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Exploring Winter Trends of Urban Heat Island Phenomena in Kathmandu Valley

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Abstract

The Urban Heat Island (UHI) effect presents a growing environmental concern for the Kathmandu Valley, significantly shaping microclimates and impacting local energy consumption. While much of the existing research emphasizes summer UHI conditions, the phenomenon's behaviour during winter months remains relatively underexamined. The study investigates the influence of surface materials & albedo characteristics on temperature variations across different urban and suburban zones during winter.

A mixed-method approach was adopted, combining field survey and spatial analysis of building albedo properties with secondary temperature data. Primary data captured details on surface types and albedo value, while secondary data from the Department of Hydrology and Meteorology (DHM) provided 10 years of temperature records, focusing specifically on December. Through trend analysis of maximum and minimum temperatures, subtle yet consistent differences in urban and suburban microclimates were observed. Trend analysis was done using Mann kendall slope and Sen's slope test, while the building materials were categorized and their albedo properties and its impact was studied.

Results show that although winter UHI intensity is relatively low compared to summer, urban zones still exhibit slightly elevated temperatures. This is primarily attributed to dense built-up areas, limited vegetative cover, and dominance of impervious surfaces like concrete and asphalt, which retain heat and hinder night-time cooling. Conversely, areas with traditional or mixed typologies—characterized by breathable materials, open courtyards, and permeable surfaces—exhibit lower UHI intensity during winter. The long-term trend analysis indicates a gradual warming of urban cores over the past decade, even during winter months, suggesting that urbanization is subtly shifting seasonal thermal patterns.

Keywords: *Winter Season, Urban Heat Island Effect, Urban Zone, Sub-urban Zone, Trend Analysis, Albedo*

1. Introduction

Urbanization in Nepal has accelerated significantly over the past few decades, reshaping the physical and environmental landscape of major cities, particularly in the Kathmandu Valley. Between 1991 and 2001, the urban population growth rate nearly doubled—from 3.6% to 6.5%—driven largely by rural-to-urban migration. More recently, the number of officially recognized urban centres surged from just 58 in 2013 to 293 by 2017, a trend projected to continue through 2050 (Timsina, 2020) (Bakrania, 2015). The Kathmandu Valley has absorbed a substantial portion of this growth, accounting for over 24% of Nepal's total urban area. Within this region, Kathmandu Metropolitan City alone is home to nearly 10% of the valley's urban population (Bakrania, 2015).

This rapid urban expansion has been largely unplanned, leading to widespread land use changes, reduced green space, increased impermeable surfaces, and mounting pressure on existing infrastructure. The urbanized area in Kathmandu Valley expanded from 20.19 km² in 1976 to 139.57 km² in 2015—an astonishing 412% increase over four decades. Much of this expansion occurred at the expense of agricultural land, which made up around 31% of the converted area (Rimal, 2008) (Ishtiaque, 2017).

While the UHI effect has been extensively studied during summer months—when heat stress and energy demand are at their peak—its behaviour in winter remains underexplored, especially in South Asian contexts like Nepal. In colder months, the UHI effect may present differently, sometimes providing slight thermal benefits but also contributing to long-term warming trends and discomfort due to altered diurnal temperature patterns.

Recent studies suggest that winter UHI dynamics in Kathmandu are emerging as a subtle but measurable phenomenon. Analysis of long-term temperature records (such as December data over a 10-year span) reveals a slow yet consistent warming trend in core urban areas, indicating that even during winter, densely built environments retain more heat overnight compared to their suburban counterparts. This thermal persistence is often associated with reduced vegetation cover, building density, and the widespread use of low-albedo and

Addressing UHI is not just a climate issue—it intersects with urban liveability, energy consumption, and public health. Warmer urban nights during winter, while seemingly beneficial, may still affect energy demand patterns, indoor comfort, and environmental quality. The UHI effect also exacerbates local air pollution levels and contributes to increased ground-level ozone, which can affect respiratory health.

Given Kathmandu Valley's rapid urbanization, growing population, and unique mix of traditional and modern built forms, it is critical to examine UHI behaviour during the winter months. The study focuses on the temperature trends and spatial patterns of winter UHI across urban and suburban zones in Kathmandu. Through a combination of ground surveys and a 10-year analysis of December temperature records from the Department of Hydrology and Meteorology (DHM), the research identifies key urban design factors—such as building materials, land use, and albedo properties—that influence winter heat retention. The findings aim to support more climate-responsive planning strategies and foster greater awareness of urban heat dynamics among policymakers, designers, and residents.

1.1 Main Objective

- To examine the trend analysis of temperature difference of the Urban Heat Island effect in the Kathmandu Valley during the winter season, with a focus on urban-suburban comparisons.

1.2 Specific Objectives

- To assess the influence of materials and albedo properties on winter UHI intensity.
- To evaluate the 10-year temperature trend (maximum and minimum temperatures for December) using secondary data from the Department of Hydrology and Meteorology (DHM) to identify any long-term winter warming patterns in urban areas.
- To compare temperature variations between urban and suburban zones.

1.3 Literature review

Urban Heat Island (UHI) is a well-documented microclimatic phenomenon where urban areas exhibit higher temperatures than their surrounding rural or suburban environments. This effect primarily arises due to changes in land surface characteristics, reduced vegetation, increased impervious surfaces, and the thermal properties of construction materials (Oke, 1982). As urbanization accelerates across developing regions, the UHI effect is becoming more pronounced, raising concerns about energy consumption, public health, and urban livability.

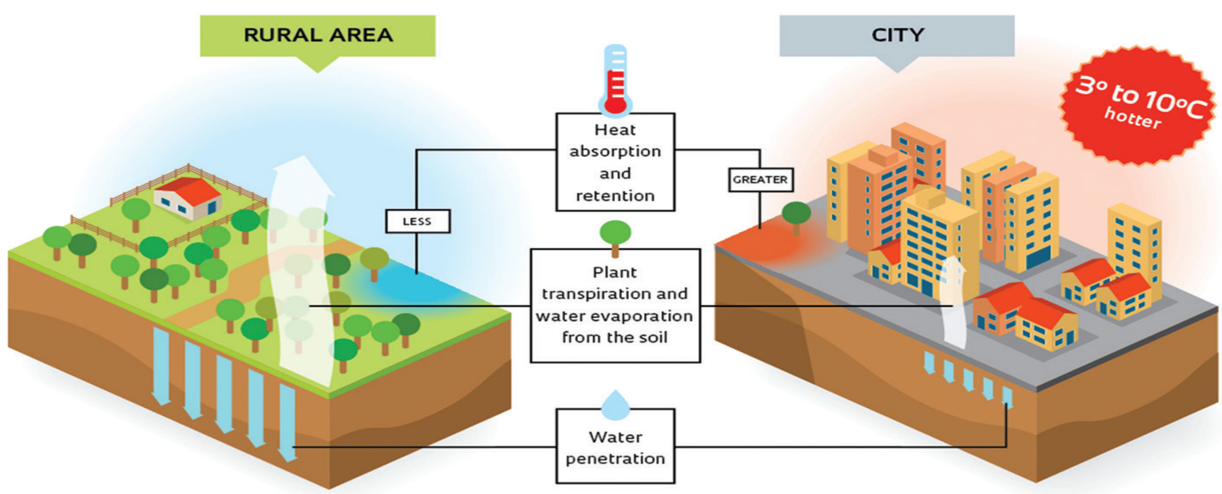

Figure 1: Urban Heat Island Effect (Nuruzzaman, 2015)

1.3.1 Urbanization and UHI

Nepal has witnessed rapid urban growth in recent decades, particularly in the Kathmandu Valley. The urban area of the Valley increased from 20.19 km² in 1976 to 139.57 km² in 2015, primarily at the expense of agricultural land (Rimal, 2008). This shift from vegetative to impervious land cover alters the local energy balance, reduces evapotranspiration, and increases heat retention. Similar studies globally (Imhoff et al., 2010; Zhou et al., 2014) confirm that urban expansion directly correlates with rising land surface temperatures (LST), a key indicator of UHI.

Urban Heat Island (UHI) effects have become a significant concern due to their impact on urban sustainability, especially in terms of energy consumption and air quality. However, despite growing global awareness, significant gaps remain in understanding UHI dynamics across different seasons (Oke, 1982) (Santamouris, 2015)

While much of the research on UHI effects has focused on summer conditions, with significant attention paid to the contribution of solar radiation, albedo, and anthropogenic heat, the winter dynamics of UHI remain significantly underexplored (Santamouris, 2015).

Filling in the seasonal gaps in UHI research would help us better understand how cities respond to changes in weather throughout the year—especially in places like Kathmandu, where the landscape and climate have a big impact on how the urban heat island effect works (Taha, 1997).

1.3.2 Surface Materials and Albedo

The thermal behavior of urban surfaces plays a critical role in the intensity of UHI. Materials such as asphalt, concrete, and metal roofs have low albedo and high heat storage capacity, leading to greater daytime heating and slower nighttime cooling (Santamouris, 2015). In contrast, permeable surfaces and traditional building materials such as mud bricks, lime plaster, and stone, which are still present in parts of Kathmandu's traditional settlements, contribute to more stable thermal performance due to their higher thermal inertia and breathability.

1.3.3 Types of Urban Heat Island

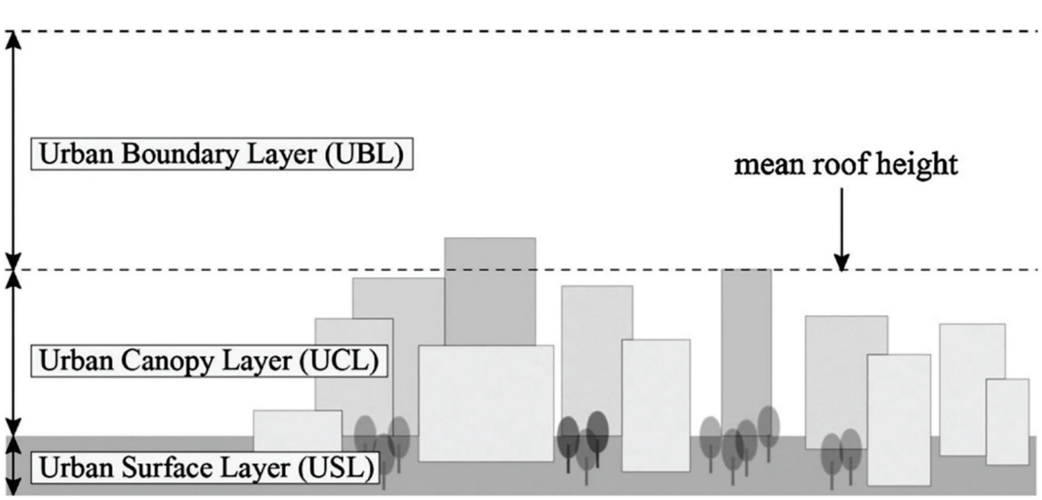

Figure 2: Different layers of UHI (Nuruzzaman, 2015)

Winter dynamics in the context of the Urban Heat Island (UHI) effect refer to how temperature disparities between urban and rural areas behave during the colder months. While the UHI phenomenon is generally more noticeable in the summer due to intense solar radiation and the heat-retaining properties of urban materials, it still plays a meaningful role in winter conditions (Oke, 1982). In winter, cities often remain slightly warmer than their rural surroundings, but the magnitude of this difference is shaped by factors such as weaker solar input, longer nights, and clearer skies.

Understanding winter UHI is crucial because it directly affects urban energy demands—particularly heating needs—which can lead to increased energy consumption (Santamouris, 2015). Moreover, winter UHI influences thermal comfort, as fluctuating urban temperatures can make cold conditions feel more intense. Additionally, cooler urban temperatures in combination with stagnant air can trap pollutants close to the ground, thereby worsening air quality and posing risks to public health (Blooshi, 2020).

1.3.4 Effects of Urban Heat Island

The Urban Heat Island (UHI) effect tends to have its most pronounced impact during the summer months, particularly in tropical and arid climates. It can significantly reduce thermal comfort in densely built city centres, placing vulnerable populations—especially those with lower heat tolerance—at increased risk of heat-related illnesses or even fatalities. Additionally, as temperatures rise, the need for artificial cooling grows, driving up energy consumption and resulting in higher expenses for both households and governments. Research indicates that for every 1°C rise in temperature, summer energy demand may increase by 2–4% (Oke, 1982). In contrast, the UHI effect can offer some benefits during winter by slightly elevating urban temperatures, thereby improving thermal comfort for residents (Santamouris, 2015) (Taha, 1997). The figure below demonstrates the broader implications of UHI on human well-being.

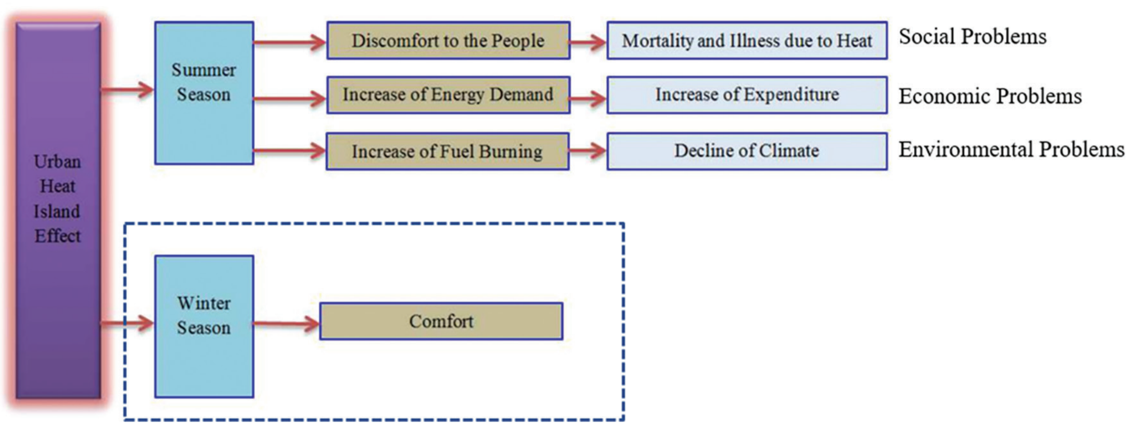

Figure 3: Effects of Urban Heat Island (Nuruzzaman, 2015)

1. Social and Health Effects

   - Improved Thermal Comfort: Warmer urban temperatures during winter can reduce exposure to extreme cold, benefiting vulnerable populations (e.g., the elderly, children).

2. Economic Effects

   - Reduced Heating Costs: The warmer microclimate in urban areas can lead to lower energy consumption for heating in winter.

   - Higher Energy Demand for Cooling: Prolonged heat retention in urban areas may increase cooling demands during unexpected warm spells in winter.

3. Environmental Effects

   - Temperature Disparities: Urban areas are warmer than surrounding rural areas during winter, which can cause ecological imbalances and disrupt local weather patterns.

2 Materials and Methods

2.1 Study Area

I. Core Urban Area

Pani Pokhari, Kathmandu: Pani Pokhari lies in the heart of Kathmandu Metropolitan City, making it a prime example of a core urban area.

Urban Characteristics

- High population density: Compact living, multi-storey apartments.
- Mixed land use: Residential, commercial, administrative (offices, embassies nearby).
- Urban morphology: Dense built form, very little open or green space.

II. Sub-Urban Area

Changunarayan, Bhaktapur: Changunarayan is a historically significant town in Bhaktapur District, located on the outskirts of the Kathmandu Valley.

Sub-Urban Characteristics

- Lower population density: More open spaces, fewer high-rise buildings.
- Dominantly residential or cultural land use: Agriculture, tourism, and heritage areas.
- Transitional area: Between rural and urban—experiencing gradual urbanization.
- Green and cultural landscape: Presence of farms, forests, and heritage sites

2.2 Study Method

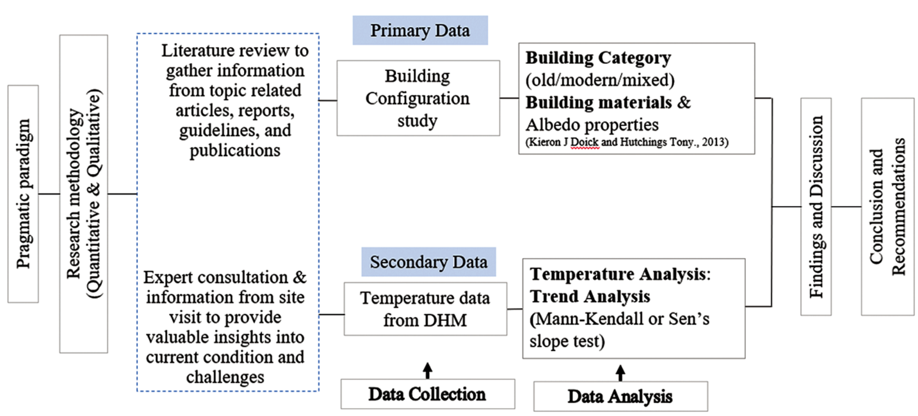

Figure 4: Research Methods

This study adopts a pragmatic research paradigm, integrating both quantitative and qualitative methodologies to explore the winter dynamics of the Urban Heat Island (UHI) effect in Kathmandu Valley. A mixed-method approach is employed to gain a holistic understanding of the phenomena. The initial phase involves an extensive literature review of relevant articles, reports, guidelines, and academic publications to frame the research context. This is supplemented by expert consultations and field visits, which offer ground-level insights into prevailing urban conditions, construction practices, and local challenges. For data collection, the study utilizes both primary and secondary data sources. The primary data includes a building configuration study, which categorizes buildings into old, modern, and mixed types while analyzing their materials and albedo properties—key factors in understanding heat absorption and reflectance in urban environments (referencing Doick & Hutchings, 2013). The buildings were categorized as per the building materials, age and technology used.

On the other hand, secondary data is sourced from the Department of Hydrology and Meteorology (DHM), specifically focusing on December temperature records over a 10-year period. To assess long-term temperature changes, a trend analysis is conducted using the Mann-Kendall test and Sen's slope estimator, which are robust non-parametric methods suitable for environmental time-series data. The Mann-Kendall test is a non-parametric test used to identify whether a monotonic trend (consistently increasing or decreasing) exists in a time series. Sen's Slope is used alongside the Mann-Kendall test to quantify the rate of the trend (how much increase or decrease is happening per unit time). In both Mann-Kendall (MK) and Sen's Slope tests, the p-value helps determine whether the observed trend (increase or decrease over time) is statistically significant—or if it might have occurred just by chance.

p-value interpretation:

- If p-value < 0.05: Reject $H_0 \Rightarrow$ There is a statistically significant trend at the 5% significance level.
- If p-value ≥ 0.05: Fail to reject $H_0 \Rightarrow$ The trend is not statistically significant.

These analyses help identify significant temperature trends that may indicate UHI behavior during winter. The findings from both data streams are synthesized in the analysis and discussion section, leading to well-informed conclusions and recommendations aimed at improving urban thermal comfort and guiding sustainable planning efforts in Kathmandu Valley.

2.3 Site Observation

2.3.1 Study Area 1: Pani Pokhari, Kathmandu (Core Urban Area)

- Location: Urban area in Kathmandu near prominent commercial and residential zones.
- Elevation: Approximately 1,320 meters above sea level.

Land Use and Land Cover (500mBuffer)

- Dense urban fabric with limited green spaces
- Predominance of modern, multi-story concrete buildings with some patches of traditional old buildings.

2.3.1.1 OLD/Traditional Buildings

Figure 5: Old/Tradition Building of Urban area

The images showcase old/traditional buildings in the Pani Pokhari area of Kathmandu, reflecting architectural styles that incorporate old/traditional design principles suited to the local climate. These structures are characterized by exposed brick facades, a limited number of floors (typically 2-3 stories), and the use of natural materials that contribute to better thermal performance compared to modern high-rise buildings. A key feature of these traditional buildings is the spatial planning, where over 50% of the land is often left open as a yard or garden space. These open areas, combined with the presence of trees and vegetation. In terms of materiality, these buildings primarily utilize exposed bricks, wood, and stone, which have higher thermal mass and better permeability compared to modern concrete structures. The use of permeable pavements in courtyards further allows for natural water percolation (Priyanka Gupta, 2025).

2.3.1.2 New/Modern Buildings

Figure 6: New/Modern Buildings of Urban area

The new/modern buildings in the Pani Pokhari area represent a shift towards high-density urban development, characterized by larger built-up areas, reduced open spaces, and the use of modern materials. Unlike traditional structures that prioritize open courtyards and greenery, modern constructions allocate minimal space for vegetation, often not meeting the open space requirements set by urban by-laws. Modern buildings in Pani Pokhari vary significantly in height, typically ranging from 2 to 8 floors, with taller structures becoming more common due to urban expansion and land-use optimization. The façade treatments predominantly consist of plaster, metal panels, and extensive glass surfaces, replacing the exposed brick and wood elements of traditional designs. Another defining feature of modern buildings is the use of non-permeable, concrete pavements, which limit water absorption and natural cooling processes (Priyanka Gupta, 2025).

2.3.1.3 Mixed Buildings

Figure 7: Mixed Buildings of Urban Area

The mixed buildings in the Pani Pokhari area represent a hybrid architectural approach, incorporating elements from both traditional and modern construction techniques. These structures blend old and new materials, creating a unique urban fabric where vernacular elements coexist with contemporary design trends. Mixed buildings typically feature a combination of traditional exposed brickwork, wooden details, and modern materials such as cement plaster, metal panels, and glass windows. While some structures retain low-rise configurations (2-3 floors), others have been vertically extended to 4-6 floors to accommodate increasing urban density. These buildings often preserve some traditional elements, such as brick façades or courtyards, while integrating modern extensions, balconies, or rooftop additions made of reinforced concrete and glass (Priyanka Gupta, 2025).

2.3.2 Study Area 2: Changunarayan, Bhaktapur (Sub Urban Area)

- Location: Peri-urban area located in Bhaktapur District.
- Elevation: Approximately 1,540 meters above sea level.

Land Use and Land Cover(500mBuffer)

- Low-density built environment with traditional Newari houses and few patches of new modern buildings.
- Presence of significant green cover, including large trees and agricultural fields, contributing to cooling effects.

2.3.2.1 OLD/Traditional Buildings

Figure 8: Old/Traditional Buildings of Sub-Urban area

The traditional buildings in Changunarayan reflect an architectural style that is deeply rooted in the vernacular design principles suited to the local climate. These buildings are typically characterized by brick masonry structures, where thick brick walls provide excellent thermal mass. Materials like wood, stone, and clay are frequently used, which are not only abundant in the region but also environmentally friendly and naturally breathable. Permeable pavements are another crucial feature in the courtyards and open spaces around these buildings. These surfaces allow rainwater to infiltrate the ground, reducing surface runoff and promoting ground cooling (Priyanka Gupta, 2025).

2.3.2.2 New/Modern Buildings

Figure 9: New/Modern buildings of Sub-urban area.

The new/modern buildings in Changunarayan reflect contemporary construction practices that prioritize structural strength and urban expansion. These buildings are primarily characterized by concrete structures. The use of modern materials and technologies, such as reinforced concrete, glass, and steel, has replaced traditional, breathable materials like wood and brick. Another key characteristic of modern development in the area is the widespread use of non-permeable concrete pavements, which prevent natural water percolation (Priyanka Gupta, 2025).

2.3.2.3 Mixed Buildings

Figure 10: Mixed Building of Sub-urban area

The mixed buildings in Changunarayan represent a blend of traditional and modern architectural elements, integrating both concrete structures and vernacular design features. These buildings primarily rely on reinforced concrete for structural strength, enabling multi-story construction and greater durability. However, unlike fully modern buildings, mixed structures often incorporate exposed brick façades, though only as an outer cladding rather than a load-bearing element. This provides a visual continuity with traditional architecture, as the core structure is still concrete. In terms of materials and technologies, mixed buildings utilize modern construction materials such as glass, steel, and cement while incorporating some traditional aesthetic elements like wooden window frames or decorative brickwork. Additionally, like fully modern buildings, mixed structures generally have non-permeable concrete pavements, limiting natural water infiltration and increasing surface runoff (Priyanka Gupta, 2025).

3 Results and Discussion

3.1 DHM Data

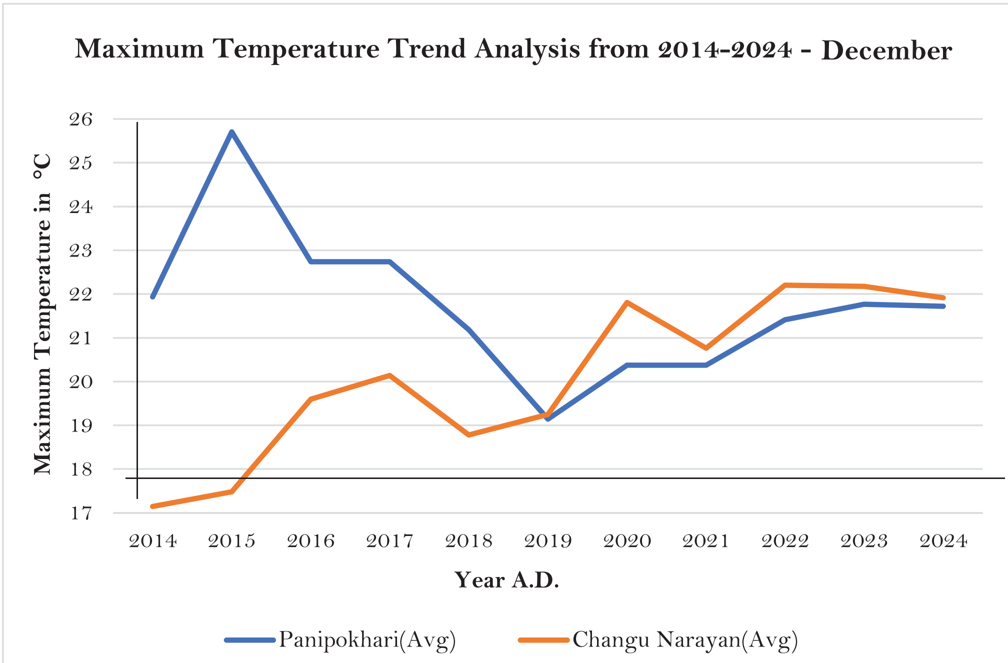

Figure 11: Trend Analysis Max, December

3.1.1 DHM Data – Trend Analysis Max, December

This graph presents maximum temperature trends in December for Panipokhari and Changu Narayan over a 10-year period (2014-2024).

Temperature Trend in Panipokhari (Blue Line)

- The temperature rises significantly from 2014 to 2015, peaking at around 25°C.
- After 2015, there is a gradual decline in maximum temperature, stabilizing around 21-22°C from 2016 to 2018.
- A sharp drop occurs in 2019, bringing the temperature down to 19°C, making it equal to Changu Narayan for the first time.
- From 2019 onwards, the temperature stabilizes and slightly increases, converging with Changu Narayan's trend in 2024.

Temperature Trend in Changu Narayan (Red Line)

- The temperature follows a gradual increasing trend from 2014 to 2016, reaching approximately 19.5°C.
- It stabilizes between 2017 and 2019, with slight fluctuations but remains lower than Panipokhari's temperature.
- In 2019, both locations record the same maximum temperature (~19°C), marking a significant point in the trend.

- From 2020 to 2023, the temperature in Changu Narayan rises slightly above Panipokhari, indicating an increase in heat retention in the suburban area.
- In 2024, both locations have nearly the same temperature (~21°C), signaling a convergence.

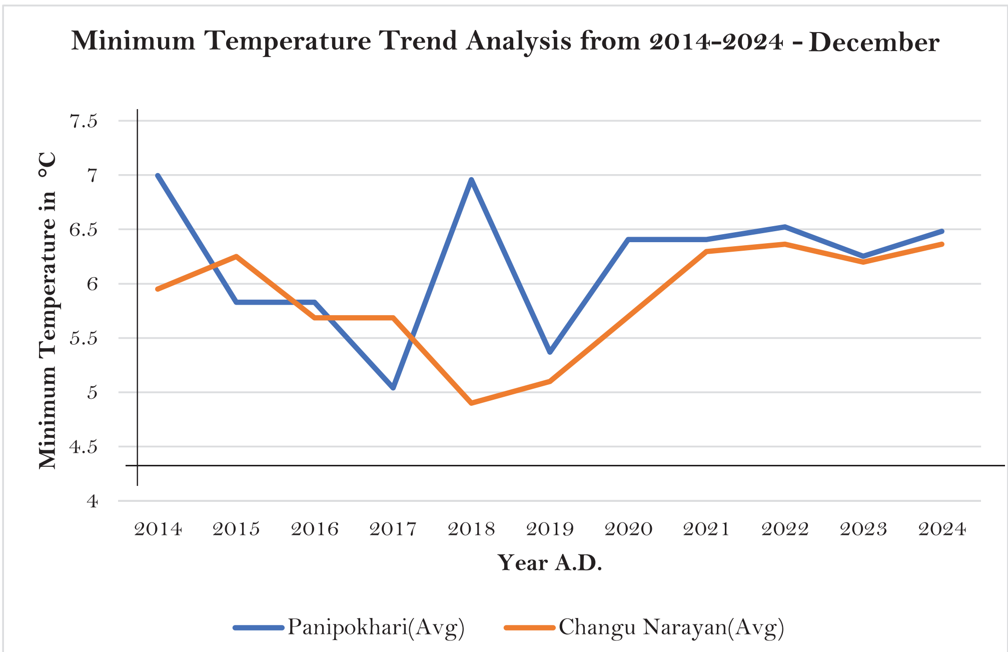

Figure 12: Trend Analysis min, December

3.1.2 DHM Data – Trend Analysis Min, December

This graph presents the minimum temperature trends in December for Panipokhari (urban area) and Changu Narayan (suburban area) from 2014 to 2024.

Temperature Trend in Panipokhari (Blue Line - Urban Area)

- 2014-2018: Declining Trend (~7°C to ~5°C)

The minimum temperature in Panipokhari declined from ~7°C in 2014 to ~5°C in 2018, showing increased cooling during December nights. Possible factors include reduced urban heat retention, lower cloud cover, or colder seasonal conditions.

- 2018-2019: Sharp Rise (~5°C to ~7°C)

A spike in 2019 (~7°C) suggests a temporary warming phase due to weather anomalies, increased urban heat trapping, or a warm winter.

- 2019-2024: Stabilization (~6-6.5°C)

The temperature fluctuated but showed a gradual increase, stabilizing around 6.5°C by 2024, indicating higher urban heat retention in recent years.

Temperature Trend in Changu Narayan (Red Line - Suburban Area)

- 2014-2018: Gradual Decrease (~6°C to ~4.8°C)

The drop in temperatures suggests increased night cooling efficiency due to lower urbanization and better natural heat dissipation in Changu Narayan.

- 2018-2024: Steady Rise (~4.8°C to ~6.3°C)

After 2018, minimum temperatures increased steadily, indicating gradual warming, likely due to suburban expansion and urban heat influence. By 2023-2024, Changu Narayan's minimum temperatures closely matched Panipokhari (~6.2-6.3°C), suggesting reduced differences between urban and suburban areas.

3.2 Sen's Slope Test

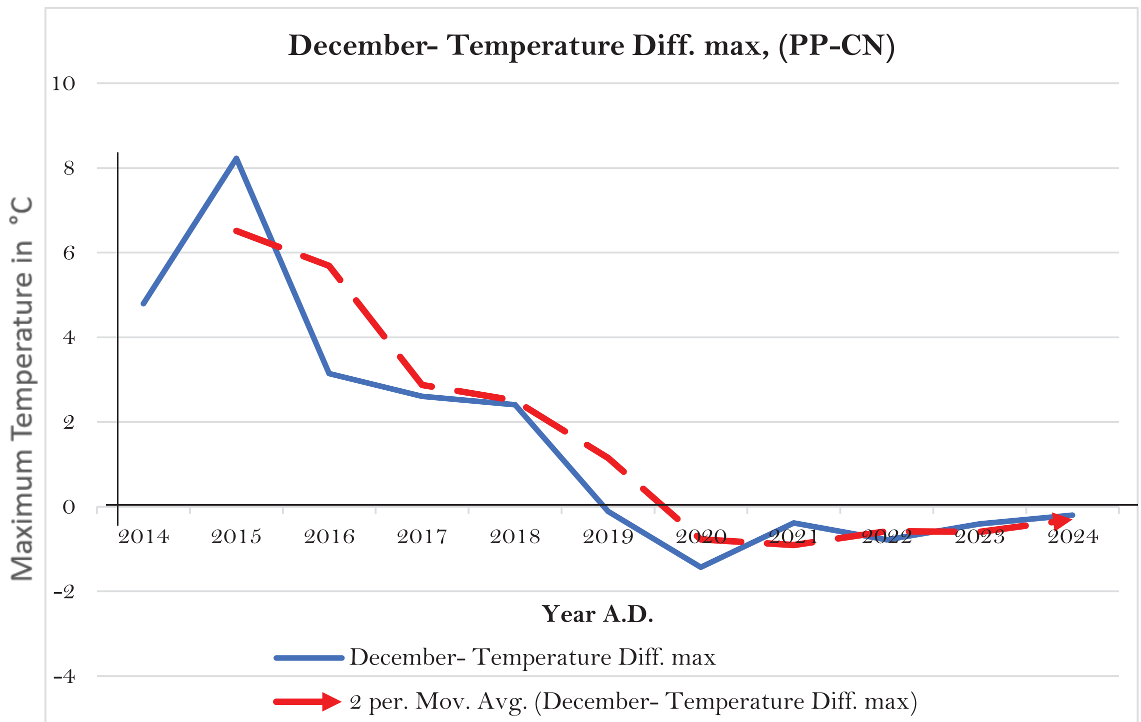

Figure 13: Sen's slope test, December Temperature Max

3.2.1 DHM Data – Sen's Slope Test, December Temperature Max

- Positive Slope (2014–2015): The temperature difference increased, peaking in 2015, which can be possible due to urbanization of Panipokhari area, reduced green cover, or increased human activities.
- Negative Slope (2015–2020): The temperature difference declined steadily, turning negative in 2020, indicates change in urban structure in Changunarayan areas.
- Fluctuations & Slight Increase (2021–2024): After hitting a low, the temperature difference stabilizes and shows a slight upward trend, which might be due to new developments, shifts in climate patterns, or seasonal variations.
- Sen's Slope = -0.6°C per year: This indicates a strong decreasing trend in the maximum temperature difference over time, on average by 0.6°C per year.
- P-value is -0.6< 0.05 (There is statistically significant trend at the 5% significance level)

This suggests that the urban heat retention effect during the day is weakening, possibly due to:

- Increased cooling strategies reducing daytime heating.
- Changes in urban material properties affecting heat absorption and urbanization of sub-urban area too.

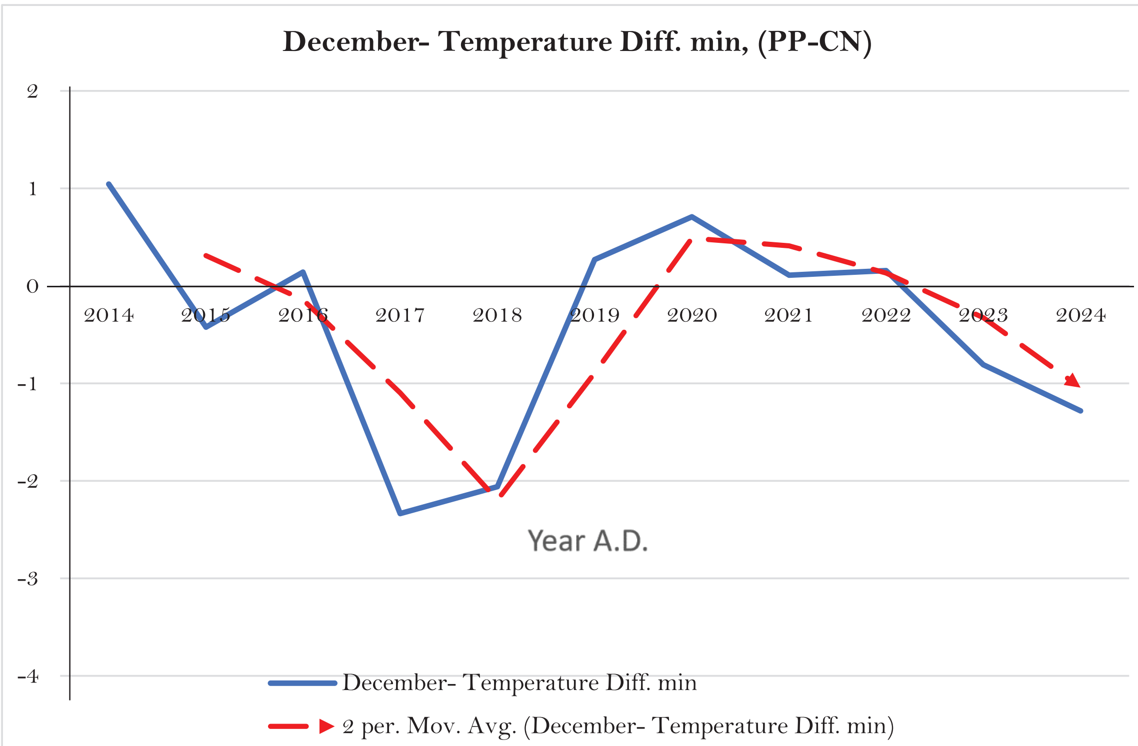

Figure 14: Sen's slope test, December Temperature Min

3.2.2 DHM Data – Sen's Slope Test, December Temperature Min

- Sharp Drop (2016–2018): The temperature difference reaches its lowest (~-2.5°C in 2018), indicates the urban area is experiencing significantly lower minimum temperatures than the warmer area.
- Recovery & Peak (2019–2020): The trend reverses, with the temperature difference rising to slightly positive values (~1°C in 2020), Possibly due to urban modifications, land-use changes, or increased heat retention in urban area.
- Gradual Decline (2021–2024): The difference drops steadily, turning negative again (~-2°C by 2024), suggests an increasing cooling effect in one area relative to the other.
- Sen's Slope = -0.125°C per year:
- P-value is -0.125< 0.05 (There is statistically significant trend at the 5% significance level)
- Indicates a gradual decreasing trend in the minimum temperature difference over time, on average by 0.125°C per year. The minimum temperature difference between the two areas is slightly declining over time, but the change is not strongly significant. This could indicate a gradual reduction in the Urban Heat Island (UHI) effect at night.

3.3 Comparing Materials Of Different Settlements With Albedo Properties

To better understand the relationship between material reflectivity and surface heat retention in winter, a comparative study of building materials was conducted across both case areas: Pani Pokhari and Changu Narayan. Each location was analyzed based on three categories of buildings: old (traditional), new (modern), and mixed (buildings. The surface materials used in walls and roofs were observed and their corresponding albedo values studied to assess how these materials contribute to the local thermal environment.

Table 1:Albedo Properties of different building categories

Location	Building Category	Common Surface Materials	Albedo Range (0-1)	UHI Contribution
Urban - **PP**	Old	Brick, stone, mud plaster	0.35 – 0.55	**Low to moderate** – Better insulation and lower heat retention
	Modern	Concrete, glass, asphalt, metal roofs	0.20 – 0.35	**High** – Retains more heat, increases UHI effect
	Mixed	Combination of old brick, concrete, and reflective surfaces	0.30 – 0.45	**Moderate to high** – Heat absorption mixed with reflective properties
Suburban - **CN**	Old	Mud walls, stone, red brick	0.50 – 0.70	**Very Low** – Higher albedo, better heat reflection, less heat retention
	Modern	White plaster, metal roofs, solar reflective tiles	0.40 – 0.65	**Moderate** – Highly reflective surfaces reduce heat absorption
	Mixed	Blend of stone, concrete, and some reflective surfaces	0.40 – 0.50	**Low to Moderate** – Less heat retention due to suburban ventilation

- Old Buildings contribute less to UHI because their materials (brick, mud, and stone) provide better insulation and release heat slowly, reducing temperature spikes.
- Modern Urban Buildings contribute the most to UHI due to high heat-retaining materials like concrete, asphalt, and glass, which trap heat during the day and release it at night.
- Suburban areas show lower UHI effects due to better ventilation, green roofs, and high-albedo surfaces in modern designs.

The table provides insights into how different building categories, surface materials, and albedo values influence the Urban Heat Island (UHI) effect in both urban (PP) and suburban (CN) zones. The albedo range, which measures a surface's reflectivity (0 being least reflective and 1 being most reflective), plays a crucial role in determining how much heat a building absorbs or reflects.

3.3.1 Urban Zone (PP)

In the urban areas of Kathmandu Valley, the built environment comprises three distinct building categories—traditional, modern, and mixed—each exhibiting varied impacts on the Urban Heat Island (UHI) effect due to differences in material properties, particularly albedo, thermal mass, and insulation capacity.

- Traditional Buildings:

  These structures are typically constructed using brick, stone, and mud plaster. With a moderate albedo ranging from 0.35 to 0.55, these materials absorb a limited amount of solar radiation. Their relatively high thermal insulation and low heat retention help reduce temperature build-up during the day and allow gradual cooling at night. As a result, such buildings contribute low to moderate levels to the winter UHI effect.

- Modern Buildings:

  Modern construction in the urban core commonly uses reinforced concrete, glass facades, asphalt surfaces, and metal roofing. These materials exhibit a low albedo (0.20 – 0.35), resulting in higher solar heat absorption and significant thermal storage throughout the day. Due to their poor insulating performance and high heat retention, modern buildings significantly amplify the intensity of UHI in winter, especially during periods of prolonged sunshine.

- Mixed-Category Buildings:

  Urban areas also contain structures combining traditional and modern elements, such as brick walls with concrete slabs and reflective roofing sheets. These buildings exhibit a moderate to high UHI contribution, depending on the surface finishes and ventilation provisions. While the presence of reflective surfaces may reduce some heat gain, the use of thermally massive materials like concrete still contributes to heat retention, especially at night.

3.3.2 Suburban Zone (CN)

Suburban zones, with lower building densities and more open spaces, show a different pattern in material usage and resulting thermal behavior. The building stock here also falls into traditional, modern, and mixed categories.

- Traditional Buildings:

  In suburban settings, older homes are predominantly made of mud walls, stone masonry, and red bricks. These materials have a higher albedo (0.50 – 0.70), reflecting a larger portion of solar radiation. Additionally, mud and stone possess strong thermal inertia, delaying heat transfer to the interior and enhancing indoor comfort. Consequently, these structures exhibit very low UHI contribution, particularly during the winter season, where heat gain is minimal and thermal losses are slow.

- Modern Buildings:

  Suburban modern structures often incorporate white plaster exteriors, metal sheet roofing, and solar-reflective tiles. These materials are intentionally selected for their high reflectivity and lower heat storage capacity. As a result, these buildings experience low to moderate UHI impact, aided further by better ventilation and spacing between structures.

- Mixed-Category Buildings:

  Buildings that blend stone masonry, cement plaster, concrete roofing, and selective reflective treatments show moderate UHI contributions. Their impact varies depending on the material balance and exposure to sun, but in general, their ability to retain and release heat is influenced by design elements such as ventilation, shading, and orientation.

  — The use of low-albedo modern materials such as concrete, asphalt, and metal in urban zones leads to increased heat retention, even during winter, thereby intensifying UHI effects.

  — In contrast, traditional materials like mud and stone used in suburban settings help moderate temperatures due to their high reflectivity and thermal buffering capacity.

  — Mixed-material buildings occupy a transitional zone, where their contribution to UHI is dependent on material combinations, design features, and microclimatic conditions.

These findings emphasize the importance of material selection and passive design strategies in mitigating winter UHI effects in Kathmandu Valley.

4 Conclusions

This analysis confirms that modern urban materials—such as concrete, glass, asphalt, and metal—significantly intensify the Urban Heat Island (UHI) effect in Kathmandu's urban core, even during winter months, by increasing surface heat retention and reducing insulation performance. In contrast, traditional and suburban buildings constructed with high-albedo and thermally insulating materials like mud, stone, and reflective plasters exhibit lower surface temperatures and reduced UHI intensity. These findings highlight the critical need to integrate climate-responsive design strategies into urban development, Specifically, the use of high-albedo roofing, green roofs, permeable surfaces, and traditional materials should be promoted through building guidelines, urban design codes, urban design policy and incentive-based policy frameworks. Moreover, urban zoning regulations must consider thermal impacts of surface materials, especially in dense neighborhoods, to ensure better winter thermal comfort and energy efficiency at both the building and neighborhood scale.

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