to handle excessive heat (Phoenix 2021b).

4.2 h2020 urban GreenUP Project

The URBAN Greenup initiative, which began in June 2017, seeks to decrease climate change risks in cities, increase resistance to its impacts, and improve air quality by creating sustainable green areas and developing and implementing nature-based solutions (Turhan & Gökçen Akkurt, 2018). The initiative will promote the advantages of re-naturing cities by showcasing nature-based solutions in the leading cities of Zmir, Turkey, Valladolid, Spain, and Liverpool, England.

The European Commission is supporting the HORIZON2020 Project URBAN GreenUP with Contract No. 730426. The URBAN GreenUP project's overarching objective is to enhance air quality by developing and implementing nature-based solutions (NBS), increasing resilience to climate change effects, and mitigating climate change risks in cities.

Turkish city of Izmir

Izmir, the third-largest city in Turkey by population (approximately 4 million people), has a mildly seasonal subtropical climate with hot, dry summers (Köppen-Geiger classification: Csa). Summers are dry and hot because to the predominance of subtropical high-pressure systems, while winters are erratic and feature wet weather due to the polar front. In the hottest month (July), the average monthly temperature is over 22°C, and in the coldest month (January), the average ranges from 18 to -3°C with at least four months over 10°C. Additionally, between 2071 and 2100, the mean outdoor temperature is expected to rise by 7°C. In addition to climate change, Izmir's dense population and urban layout contribute to a rise in UHIs.

In addition, the city is physically protected from entering airflows and winds by surrounding hills and mountains. The pattern of fast and dense urbanization in Izmir has also influenced the UHI impact. According to Coskun Hepcan and Hepcan [18], built-up areas occupied 60.5% of the urban development zone in 1995, whilst designated or natural urban green spaces and natural urban green areas occupied 31.0% and 8.5%, respectively. Within 21 years, the built-up area rose to 78.9%, while natural green spaces underwent a significant transformation and shrank to 11.1%. Due to the region's shrinking natural area, the UHIs started to have a substantial influence on urban people' lifestyle, well-being, and human health.

Method

The first analysis of Landsat photos to create the present distribution and position of land items, features, and topography is the first stage of the measurements in the URBAN Green, UP Project. The second phase involves utilizing a FIR camera mounted on a drone to gather thermal data (pictures) for the demo site locations. Ground validation of the land using measured data is the last phase.

Nature-based solutions

Izmir is a city that is rapidly expanding, and its urbanization stretches to extremely vulnerable natural areas. NBSs should therefore be adaptable enough to deal with problems. The below NBSs will be used in order to decrease the effects of UHI:

a. Green roof over a parking lot,
b. Smart Soil in green shaded buildings,
c. Cool pavements surrounding specific parking lots,
d. Shade and cooling trees next to parking lots, and
e. Parklets in avenues.

The NBS comprises a number of parking lots and on-street parklets connected to transportation, aiming to reduce air pollution and average and maximum temperatures. To lessen the impact of UHI, parking lots will be set up in various locations in the densely populated neighborhoods of Karşyaka and ili (in Sasal Natural Life Park). Cool pavements play a significant role in the local cooling measures in a city by reducing heat absorption and retention by using highly reflecting or permeable paving materials and/or thinner pavements. To lessen the impacts of UHI, cool pavement will replace the existing pavement around the parking lots. By adopting NBSs like more green space, vegetation on rooftops, and cool pavements in urban areas, UHI impacts may be reduced.

4.3 The City of India

India is the country with the most exposure to air pollution, and several of its cities are among the most polluted in the world. Similar to other cities, Indian cities are extremely susceptible to heat waves, and it is anticipated that the frequency of heatwaves in Indian cities will increase several-fold. According to reports, reducing air pollution might lessen the difference in incoming radiation between rural and urban areas, which would lessen the impact of the urban heat island effect.

Nature-Based Solutions (NBS), especially in poor nations, seem to be the best solution for environmental problems in urban settings because of their versatility and affordability. It is suggested that increasing vegetation cover and greenery can reduce UHI, reduce air pollution, and enhance thermal comfort in cities. Green areas have effects on climate change mitigation and local and global adaptation. They support carbon sequestration, which aids in the mitigation of global climate change, and reduce the UHI effect at the city scale. There are several environmental benefits to having greenery and open areas. By reducing surface runoff, they contribute to better hydrology. Compared to grass, green spaces with trees offer a larger cooling impact.

4.4 Sponge Cities in China

In the major urban regions, China is promoting the concept of "Sponge Cities." Thirty cities from all across the nation, in various climatic areas and zones, have been chosen as sponge cities, including some well-known names like Ningbo, Hangzhou, Shanghai, Beijing, Shenzhen, and Wuhan.

Compared to gray infrastructure, sponge city infrastructure takes substantially less energy to maintain. Heat reduction effects lessen dependency on air conditioning, while it lessens the workload on water treatment plants. Less materials are needed for construction, notably less concrete. Large green spaces in sponge cities also help to absorb carbon dioxide. These natural places also support biodiversity, whose decline is one of the greatest challenges to humanity, along with climate change.

Chinese regulations define a sponge city as one that has turned hard surfaces like roads and pavements into permeable surfaces that can absorb, seep, filter, and store water before releasing the stored water for usage. Similar infrastructure initiatives are referred to as low-impact development, blue-green infrastructure, or water-sensitive urban planning in different regions of the world. However, only China has done it on a city-wide basis.

Urban flooding issues have been successfully reduced by "sponge cities." But they also have the unexpected consequence of lowering heat-related fatalities in cities. This is crucial because severe heat causes death. For instance, research in Guangzhou, China revealed that porous concrete and bricks might reduce the temperature of the pavement's surface by 12 and 20 °C, respectively. Up to 1 °C of the air's temperature can be lowered.

Only if there is a distinct separation of duties, sponge city construction can be capable of linking various government agencies and improving synergy. Providing social and financial assistance may also be greatly aided by business and the private sector. Policies that specify each person's responsibilities are necessary, coupled with a technical database that contains answers to potential issues across disciplines and evaluates the effectiveness of the standard methods. By lowering the ambient temperature, enhancing outdoor thermal comfort, lowering heat-related sickness and mortality, and addressing energy poverty, sponge city projects can also increase social fairness.

CHAPTER 5: STUDY AREA

5.1 Introduction to Kathmandu Valley

The Kathmandu Valley is a bowl-shaped valley located in the Himalayan mountains of Nepal. It lies at the crossroads of ancient civilizations of the Indian subcontinent and the broader Asian continent and has at least 130 important monuments, including several pilgrimage sites for Hindus and Buddhists. There are seven World Heritage Sites within the valley. Kathmandu Valley consists of 3 Districts of Bagmati Province whose total population is 2,996,341 and a total area is 933.73 square kilometers (360.52 sq. mi). It is evident that the urban development planning for rapidly changing land patterns in urban areas of the valley is lagging. Due to a lack of successful planning, there is haphazard infill development as well as urban sprawl. A 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. The lack of green areas has made the bowl-like valley with its low velocity wind to be warmer compared to previous years.

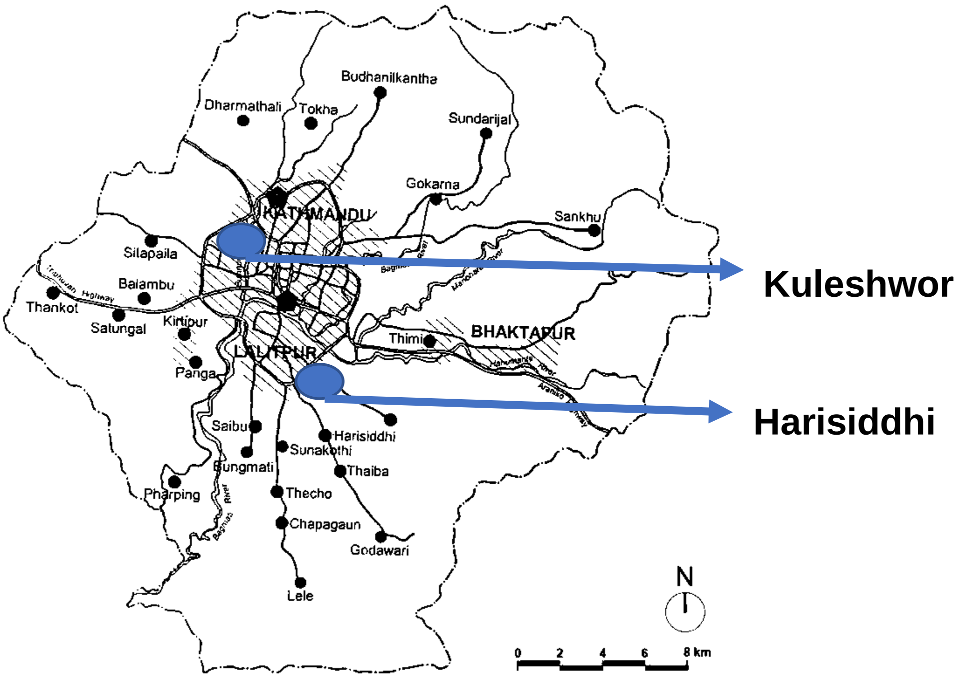

Figure 16:Map of Kathmandu Valley

Kathmandu and Lalitpur districts are used as the research region. While the Harisiddhi region is chosen for the assessment of temperature and humidity at the ancient and new settlements, the Kuleshwor site and service area is used to compare the paved and green surfaces. There are a total of four fixed stations, two in the harisiddhi region and two in kuleshwor for the measurement.

5.2 Site Selection

The two different locations for the experiment are selected within Kathmandu and Lalitpur Metropolitan City. Two stations are set at the 'Kuleshwor site and service area' in Kathmandu-14 and another two stations are set at Harisiddhi in Lalitpur Metropolitan wards 28 and 29. 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 locations are almost the same.

Depending on the parameters' following area has been chosen.

a. Pavement Area – Kuleshwor Station A
b. Green Area- Kuleshwor Station B
c. Old Traditional Settlement – Harisiddhi Station C
d. New Settlement- Harisiddhi Station D

5.2.1 Kuleshwor site and services 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 planned in 2036 BS for 26.56 ha of land and was distributed to government workers from 2039 B.S. It has a total number of 817 plots of land. Open spaces were provided in 26 spaces which is almost 4% of the total Kuleshwor Awash. Also, a community school area of 4578.63 sq. m. was provided on the high contour land(Maharjan & Raj, 2020). Open Space was created with residences on three of its sides and a road that separated it by 5 to 7 meters. The total area of open space is 1.29 ha, which is 4.85 percent of the total planned area. Open space density is 3678.84 pp. Street length is 8401 m, with an area of 3.47 ha (Maharjan & Raj, 2020).

Figure 17:Conceptual Map of Kuleshwor Site and Service Area

I. Temperature Measurement at Kuleshwor Site and Service Area

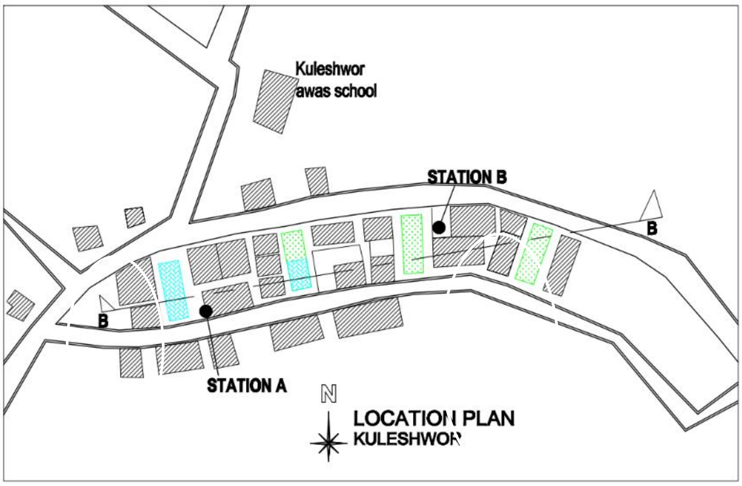

Figure 18:Station A and B at Kuleshwor Site

Figure 19: Thermometer placement at station A and B

For measurement of Temperature and Humidity at Kuleshwor, the HTC Data logger is placed at a 5' tall stand on the ground inside the louvered box to ensure its safety and proper airflow. The device is placed outside of the residential building in the east direction with respect to pavement and park. Station A is placed near the pavement surface whereas station B is placed near the green park.

5.2.2 Harisiddhi

About 8 km southeast of the capital of Kathmandu, Nepal on the way to Godawari, Lalitpur, there is a historically renowned village named Harisiddhi, where the Temple of Harisiddhi is located. The temple is at the height of about 4,400 ft. from sea level, whose latitude is 270˚38' north and longitude is 850˚21' east. About 800m west of the temple, there is a river named Karmanasha (Kodku). The climate at this place is normal i.e., hot in summer and cold in winter. The temple is surrounded by a residential area. There is a pond in the southeast direction of the temple which is believed to be one of the important holy ponds i.e., Kunda. Harisiddhi also called “Jala” in Newari terms is famous for its ancient cultural and historical monuments. Instead of Harisiddhi, the actual name of the village is “Hara siddhi” after which Harisiddhi is named by the locals. The Newari community is living widely in this village. Ancient festivals and ceremonies, traditional houses, taps, wells, temples, and ponds are famous things in Harisiddhi.

I. Temperature Measurement at Harisiddhi Site

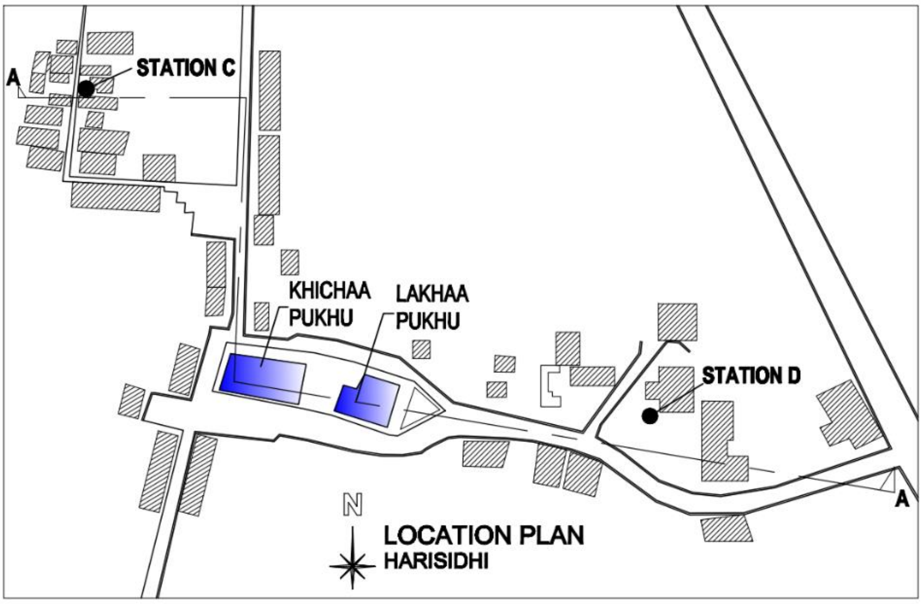

Figure 20:Station C and D at Harisiddhi Site

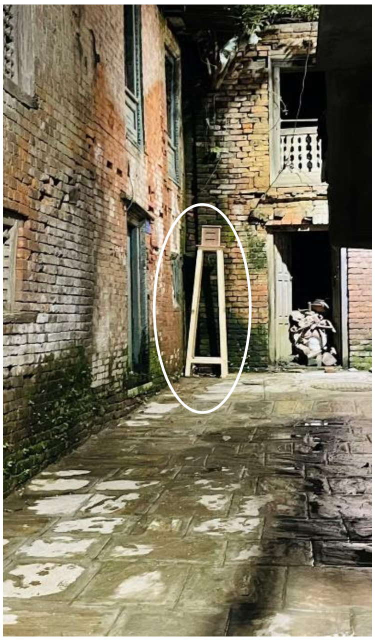

Figure 21:Thermometer placed at the station C and D

For measurement of Temperature and Humidity at Harisiddhi, the HTC Data logger is placed at a 5' tall stand on the ground inside the louvered box to ensure its safety and proper airflow. The device is placed outside of the residential building in the south direction. Station C is placed in the old Newari settlement whereas station D is placed in the modern settlement.

5.3 Observation of thermometer locations

A. Kuleshwor Site and Service Area

Figure 23:Thermometer Location at Kuleshwor (S-A/S-B)

Figure 22:Section of thermometer placement at Kuleshwor (S-A/S-B)

Kuleshwor Site and Service Area is the first planned residential at the core of Kathmandu. Most of the buildings are residential and mixed-used buildings are also there. The thermometer of station A is placed near the pavement area on the southwest part of the planning. The area is surrounded by pavement and road pavement on the east side and on the other side are residential buildings. Similarly, Station B is placed in the parking space of the planning area which is surrounded by the road pavement to the north and the other side comprises residential houses. The direction of the station selected is almost in the same direction facing towards the west side.

B. Harisiddhi Site

Figure 24:Thermometer location at Harisiddhi Area (S-C/ S-D)

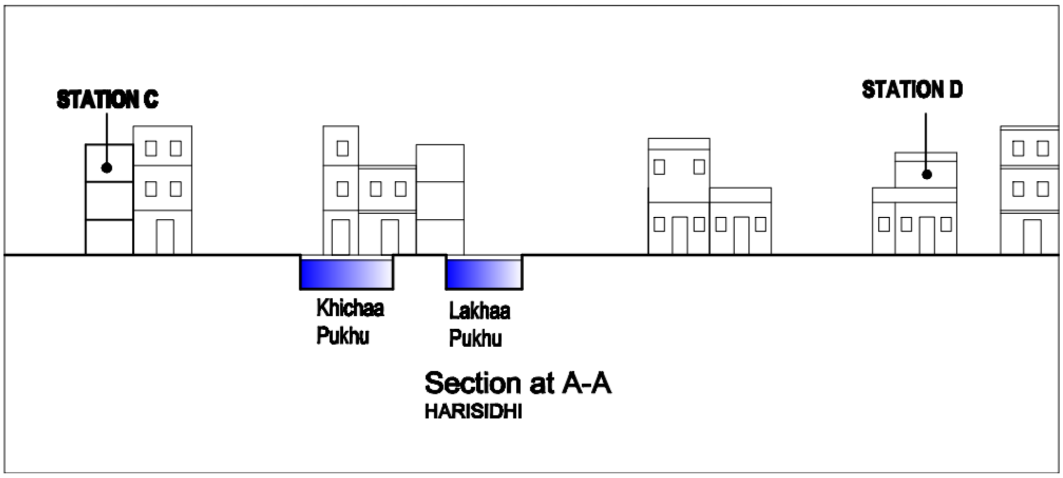

Figure 25: Section of thermometer placement at Harisiddhi Area (S-C/ S-D)

The area of Harisiddhi is the traditional settlement of Lalitpur with the Newari community. The areas of traditional settlement at station C are selected where the building is of traditional type and compacted. Whereas, the new settlement area (station D) is being expanded to the east of the old settlements. The ponds in the distance of around 100 m are selected for the measurement of the temperature and humidity of old and new settlements.

CHAPTER 6: FINDING AND DISCUSSION

Temperature and humidity are recorded from 28th July to September 4, 2022 on an hourly basis for 38 days. Observing the data from 28th July to 4th September the temperature and humidity on every day are compared. The temperature trends in Harsiddhi and Kuleshwor area at around 14:00 LST, 19:00 LST, and 23:00 LST were compared separately the analysis of data for temperature and humidity at Kuleshwor site and service area and Harsiddhi area are presented below.

6.1 Kuleshwor Site and Service Area

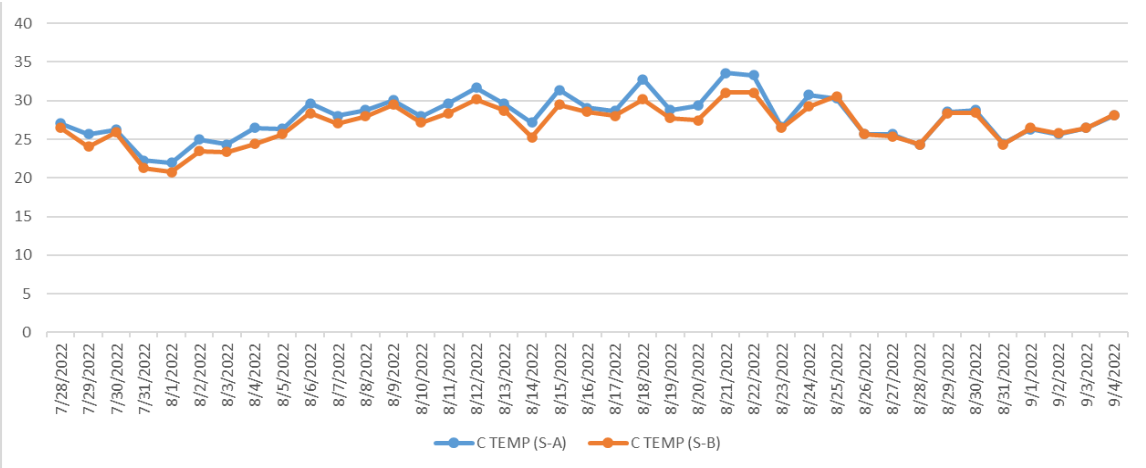

Figure 26:Temperature variation at Station A and B at 14:21 LST (Kuleshwor Area)

From the above graph for 14:21 LST, we can find the temperature graph of station A (Pavement area) to be always above station B (Green Area). The maximum difference in temperature is 2.62℃ on August 18, 2022. We can feel a hotter environment during the day in the pavement area as compared to the green area due to the albedo value of grass and pavement.

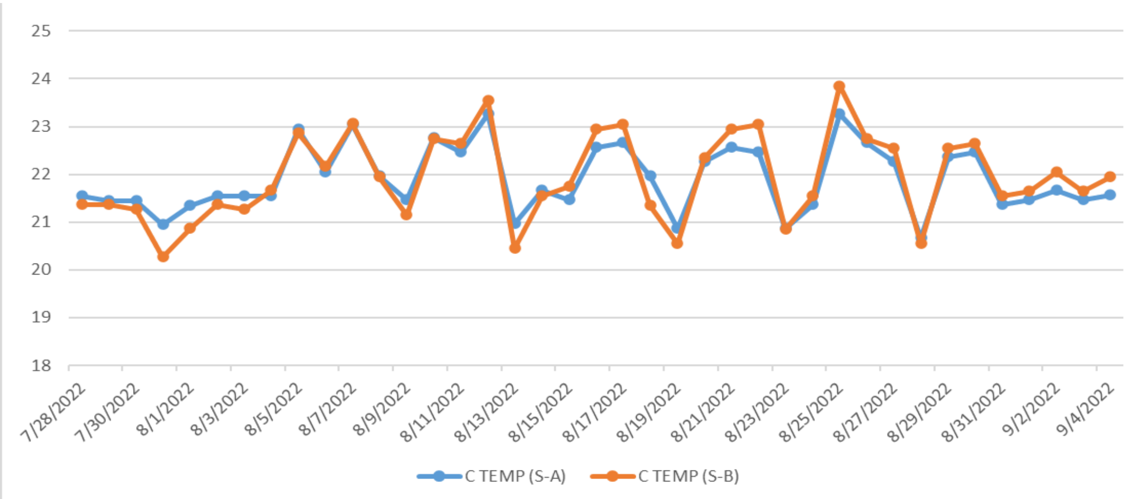

Figure 27:Temperature Variation at station A and B at 23:21 LST (Kuleshwor Area)

The temperature difference at 19:21 LST and 23:21 LST is not as much as compared to the daytime temperature. There is only the minimum difference. There is a maximum difference of 0.78℃ at evening 19:21 LST making station A hotter. Similarly, at night time 23:21 LST, the difference in temperature is further decreased to 0.68℃ again making station A warmer.

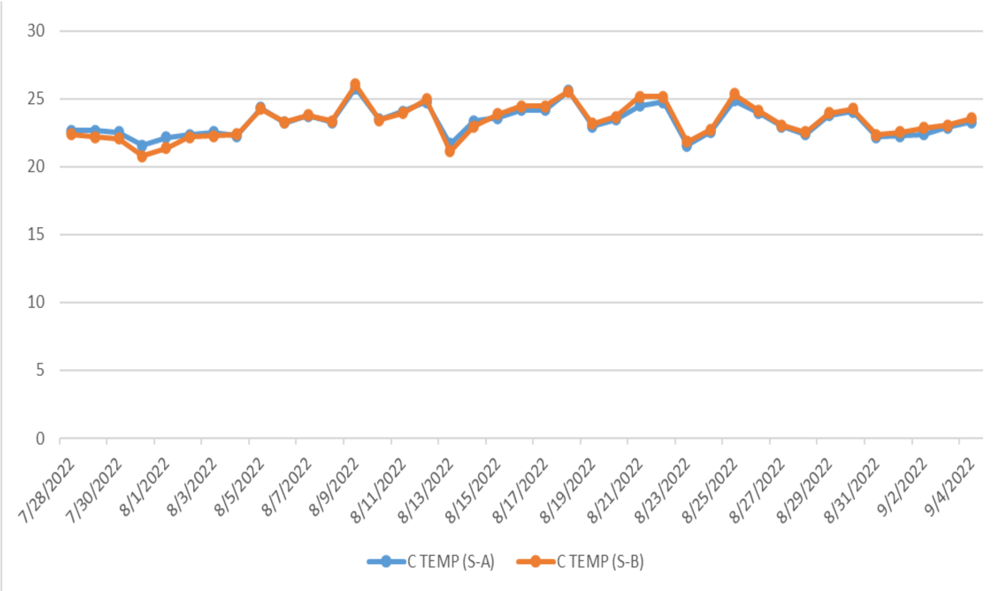

Figure 28:Temperature Variation at station A and B at 19:21 LST (Kuleshwor Area)

The temperature variation at the Kuleshwor site and service area as compared to 14:21 LST, 19:21 LST, and 23:21 LST, there we can see that station A is the Pavement Area and Station B is Green Area. The bar chart is shown below:

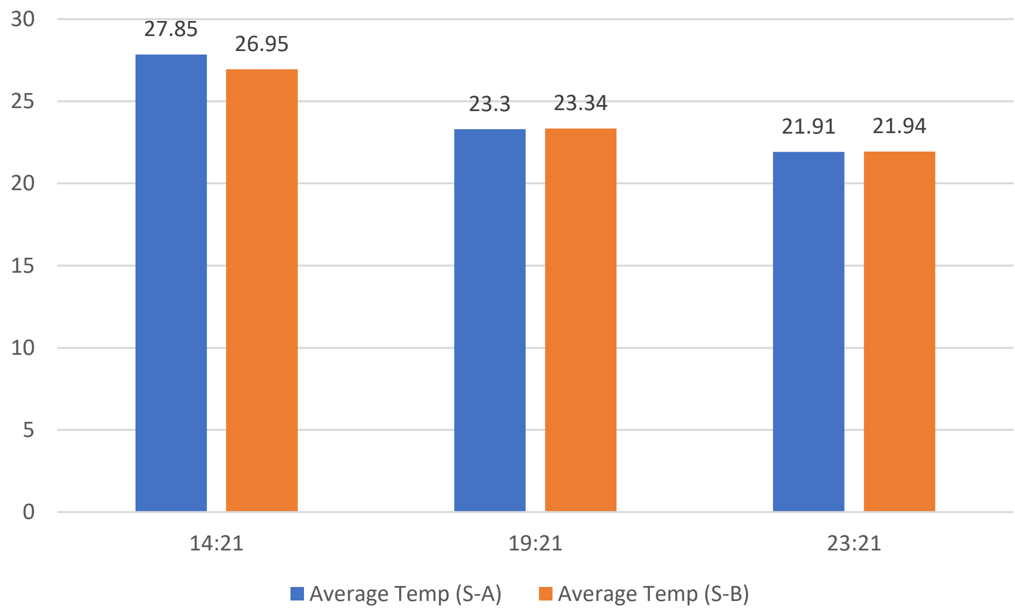

Figure 29:AverageTemperature Variation at Kuleshwor Site and Service Area

The Pavement area has a higher temperature at all times of comparison than the green area. The distance between station A and station B is only 50 meters. Within this short distance of only 50m in the Kuleshwor site and service area, the transformation of green parks into pavement for parking has given rise to the temperature as seen through the observations. The temperature difference is maximum in day time making the pavement area hotter. The maximum difference in temperature is 2.62℃ at 14:21 LST, 18 August. The average difference in temperature between pavement and green area is 0.27 ℃. This means the pavement area is 0.27℃ hotter than green areas.

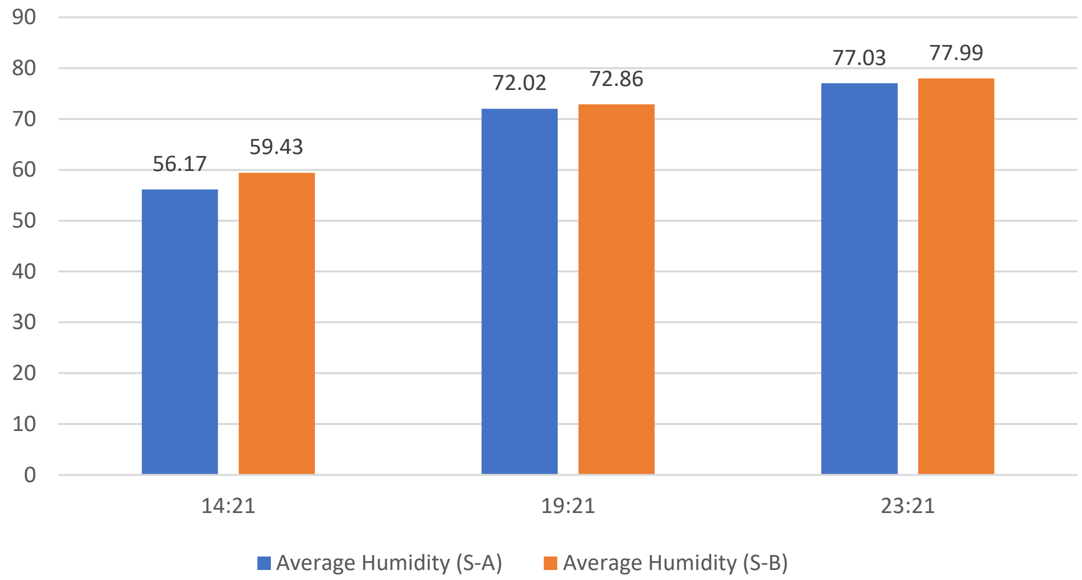

Figure 30:Average humidity recorded at station A and B (Kuleshwor Area)

The average humidity level is maximum at night time at 23:21 LST with a value of 77.99 % whereas minimum humidity is seen in the daytime at pavement area at a value of 56.17%. Human thermal comfort is dependent mainly on temperature and humidity. In general, relative humidity of 40-60% makes us feel comfortable. The humidity till the evening time is seen to be comfortable.

6.2 Harisiddhi Area

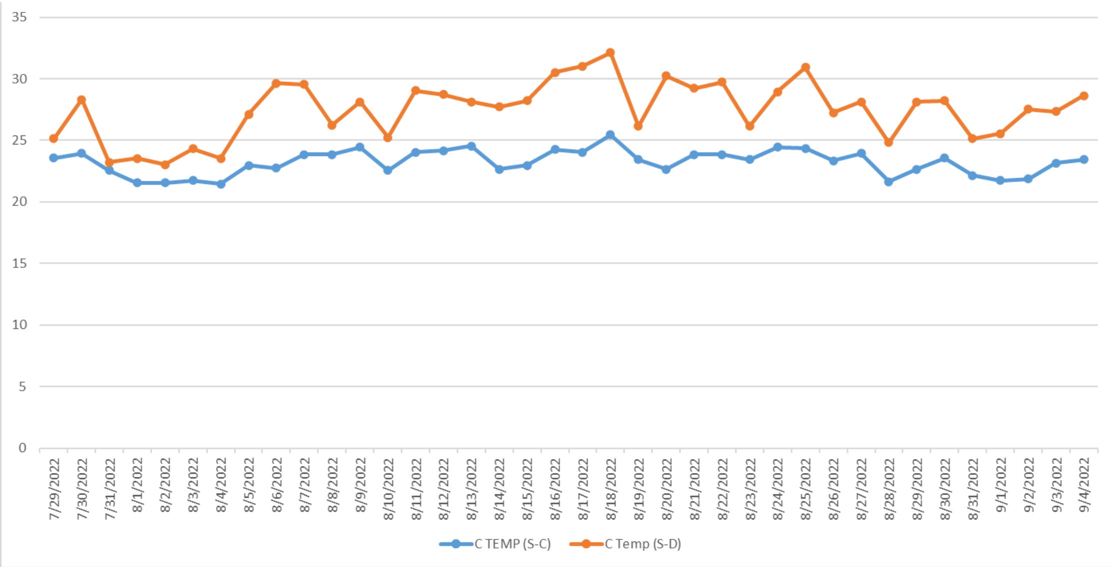

Figure 31:Temperature variation at station C and station D at 13:50 LST (Harisiddhi)

From the above graph, the temperature variation at 13:50 LST can be seen where the temperature is highest for all time in the new settlement. The maximum temperature difference between station c and station d is 7.58℃ on 20th august.

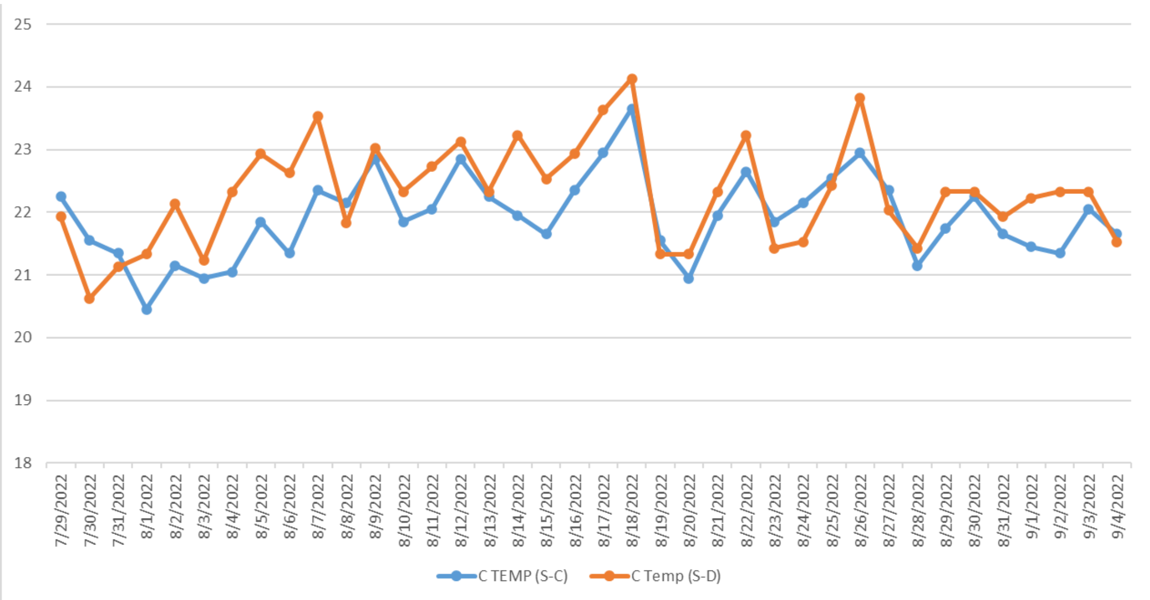

Figure 32:Temperature variation at station C and station D at 18:50 LST(Harisiddhi)

Similarly, from the temperature variation graph at 18:50 LST, we can observe the temperature difference being decreased as compared to day and the cooling effect has begun to act in the new settlement.

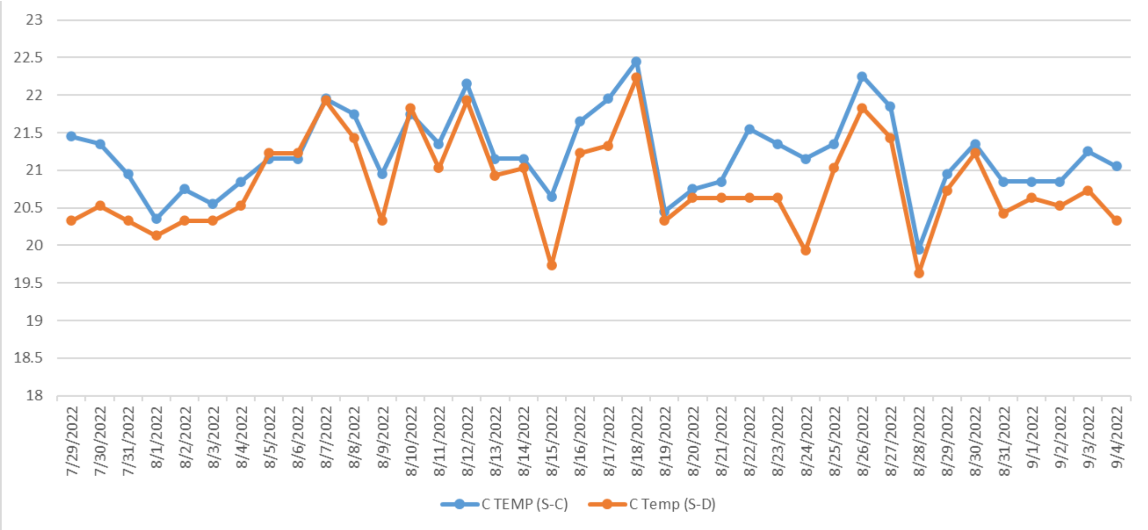

Figure 33:Temperature variation at station C and station D at 22:50 LST (Harisiddhi Area)

Now, from the 22:50 LST temperature variation graph, the new settlement is recorded with a minimum temperature than the old one. At night, the temperature near the old settlement is higher than in the new settlement. Bricks possess a low thermal conductivity which averages between 0.5 – 1.0 W/(m/K). A material's capacity to efficiently transfer heat is directly correlated with its thermal conductivity. Because they limit the flow of heat through them, materials with low thermal conductivity, such as clay brick, are referred to be thermal insulators.

In tropical regions that experience an average annual temperature between 22-35 ºC, bricks act as an excellent insulating material and can maintain a cooler indoor temperature despite the hot surrounding environment. Their low heat conductivity, excellent thermal resistance, and capacity for sustainable extraction and processing are largely responsible for their popularity. Hence, the old settlement has a cooler temperature during the day time which makes the activities at day comfortable.

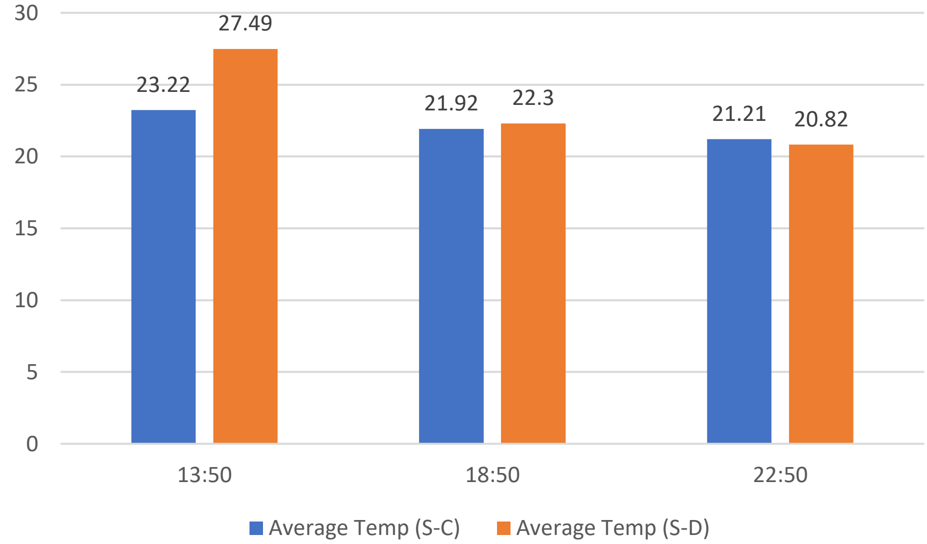

Figure 34:Average temperature recorded at station A and B (Harisiddhi Area)

Similarly, the above figure shows the daily variation of temperature in the Harisiddhi area, station C is an old settlement area with traditional buildings in its surroundings and Station D is a new settlement with newly constructed buildings around the station. From the temperature recording at 13:50 LST, 18:50 LST and 22:50 LST we can observe the average temperature of the new settlement area to be 27.49 ℃ and that of the old settlement is 23.22℃, making the difference of 4.27℃ on day time. The new settlement has a higher temperature than the old settlement due to road pavement and new construction techniques like colored paint on the building which has low albedo value than exposed bricks. The old settlement however has stone or brick paved pavement and exposed brick on the buildings.

The difference however is minimized till the evening and the temperature rises of the old settlement by 0.39℃ during 22:50 LST. Hence, new settlements are cooler in the evening but there is a maximum difference in the temperature day time.

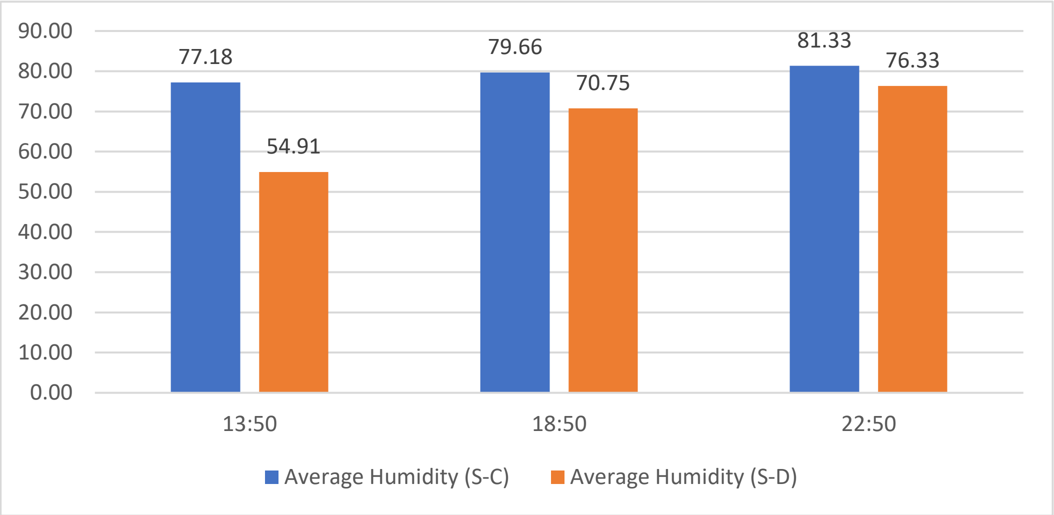

Figure 35:Average humidity recorded at Station C and Station D (Harisiddhi Area)

The average humidity level is maximum at night time at 22:50 LST with a value of 81.33 % whereas minimum humidity is seen in the daytime at the new settlement at a value of 54.91%. Human thermal comfort is dependent mainly on two factors i.e., temperature and humidity. In general, relative humidity of 40-60% gives as pleasant. ASHRAE suggests a range of 45% - 55% humidity to manage health effects and illnesses.

The temperature is inversely proportional to the humidity; temperature has been rising with lower humidity. The annual average relative humidity of Kathmandu in 2019 was 77.12 %. The humidity is maximum in the morning and decreases in the daytime. There is no "one size fits all" method for achieving thermal comfort. It is influenced by external elements like air temperature, humidity, airflow, and thermal radiation as well as inside elements like the occupant's physical activity and clothing.

According to ISO7730 comfort zone also vary from 20°C (68°F) to 26°C (78. °F) depending on the season as we can see on the graph below. Hence, the humidity level till the evening time is seen to be comfortable as per ISO7730.

Figure 36:ISO7730 comfort zone graph

On the days of observations from the 28th of July to the 4th of August, there have been frequent rainfall. As we know from the literature, due to the differences between the rate of nocturnal cooling in urban and rural surroundings they are best expressed under calm and clear weather conditions(Magee et al., 1999). The variation of the temperature and humidity could be better understood with more day observations.

Policy for Nature Based Solutions to counter Urban Heat Island and its Gap

Policy	**NBS to counter UHI**	**Recommendations**	**Inference**	**Stakeholders**
Climate Change Policy, 2011	environmental conservation, human development, and sustainable development -- all contributing towards a prosperous society.	Conservation, restoration and improved management of land in order to increase carbon storage or avoid greenhouse-gas emissions in landscapes, make building more efficient, turn cities clean and green.	The policy suggests more on the green, blue infrastructure. Urban Policy hasn't given NBS any clear design direction. Now NBS must be acknowledged, promoted, and supported as proactive investments in planning procedures.	Governmental authorities, Political representatives, Civil Society, Private Sector, Academia and research sectors, media and international organizations
Building Byelaws, 2072	One house one tree Conservation of water surfaces Preserve Public open land and declare public land as open spaces, convert them into parks.	Green area in the buildup area that is uncovered, Open space clear demarcation for the residential areas, monitoring and supervision as per the building bylaws		
National Urban Development Strategy (NUDS, 2017)	Urban Environment Management Guidelines (UEMG) Open space for an existing urban area to be 2.5% at ward level and 5% for new urban areas.	Provision for urban heat island effect in all level of government, suitable nature-based solutions to be practiced in major urban centers		
Local Governance Operation Act, 2074	Environmental and biodiversity protection through acts, regulations, and policies	Local level action plan and responsibility regarding development considering urban heat island effect and nature-based solution implication as the local resource's promotion		

	Low carbon footprint and environment-friendly development		NBS needs to be included in the combined policy, social, and scientific debates.	
Environmental Policy 1993	Reduce vehicular air pollution level	Consideration for nature-based solutions in selections of projects and climate change effects in large scale development activities		
	Preparation and implementation of Environmental Action Plan			
Fifteenth Plan (FY 2019/20-2023/24)	Adopt the concept of green development and promote clean energy to mitigate climate change	Clear indication for the criteria associated with nature-based solutions, urban heat island		

CHAPTER 7: CONCLUSION AND RECOMMENDATION

Small green spaces in the settlement/houses make the difference. Planning modification without its impact on living comfort is a problem. These green spaces also create space for social gatherings and a playground for healthy activities. The change in the use of open space has affected the micro-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 possess a low thermal conductivity making the inside environment of the house colder in the daytime. These bricks act like thermal insulators as they restrict the movement of heat passing through them. It suggests the selection of materials considering the thermal conductivity and albedo value. Hence, the low conductivity and high albedo value of bricks in the old settlement have made temperature viable for the resident.

NBS hasn't received any specific design guidance from the urban policy. Lack of knowledge and understanding of environmental issues, potential remedies, and effects is one of NBS's biggest difficulties. Lack of governmental commitment and direction, as well as budgetary restrictions and financing shortages, are additional difficulties. Through partnerships and collaborations between nonprofit organizations and volunteer community groups, funding can be obtained for the creation of those solutions. The implementation of NBS has obstacles because of a lack of qualified personnel, a lack of technical and scientific knowledge, and a lack of mechanisms for maintenance and monitoring. Now NBS must be acknowledged, promoted, and supported as proactive investments in planning procedures. They should also be encouraged in combined policy, social, and scientific debates.

Through the NBS process, several forms of cooperative governance and actor interactions might be implemented, including top-down approaches and central government decision-making, bottom-up and citizen-led approaches, public-private interactions, and cross-sectoral partnerships.

7.1 Further Studies

The study was only done over the summer season due to time constraints. The study must be conducted for a whole year, including each season, to ensure thorough comprehension. This would help plan for adopting UHI control strategies and give a better understanding of natural solutions to combat UHI in the Kathmandu Valley. It is necessary to conduct additional research in the area with low albedo value and greenery. The appropriateness of materials must be investigated because their albedo value is the primary factor in minimizing UHI. To combat UHI with NBS, it is necessary to conduct studies of the urban pattern to suggest the best place for NBS deployment.

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ANNEXES

1. Daily temperature Readings

A. Kuleshwor Site and Service Area

Station A and Station B

Date	Time	C HUMIDITY (S-A)	C TEMP (S-A)	C HUMIDITY (S-B)	C TEMP (S-B)
7/28/2022	2:21PM	56.712	27.05	59.372	26.47
	7:21 PM	69.112	22.65	71.672	22.37
	11:21 PM	76.912	21.55	76.672	21.37
7/29/2022	2:21 PM	62.812	25.65	67.372	24.07
	7:21 PM	72.712	22.65	73.172	22.17
	11:21 PM	77.712	21.45	76.672	21.37
7/30/2022	2:21 PM	60.212	26.25	61.472	25.87
	7:21 PM	74.312	22.55	74.672	22.07
	11:21 PM	83.012	21.45	79.472	21.27
7/31/2022	2:21PM	77.712	22.25	83.572	21.27
	7:21 PM	81.712	21.55	87.672	20.77
	11:21 PM	83.212	20.95	87.872	20.27
8/1/2022	2:21 PM	77.912	21.95	87.072	20.77
	7:21 PM	78.412	22.15	85.472	21.37
	11:21 PM	80.612	21.35	84.772	20.87
8/2/2022	2:21 PM	66.212	24.95	71.972	23.47
	7:21 PM	74.712	22.35	76.472	22.17
	11:21 PM	79.712	21.55	81.472	21.37
8/3/2022	2:21PM	69.812	24.35	74.572	23.37
	7:21 PM	73.212	22.55	75.972	22.27
	11:21 PM	77.412	21.55	79.372	21.27
8/4/2022	2:21 PM	64.012	26.45	70.172	24.37
	7:21 PM	77.412	22.25	76.972	22.37
	11:21 PM	80.412	21.55	81.372	21.67
8/5/2022	2:21 PM	61.612	26.35	64.772	25.67
	7:21 PM	70.612	24.35	71.372	24.27

	11:21 PM	74.912	22.95	75.472	22.87
8/6/2022	2:21 PM	50.112	29.65	55.372	28.37
	7:21 PM	72.012	23.25	72.672	23.27
	11:21 PM	76.412	22.05	76.972	22.17
8/7/2022	2:21 PM	54.012	28.05	58.472	27.07
	7:21 PM	73.212	23.75	73.872	23.77
	11:21 PM	75.812	23.05	75.572	23.07
8/8/2022	2:21PM	54.572	28.77	57.612	27.95
	7:21 PM	75.472	23.27	75.312	23.35
	11:21 PM	77.672	21.97	78.412	21.95
8/9/2022	2:21 PM	44.772	30.07	50.312	29.45
	7:21 PM	67.272	25.77	67.112	26.05
	11:21 PM	83.472	21.47	87.512	21.15
8/10/2022	2:21 PM	58.672	27.97	61.412	27.15
	7:21 PM	74.072	23.47	75.912	23.45
	11:21 PM	78.672	22.77	80.512	22.75
8/11/2022	2:21PM	53.472	29.67	57.112	28.35
	7:21 PM	69.872	24.07	71.012	23.95
	11:21 PM	74.372	22.47	73.712	22.65
8/12/2022	2:21 PM	46.472	31.67	50.912	30.15
	7:21 PM	68.672	24.77	69.112	24.95
	11:21 PM	73.772	23.27	73.512	23.55
8/13/2022	2:21 PM	49.672	29.57	50.912	28.75
	7:21 PM	83.472	21.67	88.312	21.15
	11:21 PM	83.372	20.97	89.212	20.45
8/14/2022	2:21PM	61.672	27.17	70.512	25.25
	7:21 PM	74.072	23.37	78.812	22.95
	11:21 PM	77.172	21.67	80.212	21.55
8/15/2022	2:21 PM	42.472	31.37	46.312	29.45
	7:21 PM	64.672	23.57	65.712	23.85
	11:21 PM	73.172	21.47	73.512	21.75
8/16/2022	2:21 PM	52.172	29.07	53.412	28.55
	7:21 PM	68.072	24.17	68.012	24.45

	11:21 PM	73.672	22.57	73.812	22.95
8/17/2022	2:21 PM	49.572	28.67	52.112	28.05
	7:21 PM	67.872	24.17	67.912	24.45
	11:21 PM	72.072	22.67	71.412	23.05
8/18/2022	2:21 PM	44.272	32.77	52.512	30.15
	7:21 PM	66.172	25.57	67.512	25.55
	11:21 PM	79.872	21.97	85.912	21.35
8/19/2022	2:21PM	50.372	28.77	56.012	27.75
	7:21 PM	70.172	22.97	71.312	23.15
	11:21 PM	82.572	20.87	87.012	20.55
8/20/2022	2:21 PM	50.472	29.37	56.412	27.45
	7:21 PM	68.572	23.47	69.412	23.65
	11:21 PM	74.472	22.27	75.112	22.35
8/21/2022	2:21 PM	40.372	33.57	44.412	31.05
	7:21 PM	60.972	24.47	59.712	25.15
	11:21 PM	67.572	22.57	68.112	22.95
8/22/2022	2:21PM	37.872	33.27	42.312	31.05
	7:21 PM	66.472	24.77	66.612	25.15
	11:21 PM	72.872	22.47	72.312	23.05
8/23/2022	2:21 PM	62.772	26.57	63.212	26.45
	7:21 PM	79.172	21.57	77.912	21.85
	11:21 PM	81.472	20.87	81.512	20.85
8/24/2022	2:21 PM	46.472	30.77	52.612	29.25
	7:21 PM	75.472	22.57	75.712	22.75
	11:21 PM	76.472	21.37	77.712	21.55
8/25/2022	2:21PM	45.672	30.27	45.512	30.55
	7:21 PM	66.772	24.87	65.512	25.35
	11:21 PM	68.872	23.27	67.912	23.85
8/26/2022	2:21 PM	60.272	25.67	61.412	25.65
	7:21 PM	70.272	23.97	70.212	24.15
	11:21 PM	75.872	22.67	76.512	22.75
8/27/2022	2:21 PM	64.272	25.67	64.712	25.35
	7:21 PM	74.172	22.97	75.312	23.05

	11:21 PM	74.972	22.27	74.712	22.55
8/28/2022	2:21 PM	69.772	24.27	68.512	24.35
	7:21 PM	75.872	22.37	75.612	22.55
	11:21 PM	80.972	20.67	83.712	20.55
8/29/2022	2:21 PM	51.772	28.57	52.012	28.35
	7:21 PM	71.172	23.77	71.112	23.95
	11:21 PM	74.472	22.37	74.312	22.55
8/30/2022	2:21PM	51.872	28.77	51.612	28.45
	7:21 PM	68.872	24.07	68.612	24.25
	11:21 PM	73.672	22.47	73.612	22.65
8/31/2022	2:21 PM	67.272	24.47	68.112	24.35
	7:21 PM	78.372	22.17	77.612	22.35
	11:21 PM	80.972	21.37	80.512	21.55
9/1/2022	2:21 PM	56.772	26.27	57.312	26.45
	7:21 PM	72.172	22.27	71.312	22.55
	11:21 PM	75.472	21.47	74.912	21.65
9/2/2022	2:21PM	61.572	25.67	61.412	25.75
	7:21 PM	70.572	22.37	68.812	22.85
	11:21 PM	76.072	21.67	76.112	22.05
9/3/2022	2:21 PM	58.872	26.47	59.012	26.45
	7:21 PM	71.272	22.87	71.012	23.05
	11:21 PM	78.672	21.47	79.312	21.65
9/4/2022	2:21 PM	55.272	28.07	55.812	28.15
	7:21 PM	71.272	23.27	71.112	23.55
	11:21 PM	75.172	21.57	74.612	21.95

B. **Harisiddhi Area**

Station C and Station D

Date	**Date time**	**C HUMIDITY (S-C)**	**C TEMP (S-C)**	**C Humidity (S-D)**	**C Temp (S-D)**
7/29/2022	1:50 PM	67.792	23.55	60.452	25.13
	6:50 PM	71.892	22.25	70.552	21.93
	10:50 PM	73.292	21.45	76.152	20.33
7/30/2022	1:50 PM	68.592	23.95	50.752	28.33
	6:50 PM	74.492	21.55	76.152	20.63
	10:50 PM	76.092	21.35	77.852	20.53
7/31/2022	1:50 PM	73.792	22.55	69.052	23.23
	6:50 PM	78.892	21.35	76.352	21.13
	10:50 PM	79.392	20.95	78.352	20.33
8/1/2022	1:50 PM	84.392	21.55	71.852	23.53
	6:50 PM	82.892	20.45	71.752	21.33
	10:50 PM	83.892	20.35	78.952	20.13
8/2/2022	1:50 PM	83.492	21.55	72.652	23.03
	6:50 PM	83.792	21.15	73.652	22.13
	10:50 PM	84.292	20.75	80.352	20.33
8/3/2022	1:50 PM	83.392	21.75	65.652	24.33
	6:50 PM	84.092	20.95	75.452	21.23
	10:50 PM	84.092	20.55	78.552	20.33
8/4/2022	1:50 PM	84.392	21.45	74.152	23.53
	6:50 PM	84.692	21.05	70.252	22.33
	10:50 PM	85.092	20.85	79.852	20.53
8/5/2022	1:50 PM	81.892	22.95	58.652	27.13
	6:50 PM	81.392	21.85	69.552	22.93
	10:50 PM	82.092	21.15	75.252	21.23
8/6/2022	1:50 PM	81.992	22.75	48.952	29.63
	6:50 PM	82.392	21.35	66.052	22.63
	10:50 PM	83.592	21.15	75.252	21.23
8/7/2022	1:50 PM	76.592	23.85	51.352	29.53
	6:50 PM	81.692	22.35	67.352	23.53

	10:50 PM	82.692	21.95	76.252	21.93
8/8/2022	1:50 PM	76.492	23.85	59.952	26.23
	6:50 PM	80.192	22.15	74.052	21.83
	10:50 PM	81.892	21.75	76.352	21.43
8/9/2022	1:50 PM	75.892	24.45	56.852	28.13
	6:50 PM	78.392	22.85	72.252	23.03
	10:50 PM	84.892	20.95	81.552	20.33
8/10/2022	1:50 PM	79.092	22.55	61.352	25.23
	6:50 PM	82.892	21.85	72.352	22.33
	10:50 PM	83.992	21.75	77.552	21.83
8/11/2022	1:50 PM	75.592	24.05	50.552	29.03
	6:50 PM	77.392	22.05	66.752	22.73
	10:50 PM	79.692	21.35	73.052	21.03
8/12/2022	1:50 PM	73.092	24.15	51.752	28.73
	6:50 PM	76.592	22.85	68.052	23.13
	10:50 PM	78.292	22.15	72.452	21.93
8/13/2022	1:50 PM	70.992	24.55	53.052	28.13
	6:50 PM	79.092	22.25	73.152	22.33
	10:50 PM	83.492	21.15	78.652	20.93
8/14/2022	1:50 PM	84.592	22.65	55.152	27.73
	6:50 PM	84.392	21.95	70.652	23.23
	10:50 PM	84.692	21.15	76.252	21.03
8/15/2022	1:50 PM	77.492	22.95	49.252	28.23
	6:50 PM	79.292	21.65	65.152	22.53
	10:50 PM	80.292	20.65	74.052	19.73
8/16/2022	1:50 PM	73.392	24.25	45.252	30.53
	6:50 PM	77.592	22.35	67.352	22.93
	10:50 PM	79.592	21.65	73.352	21.23
8/17/2022	1:50 PM	74.892	24.05	41.552	31.03
	6:50 PM	77.492	22.95	66.652	23.63
	10:50 PM	78.792	21.95	73.152	21.33
8/18/2022	1:50 PM	72.692	25.45	42.852	32.13
	6:50 PM	75.992	23.65	67.452	24.13

	10:50 PM	80.292	22.45	76.052	22.23
8/19/2022	1:50 PM	73.392	23.45	56.952	26.13
	6:50 PM	79.992	21.55	74.452	21.33
	10:50 PM	83.792	20.45	79.352	20.33
8/20/2022	1:50 PM	80.692	22.65	46.352	30.23
	6:50 PM	83.092	20.95	72.352	21.33
	10:50 PM	84.092	20.75	76.852	20.63
8/21/2022	1:50 PM	76.292	23.85	50.152	29.23
	6:50 PM	78.492	21.95	69.952	22.33
	10:50 PM	79.692	20.85	71.652	20.63
8/22/2022	1:50 PM	73.292	23.85	46.852	29.73
	6:50 PM	77.492	22.65	66.552	23.23
	10:50 PM	79.192	21.55	73.952	20.63
8/23/2022	1:50 PM	75.392	23.45	59.952	26.13
	6:50 PM	79.792	21.85	75.252	21.43
	10:50 PM	81.192	21.35	77.952	20.63
8/24/2022	1:50 PM	72.792	24.45	50.652	28.93
	6:50 PM	78.192	22.15	73.652	21.53
	10:50 PM	80.592	21.15	79.352	19.93
8/25/2022	1:50 PM	76.092	24.35	46.052	30.93
	6:50 PM	77.792	22.55	72.652	22.43
	10:50 PM	79.292	21.35	75.252	21.03
8/26/2022	1:50 PM	76.092	23.35	52.152	27.23
	6:50 PM	77.392	22.95	67.152	23.83
	10:50 PM	79.192	22.25	75.052	21.83
8/27/2022	1:50 PM	75.392	23.95	50.552	28.13
	6:50 PM	78.592	22.35	73.552	22.03
	10:50 PM	78.892	21.85	74.652	21.43
8/28/2022	1:50 PM	82.492	21.65	62.552	24.83
	6:50 PM	81.092	21.15	72.152	21.43
	10:50 PM	83.892	19.95	77.452	19.63
8/29/2022	1:50 PM	81.392	22.65	50.752	28.13
	6:50 PM	81.692	21.75	69.652	22.33

	10:50 PM	82.992	20.95	75.552	20.73
8/30/2022	1:50 PM	79.092	23.55	52.652	28.23
	6:50 PM	79.192	22.25	71.052	22.33
	10:50 PM	81.092	21.35	72.652	21.23
8/31/2022	1:50 PM	81.292	22.15	62.152	25.13
	6:50 PM	82.892	21.65	74.552	21.93
	10:50 PM	83.692	20.85	78.852	20.43
9/1/2022	1:50 PM	82.592	21.75	58.952	25.53
	6:50 PM	81.592	21.45	68.352	22.23
	10:50 PM	82.392	20.85	75.352	20.63
9/2/2022	1:50 PM	79.592	21.85	49.752	27.53
	6:50 PM	80.292	21.35	66.652	22.33
	10:50 PM	81.192	20.85	75.052	20.53
9/3/2022	1:50 PM	73.392	23.15	49.952	27.33
	6:50 PM	77.592	22.05	69.452	22.33
	10:50 PM	80.292	21.25	76.952	20.73
9/4/2022	1:50 PM	72.892	23.45	49.052	28.63
	6:50 PM	76.492	21.65	70.152	21.53
	10:50 PM	78.692	21.05	75.452	20.33

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