Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

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.

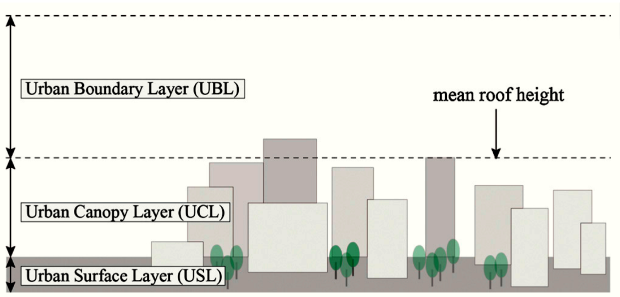

Figure 1: Different layers of UHI[9]

[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 CO2 (CO2 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.

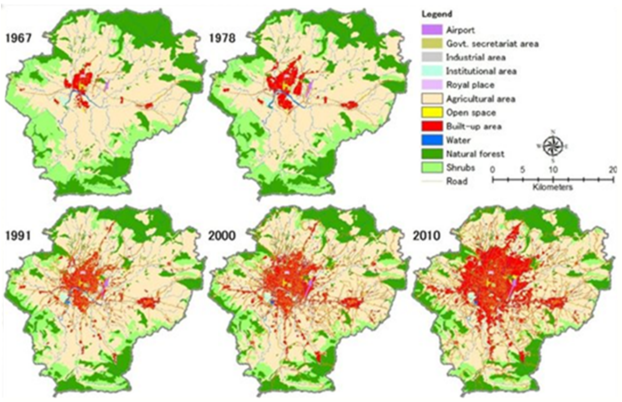

Figure 2: Urban growth in Kathmandu valley from 1967- 2010[12]

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.

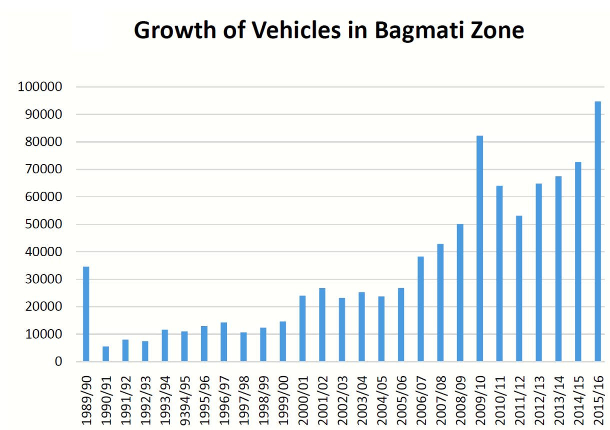

Figure 3: Growth of vehicles in Bagmati Zone (DoEnv)[13]

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.

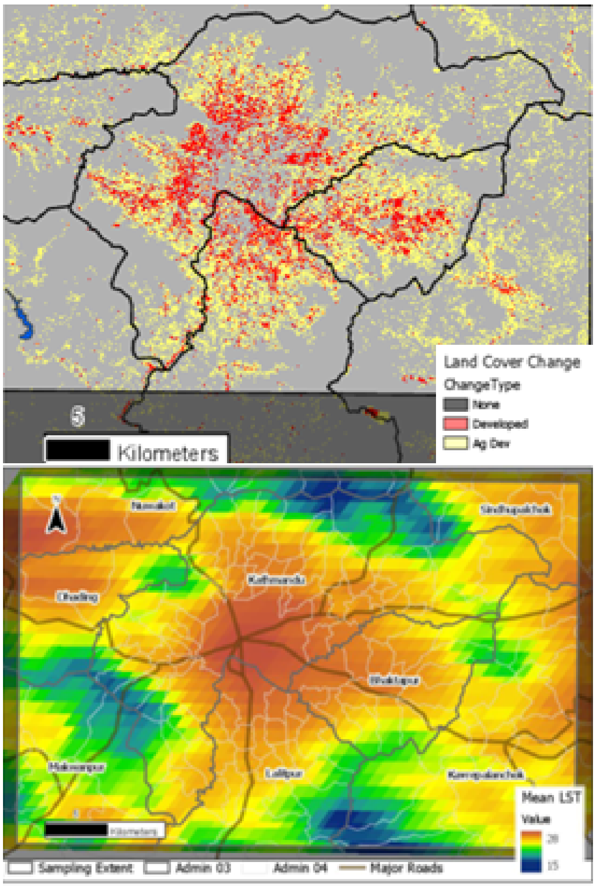

Figure 4: Land cover change type experienced from year 2000 to 2018(Above).Mean daytime surface temperature distribution for Kathmandu during the period of 2000 to 2018, driven largely by land cover such as, the heavy developed areas in central Kathmandu, and elevation (Below)[8]

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.

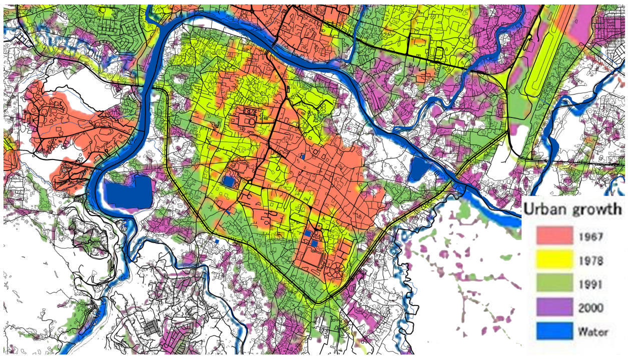

Figure 5: Urban growth in Patan from 1967 to 2000[12]

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.

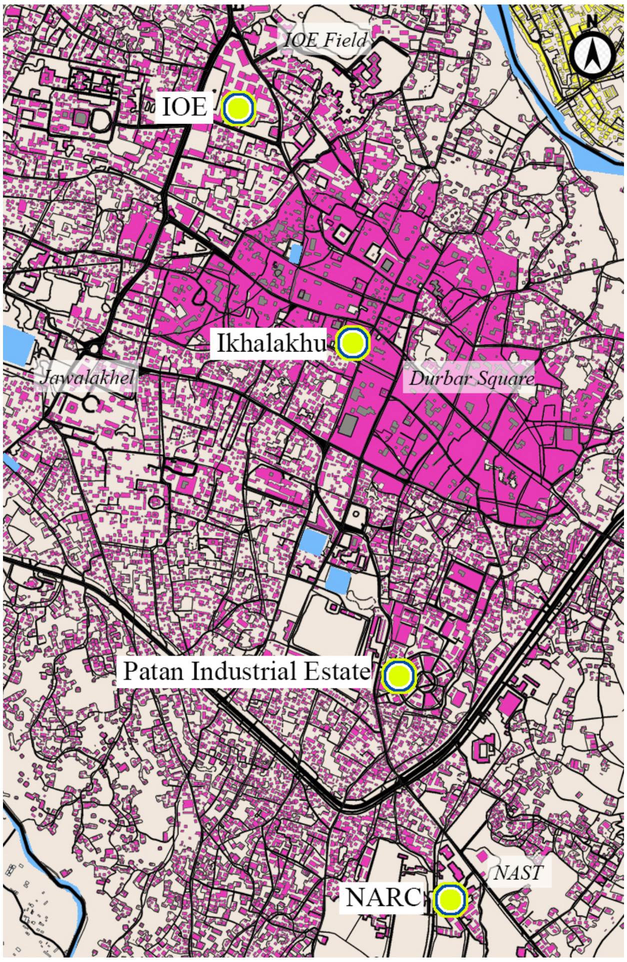

Figure 7: Position of thermometer in 4 different built-up composition selected for study

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.

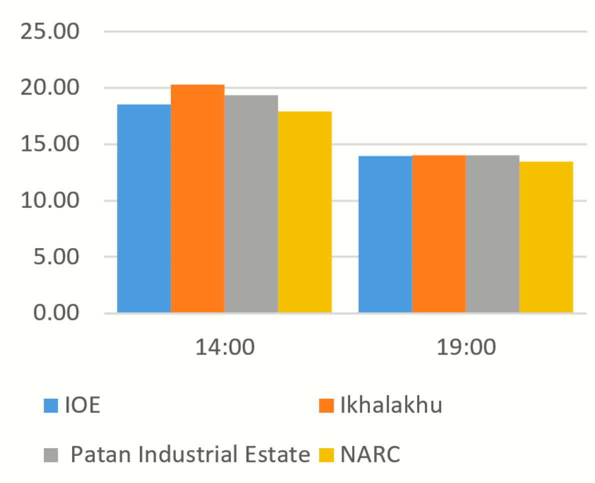

Figure 8: Average temperature recorded in different selected site taken daily at 14:00 and 19:00 from 29th January 2020 to 13th March 2020

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).

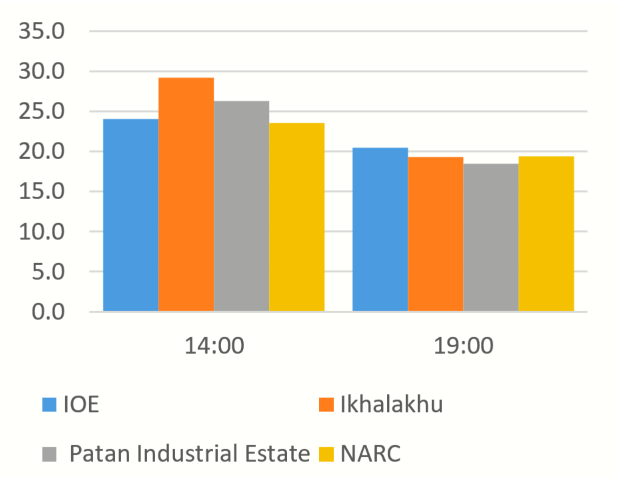

Figure 9: Temperature recorded on 12th March 2020, the hottest day during the study at 14:00 and 19:00

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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