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Urban Heat Island Effects in Kathmandu Valley: A Case of Patan

by

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A THESIS

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DEPARTMENT OF ARCHITECTURE

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DECLARATION

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The undersigned certify that they have read, approved and recommended to the Institute of Engineering for acceptance, a thesis titled **"Urban Heat Island in Kathmandu Valley: A Case of Patan"** submitted by Anuja Rajkarnikar in partial fulfillment of the requirement for the degree of Master in Urban Planning.

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ABSTRACT

Urban Heat Island (UHI) is a phenomenon where urban areas are warmer than surrounding rural counterparts. Every settlement, big or small, suffer from UHI. Researches show that when the natural environment is replaced with low albedo artificial surfaces, they radically alter the aero dynamics, radiative, thermal and moisture properties causing urban regions to be warmer than the surrounding natural areas. As the earth faces global warming, these cities which are already warm due to UHI become more vulnerable to extreme heat. Extreme heat has numerous bad effects on human health, comfort and productivity. It is also responsible for change in micro climate and precipitation. Due the unwanted effects of UHI many of the large cities are working to reduce UHI effect.

Kathmandu valley is one of the fastest growing cities in South Asia. The urban area and settlement in the valley floor has expanded from 3% to 23% in four decades (1967-2010). With the valley facing severe air pollution and densification combined with replacement of natural ground surface by urban surfaces, the valley is susceptible to greater effects of UHI. Although studies regarding UHI Effects have been done for the valley, these researches are limited to Landsat Imagery. Since Kathmandu is a valley, there is natural temperature difference induced by different altitude. Therefore, a study has been conducted at micro-level in a city of Patan.

To understand UHI effect at micro-level, the temperature has been recorded in four different places representing urban areas with unique combination of green and built areas. The results have been analyzed and depending on the results, the research has focused the questionnaire to understand the effects of increased heat on the people of Patan.

By comparing the existing policies with measures taken by different cities, it is found that a better thorough study of the cities in the valley is crucial to understand and exploit natural resources efficiently to control warming of the cities in the valley.

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Anuja Rajkarnikar

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LIST OF ABBREVATIONS

CBS: Central Bureau of Statistics

CDM: Clean Development Mechanism

DoR: Department of Roads

DoTM: Department of Transport Management

DHM: Department of Hydrology and Meteorology

EPA: Environment Protection Agency

EPI: Environmental Performance Index

GHG: Green House Gas

ICAP: Indian Cooling Aid Plan

IPCC: Intergovernmental Panel on Climate Change

LLR: Land and Land Resources

LST: Land Surface Temperature

LULC: Land Use Land Cover

LUZ: Land Use Zones

MoLRM: Ministry of Land Reform and Management

NAPA: National Adaptation Programme of Action

NARC: National Agricultural Resource Center

NASA: National Aeronautics and Space Administration

NDVI: Natural Difference in Vegetation Index

NEPAP: National Environment Policy and Action Plan

NPT: Nepal Standard Time

UBL: Urban Boundary Layer

UHI: Urban Heat Island

UNDESA: United Nations Department of Economic and Social Affairs

UNFCCC: United Nations Framework Convention on Climate Change

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1 INTRODUCTION

1.1 BACKGROUND

Urban heat island (UHI) is described as an urban area that has significantly warmer temperature than its surrounding rural areas due to human activities. Cities usually demonstrate greater temperature in its center than the surrounding rural areas (Yamamoto, 2006 cited in Muruzzaman, 2015). According to EPA, the annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. This temperature difference is found to be slightly larger at night than during the day. This phenomenon of increased temperature can be found in all small and large cities. The effect varies according to the scale of the city. This temperature change usually creates a discomfort to the city dwellers. With the temperature of earth increasing and the UHI, the cities are more prone to extreme heat.

The main cause of the difference in temperature is the modification of land surfaces according to Wikipedia. Urban area with the solid and impervious surfaces such as tar, asphalt, brick and concrete radiate heat and have higher temperature than green and lush rural areas. Additional anthropogenic heat is contributed by motorized means of transport, industries and electronics as well as the agglomeration of people. The combined effect of heat radiation and lack of cooling surfaces, makes the cities warmer compared to undeveloped land.

The undesired heat leads to excess use of appliances such as ACs, coolers in summer. These appliances add load to electricity production which rely on fossil fuels which lead to increase in air pollutant and green house gases emissions (EPA, 2019). The pollutants and gases released include Sulfur dioxide, Nitrogen oxides, particulate matter, Carbon Monoxide and mercury pose which pose a threat to human health and the environment. Air pollution associated with urban heat islands can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustions, non-fatal heat stroke and heal related mortality. (EPA, 2019). Heat Islands are also one of the cause of heat waves which are very risky for sensitive populations. Furthermore, these pollutants are primary cause of smog, and acid rain. Such gases are also the main contributors of global climate change which is one the burning issues the world is facing.

UHI also disturbs the aquatic life. Storm water in urban areas tend to get heated as it runs off into stream, rivers and ponds. Rapid temperature changes in aquatic ecosystems resulting from warm storm water runoff can be particularly stressful, even fatal to aquatic life." (EPA, 2019)

UHI is a problem the cities of the world are facing. Among those fast growing cities is Kathmandu. Kathmandu is the most populated urban region of Nepal and one of the fastest-growing urban agglomerations in South Asia (Muzzini & Aparicio, 2013). Kathmandu has a growth rate of 3.94% (UNDESA 2015) and 31% of the country's total urban population (3 million). The land use of Kathmandu has changed significantly in the last four decades (Rimal, et al., 2017) The city has expanded as much as 412%, with the majority of land converted from agricultural land to built-up areas, which has changed the valley's landscape considerably (Ishtiaque et al. 2017 c.f. Mishra, et al., 2019).

Kathmandu Valley has observed a noticeable change in weather in past few years. A study on UHI effect in Kathmandu Valley has revealed that there is a temperature difference of 5 °C between forest land and developed land on average in Kathmandu Valley. Comparing the temperature of the Valley, an annual increase of 0-2°C is detected in 18 years (Mishra, et al., 2019).

The discomfort due to temperature rise can be seen in daily life of the people. Summer has become a suffocating season specially during the day. People suffering from heat cramps and exhaustion from walking during afternoon in summer in the valley has increased. Maximum uses of electronics such as fans and ACs to cool the buildings can also be observed in summer.

1.2 NEED OF RESEARCH

The study of UHI is essential as it affects many aspects of urban life, such as infrastructure, health, energy consumption, environmental stress, and discomfort, and leads to additional costs in building infrastructure (Azevedo et al., 2016 c.f. Mishra, et al., 2019). Depending on the nature and developmental phase, UHI can have detrimental socio-economic effects (Cui et. al., 2016).

The unorganized sprawl witnessed in the Kathmandu valley has led to replacement of green areas with increasing concrete and asphalts surfaces. Having the highest density and a population of nearly 3 million people and maximum vehicular movements, the valley is likely to face UHI.

Studies also reveal that air pollution is one of the reason of UHI. The urbanizing environment of the Valley is degrading and had been ranked 177th out of 180 in terms of quality of air in 2016 by Environmental Performance Index (EPI) and Kathmandu pointed out as one of the most polluted cities in Asia.

With the degrading environment and increasing temperature, the level of discomfort to the millions of people residing in Kathmandu Valley is quite evident. The researchers claims that Kathmandu Valley is likely to face the brunt of the Urban Heat Island Effect more severely than anywhere in the country because the country's urbanization is centered here (Pyakurel, 2019). Thus, this research is necessary.

1.3 IMPORTANCE OF RESEARCH

Urban Heat Island is a global problem which has caused negative impact on human and animals. It degrades air, influences local climate, increases ground level ozone production (Lo et al., 2003). Every large city is studying the causes of UHI and coming up with measures to reduce the effects and reduce the discomfort caused by it.

Kathmandu Valley, one the fast urbanizing city in South Asia also need to be conscious of Urban Heat Island Effects, largely as the effects are becoming visible. This study is important to mitigate and prevent the consequences of UHI.

The subject of urban growth and UHI has drawn attention from ecologists, urban planners, sociologists, administrators, policy makers, and finally to the urban residents

(Bekele, 2005; Li et al., 2012). This study will help urban planners to plan the city such that the effects of UHI is minimal with sustainable planning. For the existing cities it will provide insights on how to limit the increasing heat and improve the quality of life of the million residents. The study will also help the policy makers formulate and adapt laws that will be beneficial to the city and the people residing. The outcome will also help in promoting awareness among the urban residents and encourage them to adopt measures to improve urban environment.

1.4 PROBLEM STATEMENT

Kathmandu Valley is rapidly urbanizing and there is a great change in land use. The green areas are replaced with impervious concrete and asphalt surface. The Valley is also experiencing increasing agglomeration of people, increased use of Motorized Transport in the Valley in past few years. All these factors make the Kathmandu Valley highly susceptible to UHI effects.

Kathmandu Valley has been listed as one of one of the most polluted cities in the world. The air pollution which is already in a bad state can exacerbate UHI. Extreme heat along with pollution can lead to many serious problems related to health.

As stated in Mishra, et al., 2019, the temperature of Kathmandu has increased by 0-2°C in past 18 years. The air surface temperature has significantly increased at the rate of 0.04°C yr-1 with a maximum temperature trend of 0.06°C. (Baniya, et al., 2018) The climate of Kathmandu Valley is deteriorating causing millions of people residing in the valley to suffer.

Urban Heat Island is a critical problem which if not dealt with will making living in Kathmandu Valley very difficult.

1.5 RESEARCH QUESTION

Although researches have been done to understand the extent of UHI in Kathmandu Valley, all the studies are done using Landsat. Because of difference in altitude throughout the valley, there should be a presence of natural temperature difference. Therefore, UHI study at a micro-level in one with minimum elevational difference of a core area or a dense area inside the valley is necessary. Thus, the purpose of the study is to calculate the measure of UHI in one of the dense settlements within the valley. The following research question is the basis of the thesis.

"**What is the extent of urban heat island prevalent in one of the core area of the Valley in terms of built up areas and green space ratio and how can it be reduced?**"

1.6 RESEARCH OBJECTIVES

- To assess UHI effect in one of the core areas of Kathmandu Valley in terms of temperature change and built up-open space ratio of the area
- To review the effects of UHI in the quality of life of the residents in the selected core area
- To propose different mitigation/adaptive measures to reduce urban heat island

1.7 VALIDITY OF RESEARCH

The valley is the core of urbanization attracting more people from all over the country. Because of migration, the urban area is expanding at unprecedented rate. Diminishing of surrounding green spaces and rapid change of land has rendered the Valley vulnerable to effects of urban heat island. There has been very few researches dedicated to study of urban heat island for this fast growing urbanization and even less researches that propose adaptive measures through planning perspective.

1.8 EXPECTED OUTPUT

From the research, the relationship between built up area and green areas with respect to temperature in core areas in the Valley will be determined. The research shall also produce theories on the relationship between temperature and comfort of the residents of the residents of core area. Depending on the results of the discussed parameters, suitable adaptive measures for the valley shall be proposed.

2 CONCEPTUAL FRAMEWORK OF RESEARCH AND METHODOLOGY

2.1 RESEARCH PARADIGM

Every research is governed by a paradigm. A paradigm as dictionary states is “a typical example or pattern of something”. It is a theoretical framework that influences the way knowledge is studied and interpreted (Mackenzie & Knipe, 2006). The term 'paradigm' may be defined as "a loose collection of logically related assumptions, concepts, or propositions that orient thinking and research" (Bogdan & Biklen 1998, p.22 c.f. Mackenzie & Knipe, 2006) or the philosophical intent or motivation for undertaking a study (Cohen & Manion 1994, p.38). 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). Paradigms are primarily categorized as Positivist, Post-positivist, Interpretivist, Transformative and Pragmatic.

Positivist approach is defined as a scientific research, the “systematic, controlled, empirical and critical investigation of natural phenomena guided by theory and hypothesis about the presumed relations among such phenomena” (as Fred N. Kerlinger). Positivism is concerned with uncovering truth and presenting it by empirical means. (Henning, et al., 2004). Positivist paradigm researches are carried out in a controlled environment where the role of researcher is limited to data collection and interpretation in an objective way. Because the variables in my study cannot be fully controlled and examined, this paradigm is not suited for my topic.

After the scientists came to realization that all observations, including objective reality, is fallible, post-positivist paradigm was introduced. The post-positivist perspective is that not everything is completely knowable (Krauss, 2005). Post-positivist work form the assumption that any piece of research is influenced by a number of well-developed theories apart from and as well as the one which is being tested. (Cook & Campbell, 1979) “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) Positivists and post-positivist research is most commonly aligned with quantitative methods of data collection and analysis.

The post positivist paradigm is conducted using the co-relational approach. Post-positivist is the paradigm that is well suited for my first research objective.

"Interpretivist/constructivist approaches to research have the intention of understanding "the world of human experience" (Cohen & Manion, 1994, p.36), suggesting that "reality is socially constructed" (Mertens, 2005, p.12). The interpretivist/constructivist researcher tends to rely upon the "participants' views of the situation being studied" (Creswell, 2003, p.8) and recognizes the impact on the research of their own background and experiences (Mackenzie & Knipe, 2006). This paradigm is more likely to rely on qualitative data and analysis. Research approach for interpretivist paradigm include interview, questionnaire and observations. For my second objective which is about experiences and interpretation of the weather by the people living in the core area which is to be done through interview and questionnaire this paradigm is appropriate.

Transformative researchers felt that the interpretivist/constructivist approach to research did not adequately address issues of social justice and marginalized peoples (Creswell, 2003, p.9). Transformative researchers "believe that inquiry needs to be intertwined with politics and a political agenda" (Creswell, 2003, p.9) and contain an action agenda for reform "that may change the lives of the participants, the institutions in which individuals work or live, and the researcher's life" (Creswell, 2003, pp.9-10) (Mackenzie & Knipe, 2006). It uses both quantitative and qualitative data collection and analysis method same way was Interpretivist. Since my research does not address any social injustice, this paradigm is not applicable to my research.

According to Creswell (2003) pragmatic paradigm focuses on what and how of the research problem. It is not committed to any one system of philosophy or reality (Mackenzie & Knipe, 2006). The pragmatic paradigm places "the research problem" as central and applies all approaches to understanding the problem (Creswell, 2003, p.11). Pragmatic paradigm is a simple mix of qualitative and quantitative research logics. "Pragmatism is not committed to any one system of philosophy or reality." (Mackenzie & Knipe, 2006). It can combine both positivist and interpretivism paradigm and can integrate more than one research strategies within the same study.

The research involves aspects of positivist as well as interpretivist paradigm. The proposed research is based on quantitative as well as qualitative data. The most suitable paradigm for the whole thesis is pragmatic paradigm. Qualitative data involved in the research is the perception of people on their change in lifestyle due to UHI effects while the quantitative data is represented by the temperature and built-up data. Thus, the chosen paradigm for the research is pragmatic paradigm.

Positivist and post-positivist usually adopt 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 causal relationship between concepts and variables.

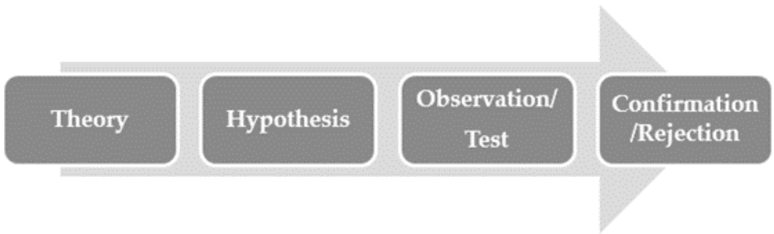


Figure 1 Deductive approach

Deductive research can be explained as reasoning from the general to the particular. (Pelissier, 2008) Studies with deductive approaches initiates from development of hypothesis from a theory. The hypothesis is then tested through quantitative methods like correlation analysis, mean, mode etc. The outcome is then analyzed which might concur to the hypothesis proposed or might reject the theory.

My thesis majorly involves in showing the core settlement have extreme UHI and the residents are affected by this unnecessary heat which is cause due to lack of green surfaces. Therefore, my research is more inclined towards deductive approach.

2.2 RESEARCH METHODOLOGY

Every research has three parts: Ontology, Epistemology and Methodology. Ontology is a system of belief that reflects an interpretation by an individual about what constitutes a fact. According to Norman Blaikie, ontological claims are about the nature of reality, claims about what exists, what it looks like and what units make it up and how these units interact with each other. The ontological claim for my research is that there is a presence of UHI in Patan and this presence has created an environment of discomfort to the residents of the area.

Epistemology includes what we need to do to produce knowledge and what scientific knowledge looks like once we have produced it (Neuman, 2014). Epistemology is the possible ways of gaining knowledge. It is concerned with sources and limitation of knowledge in the field of study. For the research only published articles are referred to. Information is also obtained through quasi-experiment to be performed. Other sources for knowledge include field survey and interviews with the stake holders which would be later interpreted. How we can learn about or know the world is rooted in our ontological assumptions (Neuman, 2014).

2.2.1 LITERATURE REVIEW

Literature review is critical analysis of a segment of a published body of knowledge through summary, classification and comparison of prior research studies, review of literature and theoretical articles. Initial works of any research for literature review will be collection of relevant literature, which will help to understand basic concept of that research. For this research major sources of literature will be study extracted from published articles. Articles and research papers related to UHI and its causes will be researched. Different research paper published in similar subject in similar context will also be reviewed. General effects of UHI shall also be covered in detail.

2.2.2 DATA COLLECTION

Data regarding how the valley has been growing shall be collected, based on the knowledge of causes and effects gained from literature review. So, the research would involve the collections of primary and secondary data on urban growth of the core areas and the surface types of this built area as well as the temperature of area.

Different researches that includes researches and studies regarding UHI prevalent in Kathmandu Valley shall be studied.

2.2.3 QUASI-EXPERIMENT

Experiments are done in completely controlled environment which is preferred but often not possible or practical to control all key factors. Therefore, it becomes necessary to implement a quasi-experimental research design. In quasi-experiment, the researcher must try to statistically control for as many variables as possible even though all of them cannot be controlled.

Quasi-experimental research is similar to experimental research in that there is manipulation of an independent variable. It differs from experimental research because either there is no control group, no random selection, no random assignment, and/or no active manipulation. (Abraham, 2011)

The first objective of the research is to examine the UHI effect in terms of built up and corresponding temperature. For this, a small experiment shall be done by setting up thermometers in different built up spaces in and out of the core area. The experiment shall involve temperature readings for a certain amount of time. The study shall determine the UHI effect in the core area.

For this experiment the places shall be chosen at the shortest distance and smallest elevation difference possible so that the weather pattern i.e. wind, rain, cloud pattern is same in all the spaces. The only variable would be the built space density and the surfaces of the area (concrete/ brick building, paved/asphalt/brick roads). From this experiment UHI effect due to built-up areas in the core area shall be determined.

2.2.4 FIELD VISIT AND COLLECTION OF DATA

The second objective is to understand how much the residents of Kathmandu Valley is affected by the temperature increment in the core area. For this, primary data is to be collected from through short interviews with the local residents of the core. Interview is the method of data collection in the interpretive paradigm.

2.2.5 FURTHER LITERATURE REVIEW

From case studies and researches, the measures big cities have adopted to reduce the effects of UHI shall also be discussed in this section.

2.2.6 POLICIES REVIEWS

Policies that support any form of mitigation/ adaptive measures that have been deduced through literature and case studies shall be reviewed. Initiatives of any sorts to prevent UHI shall also be covered in this portion.

2.2.7 RECOMMENDATION

Analyzing the results from first and second objectives, and the studies from literature review, adaptive measures that is well suited shall be devised.

2.3 LIMITATIONS

The experiment will be done only till the final thesis report submission. This includes only spring season. This may affect the outcome at a certain extent.

Due to lack of budget the thermometer will be set only in 4 places which represent different built up. The thermometers used are manual and the temperature is taken only at 14:00 and 19:00 NPT.

The variables considered are limited to surface types and the nature of area. Heat from non-motorized vehicles and electronics are not taken into consideration.

3 LITERATURE REVIEW

3.1 URBAN HEAT ISLAND (UHI)

The urban Heat Island (UHI) is a phenomenon whereby urban regions experience warmer temperature than their rural, undeveloped surroundings. (Roth, 2013) This phenomenon can be found in settlements of all sizes in all climatic regions. The introduction of artificial surfaces characteristics of those of a city that radically alters the aero dynamics, radiative, thermal and moisture properties in the urban region compared to natural surroundings. (Roth, 2013) When a huge amount of natural land is replaced by artificial built surface that absorbs incoming solar radiation or heat and re-radiate it at night (Oke 1982 and Quattrochi et al. 2000 c.f. (Muruzzaman, 2015), urban areas are bound to have higher temperature compared to its rural counterpart. The heat island effect is defined on the basis of temperature differences between urban and rural stations.

UHI was first studied by Luke Howard in 1815. He conducted the first ever systematic urban climate study measuring UHI effect based on thermometers set at 2m height in the city of London and in the countryside nearby. UHI has received great attention due to its implications on energy use, human comfort and productivity, air pollution and urban ecology. Although during winter it is advantageous as it reduces heating costs and cold related death, the disadvantage in summertime out weigh the advantages. UHI in summer increases heat-related illness and mortality, air pollution, energy demand and indirectly greenhouse gas emissions. (EPA, 2019)

Numerous factors are held accountable for this effect, including anthropogenic heat release, surface cover, climatic conditions, air pollutants, etc. (Yamamoto 2006). According to Oke, T.R. (1982) under proper conditions, UHI may be up to 10-15°C. Large cities such as New York City and London has faced up to 10°C (Yang, et al., 2016) and 9°C UHI Effect respectively (Doick & Hutchings, 2013). As a consequence of the microclimate created by the UHI, the demand for energy to cool buildings increases (Ifeanyi & Okolie, 2009). Furthermore, to meet the demand, more generation of power is needed, which results increased amount of greenhouse gases emission and decline of climate.

One of the vital reasons for the formation of UHI is the large amount of built up surfaces like concrete, asphalt which has a high heat capacity (Akbari et al. 2001). Low albedo materials are further contributing to worsening the phenomenon. According to Taha (1997), when non-reflective and water-resistant, impervious materials at the surface takes the place of natural vegetation, urban heat island is created. It is a process which varies with the built regions and geographical conditions of a metropolitan area (Grimmond & Oke 1999). Another reason that exacerbate Urban Heat Island effect is improper planning of cities (Li, K. et al.). Taha, H. (1997) says air pollutants from industrial processes, power plants, exhaust gases from the vehicles and anthropogenic heat may add to the intensity of UHI effect.

According to Akbari et al. (2001) the demand for electricity rises up from 2-4% for every 10°C rise in temperature. In a typical urban area, surfaces are darker and vegetation is less than its surroundings. The temperature difference of a typical city with its' surrounding rural areas may be as much as 2.5°C in a warm summer daytime, which may cause for additional 5-10% municipal peak electricity demand (Akbari et al. (2001). However, in the winter season, as it is cold in the environment, the UHI effect plays a positive role for the city dwellers by providing them with warm air (Shahmohamadi 2010; Voogt 2004; Mobaraki 2012). Nevertheless, UHI has a negative effect in the summertime on the comfort of human health and energy consumption both at day and night.

3.1.1 CAUSES OF URBAN HEAT ISLAND

a) Lack of Green Spaces

Urban areas have less limited or less green cover. Lesser vegetation means less cooling efficiency. Through evapotranspiration, plants cool the air temperature. During evapotranspiration two exchanges happen: evaporation and transpiration. In evaporation, water evaporates from soil, tree tops and bodies of water in to air observing the heat and in transpiration plants absorb CO_2 (CO_2 traps heat in the air increasing the temperature). Trees also intercept solar heat and prevent surfaces from heating. (Masson 2006 cf. Muruzzaman, 2015).

Urban environment has less green coverage. With reduced evaporation, the moisture required to cool down the air is not available, hence the air temperature remains increased.

b) Paved and Impermeable Surface

Urban areas are characterized by significant amount of cement, concrete and asphalt surfaces as roof surfaces, pavements and roads. These materials have thermal bulk properties that absorb more solar radiation than green cover. These materials that absorb more heat and reflect small amount are said to have a low albedo content. The absorbed heat is radiated during the night creating a warm environment.

Moreover, such surfaces are impermeable and the water runoff is redirected to storm water rather than being absorbed into soil or by plants and prevent evapotranspiration.

c) **Anthropogenic Heat Release**

The urban areas are more likely to suffer from air pollution because of heavy traffic and presence of industries. These exhaust gases trap solar radiation (Bose 2009). Urban areas usually have a large number of vehicular flow and extensive use of Fridges and ACs. Because of this, there is a large amount of heat as well as CO_2 release which results in temperature increase.

d) **Urban Canyon**

Urban Canyon effect takes place due to tall buildings in close proximity. The close proximity creates multiple surfaces reflecting and absorbing sunlight and heat. The heat released by one building is trapped by another taller building.

Taller buildings also block the wind path and prevent convectional cooling. Because of this, the polluted air remains stagnant. As stated earlier, presence of CO_2 creates a warmer environment.

e) **Agglomeration of People**

Large number of population in a small space means large amount of CO_2 release and body heat.

3.1.2 EFFECTS OF URBAN HEAT ISLAND

a) Environmental Problems

The main effect of UHI is the increased temperature. Increased temperatures and increase in extreme heat events cause heat exhausting, heat stroke, and death, especially in vulnerable populations.

Change in Weather Pattern

UHI can bring forth secondary effects on the local weather and climate. This includes changes of local wind patterns, formation of fog and clouds, precipitation rates and humidity. The unusual heat caused by UHI contributes to a more intense upward wind movement that can stimulate thunderstorm and precipitation activity.

Furthermore, urban heat island (UHI) creates a local low pressure area where cool air from its adjacent areas converges that induces the formation of clouds and rain. This increases total rainfall rates within cities.

b) Social Problems

National Institute of Environment Health Sciences states that prolonged exposure to extreme heat can cause heat exhaustion, heat cramps, heat stroke, and death, as well as exacerbate preexisting chronic conditions, such as various respiratory, cerebral, and cardiovascular diseases. These serious health consequences usually affect more vulnerable populations such as the elderly, children, and those with existing cardiovascular and respiratory diseases.

High heat related mortality can be noticed in vulnerable population. The results suggest that the UHI contributed around 50 % of the total heat-related mortality during the 2003 heatwave in the West Midlands. (Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK)

The extra heat causes discomfort in everyday life. Heat reduces the productivity of the people

c) Economic Problems

There is increased use of electronics such as Fans and ACs due to heat. The regular use of such electronics increases electricity consumption and also the electricity bill.

According to Akbari et al. (2001) the demand for electricity rises up from 2-4% for every 10°C rise in temperature. Increased consumption leads to load on production of electricity which might create a scarcity.

Extreme heat is also responsible for Low productivity from workers. Low productivity leads to loss for industries.

3.1.3 TYPES OF URBAN HEAT ISLAND

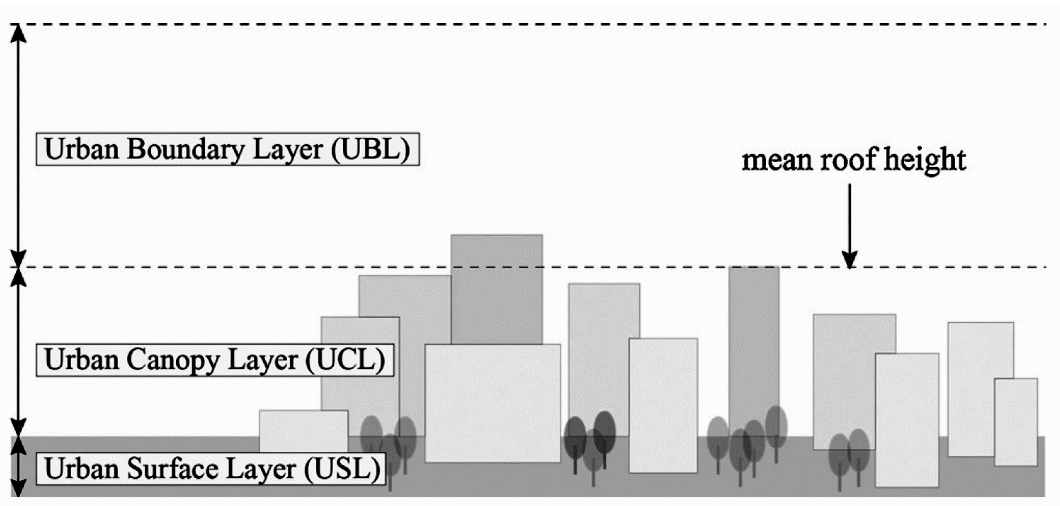


Figure 2 Different layers of UHI (Kim, et al., 2018)

There are mainly two types of urban heat island i.e. surface heat island and atmospheric heat island. The Surface Heat island is the heat trapped in the surface component; it depends on the albedo property and the heat capacity. This type of UHI is strongest during the daytime when solar heating creates large differences between dry/wet and vegetated surface to horizontal surfaces such as roofs and pavements.

The atmospheric heat island includes the canopy layer and boundary layer heat island. The canopy layer heat island exists from the ground to below the tops of trees and roofs while boundary layer heat island starts from the roof top layers up to the area where urban landscape can influence.

Canopy layer typically extends up to 1.5 km from the surface. Up to 1.5 km, the urban-rural difference is relatively small or even negative in city centers or other developments with dense and tall buildings due to shading at the surface during the daytime. The heat island intensity increases after sunset and reaches a maximum sometime between a few hours after sunset and before sunrise. The canopy-layer UHI is therefore primarily a nocturnal phenomenon and arises from reduced cooling rates observed in the city in the late afternoon and evening compared to the non-built-up areas resulting in higher urban minimum temperatures.

The urban warmth extends into the Urban Boundary Layer through convergence of sensible heat plumes from local scale areas and the entrainment of warmer air from above the Urban Boundary Layer to create the *boundary-layer UHI*. UBL heat island study is conducted with air planes, helicopter, remote sensing, balloon, and tower studies.

3.1.4 METHODS USED TO DETERMINE URBAN HEAT ISLAND

According to (Roth, 2013), there is no standard methodology to calculate UHI intensity. Therefore, it is necessary to apply strict experimental control to obtain meaningful results that can be compared across studies. There are many factors that influence Urban Heat Island.

a) Urban Canopy Geometry

The canopy of urban spaces restricts the ability of surface to release heat by radiation. Because the open sky is replaced by walls of the building any heat released by the surface below is absorbed and radiated by the surface above. Thus, the temperature of urban space during night time is greatly influenced.

b) Surface Material Properties

Many urban materials, such as those used for the construction of buildings or roads and parking lots, are dense and have a relatively high heat capacity and large surface thermal admittance. They have the ability to efficiently accept and retain heat during daytime for periods longer than that of natural surfaces and release it at night. In addition, urbanization replaces the natural impervious surfaces with waterproof materials, which results in a drier urban area where less water is available for evaporation and cooling.

c) Wind and Cloud Condition

During strong wind and clear skies, the UHI effect is minimum. UHI effect is maximum when clouds are thick and low and the wind is calm.

d) Complex Geographic Locations

Cities are often located in complex geographic locations (coastal, bottom of valley, confluence of rivers, etc.) where differences in regional land cover and/or topography generate advection and thermal wind systems at scales larger than the city (land/sea breeze or valley/slope flows), which interact with the urban atmosphere and have the potential to modulate the UHI (Fernando 2010).

Most of the UHI effect surveys have been done with measurement surface temperatures or air temperature. The spatial and temporal variability of surface temperature in urban areas has been investigated using thermal infrared measurements of upwelling thermal radiance (most often directional radiometric temperatures or directional brightness temperatures) from instruments based at ground level (e.g., pyrgeometer and thermal scanner), on aircrafts (e.g., thermal scanner), and on satellites (e.g., GOES, AVHRR, MODIS, Landsat, and Aster) (Roth, 2013). Air temperature measurements are done using direct techniques like thermocouples and thermistors. The UHI has been well documented using observations from fixed sensor networks and mobile surveys using automobiles.

The characteristics of the surface and atmosphere within the source determine the measured temperature. If the objective is to monitor the thermal environment of the canopy layer, the sensors must be exposed to area surrounded by "typical" conditions for urban terrain. Ideally, the site should be located in an open space, where the surrounding H/W ratio is representative of the local environment, away from trees buildings or other obstructions. Care should be taken to standardize practice across all sites used in a network regarding radiation shields, ventilation, height (2–5 m is acceptable given that the air in canyons is usually well mixed) and to ensure that sensors are properly calibrated against each other. Locations in urban parks, over open grass areas, or on rooftops should be avoided since they are not representative of the urban canopy (Roth, 2013)

3.1.5 MITIGATION MEASURES OF URBAN HEAT ISLAND

a) Increase Vegetation

Increasing amount of vegetation is one of the most effective ways to prevent UHI. Trees contribute to reducing the heat island effect by their evapotranspiration (Akbari et al. 2001; Dimoudi and Nikolopoulou 2003). Trees have a direct effect on reducing the UHI effect as it absorbs CO_2 (Akabari, et al., 2001). According to Theuwes et al. temperature usually decreases by 0.6K for each 10% addition of vegetation. (Muruzzaman, 2015)

In addition to cooling the environment through evapotranspiration, the shade of prevent the pavements and roads from getting heated. In the United States, near about 200,000 shade trees were planted every year between 1992 and 1996 as a strategy to mitigate heat islands, protect climate, and improve air quality in urban areas (Scott et al. 1999).

b) High Albedo Pavements and Roofs

Albedo is the heat/solar radiation reflectance factor of a material. Its value ranges from 0 to 1. An albedo of 0 means no reflecting power of a perfectly black surface (none reflected, all absorbed), an albedo of 1 means perfect reflection off a perfectly white surface (100% reflected) (Li, 2016). Higher the value, greater the ability of material to reflect heat.

High albedo pavements and roofing surfaces could reflect more solar radiation resulting in cooler pavements and roofs. Proper selection of pavement and roofing material can reduce the UHI. Light colored roofs reflect more heat than dark roofs and also results in less consumption of energy for air conditioning. Muruzzaman, (2015) states that white roofing has an albedo factor greater than 0.60 as compared to black roofing material that has an albedo of 0.05 to 0.10, thus absorbing less heat compared to black roofings. Bretz et al (1998), Akbari et al. (1998) and Konopacki et al. (1997) observed the effectiveness of albedo by using roofing materials of different albedo ranging from 0.20 to 0.60 and they found that the roof temperature dropped by 5°C for 0.60 albedo compared to that of 0.20 albedo. (Muruzzaman, 2015) Taha (1997) also demonstrated that increasing the albedo by 0.15 can reduce peak summer temperatures for urban area in Los Angles by up to 1.5°C. (Fallmann, et al., 2013)

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 – 0.40
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

Table 1 Typical albedos for urban surfaces (US EPA, 1992)

c) Pervious Pavements

Allowing water to penetrate into land will help in keeping the ground cool reducing the surface temperature. Also, evaporation of water from the ground keeps the surface cooler.

d) Water Bodies

Where water is available, evaporative cooling from strategically placed vegetation can further mitigate the thermal environment.

e) Reducing Anthropogenic Heat

There has been many studies and practices that are inclined to reducing building energy use through passive design. By reducing the energy consumption of the building, use of fans and ACs decrease. Lesser use of such electronics reduces the pollution they create which includes CO_2 content thus reducing the atmospheric condition.

Switching to more sustainable mode of transportation can reduce the air pollution thus reducing the CO_2 in the air and resulting in lesser UHI.

f) Wind Path

Promoting proper ventilation through manipulation of geometry of the building, street orientation to utilize the natural of wind can reduce the UHI effect.

3.2 CLIMATE CHANGE AND UHI

Climate Change is a topic that everyone is aware of. According to IPCC (Intergovernmental Panel on Climate Change), climate change is change any change in climate in climate over time, whether due to natural variability or as a result of human activity.

The current warming trend is more alarming because 95% of the cause of warming is the result of human activity since mid-20th Century and proceeding at an unprecedented rate. According to NASA the planet average surface temperature has risen about 0.9°C since late 19th Century. Global warming effects like warming oceans (increase of more than 0.4°F), shrinking Ice sheets (antartica lost about 127 billion tons of ice per year), Glacial Retreat (disappearing snowcaps), Extreme events like high temperature events and intense rainfall.

It is predicted that the global warming will result in frost free season, change in precipitation pattern, more drought and heat waves, stronger and more intense hurricanes and rise in sea level by 1-4 feet by 2100 and bare artic.

On the other hand, UHI is a consequence of regional, local and urban geographical features (Lowry 1977 c.f Alcoforado & Andrade, 2008). UHI is calculated by comparing temperature data from urban and nearby rural meterological stations. Oke 1997, suggests that urban-rural temperature differences may remain constant even in an overall warmer world. Nevertheless, UHI might increase due to exponential increase in temperature in the city air has more amount of green house gases.

Alcoforado & Andrade, 2008 states that cities are the most important source of green house gases and they indirectly impact upon global warming. However, Global Climate Change division under NASA has published that UHI has had little to no effect on the warming of world as scientists have accounted for it in their measurements.

Global warming and UHI have similar causes and effects as well as adaptive/ mitigation measures. Although UHI may not be accountable for global warming according to NASA, but UHI can be agrravated by global warming making cities uncomfortably hot.

3.3 INTRODUCTION TO KATHMANDU VALLEY

3.3.1 LOCATION AND CHARACTERISTICS

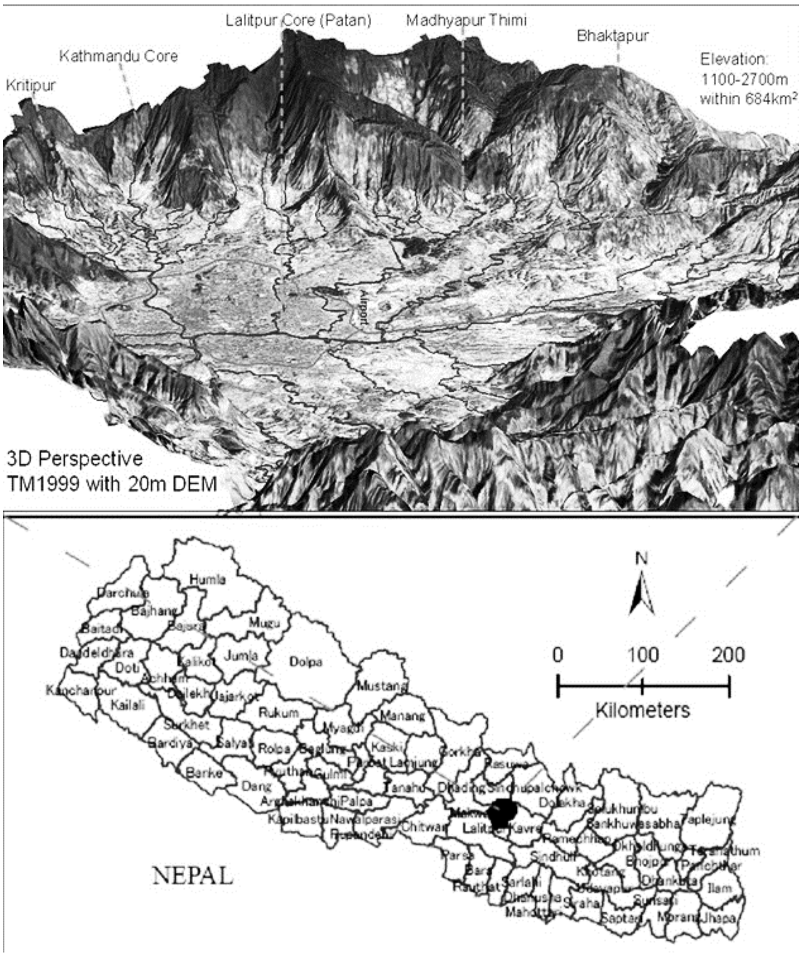


Figure 3 Location map of Kathmandu Valley Data (ICIMOD/UNEP (2001); LANDSAT TM (1999.11.04)

Kathmandu valley has a bowl shaped landscape and lies between latitude of 27$_{o}$, 32’ 13” and 27$_{o}$ 49’ 10” North and longitude of 85$_{o}$ 11’ 31” and 85$_{o}$ 31’ 38” East. It is located at a mean elevation of about 1300 meters (4265 feet) above sea level. It is located in the middle section of the Himalayan range and is surrounded by Phulchowki Hill in South West, Shivapuri in North, Champa Devi in South west and Nagarjuna in west. There are two narrow river gorges in the South-West and North-West edges.

The climate of Kathmandu valley is sub-tropical cool temperate. In general, temperature is 19°C to 27°C during summer and 2°C to 20°C during winter. (Pant & Dongol, 2009) The climate is influenced by tropical monsoon of southeast and receives average rainfall of 1400 mm during June to August. There are three main seasons: winter lies in the month of November to February; summer lies in the month of March to May; and rainy season during June to October (Pant & Dongol, 2009). The general wind direction is from South West to North East and exit through South-East Sanga Hill.

3.3.2 URBANIZATION IN KATHMANDU VALLEY

The valley is the highly populous and urban center of the Nepal. Kathmandu Metropolitan city is the largest city in Nepal and it is the cosmopolitan heart. It is also considered one the fastest growing agglomeration in South Asia (Muzzini & Aparicio, 2013) with a growth rate of 3.94% (UNDESA 2015).

The Factors responsible for rapid urban growth in the valley are physical conditions of the valley, public service accessibility, employment opportunities, real estate market, population growth, political situation and government plans and policies. (Thapa & Murayama, 2009) The Valley is the major economic hub of the country and has major commercial and government agencies in the city core. Also, the political turmoil during Maoist insurgency during 1996 to 2006 displaced many people from various parts of the country to the valley which was deemed the most secure place at that time.

Urban growth in the valley accelerated since 1980s, and the growth rate was substantially high during the 1990 decade (Sharma, 2003). With an area of less than one percent of the country’s total area only, Kathmandu valley accommodates 31% of the total urban population of the country (CBS portal, 2017). The Kathmandu Valley is characterized by sustained population growth in the urban core and rapid urban sprawl. (Muzzini & Aparicio, 2013)

Lack of effective planning and inadequate infrastructure has created blockade to sustainable urban growth of the Valley. The growth of built-up areas in the most urban settlements is haphazard and uncontrolled with a rapid loss of agricultural land. This unplanned urban development has contributed to dramatic changes in urban footprint of the Valley. According to Muzzini & Aparicio, 2013, if urban development continues through both infill in existing urban areas and outward expansion, the valley will face unprecedented stress on land resources, losing river and forest ecosystems and other environmentally sensitive areas by the next decade. The rapid and haphazard growth has made the valley vulnerable to uncontrolled densification, substandard housing, lack of open space and lack of accessibility.

3.3.3 ASPECTS OF URBANIZATION THAT CAN LEAD TO UHI

1. Decreasing Green surfaces and Increasing Urban Footprint

The built-up area has expanded rapidly and consistently mostly in the valley floor increasing from 3% to 23% of the total landscape from 1967 to 2010 (Figure 4) according to Department of Environment, 2017.

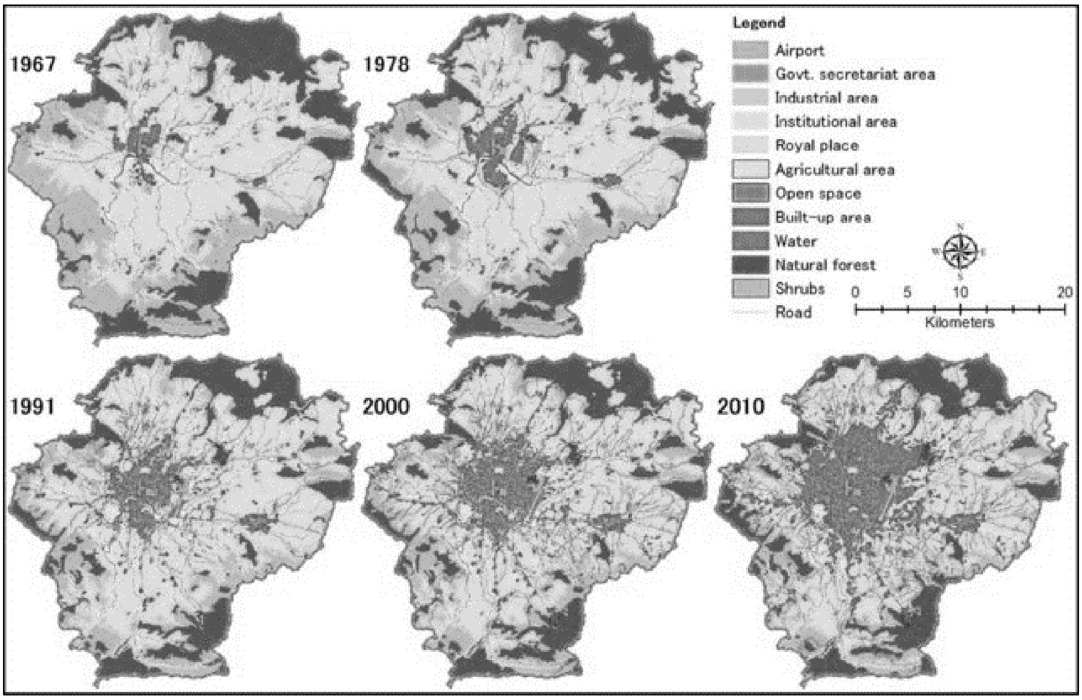


Figure 4 Urban growth of Kathmandu valley from 1967 to 2010 (Thapa, 2012)

Land Use Type	1967 (%)	1978(%)	1991(%)	2000(%)	2010(%)
Urban/ Built-up	2.94	4.91	9.22	14.19	23
Open Space	0.15	0.14	0.20	.025	0.2
Water	1.95	2.02	1.96	1.85	0.9
Agriculture	52.07	51.40	56.46	53.83	47
Shrubs	19.81	17.71	11.87	10.44	9
Forest	23.08	23.83	20.29	19.43	20

Table 2 Land use statistics from 1967 to 2010 (Thapa, 2012)

Expansion of built up are has reduced the agricultural land and shrubs land. Although the forest cover around the valley is observed to be low in decreasing trend. (Table 2) In addition, the open area hasn't increased with increase in urban area.

2. Increasing Impermeable Surfaces

There are over 2 million households in Kathmandu valley and more than 80% are made of cement mortar and concrete blocks.

About 90% of the total roads (230km approx.) in Kathmandu district is black topped while about 60% of roads (131 km approx.) in Lalitpur is black topped. All the national highways and strategic urban roads except for some sections of the urban road in Lalitpur District are black topped according to Department of Roads report, 2017.

3. Increasing Vehicular Movements

There has been significant rise in the vehicle numbers in the Kathmandu valley. Currently more than 1 lakh vehicles are added in the valley every year as shown in Figure 5

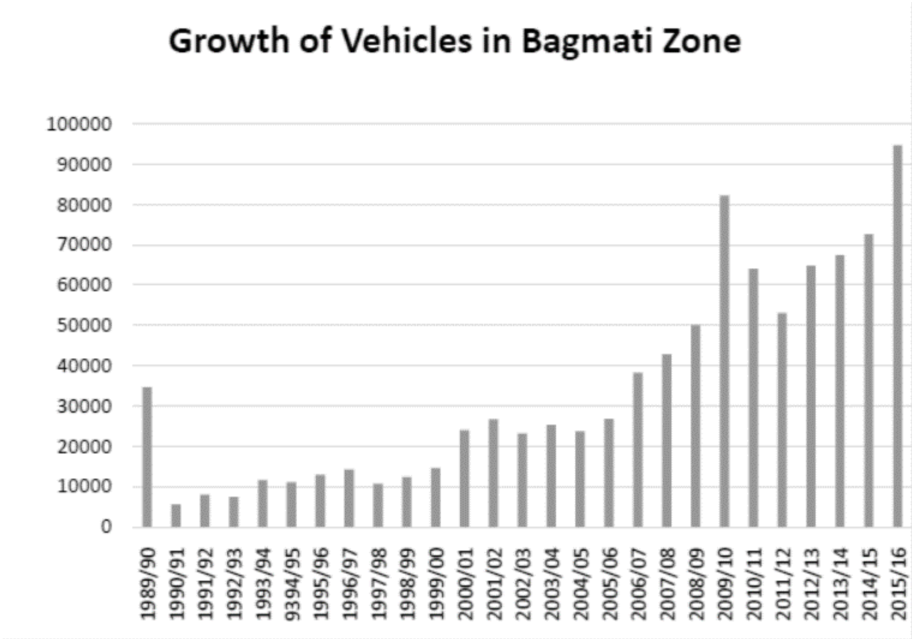


Figure 5 Growth of vehicles in Bagmati Zone (Department of Transportation Management, n.d.)

4. Increasing Population

With 51% growth from 2001 to 2011, the total population of Kathmandu valley is expected to reach almost 6 million by 2031. (CBS, 2014) CBS 2011 states that three quarter of population density inside Ring road in 2011 was over 20000 people/ sq.km while old town area has over 100000 people/ sq.km. density.

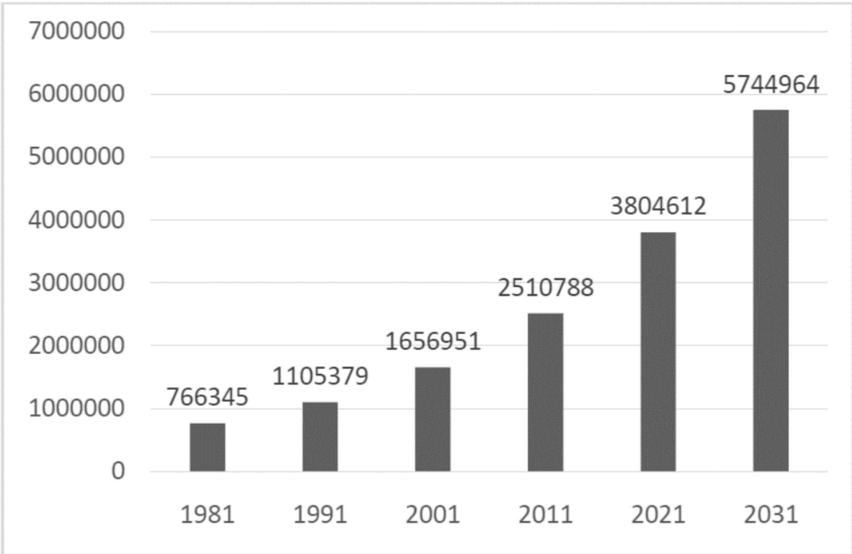


Figure 6 Population growth in Kathmandu Valley (CBS, 2014)

5. Natural Low Wind

As the Valley is surrounded by natural hills on all sides, the winds are rather calm. Low wind lack ability to flush out stagnant heat and polluted air from the valley contributing to UHI.

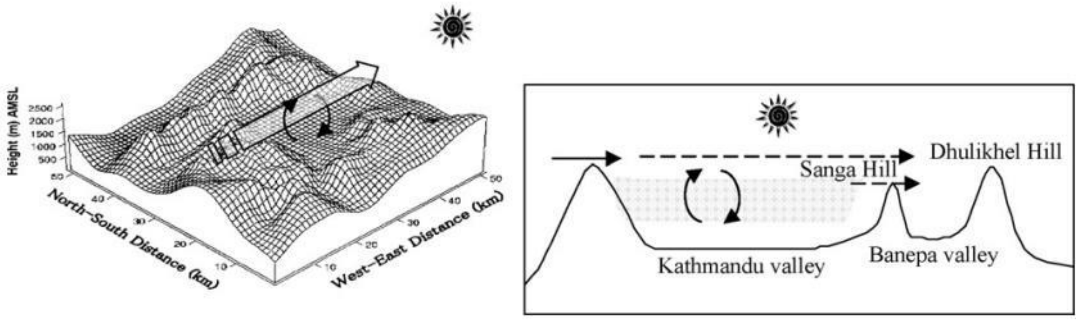


Figure 7 Low Wind in valley due to surrounding hills (Department of Environment, 2017)

4 CASE STUDY

4.1 NATIONAL CASE STUDY

4.1.1 KATHMANDU VALLEY

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

Thapa (2017) (c.f Baniya, et.al 2018) stated that the warming trend is high in the inner core of Kathmandu Valley ranges and it ranges from an annual temperature trend of 0.5-0.8°C in between 1976-2008. In the study of Baniya et.al. (2018), he states that rate of increasing temperature in the valley is higher in core compared to area in the outskirt of the valley like Nagarkot (0.02°C per year)

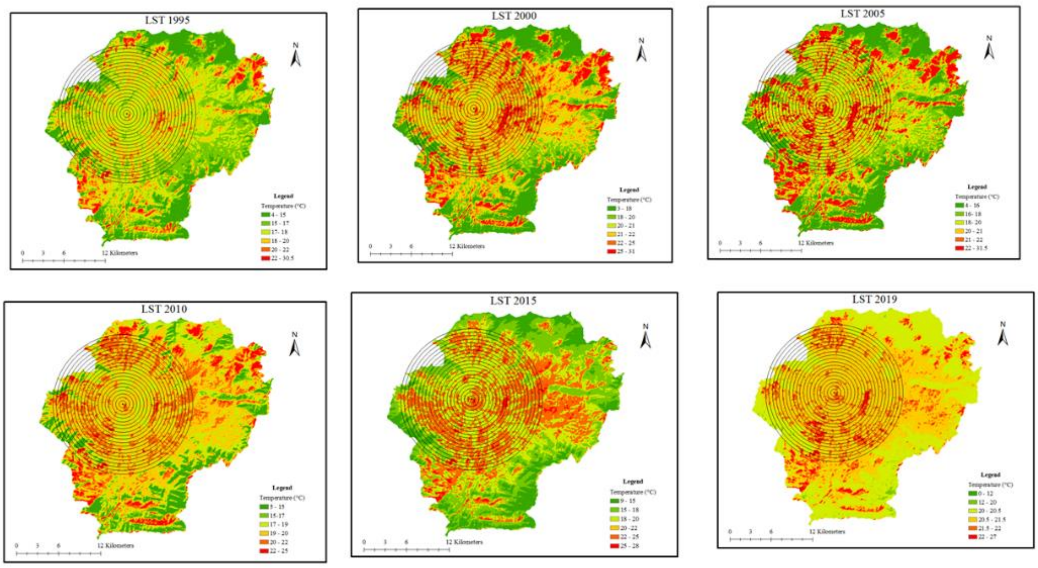


Figure 8: Land surface temperature of Kathmandu Valley from city core to fringe (Rai, 2019)

Study of Rai (2019) and Mishra et. al. (2019) also suggest that the temperature is increasing in the valley. The study of Rai (2019) carried out using Landsat-TM and Landsat 8 while the study of Mishra et al. (2019) were developed in ArcGISPro using Landsat 5 Thematic Mapper (TM) and Landsat 8 Over Land Imager (OLI) 30-meter imagery for deriving the NDVI. The study of Mishra et. al. (2018) revealed that temperature in Kathmandu increased by 0°C to 2°C between 2000 and 2018. According to Rai (2019) majority of cities observed a temperature of 17-18°C in 1995 which increased to 20.5-21.5°C in 2019 almost 3°C in 24 years.

In the study of Mishra et al. (2019) the land areas have been segmented into 3 broad classes: development, forest, and agriculture. Change in natural vegetation was monitored. The NDVI values suggested that greenery inside the valley has decreased significantly and the vegetation outwards have also been replaced by development of semi-urban areas. The study also shows how temperature is increasing outside the core of Kathmandu city in those areas where new urban and semi-urban areas are expanding. The study showed the difference between the forest LST and developed and agricultural land has a potential UHI of 5°C.

	2000			2018			Change %			
Name	***Forest***	***Dev***	***Ag***	***Forest***	***Dev***	***Ag***	***Forest***	***Dev***	***Ag***	***Name***
Kathmandu	132.9	57.2	224.0	115.0	81.5	213.5	-13.5	42.4	-4.7	Kathmandu
Lalitpur	44.9	17.1	86.4	34.4	26.5	86.2	-23.4	55.5	-0.2	Lalitpur
Kavrepalanchok	97.2	9.1	147.5	81.4	3.6	167.1	-16.3	-60.6	13.3	Kavrepalanchok
Bhaktapur	23.9	8.7	90.2	18.5	19.4	84.8	-22.3	123.4	-6.0	Bhaktapur
Makwanpur	71.2	5.6	54.6	60.8	1.4	63.6	-14.7	-75.7	16.5	Makwanpur
Nuwakot	40.8	4.9	57.3	37.5	0.9	63.2	-8.1	-80.8	10.3	Nuwakot
Dhading	33.0	4.0	55.1	29.7	2.2	59.8	-9.8	-43.7	8.6	Dhading
Sindhupalchok	24.1	3.0	39.7	20.4	1.9	44.3	-15.5	-38.9	11.7	Sindhupalchok
totals (sq. km)	468	109	755	398	137	783	-15.0	25.5	3.7	***totals (%)***

Table 3 Land Cover (2000 and 2018) and Land Cover Change Over time by Districts (Mishra, et al., 2019)

Both the study of Mishra and Rai shows how the temperature is higher in the core. Rai (2019) suggests that the haphazard expansion of city area, increased impervious neighborhood and decreasing green land has led to Urban Heat Island Effect in the Valley. However, Mishra 2019 believes more study combining NDVI, population and socio-economical attributes are needed to determine the cause of UHI.

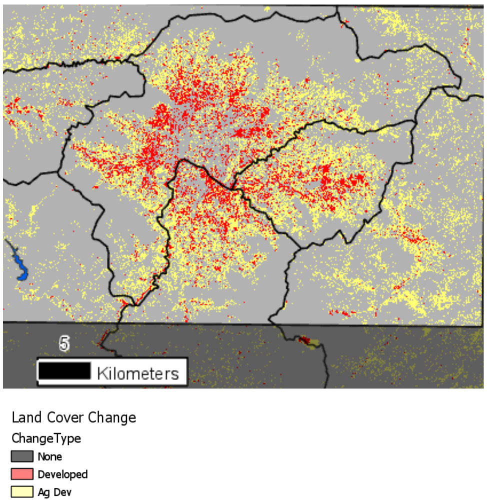


Figure 10 Land cover change type experienced from year 2000 to 2018

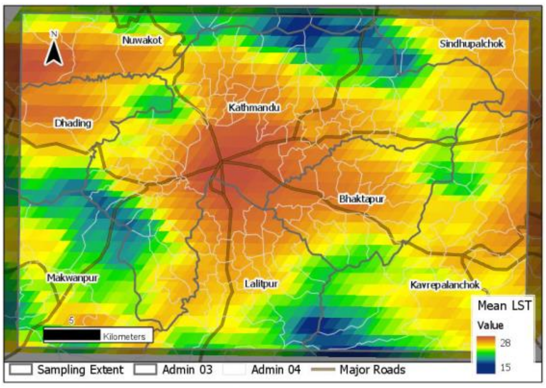


Figure 9 Mean daytime surface temperature distribution for Kathmandu during the period of 2000 to 2018, driven largely by land cover such as, the heavy developed areas in central Kathmandu, and elevation (Mishra, et al., 2019)

Inference:

The studies have all been done using Landsat imagery but Kathmandu is a valley with wide range of elevations. Presence of difference altitudes means difference in temperature which occur naturally. Nevertheless, studies show how the temperature is increasing in the core compared to the undeveloped fringes. In addition, the studies rise in temperatures can be observed in the newly developing areas at the fringes which are growing into hotspots in the Valley.

Decreasing greenery, increasing population and increasing dense impervious surfaces are causes for warming Kathmandu Valley. Such changes will increase the temperature which increases the health risks due to UHI.

4.2 INTERNATIONAL CASE STUDY

4.2.1 STUTTGART, GERMANY

4.2.1.1 LOCATION AND GENERAL INFORMATION

Stuttgart is the largest city of German State Baden-Wurttemberg in the Southern part of Germany. It is sixth largest city in Germany and fourth largest metropolitan in Germany covering an area of 207.35 km^2 with a population of nearly 6 million. It has a population of 6 million out of which 2.6 million live in the center of metropolitan region. The population density is about 5410 person/km^2 (Rinke, et al., 2016).

4.2.1.2 GENERAL CHARACTERISTIC OF STUTTGART

Stuttgart is a bowl shaped valley about 240m above sea level surrounded by hills ranging up to 500m from sea level. It is a wide basin formed by two river valleys and shielded by steep hill slopes. To the west of the city is Black Forest and the Swabia Alb lies in the south.

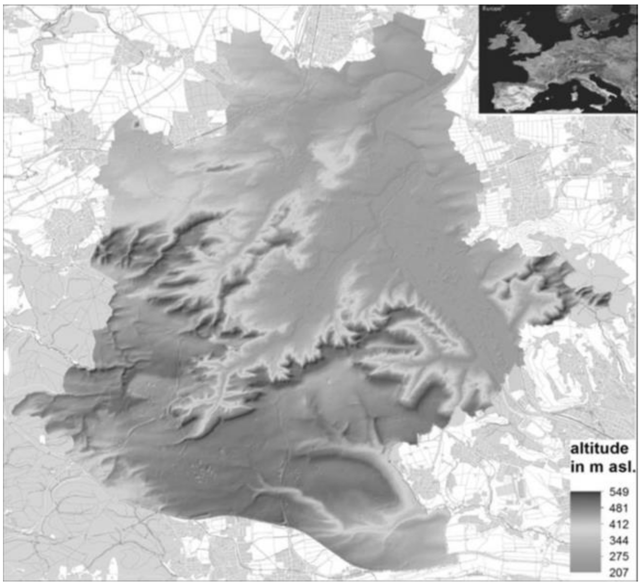


Figure 11 Topographic map of Stuttgart City area (Rinke, et al., 2016)

4.2.1.3 CLIMATE OF STUTTGART

Stuttgart has a mild climate with an average annual temperature of about 10°C in the basin of the city and about 8.4°C in the elevated outskirts. The average wind speed per year is about 1.5 m/s in the city center and about 2.5m/s in the higher regions. The location and geography of the city has a significant influence on local climate including implications for solar radiation, air temperature, humidity, precipitation and wind.

4.2.1.4 UHI IN STUTTGART

Because of the low wind condition and the topographical characteristics, there is an issue of insufficient natural air ventilation as well as heat island effects, especially in the city center. The center is also subjected to industrial activity and high volume of traffic which along with low wind has made the city susceptible to poor air quality. Development on the valley slopes has prevented air from moving through the city, which worsens the air quality and contributes to the urban heat island effect.

In 2008 UHI Project (implemented to develop mitigation and risk prevention and management strategies concerning urban heat island phenomenon in Europe), many measures and recommendations were put forwards based on topography, development density and character and provision of green space and roles of air exchange, air flow in Stuttgart.

“The following principles formed the basis for planning recommendations:

- Vegetation should be placed to surround developments and larger, connected green spaces should be created or maintained throughout developed areas to facilitate air exchange
- Valley serve as air delivery corridors and should not be developed
- Hillsides should remain undeveloped, especially when development exists in valleys, since intensive cold and fresh air transport occurs here
- Saddle-like topographies serve as air induction corridors and should not be developed
- Urban Sprawl is to be avoided
- All trees growing in the urban core with a trunk circumference of more than 80cm at a height of 1m are to be protected with a tree preservation order.” (City of Stuttgart, 2014)

Stuttgart currently is one the coolest city. ‘‘Stuttgart’s climate planning strategy is seen as one of the best examples of heat island management in the world. Stuttgart has been planned not only to respect and protect nature, but to exploit how natural wind patterns and dense vegetation can actively help the city to reduce its problems of overheating and air-pollution’’ (Rehan, 2014)

Stuttgart is one of the greenest city in Germany. According to Rehan (2014), more than 60% of the city is green. Greenery in city can be found in forms of vineyards, forests, parks, etc. 39% of the surface area has been listed as protected green belt or nature conservation area in Stuttgart. "Stuttgart contains 5000 hectares of forest and woodland, 65000 trees in parks and open spaces and 35000 street trees. 300000 sq.m. of the rooftps have been greens and 40 out of 250 km tram tracks have been grassed as of 2007. 60 hectares of greenfield land previously marked for development has been cut from the 2010 land development plan to protect existing green space. Targeted interventions such as a building ban in the hills around the town, and prevention of building projects that might obstruct the ventilation effect of nocturnal cold-air flows have resulted in preservation and enhancement of air exchange and cool air flows in the city." (City of Stuttgart, 2014)

Major emphasis has been given to public participation in greening strategies. Since 1986, the City of Stuttgart has provided financial support to green about 60,000 square meters of roofs. Since 1992, a scheme has been in place for Stuttgart residents to adopt a tree. Today some 182 caretakers have adopted almost 500 trees. They are responsible for watering the tree, reporting pest attacks, removing the leaf litter and fallen branches, and protecting the tree from dog fouling. (City of Stuttgart, 2014)

According to (Rinke, et al., 2016), the sheltered position between the surrounding mountain leads to frequent development of local wind systems specially in slopes and in the valley. With a large area in the surrounding and in the city at night cold air is produced that generate cold air streams. Despite the low speeds of this wind they have a significant role in ventilating and cooling the city. Generally, UHI in Stuttgart is identified as 1-2°C but it can reach more than 5°C. UHI makes Stuttgart inner city into a region with high heat stress.

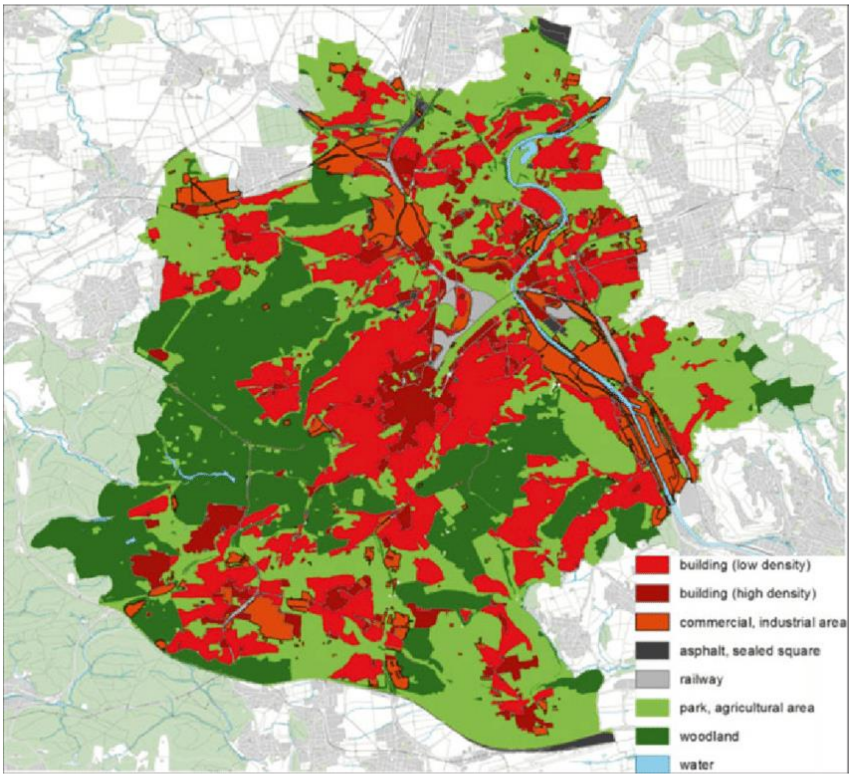


Figure 12 Land use map of Stuttgart (Rinke, et al., 2016)

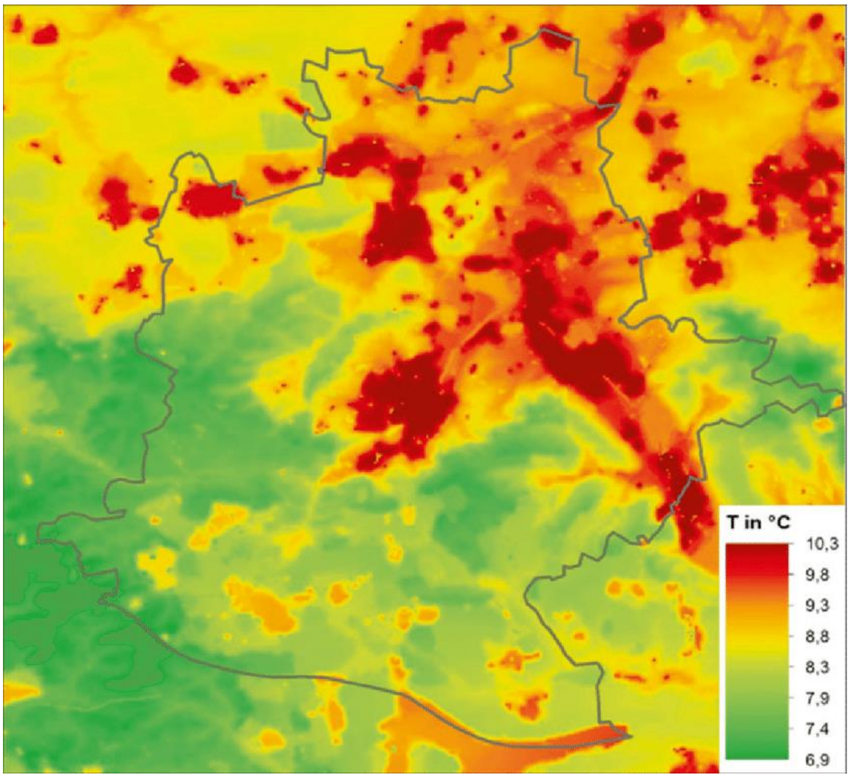


Figure 13 Temperature in Stuttgart

4.2.1.5 STRATEGIES ADOPTED BY STUTTGART

1. Green Corridors

Using construction bans at strategic places and green corridors, Stuttgart have created wide tree-flanked arteries within the city's street infrastructure. These ventilation corridors allow clean air to sweep down from the surrounding hills to the city at night.

Figure 14 Wind paths in Stuttgart

2. Green infrastructure

Figure 15 Nectar river cycle path

Strategic planning of green infrastructure which have been directed towards the improvement of essential linkages between green spaces and places of employment and living can be seen in Stuttgart.

The essential linkages are the development axes mainly along river valleys like Neckar, the Rems and the Fils, particularly for commuters within in Stuttgart Region (Rehan, 2014). **The Nectar river cycle path** is an important artery for commuters and tourists and is considered one of the greenest infrastructure. The route allows green, safe and efficient transportation between industrial and commercial centers and residential and leisure areas.

3. **Urban Parks**

Since the 70s the city has integrated green areas into large green 'U' which makes it possible to go through park environment all the way from central royal gardens to the forests at the city edges. The green "U" is an urban massive public park in the shape of a U. Stuttgart also has a lot of parks such as Mansion Mountain Park, the Wilhelma, the Leibfried Garden, the Waiting Mountain and the Killesberg Elevator Park.

Stuttgart's land-use plan is **urban-compact-green**. One of the example of this plan is Stuttgart 21 project. The concept was to replace the terminal station by underground track through station and pump natural day lighting down onto the sub terrane tracks.

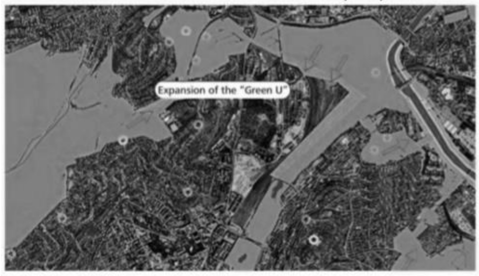


Figure 16 The Great U- green areas in Stuttgart

Using photovoltaic cells, the whole complex is virtually zero energy consuming. The objective of the project is make city more sustainable and cooler by maintaining the continuity of Rosenstein Park by transforming present rail tracks into green urban places. For sustainability, huge skylights and light wells were installed too.

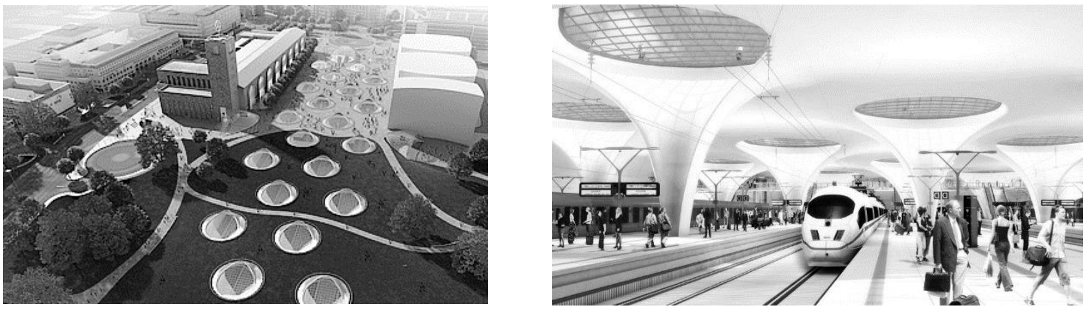


Figure 17 Stuttgart-21 Project

4. **Cool Buildings**

Many main public buildings are designed with concept of passive heating and cooling. Since 1993 all the new buildings in Stuttgart have been greened. Stuttgart has more than 300,000 sq.m. of green roofs. Even the public buses are applying green roof concept to the system's busses.

Figure 18 Green roofs in Stuttgart

5. Urban Water

Since flowing water has a cooling effect, Stuttgart has many fountains in the urban area and numerous lakes can be visible along the Rosenstein Park (Green U Park) which is located centrally in the city.

6. Materials

Materials like brick radiate heat into air during nighttime until sunrise accumulating heat in the atmosphere. Most of the facades in Stuttgart are therefore light colored.

Despite being a valley and an industrial area, Stuttgart is able to maintain a better environmental quality with cool atmosphere exploiting natural resources to combat UHI. With proper mapping and planning and clever use of vegetation and green infrastructures, Stuttgart is one of the coolest city despite the constraints.

4.2.2 SINO-SINGAPORE TIANJIN ECO-CITY, CHINA

4.2.2.1 ECO-CITY CONCEPT

Eco-city concept, founded by Richard Register, is a new concept developed with an idea of reconstructing cities that are balance with nature. It is the developed as a response to global climate change. Eco-city concept is built off the principles of living within the means of the environment in advanced cities, avoiding all the negatives effects of urbanization. The main aim of an eco-city is to eliminate all carbon emission with total dependency on renewable sources and incorporation of environment into the city. Eco-city concept also has a goal to increase economy, reduce poverty, increase population density in cities all the while improving efficiency of the city and improving health.

Chinese government are developing new-build eco-city projects reflecting the Chinese Government's goals to build a 'harmonious society" in which environment sustainability and social stability are mutual reinforcing (Caprotti, et al., 2015). Due to rapid urbanization and industrialization, China is facing severe resource and environmental problems. Expansion of urban scale, population growth and industrial agglomeration has changed the ecological patterns and have resulted in heavy emissions of pollutants to the extent that China was placed at the top of the list among countries with heavy air pollution in 2017.

Furthermore, the most appropriate land for settlement across the country occupies only 19% of the total land of China, which is densely cultivated land. Among the existing cities, more than 400 cities lack proper water facility and 110 cities suffer from water shortage. 90% of the rivers passing cities are severely polluted. As a response to the critical state of the country, China has invested on development of Eco-cities. The Sino-Singapore Tianjin Eco-city is regarded as the most typical case of Eco-City Planning.

4.2.2.2 LOCATION AND GENERAL INFORMATION

The Sino-Singapore Tianjin eco-city (SSTEC) is urban mega-project developed by Singapore and China with central involvement of International read-estate development corporation to be completed in 2020.

Tianjin Eco-City is located in the Bohai Rim region, one of China's foremost industrial areas, on the outskirts of Tianjin. It is located 40 km from Tianjin City center and 150 km from Beijing City Center.

Figure 19 Location of Tianjin Eco-City

Spread on an area of 30 sq.km., SSTEC was built on a wasteland comprising of salt pans, barren land and polluted water bodies including a 2.6 sq.km. wastewater pond. The city, planned to support 350,000 residents, places a strong emphasis on landscaping as residential towers rise amidst parks, promenades and valleys that create plan's primary network. (Arch daily, 2011)

26% of the land is designated for open space, water and greenbelt. The remaining 25 sq.km. of the land will be used for residential area making the density 14000 people/sq.km.

4.2.2.3 OBJECTIVE of SSTEC

- Developing a city with integrated approach to planning a new urban area in environmentally sustainable manner.
- Providing quality lifestyle by integrating land use and urban transport considerations and balancing employment and housing supply.
- Using Clean renewable energy source and reuse/recycle of resources.
- Promoting efficient circular economy through development of ecological industrial system

4.2.2.4 PLANNING OF THE CITY

The master plan of Tianjin Eco-city is a combination of 1 axis, 3 centers and 4 districts. The Axis refers to "Eco-Valley" which runs across the eco-city linking the 4 eco-districts and 3 centers: The City center and two Sub-centers at North and South.

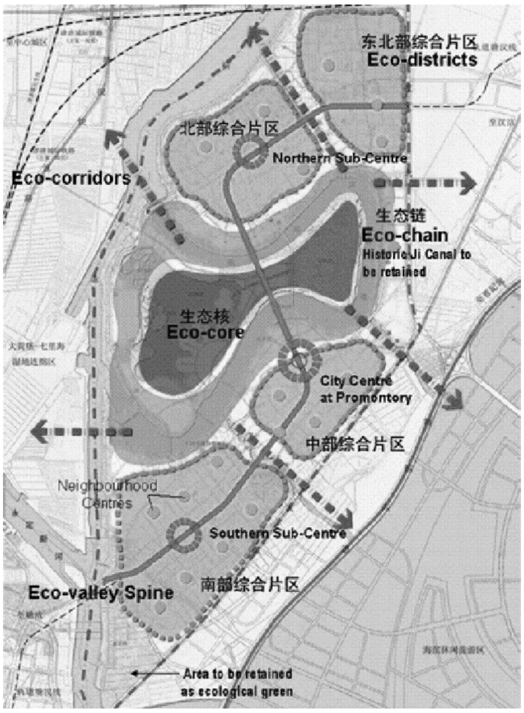
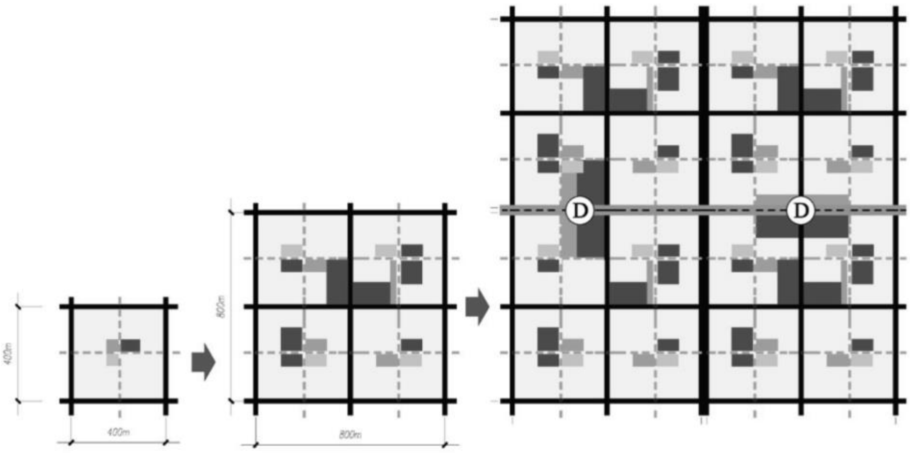


Figure 20 Planning of SSTEC (Haq, 2020)

Four Eco-districts of SSTEC are located in Southern, Central, Northern and North- Eastern Parts of Eco-city. An "Eco-District" is a combination of 4-5 Eco-communities. An Eco-community is a cluster of 4 Eco-cells. Each Eco-cell is a 400 x 400m building block that accommodates about 800 residents.

Each Eco-cell has a "Grassroots Community center" with a service radius of 200-300 m. An Eco-cell has four quadrants with pedestrian and bicycle lanes only. Roads run along the perimeter of each Eco-cell.



Eco-cell Eco-community Eco-district

Figure 21 Units of Eco-district (Haq, 2020)

Figure 22 Land use plan of SSTEC (Haq, 2020)

SSTEC is divided into six Categories of FAR allowed. The FAR ranges from low intensities along the waterfront and ecological corridors to higher intensities around the railway stations and in the city center.

4.2.2.5 STRATEGIES OF SSTEC

1. Transportation System

The city is planned with compact walkable communities. With a good mix of land uses, each district is served with amenities at walkable distance. Even Business Parks are located near residential areas so the jobs are at walkable distance.

The planning itself encourages pedestrianization, non-motorized modes of transports and public transportation.

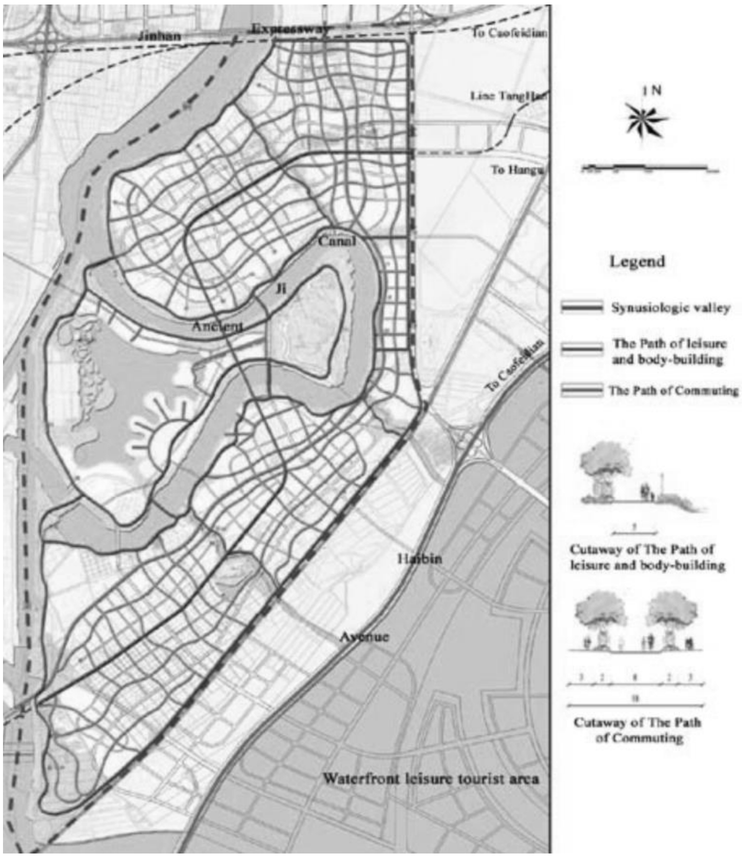


Figure 23 Green traffic system of Eco-city

For ease, 5m Wide Cycling Paths are planned on both sides of the road.

Separate networks for non-motorized and motorized lanes are provided to reduce conflicts. A tram line running along the Eco-valley to promote use of public transport. To reduce carbon emission, the advance light rail system is encouraged.

2. Green and Blue Networks

The city is planned with extensive Green and blue networks. Green network comprises of green lung at the core of the eco-city and green-relief eco corridors emanating from the lung to other parts of the eco-city. (Haq, 2020) Water Bodies are linked together for greater water circulation. This provides opportunity for better scenic environment for water front development and water based recreational activities. The waste water pond is cleaned and turned into a beautiful lake.

3. Use of Renewable resources

Tianjin eco-city is planned as a city that is partly powered by renewable energy and will function as a testing ground for environmental technologies. The plan places a significant focus on renewable power generation (especially wind and solar) (SSTEC, 2010; SSTECIDC, 2010a c.f. Caprotti, et al., 2015). The plan also calls for utilizing heat emitted from industrial sources that would otherwise have been wasted: SSTEC 'will draw on waste heat from a major nearby power plant to provide district heating' (SSTEC, 2010).

Eco-city is to be equipped with latest sustainable technologies such as solar power, wind power, rainwater recycling and wastewater treatment/ desalination of sea water.

60% of household waste will be recycles and electricity will come from renewable energy sources like wind solar and geothermal while transportation will rely on hybrid vehicles.

4. Extensive use of Passive design

The buildings in Tianjin are planned to utilize natural wind pockets and light sources. Commercial buildings will feature buildings integrated with natural lighting, façade shading devices, green roofs and vertical greens and minimized north facing opening to prevent heat loss. The design guidelines encourage the residential building to adopt South-north orientation with a generous building gaps in between to make use of natural light and ventilation.

5. Parks

26% of the land is designated for open space, water and greenbelt. Among the green parks the most notable is Tianjin Ribbon park. 75-acre Tianjin Ribbon park not only provides an ambient environment for visitors but also restores storm water retention to clean the river and cool the Central Business District. Friendship park to be located in center of the city on the Gu Dap Canal will have varies of spaces for different use groups and experiences.

SSTEC is one of the prime example of Eco-city. SSTEC is carefully planned to incorporate large population and develop a city that incorporates nature with minimum GHG emission.

4.2.3 DELHI, INDIA

4.2.3.1 LOCATION AND GENERAL INFORMATION

Delhi is the capital city of India. It is one the major metropolitan cities of India spread over an area of 1484 sq.km. The maximum density of Delhi was 11297 persons/ sq.km according to Census of India (2011). The population of Delhi is about 27 million. (Budhiraja, et al., 2020).

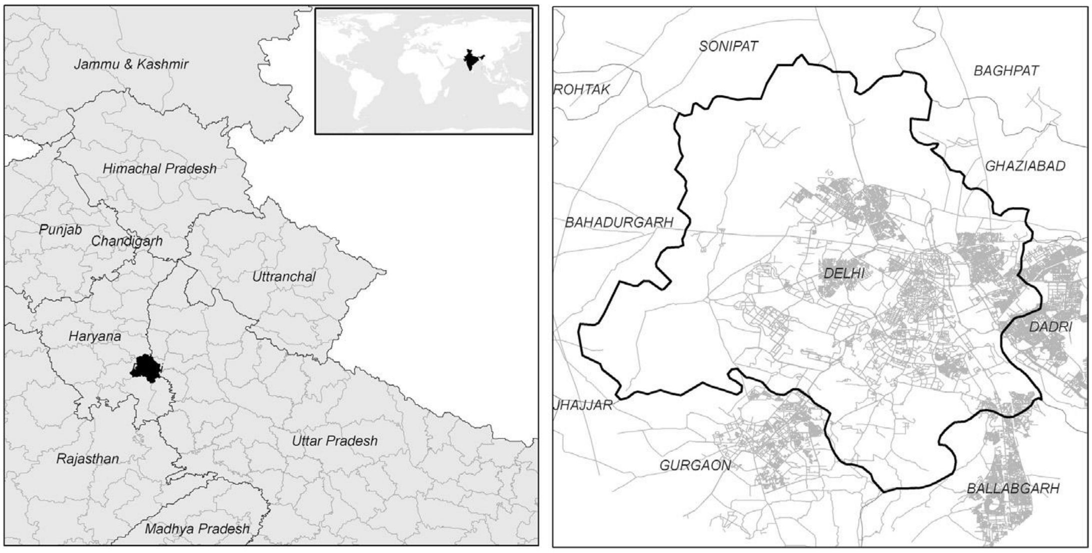


Figure 24 Location of Delhi, the capital of India

4.2.3.2 GENERAL CHARACTERISTICS

The city is a flat terrain with elevation ranging from 213 to 305m above sea level. River Yamuna flows through the Northeastern edge of city. There is a forest in the heart of Delhi. The city exhibits a wide range of land use from highly urban centers of commercial activity and residential areas to rural agricultural lands.

4.2.3.3 CLIMATE

The climate of megacity of Delhi is classified as Köppen climate between monsoon-influenced humid subtropical and semi-arid. Delhi has five distinct season: winter, spring, summer monsoon and autumn.

The average temperature of Delhi is around 25.1°C (Climate-Data, 2020). Highest average temperature recorded was 34.1°C in June and lowest average recorded 14.2°C in January. The average precipitation is 800mm concentrated in monsoon season.

4.2.3.4 UHI IN DELHI

The megacity of Delhi is a rapidly urbanizing agglomeration with fast horizontal as well as vertical growth of concrete areas. It is also one the few metros that possess reserved forests, protected forests, wildlife sanctuary and city forests. (Sinha, 2014 c.f Solanki & Garg, 2017) As per the India State of Forest Report, 2015, Delhi has a forest cover of total 188.77 sq km (12.73% of total geographical area) (ISFR, 2015). (Solanki & Garg, 2017)

Most of the Built-up area is in the central and eastern parts of Delhi. New settlements are scattered in the northern and south western area due to presence of restricted areas like administrative buildings, foreign embassy, presidential estate, etc.

The built up area of Delhi has expanded by 50% from 2001 to 2017 with development in North, North-West and South west directions.

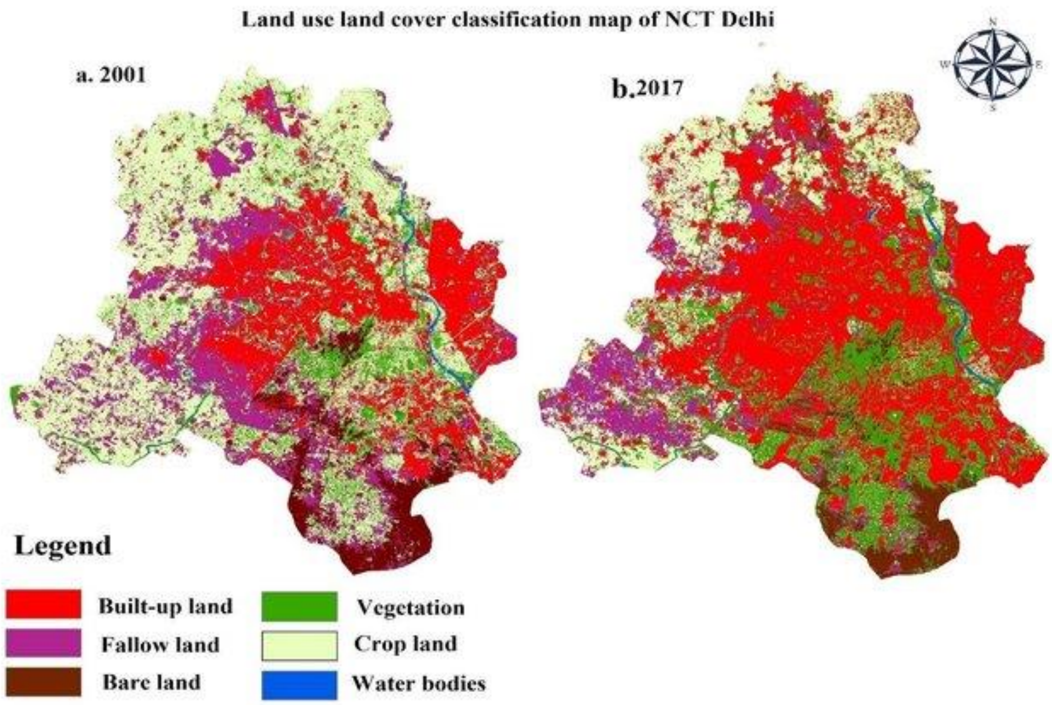


Figure 25 Landuse land cover change in NCT Delhi (Pramanik, 2018)

Study of Sharma & Joshi, 2014 showed a presence of higher temperature in urban areas of Delhi. The city centers were found to have the highest temperature during spring and monsoon which shifts to south-west part in summers and post-monsoon during the harvesting seasons. (Sharma & Joshi, 2014)The fallow agricultural land has low thermal capacity.

High UHI effects were found in major commercial and industrial sites across the city and the airport area. (Sharma & Joshi, 2014) The industrial zones are comprised of high density built up and devoid of green cover. The high activity commercial zones have dense built-up that exhibit poor thermal insulations.

The study done by Pramanik (2018) shows that LST was concentrated from the South to the south West, North and North East (similar to study by Sharma 2014) but during the night-time LST was mainly concentrated in the central portion of Delhi, where the built-up area is maximum in proportion as shown in Figure 26.

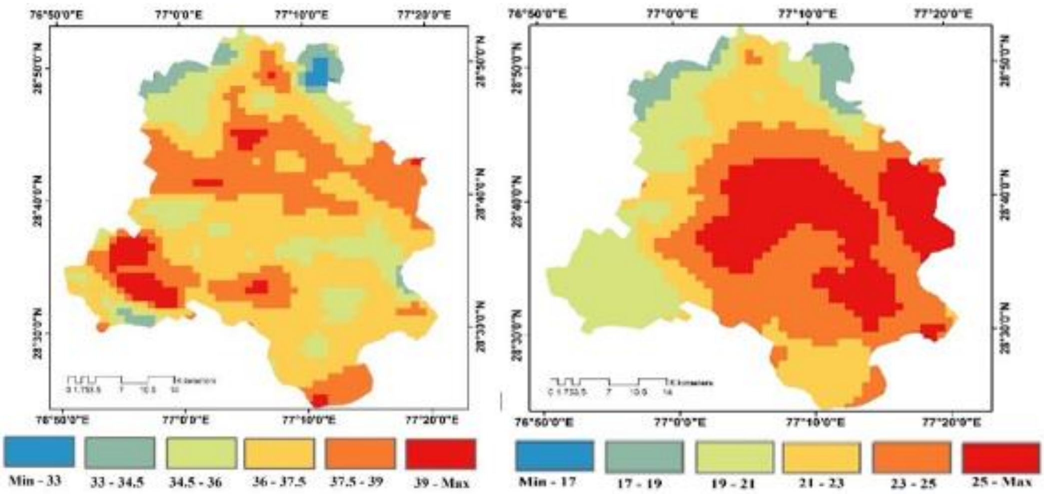


Figure 26 LST at daytime (Left) and nighttime (Right) on 30th March 2017 (Pramanik, 2018)

4.2.3.5 STRATEGIES ADOPTED BY DELHI

There has been many studies and concerns regarding the development of UHI in India. Many cities including Delhi have faced heat waves. Delhi has faced temperature to heat waves with temperature as high as 47.6°C in May 2020. However, specific actions directed to overcome Urban Heat Island are lacking.

To improve sustainable cooling and thermal comfort for while securing environmental and socio-economic benefits, India has put forth India Cooling Action Plan (ICAP) Draft under leadership of Ministry of Environment, Forests and Climate Change. ICAP aims assess cooling requirements across sectors in next 20 years.

Some of the recommendation include:

- Approaches for energy efficient buildings with mandatory minimum indoor temperature (adaptive thermal comfort standard) to reduce cooling requirement and energy consumption
- Adoption of Energy conservation building code for residential and commercial buildings
- Development of heat action plan
- Incentives with awareness campaign to increase demand of energy efficient cooling appliances and equipment
- Improving cooling efficiency of cooling equipment.
- Training AC and refrigerator technicians to promote proper utilization and operation of technology as well as energy efficiency
- Investing in research and development (R&D) of refrigerant gases that do not harm the planet.

The main goal of ICAP is to reduce cooling demand across all sectors by 20-25% and training 100000 technicians to produce more efficient air conditioning and related cooling equipment.

Studies show that many major cities in India are suffering from Urban Heat Island Effect but it has not been addressed directly. Although plan to adjust with Heat waves due to UHI has been drafted which is focused on maintaining a cooler indoor temperature adopting both effective active and passive cooling.

5 POLICIES AND PROGRAMS REVIEW

5.1 CLIMATE CHANGE POLICY 2011

The Fourth assessment of IPCC indicated that global climate change has accelerated due to human activities. Increasing GHG emission is the main contributor to atmospheric temperature rise and change in rainfall pattern. The changes in climate is affecting every sectors from agriculture to health, infrastructure to livelihoods. To minimize the effects UNFCCC (United Nations Framework Convention on Climate Change) opened a convention for countries to participate. Nepal signed this convention on 12 June 1992.

Climate Change policy was introduced after Nepal signed the convention. Although Nepal's contribution to GHG emission is only 0.025% in the world, Nepal is one the country that is likely to be affected more by climate change. Nepal is experiencing maximum annual temperature increase of 0.06°C. The rate of increase is observed to be higher in the mountains. Change in annual rainfall cycle, intense rainfall and longer drought can also be observed. With all these visible impacts, the policy was submitted to address these issues and utilize the opportunity to improve livelihoods and achieve climate-friendly physical, social and economic development.

Under this policy, National Low Carbon emission and climate-resilient development path for sustainable socio-economic growth was proposed to be adopted. For this, National Low Carbon Development Strategy was to be formulated by 2014 and a national strategy on carbon trade to benefit from Clean Development Mechanism (CDM) by 2012.

GHG emission reduction through utilization of clean, renewable and alternative energy technologies were put forth. To assure use of appropriate technology and reduce emission of pollutant at source, incentives was proposed. In transport sector use of electric mode of transportation was suggested. "Polluter pays" principle was adopted to generate financial resources. To promote people's participation and empowerment, information and capacity from local to policy levels were to be updated and published.

5.1.1 NATIONAL LOW CARBON ECONOMIC DEVELOPMENT STRATEGY (DRAFT)

Although this strategy was to be finalized by 2014, it is still in draft stage. To guide the country to follow low carbon development path some goals were set under this strategy. The strategy involves reduction in dependency on fossil fuel by development of hydropower and other renewable energy. Technologies that emit low carbon are to be promoted. Under this strategy, use of environmentally sustainable transport systems are proposed, utilization of waste as a resource put forth and urban plantation are suggested. Also hydropower and renewable energy development (4000 MW by 2020 and 12000MW by 2030) and 2100 MW of solar energy by 2030 is targeted.

Inference:

The policy works to reduce carbon footprint and promote green energy usage. Through incentives such as low or no tax, and principles such as "polluters pay", the policy might reduce the pollution caused through industry and transportation sectors and therefore reduce the carbon emission.

But the strategies to support the policy are not promulgated yet. The strategies that were supposed to be finalized by 2017 are still in draft version. The failure to pass the strategies is a great set-back.

5.2 LAND-USE POLICY 2015

Land Use policy is introduced for protection, promotion and optimum use as well as effective management of Land and Land Resources (LLRs). The growing population of Nepal, uneven migration has led to unmanaged urbanization and encroachment of arable land and forests, government and public lands and various resources. The uneven pressure on land and changes in land geographical and geological condition has paved way for disaster like flood, landslides and soil erosion. To provide a safer settlement, maintain ecological balance and for food security, Land Use Policy 2013 was adopted. The main agenda of Land Use Policy, 2013 was protection of arable land ensuring food security.

The earthquake of 2015 brought into light the need to focus on secured settlement as well and disaster risk mitigation to escape the vulnerability from such devastating disaster. Thus, Land Use Policy 2015 came into existence upon making a review over Land Use Policy 2013. (Ministry of Land Reform and Management (MoLRM), 2015)

Land Use Policy 2015, aims for social, economic and ecological development by optimum use of available Land and Land Resources (LLR) thus leading the country towards prosperity. The objective of Land Use Policy 2015 is to categorize lands into specific land use zones thus making it easy for protection of agricultural land, forest land and develop better sustainable settlement all the while reducing the risk of disastrous hazards.

Problems addressed by Land Use Policy 2015

- Reduced agriculture produce and low productivity due to encroachment of arable land
- Problem in protection of life and property and disaster management due to lack of approach of scientific classification, development and management of land
- Encroachment of arable land, forests, Government and public lands and natural resources
- Ecological degradation and imbalance in biodiversity, reduction of natural resources due to environmental pollution and climate change

- Negative impact in lower riparian areas without proper conservation of Himalayan regions, Hills and Churia Zones
- Lack of open spaces in urban areas

Challenges to Overcome

- Developing a proper utilization of land upon scientific classification in a special manner
- Ensuring institutional and coordinating roles by stakeholders
- Ensuring food security by boosting agriculture and preserving arable lands
- Creating a hygienic, beautiful, well facilitated and safe human settlement for sustainable urbanization
- Mitigating climatic chances and new natural hazards, protecting biological diversities and environment by conserving, developing and managing critical natural resources
- Effectively enforcing LUP once it is formulated

Policies in Land Use Plan 2015

Policies that help conserve the open spaces and promote greenery as well prevent urban sprawl only are cited below for reviewing.

Policy 1: Classification into Land Use Zones (LUZ)

- Agricultural Zone
- Residential Zone
- Commercial Zone
- Mines and Mineral
- Cultural and Archeological Zone
- River and Lake Reservoir
- Forest
- Public Use and Open spaces
- Building Material (Sand, Stone, Concrete) Excavation
- Other Zones as per necessity

The classification is to be done according to existing land use, the capacity of the land, geographical and geological land composition. A well-studied geographical and geological land composition can reduce human and property loss factor by assigning lower risk zones for high human density areas. Moreover, such classification can help in conservation of arable lands, forests and other public spaces as use of land not conforming to specification is prohibited. Classification of land use allows for better control over the development of land and unchecked urbanization as different land requires different set of rules and regulations suited for its specific land use type. It also helps ease budget distribution according to the need of specific zones.

Policy 3: The use of Land and Land Resources (LLR) ensured on the basis of Specific Land Use Zone (SLUZ) and Land Use Plan (LUP)

The land use plan is to be devised according to land resources available. The classification therefore helps in optimum utilization of the resources in that zone. This check for overexploitation thus preventing environmental degradation and avoiding induced disaster risks.

The policy also ensures proper land use and has strategies in place to promote the use of land as intended by discouraging improper use and revoking the land use not conforming to the policy 1.

Policy 5: Optimum use and protection of arable lands shall be ensured of upon discouraging of non-agricultural use of arable lands and trend of keeping land fallow and rampant fragmentation

Agricultural zones have been allocated in various parts for food security. To promote agriculture in these zones, grant and/or compensation has been facilitated. Irrigation channels have also been assigned thus encouraging commercial farming. Highlands of mountainous regions, land with irrigation facility and under command area of planned irrigation are classified as agricultural zones. These lands are provided with specified facilities.

Any non-agricultural land use or land left vacant in these zones might be imposed with additional tax. This prevents encroachment of agriculture land as well as promotes densification of the core areas.

Policy 6: A hygienic, beautiful, well-facilitated and safe human settlement as well as a planned and sustainable urbanization of the country shall be ensured of.

The earthquake of 2015 spread light upon many residential areas on high risk lands as well as risk due to unmanaged sprawl. For safe human settlement, the policy states that residential zones be allocated in less risk areas according to geological study to reduce the impacts in case of disasters. It has strategies in place vulnerable or unsecured human settlements to be moved to safer areas and prevent any further high risk development in such zones. New towns to be proposed shall have proper planned infrastructure with standard bye laws and proper demarcation of open spaces as safe zones.

Also, need of new secured low cost housing for the landless or people who have difficult access to land is addressed which prevents squatter settlements, encroachment of open spaces, forests and public areas. This diminishes environmental degradation as well as maintains necessary open spaces. For this, Government/ public-private partnership (PPP concept) and/or public-cooperatives are encouraged to participate.

Policy 7: Conservation and optimum use of forests and other natural heritages shall be ensured of.

Demarcation of forests and reserve areas in land use plan indicates the maximum protection of green areas to integrate with the planning process thus preventing deforestation. In case there is use of forest area for any National Priority Project, the policy demands equivalent or more afforestation.

The policy mainly focuses on conservation of Churia Bhabhar Hill Area and relocation of vulnerable human settlement from sensitive part. It also suggests forest area having bio track for living being or potential biodiversity to be converted into forest reserve.

The policy also focuses on conservation of water shed areas, wet land areas, reserves, intermediary areas, national parks and wildlife reserves and pasture areas to maintain ecological biodiversity.

Lands in mountainous and hill areas having low productivity are to be converted to forest zone. Human settlement in forest zones obliged to relocate other appropriate zones and be encouraged to develop forests into such areas.

Policy 8: Incentive-oriented programs shall be operated in order to motivate people for the use of Land and Land Resources (LLRs) in accordance with Land Use Zones (LUZs) or Land Use Plans (LUPs).

This policy encourages the people to use land in productive sector. If any industry, housing company, private sector, co-operative sector, among others, became interested for agricultural development in line with land use plans and the policy concerned, the state can provide additional subsidy/facility to them. Private sector is encouraged if they come to develop the 'unused land' under the Specific Land Use Zones (SLUZs) and Land Use Zones (SLUZs). It will motivate the person or institution to invest for the purposes of commercial farming, tourist hubs, research center, scientific laboratory, entertainment venues, games & sports, among others, which can uplift the economic condition of a person or institution

Policy 9: Keeping lands under conditions of 'non-use' or 'under-use', 'misuse and 'excessive use' shall be discouraged.

This policy ensures conservation of rivers, lake-reservoirs, bio-track, public pond, wetlands and pasture lands. According to the policy, no acts that encroach or affect these specific areas shall be conducted. These areas are to be developed for promotion of tourism without affecting their natural features. The policy also discourages changes in natural features and encourages protection of soil at maintaining its natural core. Acts that encroach arable land and makes the area vulnerable is discouraged by this policy. It will reduce the vulnerability of landslide of nearer area.

In order to bring 'non-use' type of Govt., or public lands, 'underused' or 'low graded' type of lands into Specific Land Use Zones (SLUZs), land development programs are encouraged on such lands. This can motivate a person or institution to invest on unused government land in any agriculture, commercial, industrial or for productive purpose.

Policy 10: In order to keep balance between development and environment for the mitigation of natural and human created-hazards, vulnerable zones shall be identified and the provision thereof shall be made to ensure of operating of certain activities only in those zones.

The policy urges to identify highly hazardous zones of natural disasters and allow only certain activities to be operated in such places. It suggests adaptation of sustainable development to maintain balance between land, environment and development. It also focuses on secure flow of river and sustainable embankment. The upper level Govt. lands so made are to be used on the basis of appropriateness, for agriculture, forest, road, green belt and open places/zones.

Policy 12: Minimum valuation and land tax system shall be developed as per a plot based land records upon referring Land Use Zones (LUZs) on the basis of specific land use

This policy aims to complete the surveying and record keeping of all lands that are not yet in records. It is aimed to implement taxation on the basis of land use and benefits, and to levy it progressively. It can provide tax subsidy given to the land used for agricultural purposes

Inference:

The Land Use Plan formed under Land Use Policy can help in conserving the existing forest areas as well as agricultural area and public lands. It also assists in protection of existing rivers, watershed areas, wet land areas and reserves. The policy ensures prevention from encroachment of open spaces, forest area, and river banks. Through proper supervision and strict laws, Land Use policy can prevent urban sprawl, appropriate demarcation of open spaces and proper development of land without over-exploitation of environment. It promotes Government/ public-private partnership (PPP concept) and/or public-cooperatives to ensure local people participation.

In Nepal's context urban forestry is rank low in the local agenda; this policy is not implemented in most of the planning process. Even in Kathmandu, there is no any initiation of conserving forest. The valuable arable land has been converted into dense settlement and no actions have been taken. Furthermore, encroachment of river banks by squatters and private buildings; encroachment of arable land is still prevalent.

Despite all the polices regarding land management acts and regulation, due to lack of sufficient co-ordination between interdisciplinary institution and local stake holders an effective implementation of policies cannot be observed.

5.3 ENVIRONMENTAL POLICY 1993

The National Environment Policy and Action Plan (NEPAP) was prepared in response to the growing global awareness about the importance of maintaining a balance between economic development and environmental conservation, which culminated in the United Nations Conference on Environment and Development in 1992.

The five main aims of environmental policy are

- To manage efficiently and sustainably natural and physical resources
- To balance development efforts and environmental conservation for sustainable fulfillment of the basic needs of the people
- To safeguard national heritage
- To mitigate the adverse environmental impacts of development projects and human actions
- To integrate environment and development through appropriate institutions, adequate legislation and economic incentives, and sufficient public resources.

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

1. SUSTAINABLE MANAGEMENT OF NATURAL RESOURCES

Forest and Rangeland Management depicts concern on deforestation and forest degradation. For improvement of forests and rangelands, proposed policies are to include adoption of a national land use plan based on appropriate resource use in different agro-ecological zones, formulation of a national energy policy that emphasizes increased energy use efficiency and development of alternative sources, better integration of related sectors such as agriculture, livestock and soil conservation, and greater participation of local communities and the private sector in the management of forests and rangelands.

Implementation of the above policies will be made effective through a number of actions, including: simplification of the rules governing the allocation of forests for private, leasehold and community management and promotion of agro-forestry, to expand income and employment opportunities, adoption of a long-term land use plan and a system of zoning to better manage natural resources, institutionalization of necessary legal reforms and forestry research and extension geared to increase community participation.

Under Water Resource Management, the policy states the need to protect the water sheds which comprise over two-thirds of country's land area and have degraded due to misappropriate farming practice and de-vegetation.

3. SAFEGUARDING NATIONAL HERITAGE

The section concerns about the degradation of natural and cultural heritage. It states that policy interventions and actions plans are needed urgently to preserve bio-diversity inside as well as outside protected areas, improving the relationship between local communities and park management, demarcating the core areas inside parks for strict conservation and buffer areas for sustainable resource management and involving local and private organization in preservation and maintenance of natural and cultural heritage resources.

4. MITIGATING ADVERSE ENVIRONMENTAL IMPACTS

This section is focused on the impacts of urbanization and industrialization that have caused serious environmental problems in some areas of Nepal. Due to rapid expansion of road network, several semi-urban sprawls have emerged. These settlements lack adequate facilities. Thus, the urgent need to formulate policies and actions to systemize such settlements with improved environmental conditions are addressed in this section.

Environmental conditions have deteriorated rapidly in the Kathmandu Valley and some other towns, particularly in the Terai. Rapidly expanding, unplanned urban settlements have generated a range of environmental problems affecting human health and welfare. Air and water pollution has worsened due to inadequate sewerage, improper disposal of solid wastes, industrial effluents and discharges, and emissions from motor vehicles.

The current trend of urban sprawl and industrial expansion in and around densely populated areas is unsustainable and poses a serious threat to a clean environment. Policies and actions to remedy the environmental problems associated with urban growth and industrial development, and to prevent similar consequences from happening in future include defining and implementing appropriate zoning regulations, setting of standards for air and water pollution and their enforcement through a carefully designed package of incentives and regulation, and the clear designation of responsible institutions for providing infrastructure and utility services.

Some notable actions proposed are:

1. Reduce level of vehicular air pollution by continuing to review pricing policies for petroleum products
2. Improving data availability on air pollution by setting up pollution monitoring stations
3. Involve NGOs, private sectors and donors in urban development and environment protection by preparing and implementing Environmental Action Plan for Kathmandu valet addressing the problem of degradation
4. Promote the use of environment friendly road construction methods by investigating the potential for more widespread use of the “green roads” approach
5. Improve the capacity of DOR to undertake environmental assessments of roads project by strengthening Environmental Management Unit in DOR to enable it to monitor road contractors to ensure necessary environmental measures and develop EIA sector guidelines for road construction

Inference

The policy was formed in 1993 with great concern on impact of urbanization and urban sprawl on environment. Despite the policies addressing on urgent need to control urban sprawl and expansion of urban areas, the failure to implement the action caused the degradation of environment in the valley.

5.4 NATIONAL SUSTAINABLE TRANSPORT STRATEGY (NSTS) (2015-2040) (DRAFT)

The vision of the strategy is developing a transport system that is efficient, accessible, people-centric, affordable, reliable, safe, inclusive, environmental friendly, and climate and disaster resilient.

Environmental targets of this strategy are:

- Ensuing sustainability in use of natural resources and nature conservation by minimizing use of arable lands for infrastructure and impacts on ecological resources
- Maintaining the standards of vehicle or engine condition by limiting on vehicle age and emission compliance rate
- Minimizing local pollution and noise effect by minimizing car/motor cycle ownership and promoting public transport
- Promoting electric vehicles
- Minimizing carbon dioxide emissions from transport
- Increasing climate and disaster resiliency by transport infrastructure by revising design standards and codes
- By promoting green transport like higher standard of truck engines (Euro IV) and planning to shift to rail/ water transport

Inference

The strategy addresses the need to curb pollution by transportation section. It suggests many action to taken to reduce the negative impact of transport sector on the environment.

6 STUDY AREA OVERVIEW

A few researches has been done regarding UHI effect in Valley. All the researches have used Landsat satellite imagery to determine UHI Effect. Because Kathmandu is a valley, there is a presence of natural temperature variations with different elevation levels in the valley. Studies using satellites therefore may not be able to portray the actual UHI effects in the settlements of the valley.

Valley has many small cities with dense population. For the purpose of studying UHI effect at macro level ancient city of Patan has been chosen.

6.1 INTRODUCTION TO PATAN

Patan is the oldest settlement area in Kathmandu Valley built around third century BC by Kirat dynasty, expanded by Lichchavis in the sixth century. The settlement was further expanded during the medieval period by Malla. (Shrestha 2015). At present, it is the third largest city in Nepal and second largest in the Kathmandu valley.

The historic town of Patan lies in Lalitpur Metropolitan City. Patan Durbar Square which the center of the ancient town is listed in World Heritage Site. The city is considered as a living heritage which is inhabited mostly by local indigenous people.

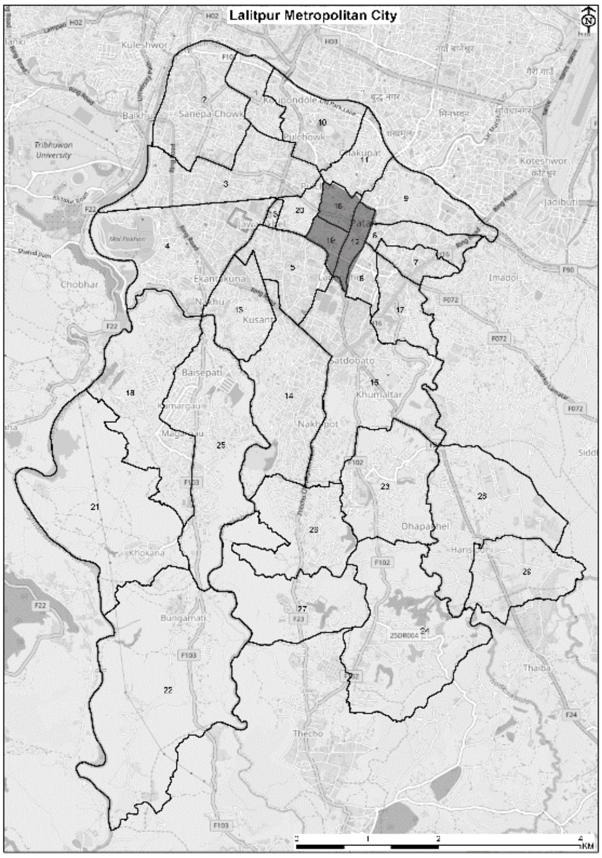


Figure 27 Wards of Lalitpur Metropolitan City

Currently the city center comprising of the Malla Durbar Square lies in ward 12 of Lalitpur Metropolitan City with a population of 5819 living in an area of 0.13 sq.km. The density of this ward is about 450 people/ hectare with 1342 number of households. Ward 19 and 16 which also fall under the ancient settlement have higher density than city center with 461 people/ hectare and 545 people/ hectare respectively. No of households is 1174 and 858 spread over 0.16 sq.km and 0.08 sq.km respectively.

The built environment of the old city shows changing traditional character to modern architectural character. Many of the traditional buildings in Patan have been converted from brick and wooden to concrete and plaster. The low rise traditional buildings have been changed to more than 4 stories although the courtyard size and streets remains the same preventing flow of wind.

Within these wards, there are a very few to zero green areas with an exception a small lush green patch to the west of Durban Square.

6.1.1 OLD CITY PLANNING

The historic town of Patan like the settlements in the valley was dense and contained within a defined boundary with pit conduit water supply fed by a reservoir at the highest level. The town had irrigable agricultural land at the outskirts. A basic principle that a settlement should not expand outwards and engulf its own economic base prevented expansion of the settlement.

During the Malla period the population increased and the park spaces located in Mangah, Saugah and Yacchu were converted into settlement area leaving the city with no greenery. As the city green vanished, another kind of green space called *Khyo* was provided just outside of its built boundary. (Tiwari, n.d.) These large green areas acted as the lung space for the small town of Patan.

The agricultural land and forested hillocks were protected and preserved. The watershed and sources of rivers were marked religious which preserved them from degradation.

The settlements were planned to maintain a warm micro climate. For this purpose, the settlements were of high density and low rise. The courtyards and streets that were paved to capture heat and maintain the warmth.

For water management, there were pit conduits and wells. Water were brought through canals that stretch from the foothills of the valley to feed ponds which in turn recharged supply to recessed pit conduits. Moreover, the pavements were made of pervious materials which helped recharge the underground water table.

6.1.2 URBAN GROWTH IN PATAN

During the Rana rules, large palaces were built in the agricultural lands. Facilities such as drinking water, electricity and roads were supplemented with for the comfortable and lavish life of Ranas. Eventually new settlements developed in the agricultural lands around the palaces. Thus began the process of encroachment of agricultural lands. As the core area lies towards the North of Lalitpur district and expansion can be noticed towards the west and south of the core area.

Around the 70 till 90s, Ring road construction started. By 1991, most of the area within the Ringroad was changed to built-up areas and new settlements were developed along the road. As the area inside the Ring road decreasing, urban sprawl can be observed outside the Ring road towards the East, South-East and South. By 2011, most of the area with in Ringroad showed over 150 person per hectare in Lalitpur. (JICA, 2012)

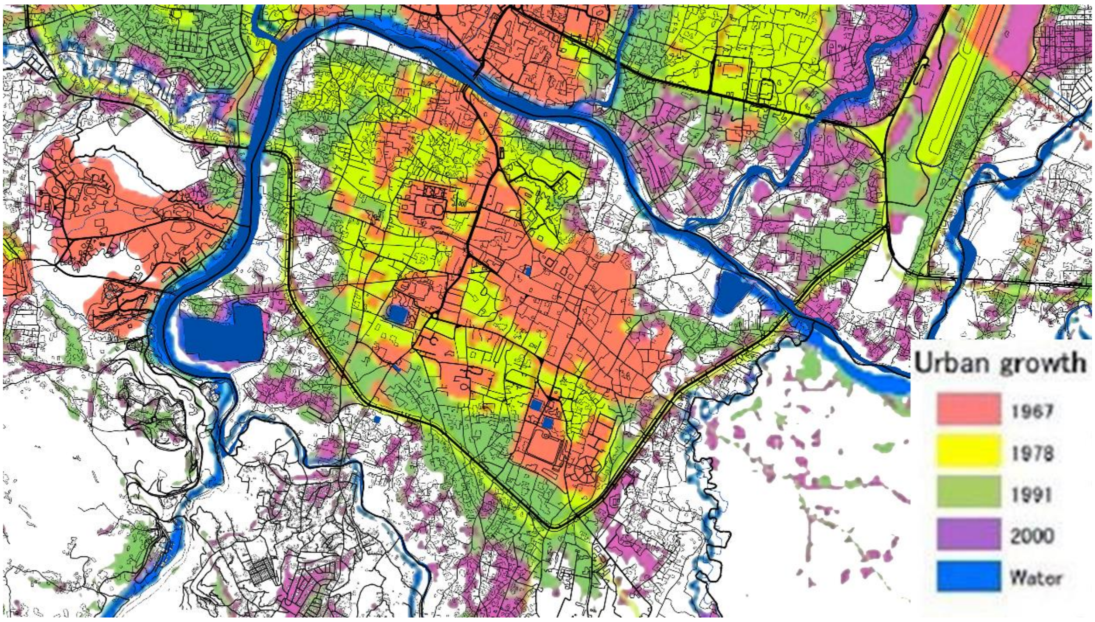


Figure 28 Urban growth in Patan from 1967 to 2000 (Thapa, 2012)

Currently, the urban areas have expanded outside the Ringroad area and new settlements have emerged mostly to the South towards Bhaisepati and to the East towards Gwarko and Imadol of the old city.

Despite the traditional belief that the settlement should not expand to the agricultural fields, development outside the traditional town can be observed in the later years. The Khyos or lungs of the old city were converted into settlements. The few remaining khyos are in Jawalakhel, Lagankhel and Balkumari.

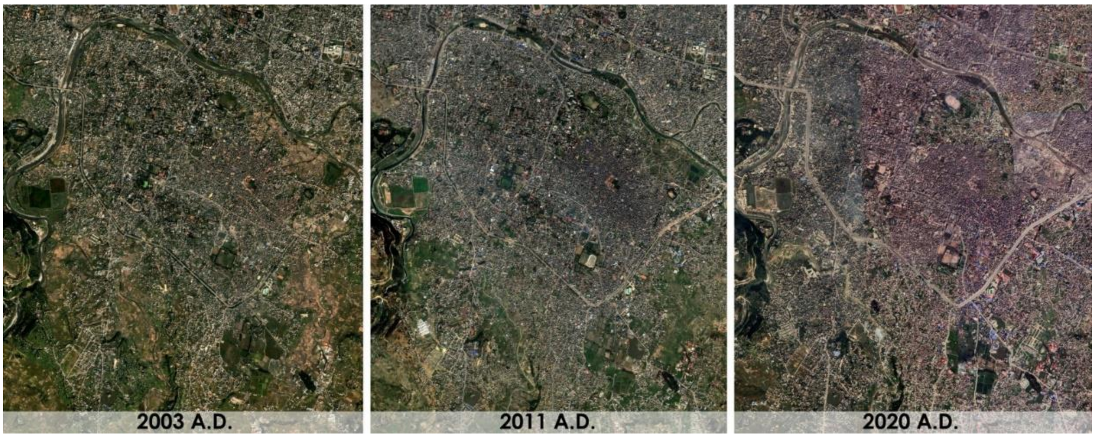


Figure 29 Urban growth of Patan from 2003 to 2020

As the urban area expanded without proper planning, the city lost its remaining open grounds. As the old town was designed to maintain the warm climate, loss of surrounding agricultural lands and open spaces would make this town, which is devoid of greenery at the core, hotter.

Nevertheless, there are a few agricultural lands remaining in the periphery, towards the South east. Establishment of National Agricultural Research Center in Satdobato has indeed helped in maintaining a large chunk of land for agricultural purpose.

6.2 FUTURE PLANNING: LALITPUR AS GREEN CITY

The budget for fiscal year 2015-16 has envisaged of developing modern, green and smart cities. Kathmandu and Bhaktapur is planned to be developed as smart city through ICT enhancement in urban services. Lalitpur Metropolitan City is to be developed as green city.

Lalitpur as a member of CITYNET, hopes to develop Lalitpur as Sustainable green city. Mayor of Lalitpur Chiribabu Maharjan stated in 38th Executive Committee meeting of CITYNET that Lalitpur is planting more trees and buildings green parks to make the area greener. He also stated that the city is planning to make garden and parks in every ward. 2681 saplings of nine different species planted in the newly constructed 10.5km Kalanki-Satdobato-Koteshwor road section on National Plantation Day. Lalitpur City vowed to care for 90% plants that come under the territory of the city as stated in news posted by the Kathmandu Post on August 2019. To maintain greenery in the city, water tankers are bought by the Mayor of Lalitpur City.

Mayor Maharjan also talked about reducing carbon footprint by investing in electric vehicles and promoting bicycle usage by providing bicycle lanes in the CITYNET conference. Mayor plans to rid the core heritage route within Patan from all motorized vehicles and build 100 cycle stands in 10 areas along the main road passing through Lalitpur. Also, a cycle lane was marked from Kupondole to Lagankhel.

Lalitpur has also joined Breathelife in June 2019 to take action in reducing air pollution. Breathelife is a joint campaign led by World Health Organization (WHO), United Nations Environment and the Climate & Clean Air Coalition (CCAC) to mobilize cities and individuals to protect health and plant from the effects of air pollution. To reduce the air pollution Lalitpur plans to minimize road dust, increase reforestation and green spaces, invest in improving its public transport system, support air pollution monitoring, improve waste management systems and crack down on open burning.

6.3 QUASI-EXPERIMENT METHODOLOGY

6.3.1 SITE SELECTION

To measure UHI Effect, thermometers were planted in 3 different areas. One of the site has meteorological station in the vicinity and the data has been taken from Department of Hydrology and Meteorology (DHM). The Station located in Khulmaltar is an agrometeorology station (Index no: 1029).

The site is selected in such a way that each location represents a unique combination of urban character in terms of built forms, greenery and surface types. To eliminate variables such as weather changes, the site is selected at the shortest distance and similar elevation level possible so that the weather is same in all the area.

Depending on the parameter following area has been chosen.

- Semi Dense area- IOE Pulchowk Campus
- Dense Settlement- Ikhalakhu
- Dense Settlement-Patan Industrial Estate
- Open space- NARC / Khumaltar Station

The distance between the farthest thermometer locations is approximately 3 km (Figure 30 Study area) and elevation difference of approximately 50 m (Figure 31). For study purpose the built up area of 100 x 100m is taken with thermometer placed at the center. The 50m radius is taken to exclude the influence of heat from vehicular emission as this parameter has not been considered in the study.

The ratio of green surfaces to artificial surfaces has been analyzed to categorize the areas. Artificial surfaces have been further divided into vertical and horizontal surfaces. All of the vertical surfaces is made of brick walls (plastered/ non-plastered) and is labelled as built-up area. The horizontal surfaces are further classified according to the material used. The classification categories include brick pavement, concrete pavement and asphalt road.

The vertical surfaces have been considered to acknowledge urban canopy layer. Urban canopy layer affects the airflow and prevents wind from flushing stagnant heat.

To calculate heat radiation from the surfaces, albedo value of each surface type have been taken from the values in US EPA, 1992.

For simpler comparison, a cumulative albedo of the location is calculated using the following formula:

$$\text{Av. Albedo} = \sum\left(\text{Built-up (in\%)} * \text{albedo of surface}\right)$$

Figure 30 Study area

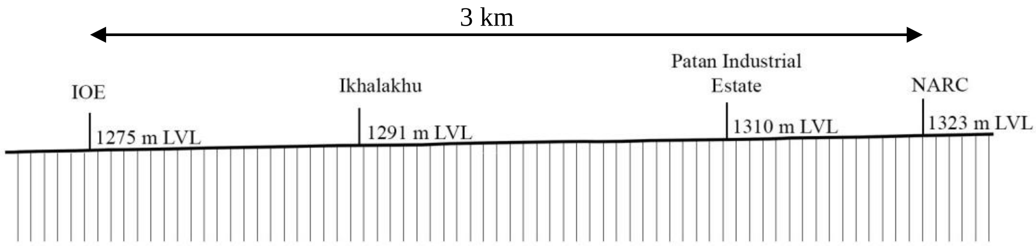


Figure 31 Cross-section of the site

6.3.2 FIELD MEASUREMENT

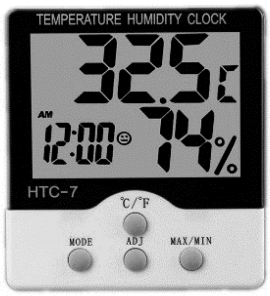


Figure 32 Device used to take temperature

The temperature has been recorded by a digital indoor/outdoor thermometer. The device used is HTC-7 Digital Indoor//Outdoor Thermometer/ Hygrometer (Figure 32). All the used devices have been calibrated with the thermometer in Department of Hydrology and Meteorology as shown in Table 4.

Thermometer	DHM	A		B		C		D	
		(Ikhalakhu)		(Discarded)		(Industrial Estate)		(IOE)	
Time	Reading	Reading	Error	Reading	Error	Reading	Error	Reading	Error
11:45 AM	19.8	19.5	-0.3	19.4	-0.4	19.8	0.0	19.4	-0.4
11:55 AM	19.7	19.6	-0.1	19.5	-0.2	19.6	-0.1	19.3	-0.4
12:05 AM	20.1	19.9	-0.2	20.0	-0.1	20.0	-0.1	19.7	-0.4
12:15 AM	19.8	19.8	0.0	20.0	0.2	19.9	0.1	19.4	-0.4
12:25 AM	20.1	20.1	0.0	20.2	0.1	20.2	0.1	19.8	-0.3
12:35 AM	20.2	20.2	0.0	20.3	0.1	20.3	0.1	19.9	-0.3
12:45 AM	20.3	20.4	0.1	20.5	0.2	20.4	0.1	19.9	-0.4
Error			0.0		0.0		0.0		-0.4
Correction							+0.1		+0.4

Table 4 Thermometer calibration with comparison to thermometer in DHM

As per guidelines for measuring outdoor temperature, the thermometer must be placed in shade and not in direct sunlight. It should be kept in a covered area for protection from weather. Thus, the device has been kept in a wooden box (1’ x 1’ x 1’-3”) with louvered ventilation in all directions. The box has been fixed to wooden stand that is 5 ft. tall as shown in Figure 33 Thermometer box.


Figure 33 Thermometer box

According to guidelines for measuring outdoor temperature, thermometer should be placed at 4-6 ft height form ground so that the atmospheric temperature is not affected by ground surface temperature. Therefore, a sound height of 5 ft has been maintained from the ground to get a more accurate air temperature. The stand has been placed such that it falls in shade of a tree or a building around 14:00 NPT.

The temperature recording is taken daily at 14:00 NPT during the day and at 19:00 NPT in the evening from 29th January 2020 to 13th March 2020, a total of 45 days.

The temperature rises sharply during the day and reaches at its peak value at around 14:00 NPT and drops slowly after that. So, temperature reading is to be taken at 14:00 NPT.

The sun sets around 18:00 NPT and the effect of canyon level UHI is most visible after sunset. So, 19:00 NPT is chosen to observe the effect of canyon level UHI.

The data has been noted and average has taken out for comparison.

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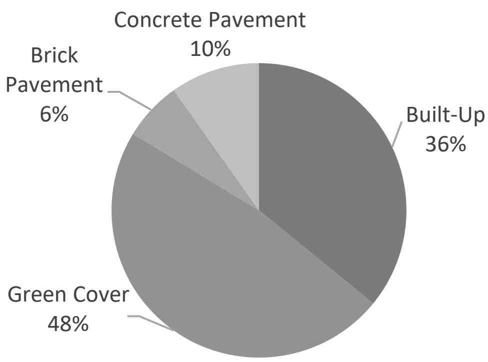
7 OBSERVATIONS, SURVEY & ANALYSIS

7.1 ANALYSIS OF URBAN CHARACTERISTICS

7.1.1 IOE PULCHOWK CAMPUS

Category	Semi-Dense
Built up	36%
Green cover	48%
Brick Pavement	6%
Concrete Pavement	9%
Asphalt	1%

Figure 34 100m x 100m area in Pulchowk Campus



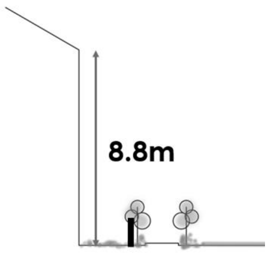


Figure 35 Cross section along thermometer in Pulchowk Campus

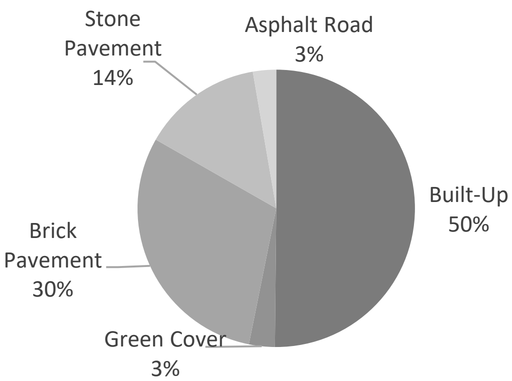
Pulchowk Campus is taken as semi dense area. Being an educational institute, Pulchowk campus has green barriers and open grounds around the academic buildings for better academic environment. The thermometer has been placed at the ground to the east of architecture block and south of administration block. Pulchowk Campus is the second greenest area with an average albedo of 0.19 (Refer Table 5).

Considering the selected 100m by 100m area, there is unrestricted or little restriction in wind flow as there is an academic block in the West. The thermometer is kept at a distance of almost 9m from administration block and about 13m from architecture department.

7.1.2 IKHALAKHU

Category	Dense
Built up	50%
Green cover	3%
Brick Pavement	30%
Stone Pavement	14%
Asphalt	3%

Figure 36 100m x 100m area in Ikhalakhu



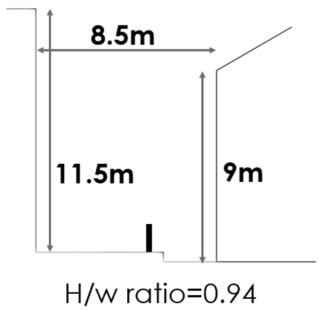


Figure 37 Cross section along thermometer in Ikhalakhu

Situated in the old settlement another selected area is a small courtyard in Ikhalakhu labelled as the dense non-green zone. The courtyard is about 8.5m by 10m approximately. Enclosed from three sides, the courtyard consists of a small garden towards the East. The thermometer is kept at 3m from the building in south such that building casts its shadow on the stand at 14:00 NPT.

Ikhalakhu, with least green area, has an average albedo of 0.17 (Refer Table 5) and wind restriction in all directions. In addition to less green surfaces and wind restriction due the tall buildings all around, the surfaces in the courtyard are also non-permeable and has low albedo.

7.1.3 PATAN INDUSTRIAL ESTATE

Category	Dense
Built up	80%
Green cover	5%
Brick Pavement	0%
Concrete Pavement	5%
Asphalt	10%

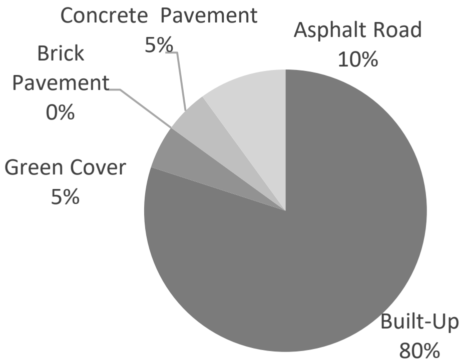


Figure 38 100m x 100m area in Patan Industrial Estate

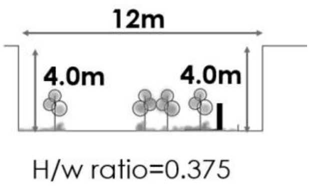


Figure 39 Cross section along thermometer in Patan Industrial Estate

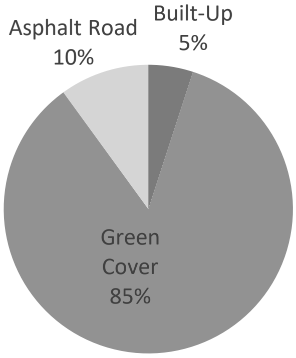
Another dense area is Patan Industrial Estate. Patan Industrial Estate has a different environment compared to residential area in the core city. Presence of industries and more impermeable surfaces, Industrial zone is selected for comparison of temperature effect on residential and industrial area. Because it is a designated industrial zone, Patan Industrial Estate is planned with a unique pattern of circulation and every industry has a narrow green belt around it.

The average albedo of Patan Industrial Estate is 0.12 (Refer Table 5). Although pointed out as dense area, due to its unique circulation pattern roads and the selected area having low-rise buildings, Patan Industrial Estate allows better wind flow compared to courtyard in Ikhalakhu through the street running West to East.

7.1.4 NARC

Category	Open Area
Built up	5%
Green cover	85%
Brick Pavement	0%
Stone Pavement	0%
Asphalt	10%

Figure 40 100m x 100m area in NARC



As the open green space, National Agricultural Research Center (NARC) has been chosen. NARC has vast agricultural land and few buildings which houses research labs, offices, seminar halls, exhibition halls etc. To help with the researches, an agrometeorology station is established near NARC area which monitors weather and temperature. NARC being the greenest area with 85% green surface and unobstructed wind, has the highest average albedo of 0.23 on average (Refer Table 5).

	Built-Up	**Green Cover**	**Brick pavement**	**Concrete Pavement**	**Asphalt Road**	**Average albedo**
IOE	36%	48%	6%	9%	1%	0.19
Ikhalakhu	50%	3%	30%	14%	3%	0.17
Patan Industrial Estate	80%	5%	0	5%	10%	0.12
NARC	5%	85%	0	0	10%	0.23
Albedo	0.12	0.25	0.3	0.12	0.12	

Table 5 Comparative Chart of Albedo Content

7.2 ANALYSIS OF THE TEMPERATURE RECORDED

Temperature has been recorded for 45 days in total from 29th January to 13th March at 14:00 NPT and 19:00 NPT. Observing the data, the hottest day was recorded on 12th March.

Temperature difference of 2.88°C was observed at 14:00 NPT and 0.66°C at 19:00 NPT. The temperature difference at 19:00 NPT however is not found to be significant.

Highest average temperature can be observed in Ikhalakhu at 14:00 NPT as well as 19:00 NPT (Figure 41) while the lowest average temperature is recorded in NARC in both cases.

NARC having the highest average albedo (0.23) and no wind restriction has the lowest temperature in the evening as well the day. The role of green surface and unobstructed wind in maintaining a low temperature can be observed in the chart.

The maximum recorded temperature for NARC during the study period was 23.5°C on March 12th which is the lowest compared to 24.0°C of Pulchowk Campus, 26.3°C of Industrial Estate and 29.2°C of Ikhalakhu at 14:00 NPT on the same day (Figure 42).

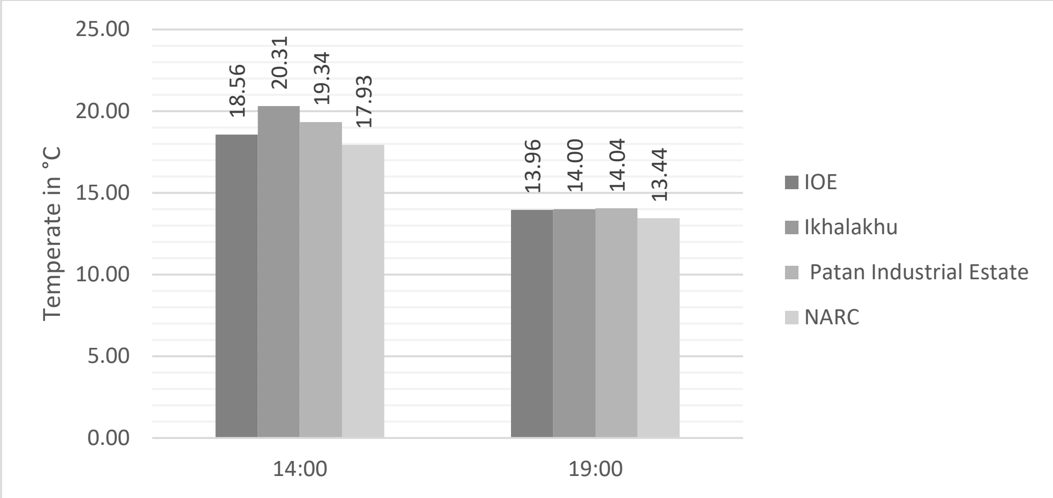


Figure 41Average temperature recorded in different selected site taken daily at 14:00 and 19:00 from 29 January to 13 March 2020

Pulchowk campus (albedo: 0.19) with little wind obstruction and almost 50% green area also has lower temperature during the day and night compared to Ikhalakhu (albedo: 0.17) and Patan Industrial Estate (albedo: 0.12) despite having an average albedo value almost similar to Ikhalakhu. Although the campus has brick pavements and buildings radiating the heat, the temperature is quite low compared to dense residential and industrial zone. The reading further proves the importance of green surface and the ability of wind to reduce the temperature.

Maximum temperature was recorded in Ikhalakhu and Patan Industrial Estate. With least green areas and more impermeable surfaces, the temperature recorded in Ikhalakhu and Patan Estate is 20.3°C and 19.3° C respectively at 14:00 NPT. Although albedo of Industrial Estate is much lower compared to Ikhalakhu, and the high probability of air pollution in the area, the temperature of Industrial Estate is fairly less than Ikhalakhu. The reason for this lower temperature could be the presence green boundary around each industrial section and the allowance of wind along the circulation.

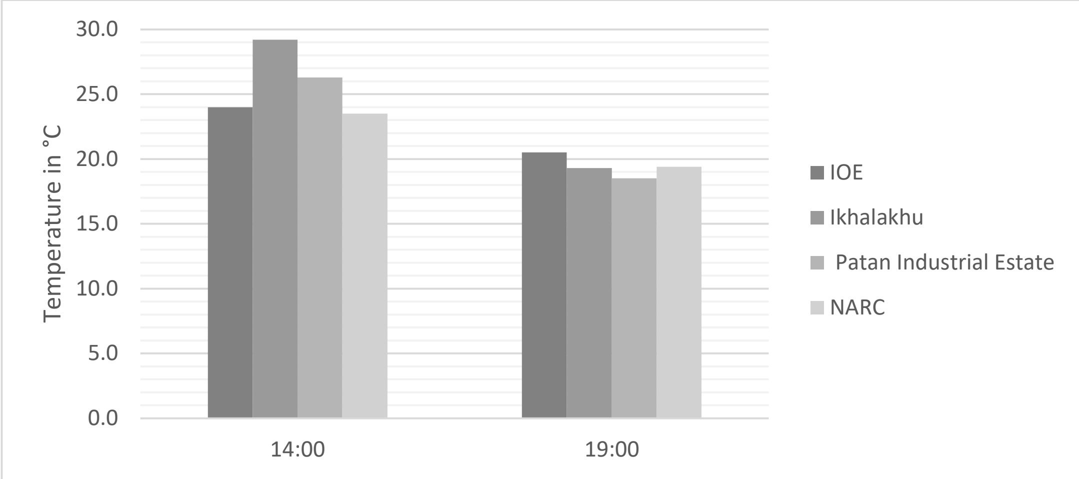


Figure 42 Temperature recorded on 12 March 2020, the hottest day during the study at 14:00

Overall, an UHI Effect of 2.28°C can be noticed at 14:00 and 0.66°C at 19:00. The study of Mishra et.al (2019) stated the UHI Effect of 0-2°C in the valley. The above study shows that at micro level, Patan city has UHI Effect more than 2°C on average and in some days the effect reaches up to 5°C.

7.3 ANALYSIS OF QUESTIONAIRE

A temperature difference of more than 2°C can be observed in Patan area at 14:00 NPT. The questionnaire survey was conducted in the core area in Patan City to understand if this 2.88°C UHI affects the dwellers of Patan City. The questions are concentrated on social and economic effects. As UHI was observed during daytime, the questions are focused on daytime environment quality.

A total of 30 surveys were done. 28 out of 30 participants are the residents of core city who have lived there for more than 5 years. Remainder constitute the people who work in the core area.

The participants are involved in various occupations in and out of the core area. Occupations include career in Banks to medical personals, students, architects and shopkeepers in the locality.

Occupations reveal the kind of environment a person lives in throughout the day time. Occupation like the bankers, businessmen and medical personnel are more inclined to work in a controlled environment while students and shopkeepers are more bound to work in spaces without cooling devices. Other occupations include the ones who need to keep moving from place to place. The type of occupation determines the responses to other questions in the survey.

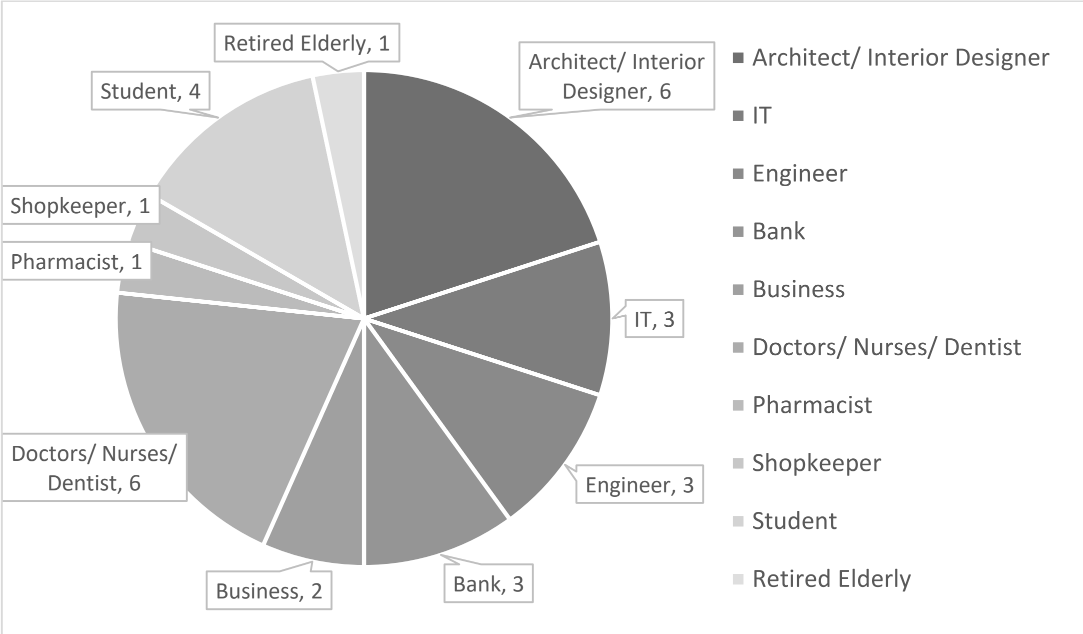


Figure 43 Pie-chart representing the occupations of respondents

The questionnaire was conducted among the people above 15 years. 26 participants are aged between 20 to 40, 2 are less than 19 years old and 2 are above 40 years old.

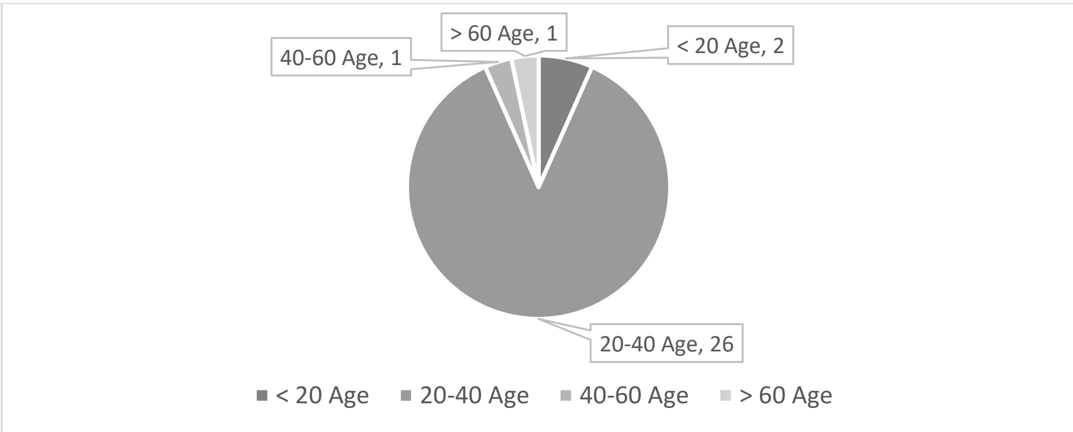


Figure 44 Pie-chart representing the age group category of the respondents of questionnaire

7.3.1 AWARENESS OF WARM TEMPERATURE IN PATAN

28 respondents acknowledged that the temperature is rising in their area, 2 admitted that to not feeling any difference while the rest are unsure.

Among the participants, 13 are sure that the place they live in is warmer than the surrounding less dense areas. When enquired about how they are sure, the participants stated that the houses of their relatives/ friends who live outside the core or some restaurants (near Ring road or beyond) are cooler than their house. 9 out 30 have disagreed to the statement and rest are uncertain.

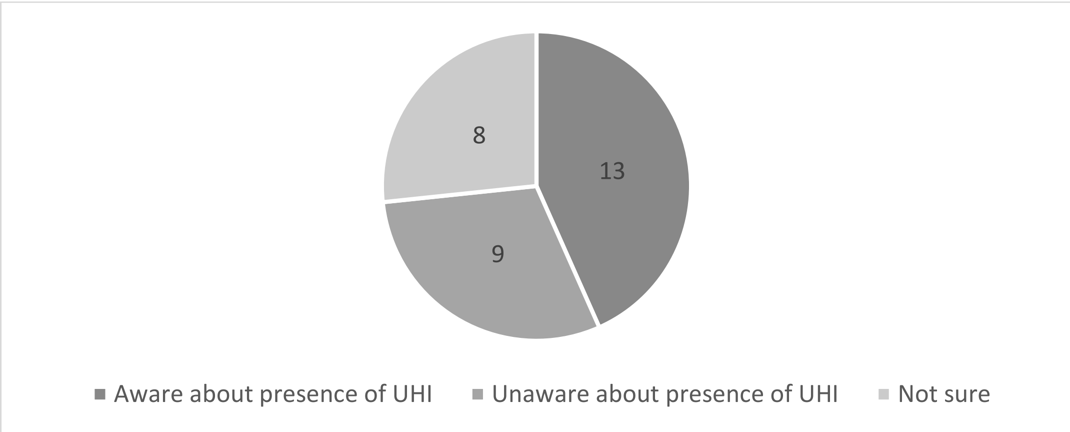


Figure 45 Pie-chart showing people who are aware of presence of UHI in Patan

Some of the people who have disagreed to living in warmer area have their houses along a narrow gully facing the north or the houses that are deprived of southern sunlight. Some of the people who have disagreed, live in traditional residences.

7.3.2 SOCIAL EFFECTS

Effects on Productivity

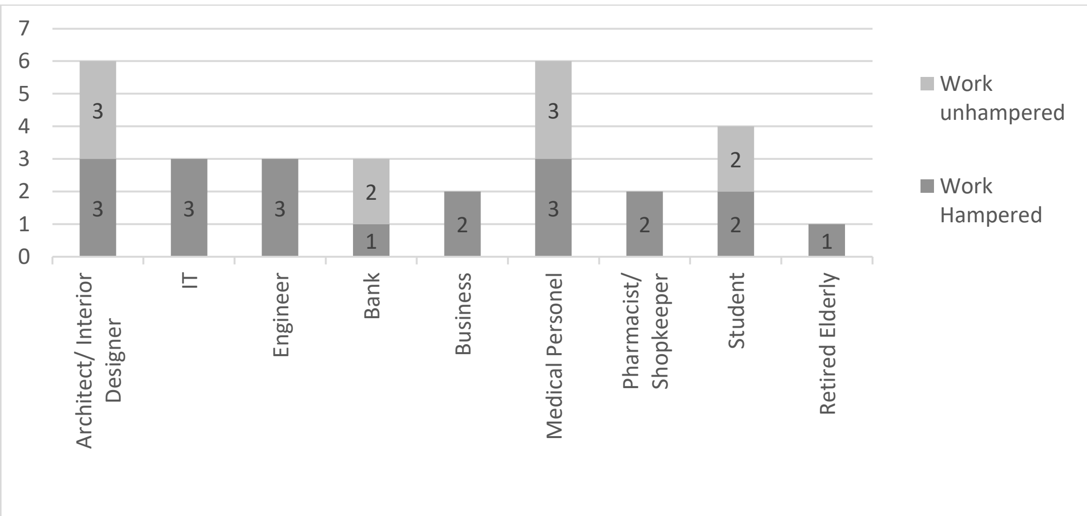


Figure 46 Bar-chart showing if productivity is hampered among different occupation

Two-third people have said that the increased temperature has hampered their work. Most of the people whose work has been hampered are the ones, who have to constantly move around like the site/civil engineers, interior designers and sales representatives, or people who stay in rooms without ACs like the shopkeeper, students and elderly respondents. The students, architects and a few doctors have complained about their decreased productivity due to lack of concentration and laziness created by the heat and others complain about suffocation, discomfort and dehydration.

However, most of the respondents working in bank and a few from medical field as well as architecture field who are fortunate to work under controlled environment remain unaffected by the heat.

Effects on health

Because the streets of Patan have been black-topped in most areas, the pedestrians are most affected. To understand the effects of UHI, the questionnaire is focused on people who walk through the streets on Patan.

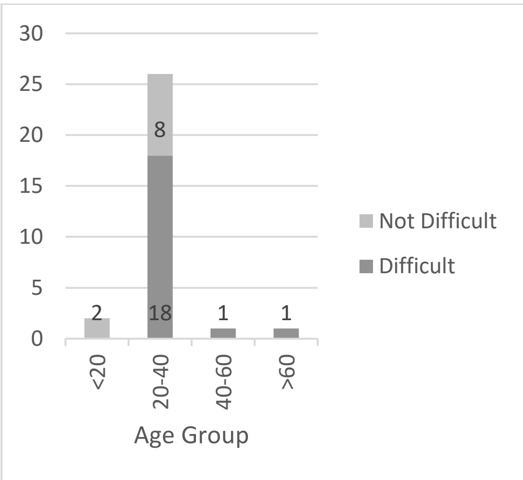


Figure 47 Bar-chart showing if respondent have difficulty walking in streets of Patan according to Age Group

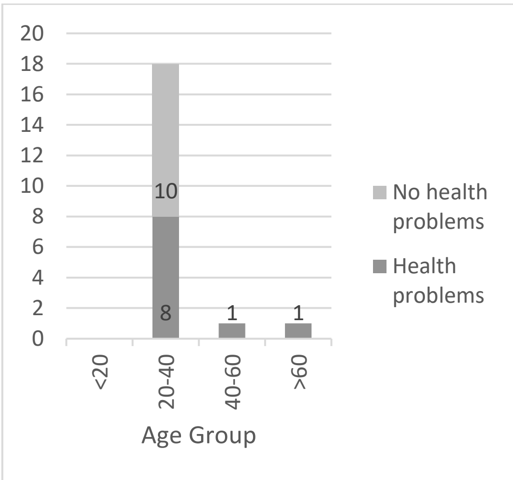


Figure 48 Bar-chart showing if respondent who have difficulty walking in streets of Patan have health problems due to walking in heat according to Age

All the participants have experienced walking through the streets. Among all the participants, two-third say that they have experienced difficultly walking due to increased heat and half among these (one-third among all the participants) have admitted to suffering from heat related problems like heat exhaustion, heat cramps and weakness due to walking in the heat. 2 older participants have complained about heat exhaustion and stress while walking down the road and therefore they rarely pursue walking during the day time.

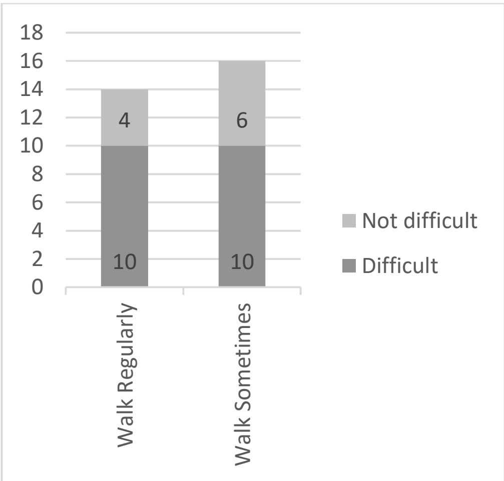


Figure 49 Bar-chart showing the number of respondents having difficulty walking in street of Patan

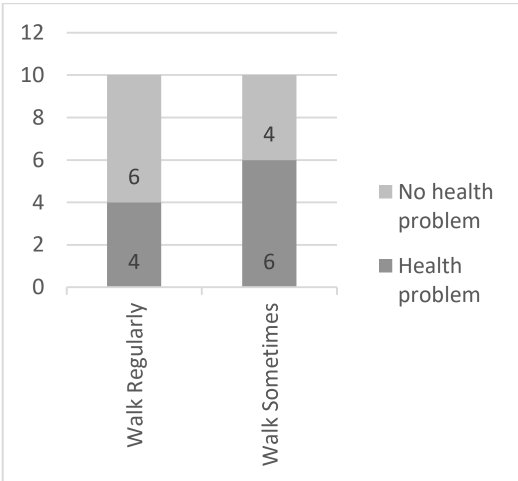


Figure 50 Bar-chart showing number of people with health problems among the respondents who have difficulty walking in streets of Patan

14 out of 30 respondents walk around regularly. Among the 14 participants who regularly walk in streets in Patan 10 say walking has become difficult. However, only 4 of regular walkers suffer from exhaustion and weakness due to heat.

Among the other 16 participants, 10 admit to having experience difficulty wandering through streets of Patan. And 6 of these 10 get exhausted or have other health issues like weakness and heat cramps from walking for a few minutes.

7.3.3 ECONOMIC EFFECTS

Summer Scenario

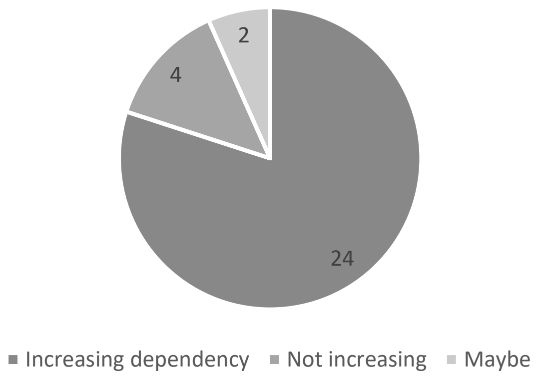


Figure 51 Pie-chart showing the number of people who believe their use of cooling devices have increased compared to prior years in summer

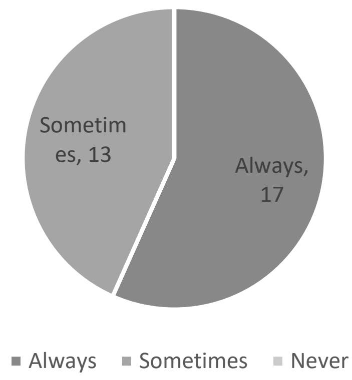


Figure 52 Pie-chart showing the frequency of the use of cooling devices during summer

24 of the respondents are sure that their use of fans and ACs are increasing yearly during summer. 4 are not sure while 2 have denied the increment in use of electronics.

17 out of 30 people use electronic mediums all the time to fend the heat. The rest of them depend on electronics sometimes only.

Winter Scenario

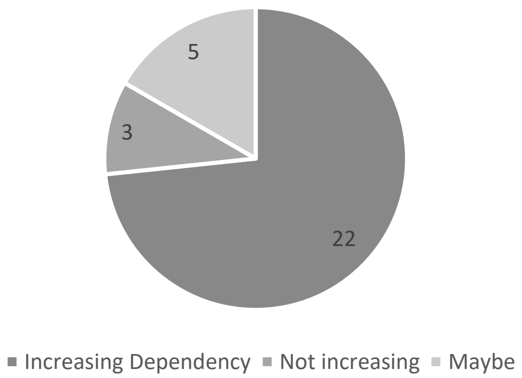


Figure 53 Pie-chart showing the number of people who believe their use of heating devices have increased compared to prior years in winter

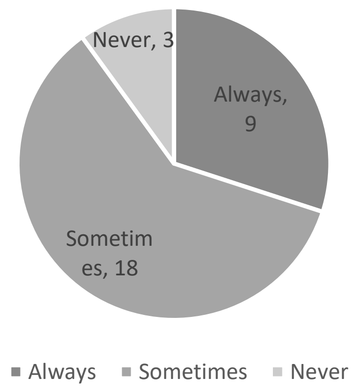


Figure 54 Pie-chart showing the frequency of the use of heating devices during winter

22 of the respondents are sure that their use of heaters and ACs are increasing yearly during winter. 5 are not sure while 3 have denied the increment in use of electronics to warm their rooms.

9 out of 30 people use electronic mediums all the time to heat their homes. 18 depend on electronics and heaters sometimes and 3 do not use any medium to heat their houses.

More number of people are dependent on electronics and AC to control indoor environment in summer than winter. Use of these electronics is more frequent in the summer than winter. The survey illustrates how increasing temperature has more people dependent on artificial means to cool their indoor environment.

29 out of 30 respondents are confident that their electricity consumption has been increasing compared to prior years. 11 said it has increased by a few units about 10-30 compared to previous years; 8 say it has increased by a quarter of the previous year's consumption; 7 believe it had increased by almost half of the prior years; 2 people say the consumption has doubled and 1 said it has increased by 4 times the previous years.

24 of the participants believe their meter reading is increasing due to excessive use of electronics to control the indoor environment. They have said that the installment of ACs are have increased their consumption by more than half to double or more than that compared to prior years.

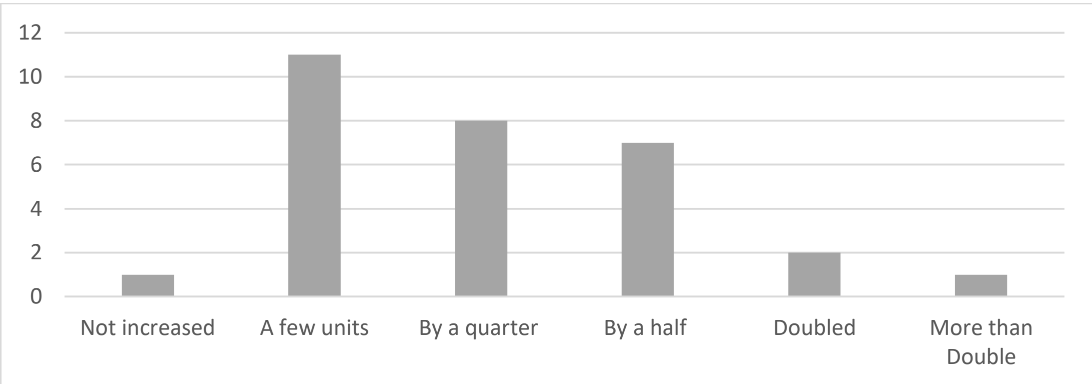


Figure 55 Bar-chart showing by how much the electricity consumption has increased

7.4 POLICIES THAT CAN HELP COUNTERACT UHI

Mitigation Measures adopted and policies in Nepal that might help/support

Mitigation Measures	Strategies adopted by other countries	Policies of Nepal that support Mitigation measures for UHI
Maximum Vegetation	Stuttgart • 60% of the city is green • Presence of Urban Parks • Green road networks • Green roofs SSTEC • 26% of land classified for open space, water and green belt. • Presence of large parks	Land use Policy, • Policy 5 works in preservation, optimum use and protection of arable lands • Policy 7 to conserve forest and other natural resources Climate Change Policy • Promotion of Urban Plantation
Green Transportation	Stuttgart • Provision of cycle paths and parks linkages between business centers, commercial and residential as well as leisure area • Underground railway station provided with skylight, and green cover above the tracks (Rosenstein Park) SSTEC • Mix land use planning – walkable city • 5m separate cycle Path provided • Provision of advance light rail system to encourage public transport usage	Climate Change Policy: • National Low Carbon Economic Development Strategy to be formed to reduce carbon footprint • Promote green energy usage • Promote urban plantation National Sustainable Transport Strategy to invest in pedestrian and NMT Infrastructure in Kathmandu. Master plan for mass transit

Mitigation Measures	Strategies adopted by other countries	Policies of Nepal that support Mitigation measures for UHI
Water Bodies	Stuttgart • Presence of many fountains in the urban area • Presence of lakes along Rosenstein Park located centrally SSTEC • Linked water bodies for water circulation • Conversion of waste water pond into a lake	Land Use Policy, • Policy 9 ensures conservation of rivers, lake-reservoirs, bio-track, public pond, wetlands and pasture lands • Policy 10 focuses on secure flow of river and sustainable embankment
Passive Building Design	Stuttgart • More than 300,000 sq.m. of green roof buildings SSTEC • Buildings designed to utilize natural wind pockets and light source • Use of proper façade shading devices, green roofs, vertical green • South-north Orientation of buildings with generous gaps	Awareness and support on Kausi-kheti

Mitigation Measures	Strategies adopted by other countries	Policies of Nepal that support Mitigation measures for UHI
Renewable Resources	Stuttgart • PV cells to run under railway tracks • Sky lighting the underground stations SSTEC • Equipped with latest technologies (Solar power, Wind Power, rainwater recycling and waste water treatment/ desalination of sea water)	Climate Change Policy • Promotion of Hydropower and other renewable energy sources
Wind Path	Stuttgart • Green corridors within the city's street infrastructure using construction bans at strategic places	
Material	Stuttgart • Light colored façade	
Local Participation	Stuttgart • Campaign of adopt a tree.	

There are numerous policies and strategies in Nepal that would help counteract UHI for the cities like Patan. Conservation of arable land, forests and water bodies are mentioned in Environment Policy and Land Use policy. For promotion of green mode of transport by promoting green vehicles like cycles and electric vehicles, Climate change Policy and Sustainable Transport Strategy are formulated.

Some of the strategies are still in draft version and some of the policies are lacking actions. There has always been a gap in policy making and implementation. Because these reasons, the policies have become inefficient and has led to chaotic urban sprawl and UHI.

Environment Policy, Land use policy are focused in proper and controlled development of expanding urban areas in the country to create hygienic, beautiful, well-facilitated and safe settlement area in a planned manner with sufficient open areas and better environment. Despite the policies, actions are lacking in planned development of urban area. There is haphazard expansion of urban areas which has led to encroachment of agricultural land and degradation of water bodies in the valley (shown in Figure 4 and Table 2).

With number of migrants increasing in the valley, it is difficult to control urbanization. As government lacked implementation of the policies, the predominant suppliers of land for urban housing was done by land brokers. (UN-Habitat) Land brokers would buy large chunks of agricultural land, provided a minimum level of basic infrastructure which may or may not include roads, sewerage disposal. Water supply and electricity poles. Due to this trend, the immigrants buy lands that are in the fields at low price. Thus, Kathmandu valley faced urban sprawl with lack of basic amenities. It has become difficult to create the sustainable cities with better environment that the policies have envisioned. The failure of these policies is one of the reasons of UHI.

In case of Patan as well, the difficulty to control urban sprawl and preserve arable lands is noticeable. But the city is working to increase green areas in the core itself. Parks have been built along the river corridor and plantation has initiated along the roads. Mayor of LMC Chiribabu Maharjan has vowed that the municipality will care for 90% of the plants and LMC is planning to create as many parks as possible: at least a park in each ward. Moreover, vocational training classes have been set to make people aware on importance and advantage of roof top gardening.

National Low Carbon Economic Development Strategy and National Sustainable Transport Strategy support promotion of electric vehicles and green transport system. The goal of these strategy has been to reduce the carbon foot print and create a livable environment but both these strategies are still in draft versions. Moreover, National Low Carbon Economic Development Strategy was to be pass by 2014.

According to these policies, taxes were imposed upon ownership of motorized vehicles and extra tax added to fuel based ones to dissuade their use. Taxes on electric vehicles were less comparatively. With tax concession on electric vehicles and charging units established in areas like the shopping malls, electric vehicles have just started to gain the interest in the local market. The recent increment in tax for electric vehicles which goes against the policies and have been highly criticized will definitely dissuade inclination towards them.

In LMC, municipality is promoting use of environmental friendly vehicles: cycles by creating cycle track from Jawalakhel to Thapathali and cycle stands in public places. The cycle track is to extend till Godawari. But the cycle tracks are quite unsafe. Moreover, the committee that is responsible for creating tracks said they have created the tracks till the areas that they have jurisdiction on and said that for continuous tracks other municipalities need to co-operate.

As for the renewable energy many hydropower projects have been opened and to prevent negative impacts Hydropower Development Policy have been passed. Also, to increase electricity supply, a largest solar power project, Devighat Electric Project was launched. Moreover, there has also been rise in use of solar energy for electric and hot water supply. Although the bye-laws of Lalitpur demands for installment of solar line, it is not checked after the awarding project completion certificate of the project.

8 DISCUSSION

Till the Malla era, the settlements had a close boundary. Densification occurred within the boundary and open areas were kept at the periphery of the old city. The city was designed to accumulate as much heat possible to create a warm micro-climate. Because the core was a dry land devoid of greenery, the ground was made of permeable surface that allowed penetration of rain water. Excess water was drained into the field. The town was an exemplary sustainable eco-city for that era.

From Rana period, a new era started which was supplemented with motorized vehicles, electricity and tap water. It was during this era, encroachment of agricultural field initiated. As Rana palaces had many modern facilities, settlements developed around them. Slowly, the bounded traditional city expanded and the open areas decreased.

New settlements were facilitated with many impervious and low albedo properties. As the settlements expanded so did the concrete and asphalt surfaces. As the valley lost its greenery, the temperature increased. The new developing settlement has more attributes that increased the temperature and prevented the core area from cooling.

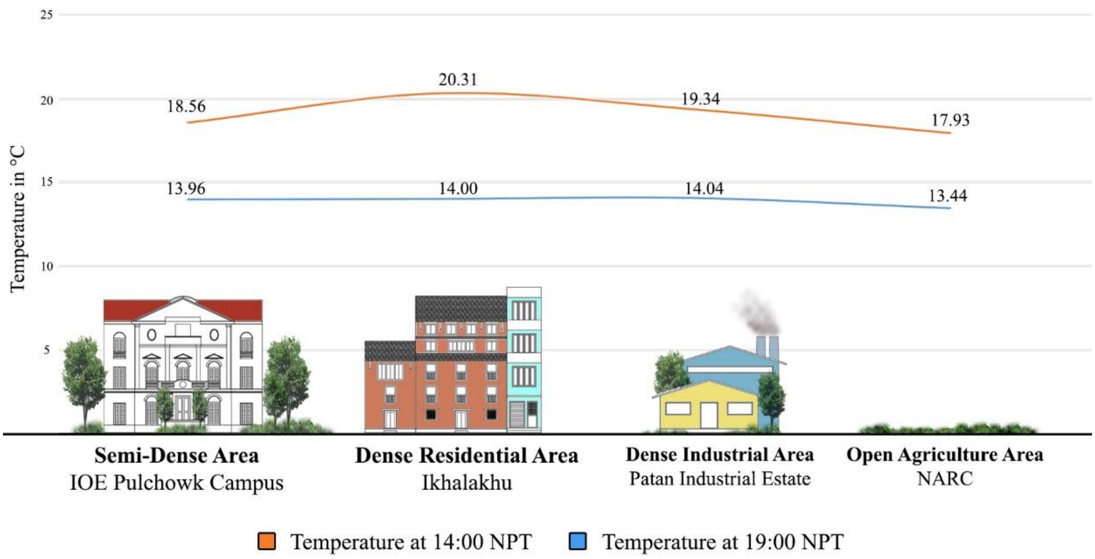


Figure 56 UHI in Patan

UHI between agricultural land and city core

Temperature was recorded in remaining agricultural field and in the core for spring season i.e. from January to March. The temperature difference during spring season was found to be 2.88°C between the core and the agricultural land at 14:00 NPT. However, the temperature difference reached up to 5°C on the hottest day recorded during the study period. UHI could be greater than observed on hottest day in the year as temperature has been recorded up to a maximum of 33°C in the valley in 2019 which is more than maximum recorded for the time period of the experiment conducted (29.2°C on March 12th).

In the case study of Delhi, the agricultural lands exhibited temperature greater than the city centers during the harvesting season when the lands were fallow. Nevertheless, the field cooled down rapidly after sunset compared to the city area which retained the heat.

In the study although, the temperature of the agricultural land was lowest at 19:00 NPT, the city remained only 0.6°C cooler than core area. This dismissed the presence of Canyon UHI. Unlike the case of in Delhi after sunset/ night time, the heat escaped the core area in Patan.

UHI between the City center and Industrial area

In between city center and industrial area, Industrial Estate has more concrete and asphalt surfaces which have lower albedo value compared to brick surfaces observed in Ikhalakhu. The Industrial Estate is more polluted compared to Ikhalakhu. Despite the pollution and more of lower albedo surfaces, Patan Industrial Estate had lower temperature than Ikhalakhu, a small courtyard. Ikhalakhu was a whole 1°C warmer than Patan Industrial Estate.

Patan Industrial Estate had been planned with unobstructed roadways and plants around every land of individual industry. The roads in industrial state has greenery on both sides. While the site in Ikhalakhu is blocked on all four sides with buildings up to 4-5 stories (9m - 11m tall), is brick paved and lacks green areas. The presence of trees could have led to prevention of the surfaces from being heated during the day.

Moreover, the heat could have been flushed out when the wind blows along the unobstructed roads.

The comparison between the temperature of these two area shows the importance of green surfaces and trees as well as free flow of wind in maintaining the cooler environment. The study reveals how elements like greenery along an unobstructed pathway can help reduce a few degree of heat from a dense area. Moreover, with tree plantation, the concrete having low albedo can be shaded and prevent the surface from retaining heat.

Secondly, comparing the average temperature at 14:00 and 19:00 it can be noticed that Ikhalakhu loses more heat compared to Industrial Estate. Pollution is less in courtyard as there is no access of vehicles. Presence of industries in Patan Estate means the CO_2 or other pollutant traps heat and makes the area warmer. Absence of pollutants in the air helps cool a zone quite fairly.

Social Effects of UHI on residents of core area

Patan has an average temperature of 17.8°C (Climate-Data, 2020). The temperature reaches up to 27°C on average in the month of June (World Weather Online, 2020). This is the temperature that people have adapted to. Temperature up to 27°C is adjustable in the valley. Temperature above this level is difficult to adjust to without depending on active cooling medium. Core area in Patan showed an average 20.31°C during the course of study which should have usually been around 11-12°C in average. Temperature above 27°C was observed in March which has crossed the comfortable temperature.

Most people have experienced that the temperature is warmer than prior years but many are unaware of the presence of UHI in Patan. Since canyon UHI is minimum (0.6°C at 19:00 NPT) it is quite obvious that most people do not experience extra heat in Patan. During the day time, they are mostly inside the building under the influence of active cooling devices.

Increase heat however has effects on nearly two-third of the population. Increased heat has dissuaded people from walking regularly as nearly one-third people suffer from heat exhaustion and fatigue travelling during the day time. The elderly population are found to be more at risk to heat exhaustion.

Heat has made people lazier and lose concentration on their work. It has contained the people in their rooms which are facilitated with fans/ AC or other cooling devices. People have become completely dependent on artificial cooling methods.

Residents of traditional houses are spared from dependency on cooling technology but with more people rejecting traditional building and converting them into modern ones, dependency is unavoidable.

Economic Effects of UHI on residents of core area

As people are depending on active cooling/ heating technology, they are forced to pay one-third to double more of what they are used to pay in prior years. With new expensive technologies, the electric bill for many is soaring high which seems to be the common complaint.

Excess use of electricity has also put load on supply. There still are power cuts because of overloading and short-circuiting of transformer.

Increasing heat has also reduced productivity of people who are not facilitated with cooling aids.

The effects of Urban Heat Island do have effects on quality of living of people in core area but the effects are not extreme. The dependency on active cooling has increased but overall the heat has been bearable.

Mitigations measures and policies

The policies are good enough and cover most of the measures that can control UHI Effects. But the policies are have not given the desired results. Slow reaction to strategy promulgation, lack of commitment to the proposed action and contradicting actions by the government has led to failure of policies. The planning of urban spaces with a systemized and planned settlements that are secure, supplemented with open spaces and improved environmental condition is evidently a failure due to slow governmental response. Added with decisions of increasing taxes on eco-friendly vehicles which is against Climate Change Policy and National Sustainable Transport Strategy, is another step backwards on creating a better urban environment.

Nevertheless, due to COVID-19 pandemic, the concept of shifting transportation to greener approaches like cycling are being discussed. The valley might see better safer cycling routes in future. Like Stuttgart, a safe, green walkways connecting some of the business areas and residential zones can be created along the Bagmati river. Such connection will preserve the river, enhance greenery as well as provide a green walkable/ cycle-able path.

Another means to reduce UHI is through passive designing. There are no provisions to promote passive designs in Nepal. Although these concepts are included in architecture studies, very few building opt to approach passive design. Like Stuttgart and Eco-City Valley should also put a few guidelines towards passive design. Passive buildings will not only reduce artificial heating cooling need but will create a better indoor living environment. Government can encourage people towards passive design through awareness campaign and allocating subsidiaries to buildings that follow passive design.

Polices have been thoroughly thought and put forth. Due to lack of proper implementation, weak institutional arrangements and clear definition of roles and responsibilities the policies have disappointing results.

9 CONCLUSION & RECOMMENDATION

UHI is prevalent in Patan and the residents in the core area are affected. Though many residents may not feel the effects currently, if UHI is not controlled, living in Patan might start to get difficult soon.

There are many policies drafted supporting the measures that international cities have adopted to counteract UHI. However, most of the policies in Nepal fail to achieve the goals that they were intended for. Failure of polices is one of the reasons for the current degrading situation of the valley.

Currently, due to global warming and climate change, movements towards sustainable and smart cities are gaining momentum and international interest. Under such influence, there is also an increased interest in developing Patan as a green city. Steps have been taken towards cleaning the river, developing Bagmati river corridors as parks and making roads greener though plantation along the roads. Programs such as Kausi Kheti or roof-top farming has been gaining popularity which helps compensate for loss of greenery due to the buildings. Such strategies will be very helpful in maintaining UHI Effect in Patan, thus ensuring comfortable life for the dwellers. These steps are positive approaches for a better environment with less UHI Effect. But these actions are not enough to overcome UHI in the core area.

The core area needs more of the greener surfaces and less pollution. Following recommendations may help improve the condition of core areas in Patan:

1. Increasing green surfaces
   Increasing vegetation is one of cheapest option for reducing UHI. Therefore, Stuttgart and Eco-city has invested in more green surfaces with numerous parks, street vegetation and green roofs. Even in the case study of Delhi, the temperature of the forest in the heart of the city remains low compared to urban area. The quasi-experiment also shows how green surface help in reducing temperature. The core area which is devoid of greenery thus, need to embrace more greenery. Green surface can be incorporated in core city in form of:
   - Soft pavements in the courtyards instead of non-permeable surface. It would result if the percentage of green area be allocated in bye-laws instead of vaguely stating open area.

- Green roof
- Urban agriculture/ Kausi-kheti
- Parks along the river banks which also helps in conservation of rivers

2. Reduction in pollution

   It is seen in the quasi-experiment that due to pollution, the area lacks the capacity of cooling. It will therefore help the core areas if the mode of transport switched to green, eco-friendly version to reduce pollution as seen in Stuttgart and Eco-city.

   A better safer greener cycle paths and walking pathways can be developed along banks of Bagmati river and its tributaries. Since the Bagmati river and its tributaries connects most of the business, commercial and residential areas, these connections will promote walking and cycling activities and reduce the dependency on motorized vehicles thus reducing pollution.

3. Reduce dependency on active cooling

   The inclination towards modern buildings is evident in the core area. Many of the traditional buildings have been transformed into the modern concrete buildings which are dependent on active cooling. This dependency can be reduced by promoting passive designs through awareness and incentives.

   The use of low albedo material for roof and pavements will also help in reducing temperature in the core area.

4. Temperature can be reduced by exploiting wind to flush out the warm polluted air in the core area. For this wind pattern must be studied and wind paths must be planned. Strategically locating parks along the wind path will give better results in cooling and purifying the air of the core area.

The new settlements should also be planned with more focus on use of wind and vegetation. It must have enough greenery to keep the settlement cool (the percentage of green surface maybe in included in byelaws and enforced strictly). Focus should also be on use of passive design and low albedo materials to reduce dependency on active cooling.

9.1 FURTHER STUDIES

Due to limitation of time, the study has been carried out only for spring season. For a complete understanding the study must be carried out for a whole year covering every seasons. This will provide better insight on the characteristics of UHI in Patan and help plan for adapting measures to control UHI.

Further study of the city and wind patterns must be done. As wind is one of the main factor that help in reducing UHI, wind pattern, its velocity is to be studied. To formulate better strategies and plans to combat UHI, studies of urban pattern must be done so that appropriate location for open space and parks and wind path can be proposed. Adding green parks at nodes of wind path should help in cooling the hot air as the air flows into the city.

Feasibility study for extension of parks along Bagmati river and its tributaries must be done.

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ANNEXES

ANNEX I: TEMPERATURE LOG DATA

Temperature Log Data								
Station	Pulchowk Campus		Ikhalakhu		Patan Industrial Estate		NARC	
Date	14:00	19:00	14:00	19:00	14:00	19:00	14:00	19:00
29-Jan-20	20.9	15.6	21.5	15.1	22.2	15.9	18.2	13.0
30-Jan-20	16.5	11.2	18.8	11.4	17.3	11.9	14.2	10.7
31-Jan-20	13.5	11.8	18.1	12.0	18.1	12.0	16.3	11.4
1-Feb-20	16.1	10.5	17.2	10.8	17.1	12.3	15.3	9.8
2-Feb-20	14.5	8.9	18.6	10.9	17.6	12.9	14.6	10.1
3-Feb-20	14.8	10.9	19.4	10.9	17.7	11.0	16.4	10.1
4-Feb-20	16.4	12.3	18.0	12.2	17.4	11.5	15.8	11.5
5-Feb-20	16.0	10.6	19.2	11.1	16.9	11.0	15.3	10.8
6-Feb-20	15.8	11.3	15.9	11.2	16.8	10.9	15.3	10.5
7-Feb-20	14.7	11.7	16.8	11.0	17.1	11.1	14.9	10.4
8-Feb-20	15.1	10.7	16.1	10.8	14.8	10.6	14.3	10.2
9-Feb-20	14.6	10.7	18.1	11.0	18.3	11.6	15.4	11.5
10-Feb-20	15.1	11.7	22.0	12.8	19.3	12.6	17.9	12.4
11-Feb-20	19.3	13.2	22.1	13.5	19.2	13.5	18.4	12.8
12-Feb-20	19.1	12.6	21.5	14.1	20.6	13.6	18.6	13.6
13-Feb-20	19.2	13.6	22.4	14.1	21.7	14.1	20.1	13.9
14-Feb-20	19.5	14.1	24.5	14.9	22.0	15.2	20.2	14.3
15-Feb-20	17.6	13.6	21.1	14.1	21.6	15.3	17.8	13.6
16-Feb-20	18.8	14.3	20.6	15.1	21.3	15.4	19.6	14.5
17-Feb-20	19.8	14.9	21.8	15.7	20.1	16.2	19.1	15.3
18-Feb-20	19.0	15.1	22.8	15.6	21.2	15.9	20.0	14.9
19-Feb-20	20.9	16.2	20.2	15.5	20.7	15.4	19.4	14.5
20-Feb-20	19.3	13.8	21.1	14.8	19.9	15.6	18.8	14.3
21-Feb-20	16.5	13.2	15.7	14.1	16.2	12.1	15.6	13.3
22-Feb-20	21.2	15.2	19.6	14.8	18.6	16.3	18.0	15.1
23-Feb-20	19.5	14.3	19.8	15.1	18.3	14.7	18.7	14.3

24-Feb-20	19.9	14.4	19.9	13.2	19.7	12.9	18.5	12.1
25-Feb-20	17.8	11.9	18.7	12.7	19.3	13.3	17.6	11.7
26-Feb-20	12.6	10.7	12.5	11.0	13.0	11.0	12.0	10.5
27-Feb-20	20.2	14.7	22.2	13.7	18.9	13.7	17.3	13.0
28-Feb-20	21.1	15.6	21.3	15.6	20.8	13.2	19.5	14.9
29-Feb-20	21.5	16.7	23.4	16.4	22.5	16.6	20.8	15.9
1-Mar-20	22.3	16.9	20.7	16.6	20.7	15.9	19.5	16.4
2-Mar-20	20.2	14.6	19.0	13.7	17.5	13.5	19.7	13.0
3-Mar-20	23.0	17.5	21.2	15.9	18.9	15.9	18.0	15.8
4-Mar-20	20.1	16.3	22.1	16.7	21.5	15.8	20.6	15.4
5-Mar-20	22.2	18.0	19.3	14.9	21.0	15.3	19.3	14.8
6-Mar-20	13.6	12.9	19.2	14.8	19.3	14.3	19.8	15.2
7-Mar-20	17.1	13.3	12.9	12.7	13.2	13.0	12.3	12.1
8-Mar-20	20.5	15.5	24.0	15.9	20.6	15.2	18.9	15.3
9-Mar-20	22.7	17.2	24.7	14.9	22.6	16.6	21.4	14.7
10-Mar-20	20.6	15.6	26.5	16.5	20.7	16.0	21.4	15.7
11-Mar-20	23.3	18.7	28.7	18.4	25.9	18.5	23.7	18.2
12-Mar-20	24.0	20.5	29.2	19.3	26.3	18.5	23.5	19.4
13-Mar-20	18.7	15.3	15.5	14.4	15.7	14.2	14.8	13.9
Average	18.6	14.0	20.3	14.0	19.3	14.0	17.9	13.4

ANNEX II: QUESTIONAIRE

Age: ………………………………………

Address: …………………………………….

Occupation: …………………………………

1. How long have you lived in the core area of Patan?

   ………………………………………………………………………..

2. Have you experienced temperature increase on yearly basis?

   ☐ Yes ☐ No ☐ Not sure

3. Do you feel that the place you are living is warmer than less dense areas around Patan?

   ☐ Yes ☐ No ☐ Not sure

4. If yes, how are you sure?

   ………………………………………………………………………..

5. Is your work hampered due to increased temperature?

   ☐ Yes ☐ No

6. If yes, how? If no, how?

   ………………………………………………………………………….

7. How often do you walk in the street in the Patan during the day?

   ☐ Always ☐ Sometimes ☐ Never

8. Has walking in street of Patan at day time in summer become difficult lately?

   ☐ Yes ☐ No

9. Does walking for a few minutes make you exhausted?

☐ Yes ☐ No

10. Have you experienced any other health problems like weakness or heat cramps after going for walks in Patan?

☐ Yes ☐ No

11. How frequently do you have to use fans/ AC during summer?

☐ Always ☐ Sometimes ☐ Never

12. Do you think the use of fan/AC has increased/ decreased?

☐ Yes ☐ No ☐ Not sure

13. How frequently do you have to use heater/ AC during winter?

☐ Always ☐ Sometimes ☐ Never

14. Do you think the use of heater/AC has increased/ decreased?

☐ Yes ☐ No ☐ Not sure

15. Has your electricity consumption increased prior to past years?

☐ Yes ☐ No

16. By how much has your electricity consumption increased from past year?

☐ A few units ☐ Quarter of previous ☐ Half of previous

☐ Double of previous ☐ More than double

17. The increase in consumption of electricity is due more use of appliances used to fend heat?

☐ Yes ☐ No

ANNEX III: MATRIX SHEET

S.No.	Comments	Response
1.	To take inference from Delhi on how the green forest area has lower temperature compared to the dense built area.	Addressed in Conclusion and Recommendation on page 91.
2.	To mention promotion of urban agriculture as a medium to increase greenery and reduce UHI	Addressed in Conclusion and Recommendation on page 92.
3.	To make a UHI graph with picture representation and curve as the final output	Addressed in Discussion on page 86.
4.	Mention the comfortable temperature of Patan up to which the people are not suffered and use as reference to compare comfort	Addressed in Discussion under the heading Social Effects of UHI on residents of core area on page 88.

ANNEX IV: ARTICLE

Urban Heat Island in Kathmandu Valley: A Case of Patan

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Abstract

Urban Heat Island (UHI) is the phenomenon where a city has greater temperature compared to its rural surrounding and it can be experienced in cities of all sizes. The phenomenon has piqued interest of planners as increased UHI has negative effects on human comfort and productivity, economy and ecology and the through proper planning can be controlled to some extent. Kathmandu valley, one of the emerging fastest growing agglomeration in South Asia is also experiencing UHI. The temperature in the valley is increasing at rate of 0.04℃ per annum with maximum trend of 0.06℃. The few studies conducted regarding urban heat island effects in the Kathmandu valley have been done though Landsat imagery. Since Kathmandu is a valley, difference in temperature due to wide range of altitudes is inevitable and the results of Landsat may not accurately justify UHI Effects in the cities of the valley. To understand UHI at micro level, the research has been conducted to study UHI in Patan, the second largest city in the valley, using thermometers to record temperature at four different locations representing different built-up composition. The study shows the role of green cover and vegetation as well as the role of a planned wind path in cooling the cities.

Keywords

Temperature – Green Spaces – Built-up – Kathmandu valley – Patan

1. Introduction

The urban heat island (UHI) is a phenomenon where urban regions experience warmer temperature than their rural, undeveloped surroundings.[1] The phenomenon can be found in settlements of all sizes and in all climatic regions.

According to United Nations Environmental Protection Agency (EPA)[2], the annual mean air temperature of a city with 1 million people or more experience 1-3°C warmer temperature compared to its rural surroundings. However large cities such as New York City and London has faced up to 10°C and 9°C UHI Effect respectively.[3, 4] Moreover, the Global Warming will increase the already higher temperatures of the sites[2]. Due to the excess heat, the quality of life in urban areas has been compromised. Many of the large cities such as Stuttgart in Germany and London in UK are therefore planning ways they can reduce the UHI effects.

Urban heat island has received a great attention due to its implications on energy use, human comfort and productivity, air pollution and urban ecology. Numerous factors are held accountable for this effect, including anthropogenic heat release, surface cover, climatic condition, air pollutants, etc.[5]

Kathmandu is the most populated urban region of Nepal and one of the fastest-growing urban agglomerations in South Asia.[6] According to United Nations Department of Economic and Social Affairs (UN DESA), Kathmandu has a growth rate of 3.94% and 29% of the country's total urban population. The land use of Kathmandu valley has changed significantly in the last four decades. The city has expanded as much as 412%, with the majority of land converted from agricultural land to built-up areas, which has changed the valley's landscape considerably.[7]

Study of Bijesh Mishra on Urban Heat island in Kathmandu[8] shows a temperature difference of 5°C between forest land and developed land on average in Kathmandu valley. Furthermore, an annual increase of 0-2°C is also noticed in 18 years. Consequently, valley has also seen change in weather patterns.

2. Research Objective

The limited researches conducted regarding UHI effect in valley involve Landsat imagery to determine UHI Effect. Kathmandu is a valley and the temperature difference is inevitable with change in altitude. Therefore, satellite experiment may not accurately portray the UHI Effects occurring in the main cities in the valley.

Thus, the objective of this paper is to study UHI Effects at micro level in one of the core cities of the valley. The study is conducted in the second largest city of the valley: Patan.

3. Literature Review

Introduction of artificial surfaces characteristics of those of a city radically alters the aero dynamics, radiative, thermal and moisture properties in the urban region compared to natural surroundings.[1] When a huge amount of natural land is replaced by artificial built surface that absorbs incoming solar radiation or heat and re-radiate it at night, areas with such surfaces are bound to be warmer compared to their rural counterpart.[5] This phenomenon of urban area having warmer temperature than the surrounding rural settlement is called urban heat island effect.

UHI can be categorized into two types: surface heat island and atmospheric heat island. The surface heat island is the heat trapped in the surface component; it depends on the albedo property[1] and the heat capacity of the urban surfaces. This type of UHI is strongest during the daytime when solar heating creates large differences between dry/wet and vegetated surface to horizontal surfaces such as roofs and pavements.

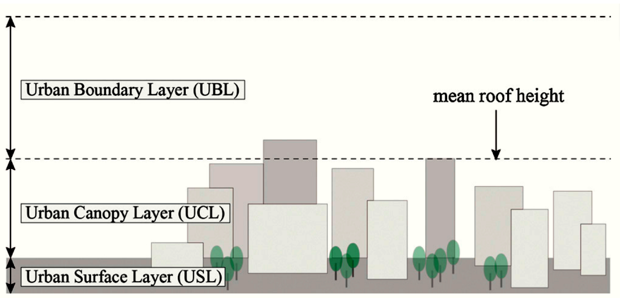

Figure 1: Different layers of UHI[9]

[1]Albedo is the heat orsolar radiation reflectance factor of a material. Its value ranges from 0 to 1. An albedo of 0 means no reflecting power of a perfectly black surface (none reflected, all absorbed), an albedo of 1 means perfect reflection off a perfectly white surface (100 % reflected)

Atmospheric heat island can be further classified into canopy layer and boundary layer UHI. The canopy layer heat island exists from the ground to below the tops of trees and roofs while boundary layer heat island starts from the roof top layers up to the area where urban landscape can influence.

The canopy heat island intensity increases after sunset and reaches a maximum sometime between a few hours after sunset and before sunrise. The canopy-layer UHI is therefore primarily a nocturnal phenomenon and arises from reduced cooling rates observed in the city in the late afternoon and evening compared to the non-built-up areas resulting in higher urban minimum temperatures.

3.1 Causes of UHI

1. Loss of Green Spaces

   Vegetation through evapotranspiration process maintain a cool environment. Evapotranspiration involves two processes: evaporation and transpiration. In evaporation, water evaporates from soil, tree tops and bodies of water into air reducing the temperature of the surface and in transpiration plants absorb CO_2 (CO_2 traps heat in the air increasing the temperature).

   Trees also intercept solar heat and prevent surfaces from heating.[5] Urban environment has less of green areas making it warmer compared to rural counterpart.

2. Paved and Impermeable Surface

   Urban areas are characterized by significant amount of cement, concrete and asphalt surfaces as roof surfaces, pavements and roads. These materials have thermal bulk properties that absorb more heat than green cover. Moreover, these surfaces are impermeable and the water runoff is redirected to storm water rather than being absorbed into soil or by plants and prevent evapotranspiration.

3. Anthropogenic Heat Release

   The urban areas are more likely to suffer from air pollution because of heavy traffic and presence of industries. These exhaust gases trap solar radiation.

   Urban areas usually have a large number of vehicular flow and extensive use of Fridges and

ACs. The engines and the exhaust from them produce a large amount of anthropogenic heat as well as CO2 which results in temperature increase.

4. Urban Canyon

   Urban canyon effect takes place due to tall buildings in close proximity. The close proximity creates multiple surfaces reflecting and absorbing sunlight and heat. The heat released by one building is trapped by another taller building.

   Taller buildings also block the wind path and prevent convectional cooling. The effect is measure in height of building to the width between the buildings.

5. Agglomeration of People

   Large number of population in a small space means large amount of CO2 release and heat emission.

3.2 Effects of Urban Heat Island

Effects of UHI include change in micro climate which leads to change in weather pattern. This includes changes of local wind patterns, formation of fog and clouds, change in precipitation rates and humidity. The unusual heat caused by UHI contributes to a more intense upward wind movement that can stimulate thunderstorm and precipitation activity.

National Institute of Environment Health Sciences state that exposure to extreme heat can cause heat exhaustion, heat cramps, heat stroke, and death, as well as exacerbate pre-existing chronic conditions, such as various respiratory, cerebral, and cardiovascular diseases. Children and elderly are more susceptible to such conditions during heat.

Rise in temperature increases the demand of active cooling like fans and AC. The regular use of such electronics increases electricity consumption and also the electricity bill. Increased consumption leads to load on production of electricity which might create a scarcity.

Extreme heat is also responsible for Low productivity from workers. Low productivity leads to loss for industries.

3.3 UHI in Kathmandu Valley

Kathmandu valley has a bowl shaped landscape. It is located at a mean elevation of about 1300 meters (4265 feet) above sea level. Situated in the middle section of the Himalayan range, the valley is surrounded by Phulchowki Hill in South West, Shivapuri in North, Champa Devi in South west and Nagarjuna in west. There are two narrow river gorges in the South-West and North-West edges.

The climate of Kathmandu valley is sub-tropical cool temperate. Maximum temperature is 35.6°C in April and minimum is -3°C in January. In general, temperature is 19°C to 27°C during summer and 2°C to 20°C during winter. The climate is influenced by tropical monsoon of southeast and receives average rainfall of 1400 mm. during June to August.[10] The general wind direction is from South West to North East and exit through South-East Sanga Hill.

The valley is the most populous urban center of Nepal. Many pull factors such as physical conditions of the valley, public service accessibility, employment opportunities, real estate market, population growth, political situation and government plans and policies has caused the population to rise in the valley.[11]

Urban growth in the valley accelerated since 1980s, and the growth rate was substantially high during the 1990 decade. Covering only one percent of the country's total area, Kathmandu valley accommodates 31% of the total urban population of the country. The Kathmandu valley is characterized by sustained population growth in the urban core and rapid urban sprawl.[6]

Lack of effective planning and inadequate infrastructure has created blockade to sustainable urban growth of the valley. The growth of built-up areas in the most urban settlements is haphazard and uncontrolled with a rapid decrease in agricultural land. This unplanned urban development has contributed to dramatic changes in urban footprint of the valley.

Following factors make Kathmandu valley susceptible to UHI:

1. Increasing Impermeable and High Albedo Surfaces

   There are over 2 million households in Kathmandu valley and more than 80% are made of cement mortar and concrete blocks. About 90% of the total roads (230km approx.) in

Kathmandu district is black topped while about 60% of roads (131 km approx.) in Lalitpur is black topped. All the national highways and strategic urban roads except for some sections of the urban road in Lalitpur District are black topped according to Department of Roads report, 2017.

2. Decreasing Green Surfaces and Increasing Urban Footprint

   The built-up area has expanded rapidly and consistently mostly in the valley floor increasing from 3% to 23% of the total landscape from 1967 to 2010 (Figure 2) according to Department of Environment, 2017.

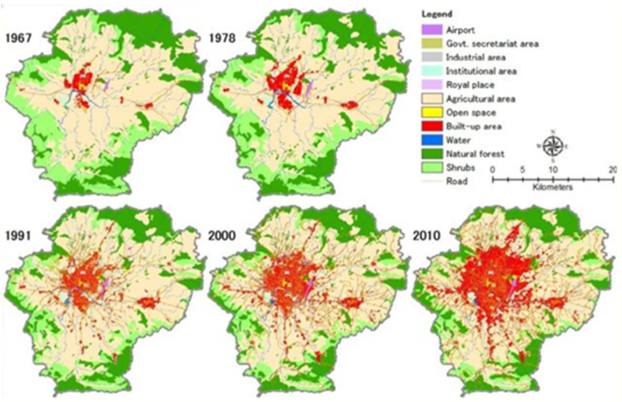

Figure 2: Urban growth in Kathmandu valley from 1967- 2010[12]

3. Increasing Vehicular Movement There has been significant rise in the vehicle numbers in the Kathmandu valley. Currently more than 1 lakh vehicles are added in the valley every year as shown in Figure 3.

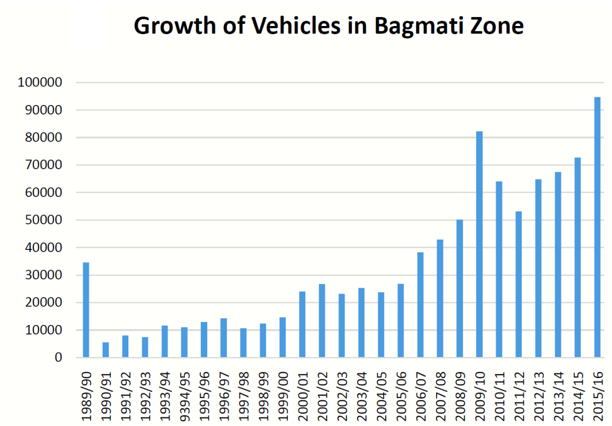

Figure 3: Growth of vehicles in Bagmati Zone (DoEnv)[13]

4. Increasing population

   With 51% growth from 2001 to 2011, the total population of Kathmandu valley is expected to reach almost 6 million by 2031.[14] CBS 2011 states that three quarter of population density inside Ring road in 2011 was over 200 people/ hectare while old town area has over 1000 people/ hectare density.[15]

5. Natural Low Wind

   As the valley is surrounded by natural hills on all sides, the winds are rather calm. Low wind lack ability to flush out stagnant heat and polluted air from the valley contributing to UHI.

The valley is, therefore, very susceptible to extreme UHI effects. Moreover, Thapa[cited in[16]] relates that the warming trend is high in the inner core of Kathmandu valley and it ranges from an annual temperature trend of 0.5-0.8°C in between 1976-2008. The study of Baniya mentions the rate of increasing temperature in the valley is higher (0.06- 0.1°C per year) in core as compared to the outskirts like Nagarkot (0.02°C per year).[16]

Study using Landsat imagery also points that the temperature is increasing in the valley.[17, 8] The study of Mishra(2018) revealed that temperature in Kathmandu increased by 0°C to 2°C between 2000 and 2018 while Rai's study shows a rise of 3°C in 24 years. Her study observed a temperature of 17-18°C in 1995 which increased to 20.5-21.5°C in 2019 in the majority of cities.[8, 17]

The study of Mishra segmented the land areas into 3 broad classes: development, forest, and agriculture and monitored the change in natural vegetation. The Normalized Difference Vegetation Index (NDVI) values suggested that greenery inside the valley has decreased significantly and the vegetation outwards have also been replaced by development of semi-urban areas (Figure 4). The study reveals how temperature is increasing outside the core of Kathmandu city in the areas where new urban and semi-urban areas are expanding as shown in Figure 4.[8]

The difference between the forest Land Surface Temperature (LST) and LST of developed and agricultural land has is about 5°C.

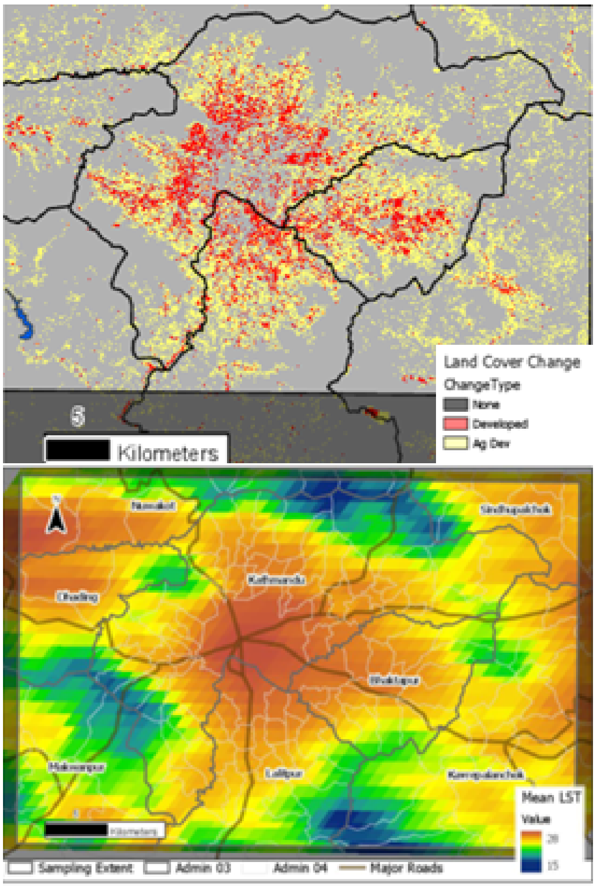

Figure 4: Land cover change type experienced from year 2000 to 2018(Above).Mean daytime surface temperature distribution for Kathmandu during the period of 2000 to 2018, driven largely by land cover such as, the heavy developed areas in central Kathmandu, and elevation (Below)[8]

Both the study of Mishra and Rai points to the core as the hottest spots. Rai suggests that the haphazard expansion of city area, increased impervious neighborhood and decreasing green land has led to this Urban Heat Island Effect in the valley. However, Mishra believes more study combining NDVI, population and socio-economical attributes are needed to determine the cause of UHI. Nevertheless, prevalance of UHI Effect in the valley has been proven.[8, 17]

4. Study Area

Patan is the oldest settlement area in Kathmandu valley built around third century BC. It is the third largest city in Nepal and second largest in the valley.

Currently the city center lies in ward 12 with a population of 5819 living in an area of 0.13 sq.km. The density of the core is about 450 people/ hectare and accommodates 1342 households. Ward 19 and 16 are also the part of the ancient settlement and their density is 461 persons/hectare and 545 persons/hectare respectively. Number of households is 1174 and 858 spread over 0.16 sq.km and 0.08 sq.km respectively.

The urban growth of Patan is not as large as Kathmandu but it is also growing rapidly outside the core city. Patan has been expanding outwards and losing surrounding agricultural lands to development and urban sprawl. While the core is experiencing infill development and the density has reached about 500 persons/hectare with 10,000 households /sq.km.

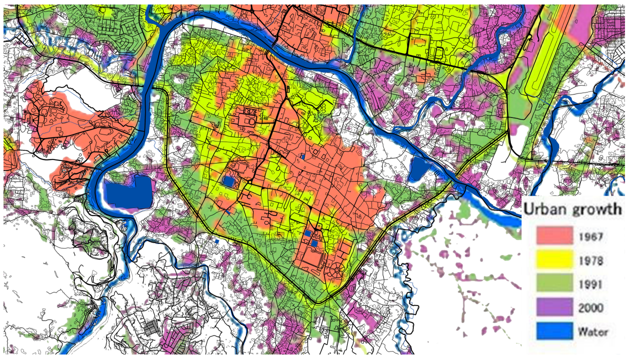

Figure 5: Urban growth in Patan from 1967 to 2000[12]

The core area lies towards the North of Lalitpur Metropolitan City (LMC) and expansion can be noticed towards the west and south of the old settlement before construction of Ring road (Figure 5). Ring road was built around the 70s and development towards and along the new Ring road can be seen by the 1990s. As the area inside the Ring road decreasing, urban sprawl can be observed outside the Ring road towards the East, South-East and South. With urban area sprawling and expanding, paved roads and built up areas are replacing the open green agricultural lands in Lalitpur district.

5. Methodology

The research has been conducted by following post-positivist paradigm. It follows deductive reasoning with a hypothesis saying "Vegetation and green cover along with proper air flow creates a cooler atmosphere in the area compared to hard, non-porous and artificial surfaces of an urban landscape where air flow is limited".

Quantitative approaches were used to determine the results as UHI Effect is the difference in temperature of city and rural area.

To measure UHI Effect, thermometers were planted in 3 different areas. One of the site has meteorological station and the data has been taken from Department of Hydrology and Meteorology (DHM). The Station located in Khulmaltar is an agrometeorology station (Index no: 1029).

The selected site for placement of thermometers is done in such a way that each location represents a unique combination of urban character in terms of built forms, greenery and surface types. To eliminate variables such as weather changes, the site is selected at the shortest distance possible so that the weather at a time is same in all the area.

Depending on the parameter following area has been chosen.

- Semi dense area- IOE Pulchowk Campus
- Dense settlement- Ikhalakhu
- Dense settlement-Patan Industrial State
- Open space- NARC

The distance between the farthest thermometer locations is approximately 3km. For study purpose the built up area of 100 x 100m is taken with thermometer placed at the center. The 50m radius is taken to exclude the influence of heat from vehicular emission as this parameter has not been considered in the study.

The ratio of green surfaces to artificial surfaces has been analyzed to categorize the areas. Artificial surfaces have been further divided into vertical and horizontal surfaces. All of the vertical surfaces is made of brick walls (plastered/ non-plastered) and is labelled as built-up area. The horizontal surfaces are further classified according to the material used. The classification categories include brick pavement, concrete pavement and asphalt road.

The vertical surfaces have been considered to acknowledge urban canopy layer. Urban canopy layer affects the airflow and prevents wind from flushing stagnant heat.

To calculate heat radiation from the surfaces, albedo value of each surface type have been taken from the values in US EPA.[2]

For simpler comparison, a cumulative albedo of the location is calculated.

$$\text{Avg. Albedo} = \sum \begin{bmatrix} \text{Built-up} & \times & \text{Albedo of} \\ \text{(in\%)} & & \text{surface} \end{bmatrix}$$

The temperature has been recorded by a digital indoor/outdoor thermometer. The device used is HTC-7 Digital Indoor/Outdoor Thermometer/ Hygrometer. All the used devices have been calibrated with the thermometer in Department of Hydrology and Meteorology.

Figure 6: Thermometer stand

As per guidelines for measuring outdoor temperature, the thermometer must be placed in shade and not in direct sunlight. It should be kept in a covered area for protection from weather. Thus, the device has been kept in a wooden box (1’ x 1’ x 1’-3”) with louvered ventilation in all directions. The box has been fixed to wooden stand that is 5 ft. tall as shown in Figure 6. According to guidelines for measuring outdoor temperature, thermometer should be placed at 4-6 ft height form ground so that the atmospheric temperature is not affected by surface temperature. Therefore, a sound height of 5 ft has been maintained from the ground to get a more accurate air temperature. The stand has been placed such that it falls in shade of a tree or a building around 14:00 LST.

The temperature recording is taken daily at 14:00 LST during the day and at 19:00 LST in the evening from

29th January 2020 to 13th March 2020, a total of 45 days.

The temperature rises sharply during the day and reaches at its peak value at around 14:00 LST and drops slowly after that. So, temperature reading is to be taken at 14:00 LST.

The sun sets around 18:00 LST and the effect of canyon level UHI is most visible after sunset. So, 19:00 LST is chosen to observe the effect of canyon level UHI.

The data has been noted and the average calculated for comparison.

5.1 Limitation

Due to various reasons, the study has been limited to spring season only. Study of temperature for a whole year would have given more accurate data and understanding. However, study including all seasons could not be performed.

6. Data and Analysis

6.1 Study Area

As shown in Figure 7 for the open green space, National Agricultural Research Center (NARC) has been chosen. NARC has vast agricultural land and few buildings which houses research labs, offices, seminar halls, exhibition halls etc. To help with the researches, an agrometerology station is established near NARC area which monitors weather and temperature. NARC being the greenest area with 85% green surface and unobstructed wind, has the highest average albedo of 0.23 on average.

As semi open area Pulchowk Campus ground is selected. Being an educational institute, Pulchowk campus has green barriers around the academic buildings for better study environment. The thermometer has been placed at the ground to the east of architecture block and south of administration block. Pulchowk Campus is the second greenest area with an average albedo of 0.19. Considering the selected 100m by 100m area, there unrestricted or little restriction in wind flow as buildings are aligned only to the North and West with a good gap of more than 3 meters.

Situated in the old settlement another selected area is a small courtyard in Ikhalakhu labelled as the dense non-green zone. Enclosed from all the sides, the courtyard consists of only a small garden towards the west. Ikhalakhu, with least green area, has an average albedo of 0.17 and wind restriction in all directions. In addition to less green surfaces and wind restriction due the tall buildings all around, the surfaces in the courtyard are also non-permeable and has low albedo.

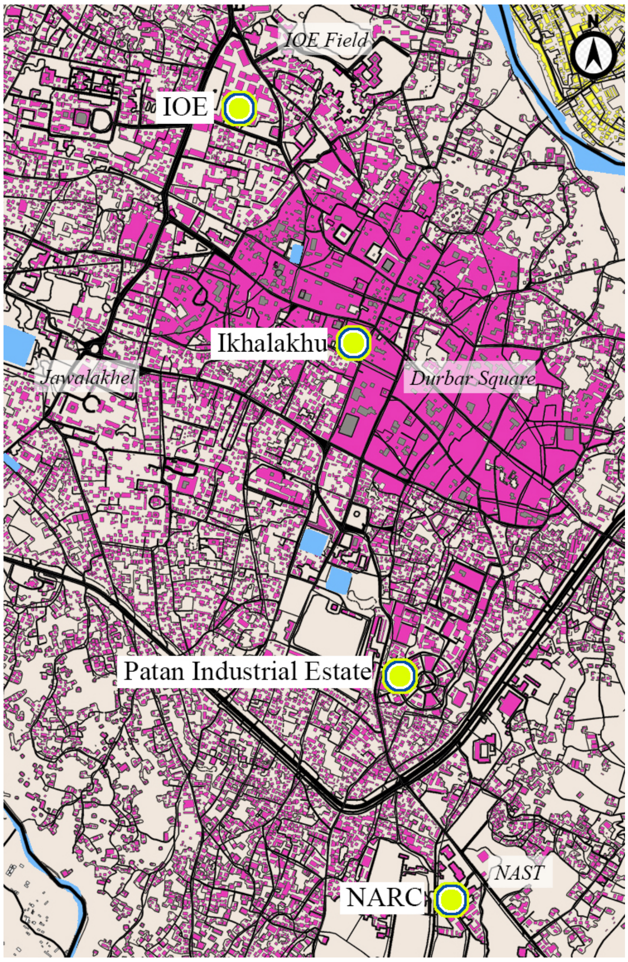

Figure 7: Position of thermometer in 4 different built-up composition selected for study

Another dense area, Patan Industrial Estate has a different environment compared to residential area in the core city. Presence of industries and more impermeable surfaces, Industrial zone is selected for comparison of temperature effect on residential and industrial area. Because it is a designated and planned industrial zone, Patan Industrial Estate has a unique pattern of circulation and every industry has a narrow green belt around it. The average albedo of Patan Industrial Estate is 0.12. Although pointed out as dense area, due to its unique circulation pattern and the selected area having low-rise buildings, Patan Industrial Estate allows better wind flow compared to Ikhalakhu through the street running West to East.

	Built-Up	Green Cover	Brick Pavement	Concrete Pavement	Asphalt Road	Average Albedo
IOE	36%	48%	6%	9%	1%	0.19
Ikhalakhu	50%	3%	30%	14%	3%	0.17
Patan Industrial Estate	80%	5%	0	5%	10%	0.12
NARC	5%	85%	0	0	10%	0.23
Albedo	0.12	0.25	0.3	0.12	0.12	

Table 1: Characteristics of the selected sites around the thermometer in 100m x 100m area

6.2 Analysis of the temperature recorded

Temperature has been recorded for 45 days in total from 29th January to 13th March at 14:00 LST and 19:00 LST. Observing the data, the hottest day was recorded on 12th March.

Comparing the average temperatures (Figure 8), the highest average temperature at 14:00 LST as well as 19:00 LST can be observed in Ikhalakhu while the lowest average temperature is recorded in NARC in both cases.

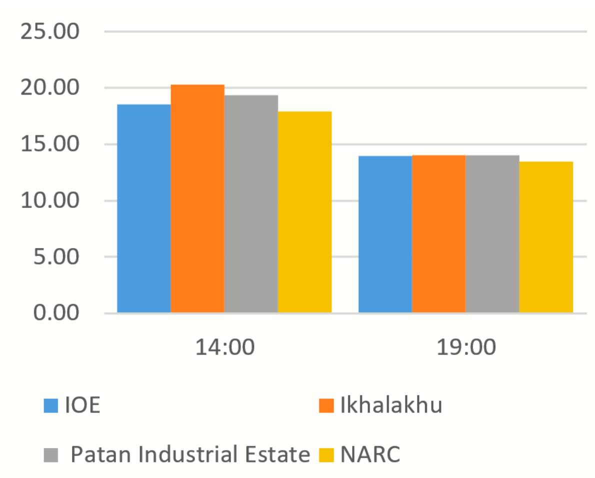

Figure 8: Average temperature recorded in different selected site taken daily at 14:00 and 19:00 from 29th January 2020 to 13th March 2020

NARC having the highest average albedo (0.23) and no wind restriction has the lowest temperature at night as well the day. The role of green surface and unobstructed wind in maintaining a low temperature can be seen in the chart. The maximum recorded temperature for NARC during the study period was 23.5°C on March 12th which is the lowest compared to 24.0°C of Pulchowk Campus, 26.3°C of Industrial Estate and 29.2°C of Ikhalakhu at 14:00 LST on the same day (Figure 9).

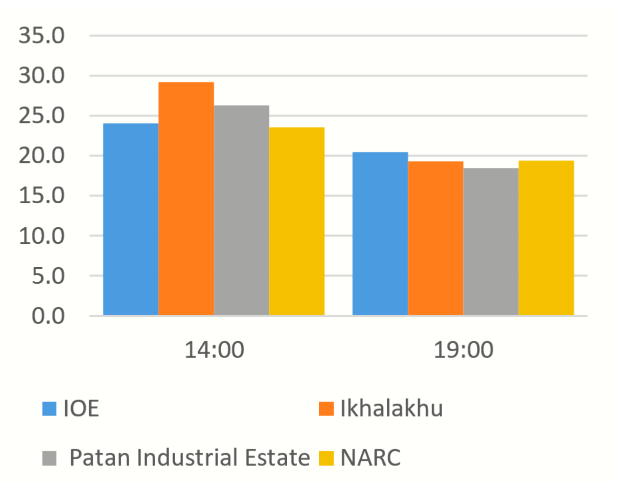

Figure 9: Temperature recorded on 12th March 2020, the hottest day during the study at 14:00 and 19:00

Pulchowk Campus (albedo: 0.19) with little wind obstruction and almost 50% green area also has a lower temperature during the day and night compared to Ikhalakhu (albedo: 0.17) and Patan Industrial Estate (albedo: 0.12) despite having an albedo value almost similar to Ikhalakhu. Although the campus has bricked pavements and buildings radiating the heat, the temperature is quite low compared to dense residential and industrial zone. The reading further proves the importance of green surface and the power of wind in reducing temperature.

Maximum temperature was recorded in Ikhalakhu and Patan Industrial Estate. With least green areas and more impermeable surfaces, the temperature recorded in Ikhalakhu and Patan Industrial Estate is 20.3°C and 19.3°C respectively at 14:00 LST.

Although albedo of Industrial Estate is much lower compared to Ikhalakhu, and the high probability of air pollution in the area, the temperature of Industrial Estate is fairly less than Ikhalakhu. The reason for this lower temperature could be the presence green boundary around each industrial section and the allowance of wind along the circulation.

Overall, an UHI Effect of 2.28°C can be noticed at 14:00 and 0.66°C at 19:00. The study of Mishra stated the UHI Effect of 0-2°C in the valley. The above study shows that at micro level, Patan city has UHI Effect more than 2°C on average and in some days the effect reaches up to 5°C.[8]

7. Discussion

The UHI Effect during spring season is 2°C and reached up to 5°C on the hottest day during the study period. UHI could be far greater on hottest day in the year as temperature has been recorded up to maximum 33°C in 2019 which is more than maximum recorded for the time period of the experiment conducted.

Among the dense areas, Industrial Estate with its polluted air and lower albedo compared to Ikhalakhu, had lower temperature than Ikhalakhu, a small courtyard exposed to less pollution. The comparison shows the importance of green surfaces and a free flow of wind in maintaining the cooler environment. The study reveals how elements like greenery along an unobstructed pathway can help reduce a few degree of heat from a dense area.

Secondly, observing at the cooling rate of the allocated dense zones, Ikhalakhu loses more heat compared to Industrial Estate. Less exposure to CO2 or heat trapping pollutants in the air helps cool a zone quite fairly.

In ancient times, Patan was a compact settlement surrounded by agricultural land. Temperature then was colder compared to present and a compact city with less green area helped maintain a comfortable warmer environment. However, with encroachment of peripheral agricultural land and the few green areas in the core area, the city has become hotter causing discomfort to dwellers.

Currently, due to global warming, movements towards sustainable and smart cities is rampant. Under such influence, there is also a notion of developing Patan as a green city. Step have been taken towards cleaning the river and developing Bagmati river corridors as parks and making roads greener though plantation along the roads. Programs such as Kausi Kheti or roof-top farming has been prevalent which helps compensate for loss of greenery due to the buildings. Such tactics will be very helpful in maintaining UHI Effect in Patan, thus ensuring comfortable life of the dwellers. These steps are positive approaches for better environment with less UHI Effect.

Further study of the city and wind patterns must be done. Wind path should be created exploiting the existing natural wind to cool the city. Adding green parks at nodes of wind path inside the city will help as well. Furthermore, prevention of urban sprawl and encroachment of available agricultural lands must be curbed for a better, green city.

8. Conclusion

Patan city has UHI effect of 2.88°C on average in spring. The maximum UHI effect reached up to 5°C. The effect may be greater on warmer days. Extended experiment must be performed for more accuracy on study of UHI Effect in Patan.

Through proper study and planning, UHI can be controlled. The study clearly shows how introduction of green surface and properly planned pathway that allow unobstructed wind flow play a vital role in maintaining cool environment.

As Lalitpur has been proposed to be developed as a green city, and applaudable steps taken towards achieving that goal, the UHI effect could possibly be controlled.

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