URBAN HEAT ISLAND EFFECT ANALYSIS OF KATHMANDU METROPOLITAN CITY IN NEPAL

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ABSTRACT

Rapid urbanization and anthropogenic activities have significantly altered the thermal environment of Kathmandu Metropolitan City, creating pronounced Urban Heat Island (UHI) effects that threaten urban livability and climate resilience. This study examines the spatial-temporal evolution of UHI patterns in Kathmandu over a decade (2015-2024) using multi-temporal satellite remote sensing data. The research integrates Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Land Surface Temperature (LST) derived from Landsat 8/9 thermal infrared bands and Sentinel-2 multispectral imagery to quantify land cover transformations and their relationship with urban thermal patterns. Results indicate drastic urban expansion accompanied by severe vegetation loss, leading to intensified heat island effects across rapidly developing areas. Maximum LST increased substantially from 26.28°C in 2015 to 35.85°C in 2023, representing a 9.57°C increase over eight years. The urban-rural temperature gradient intensified from 5.2°C to 8.7°C, while built-up areas expanded by 15.2% with dense vegetation declining by 8.7% of the total area. Strong correlations were observed between NDBI and LST (r = 0.78), NDVI and LST (r = -0.72), confirming the cooling effect of vegetation and heating effect of built surfaces. The eastern and northern sectors of the city experienced the most pronounced thermal intensification, with newly developed areas showing temperature increases of 7.1-8.2°C. Urban heat islands are increasingly problematic in an era of rapid urbanization and climate change.

KEYWORDS: Urban Heat Island, Normalized Diffference Vegetation Index(NDVI), Normalized Difference Built up Index(NDBI), Land Surface Temparature (LST)

1. INTRODUCTION

Urban Heat Island (UHI) is a situation where cities become much warmer than the areas around them, mainly because buildings, roads, and other artificial surfaces trap heat from the sun(Sarif, Rimal, and Stork 2020). This extra heat can make city life uncomfortable, increase energy use, worsen air pollution, and harm the local environment. According to United Nations Environmental Protection Agency (EPA), 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. Due to the excess heat, the quality of life in urban areas has been compromised.

The Urban Heat Island (UHI) effect arises from multiple interrelated factors. Predominantly, urban surfaces such as pavements, roads, and buildings possess higher thermal absorptivity compared to natural vegetated areas, resulting in increased solar radiation retention(Feng et al. 2019). The significant reduction in vegetation cover within urban environments diminishes evapotranspiration processes, thereby limiting the natural cooling effects typically provided by plant transpiration. Furthermore, anthropogenic heat emissions from transportation, industrial activities, and air conditioning systems contribute additional thermal energy to the urban atmosphere. The complex urban morphology, characterized by tall buildings and narrow street canyons, impedes airflow and traps heat, creating thermal accumulation. Lastly, the generally low albedo of urban materials leads to decreased reflectivity and enhanced absorption of solar radiation, collectively intensifying the temperature disparity between urban centers and their rural surroundings(City 2022).

Kathmandu, the capital city of Nepal, has experienced unprecedented urbanization in recent decades, transforming from a cultural hub into a sprawling metropolitan center(Chaudhary, Pradhan, and Naryan 2021). 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(Nations 2018). 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. The growth of built-up areas in the most urban settlements is haphazard and uncontrolled with a rapid decrease in agricultural land(Wu et al. 2019). Covering only one percent of the country's total area, Kathmandu valley accommodates 31% of the total urban population of the country. Central Bureau of Statistics (CBS) of Nepal has stated Kathmandu valley is characterized by sustained population growth in the urban core and rapid urban sprawl. With 51% growth from 2001 to 2011, the total population of Kathmandu valley is expected to reach almost 6 million by 2031. This unplanned urban development has contributed to dramatic changes in urban footprint of the valley. More people moving to cities creates two compounding effects: larger populations are exposed to the negative impacts of heat islands (increased energy consumption, compromised health, elevated air pollution), and as cities become larger and more densely populated, heat island intensity typically increases(Reality 2024).

This research aims to provide a comprehensive analysis of UHI patterns and their relationships with land cover changes over the past decade (2015-2024) by integrating multiple remote sensing indices (NDVI, NDBI, LST). Studying the UHI effect in Kathmandu from 2015 to 2024 will help us understand how much the city has warmed, what is causing it, and what can be done to make the city cooler and more comfortable.

2. MATERIALS AND METHODS

2.1 Study Area:

For Analyzing the UHI effect trend in Kathmandu Metropolitan city the study area, situated at approximately 1400 meters above sea level at Latitude Range: 27.67°N to 27.74°N and Longitude Range: 85°16'5" E to 85°22'32" E covering area about 50.67 sq. km, is delineated to include the metropolitan boundaries and adjacent rural surrounding.

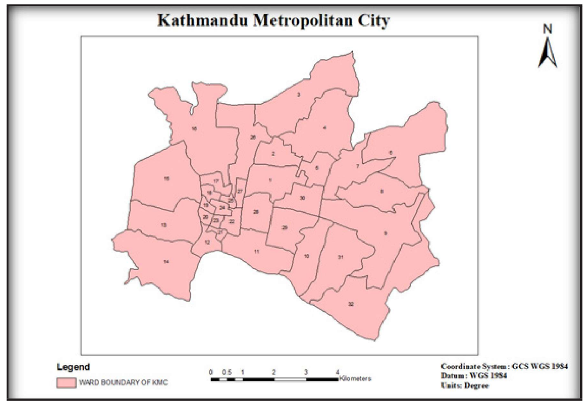


Figure 1. Study Area Map

2.2 Data acquisition

For data acquisition, multispectral Sentinel-2 imagery, cloud masked and processed, with 10 m spatial resolution is utilized to calculate the indices such as NDVI, using the red (Band 4, 665 nm) and near-infrared (Band 8, 842 nm) bands. NDVI serves as an indicator of vegetation density and health, which is critical in assessing urban cooling effects through evapotranspiration.Landsat 8/9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) data provide thermal bands (Band 10 and Band 11) used to derive Land Surface Temperature (LST) and Normalized Difference Built-up Index (NDBI). NDBI, calculated from shortwave infrared (SWIR) and near-infrared bands, identifies built-up areas contributing to heat accumulation. LST is estimated using the mono-window algorithm, which incorporates atmospheric correction and emissivity adjustment to convert thermal band data into accurate surface temperature measurements. All satellite data processing, including image acquisition, pre-processing, and index calculations, is conducted on the Google Earth Engine (GEE) platform, enabling efficient handling of large temporal datasets from 2015 to 2024.

Table 1:Parameters of UHI Analysis

Index	Equation	References(s)
NDVI (Normalized Difference Vegetation Index	NDVI= $\frac{NIR-RED}{NIR+RED}$	(Ustuner et al. 2014)
NDBI (Normalized Difference Built-up Index)	NDBI= $\frac{SWIR-NIR}{SWIR+NIR}$	(Zha et al. 2003)
LST (Land Surface Temperature)	LST = $\frac{TB}{1 + (\lambda\ \sigma TB/(hc))\ \ln \epsilon}$ with atmospheric correction and emissivity adjustment applied to thermal band data.	(Weng and Schubring, 2004)

The major parameters for UHI which are indices such as NDVI, NDBI, and LST are analyzed spatially and temporally to understand the relationship between land cover changes and surface temperature variations. NDVI highlights vegetated areas that mitigate heat, while NDBI maps urban expansion and impervious surfaces that exacerbate heat retention. LST quantifies the thermal intensity across the valley, allowing identification of urban heat hotspots and the extent of the UHI effect. This integrated methodology provides a comprehensive framework to assess how urbanization and land cover dynamics influence thermal patterns in Kathmandu, supporting urban planning and heat mitigation strategies.

Table 2. Parameters for Classification based on Normalized Difference Vegetation index

Land Cover Class	Range	Reference
Water	0 to 0.015	*Nepal Land Cover Monitoring System (FRTC, 2023)*
Built-up Area	0.015-0.14	*Idrees et al. ,2022*
Barren Land	0.14-0.18	*Idrees et al. ,2022*
Grassland	0.18-0.27	*Nepal Land Cover Monitoring System(FRCT,2023)*
Sparse Vegetation	0.27-0.36	*Bedunkevich,2025*
Dense Vegetation	0.36-0.63	*(USGS,2017)*

3. RESULTS AND ANALYSIS

Table 3. NDBI TREND ANALYSIS

Year	NDBI Maximum	NDBI Minimum	Mean NDBI
2015	0.274864	-0.717677	-0.221
2016	0.259421	-0.486409	-0.113
2017	0.312301	-0.420260	-0.054
2018	0.431514	-0.369096	0.031
2019	0.441835	-0.355450	0.043
2020	0.446978	-0.348627	0.049
2021	0.452155	-0.341803	0.055
2022	0.383615	-0.321303	0.067
2023	0.315075	-0.300803	0.079
2024	0.315075	-0.239641	0.091

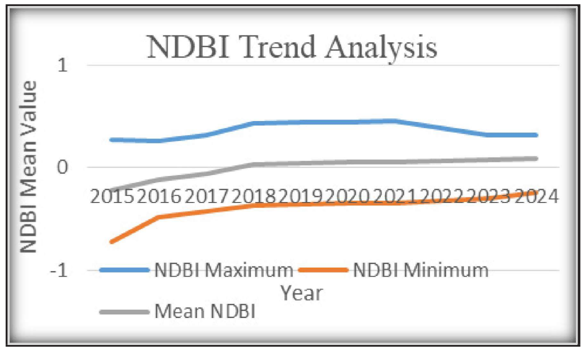


Figure 2. Line Char of NDBI Value per Time (2015-2024)

Over the timeline, the mean NDBI values steadily rose from -0.221 in 2015 to 0.091 in 2024, transitioning from negative to positive values, which indicates a significant expansion of built-up areas. The maximum NDBI values increased gradually, reaching a peak of 0.452 in 2021 before declining to 0.315 by 2023 and 2024. Meanwhile, the minimum NDBI values also rose from -0.718 in 2015 to -0.240 in 2024, reflecting a reduction in the extent of non-urban land cover. This overall positive trajectory in mean NDBI values, especially the rapid increase observed between 2017 and 2018, highlights accelerating urban growth. The slight decline in maximum values after 2021 suggests that core urban areas may be approaching saturation, while the increase in minimum values points to a decrease in undeveloped or vegetated land. Together, these trends indicate a marked transformation of the landscape towards more built-up environments over the analyzed period.

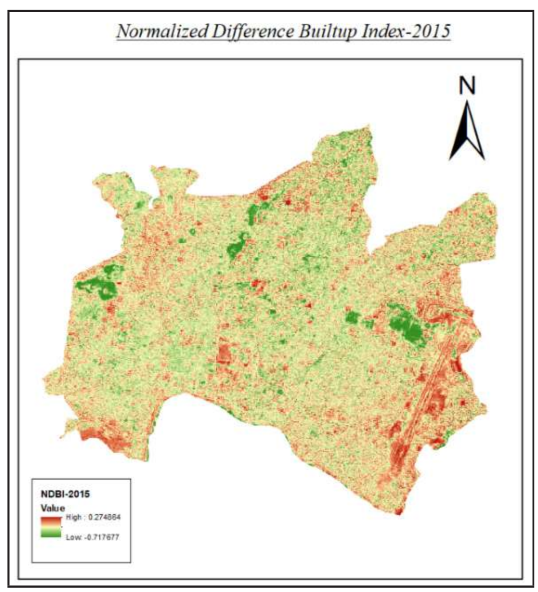


Figure 3. NDVI-2015 Map

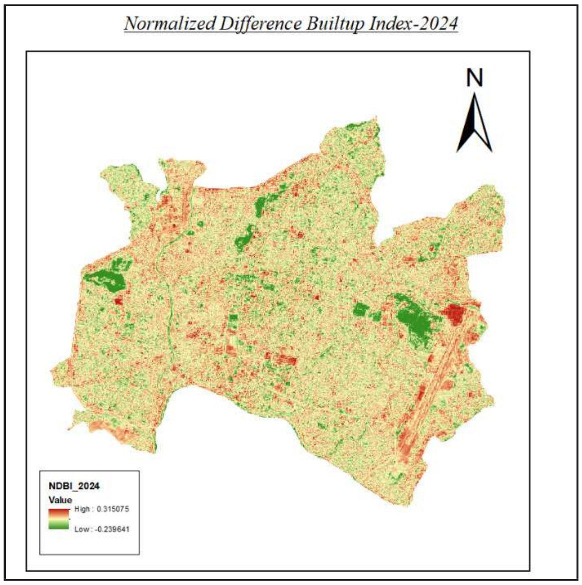


Figure 4. NDBI-2024 Map

Table 4. LST Trend Analysis

Year	LST Maximum (°C)	LST Minimum (°C)	LST Range (°C)
2015	26.2754	17.2979	8.98
2016	30.7906	19.2838	11.51
2017	32.8773	21.6029	11.27
2018	36.0611	23.5854	12.48
2019	27.5007	15.9581	11.54
2020	32.8226	19.2154	13.61
2021	28.2014	16.5118	11.69
2022	29.5857	18.6446	10.94
2023	35.8458	20.7108	15.14
2024	32.3806	17.7559	14.62

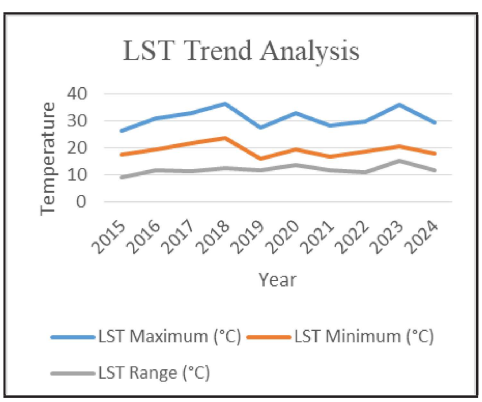
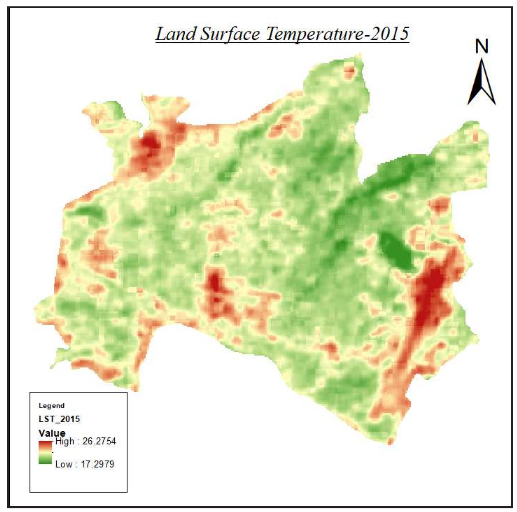


Figure 5. LIne Chart of LST per Year

The Land Surface Temperature (LST) data from 2015 to 2024 shows notable fluctuations in temperature extremes and variability over the years. The maximum LST values generally increased from 26.28°C in 2015 to a peak of 36.06°C in 2018, followed by some variation, with another high of 35.85°C recorded in 2023. Minimum LST values also rose from 17.30°C in 2015 to a maximum of 23.59°C in 2018, indicating a warming trend in both daytime and nighttime temperatures. The LST range, which represents the difference between maximum and minimum temperatures, varied between 8.98°C and 15.14°C, with the widest range occurring in 2023. These variations suggest increased temperature extremes and greater diurnal temperature variability in recent years, which could be linked to factors such as urban expansion, changes in land use, and climatic influences in the region.



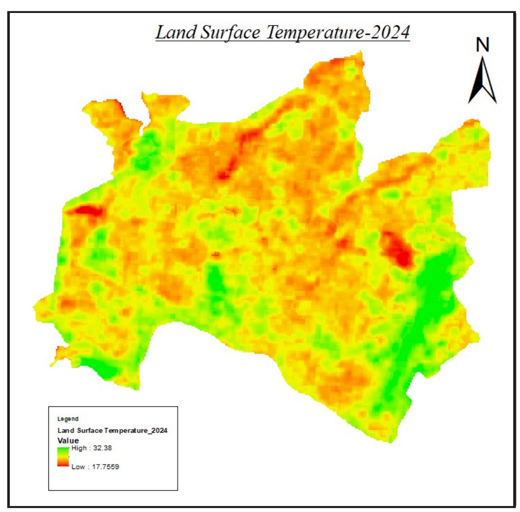


Table 5. NDVI Trend Analysis

Year	NDVI Maximum	NDVI Minimum	Mean NDVI
2015	0.724301	0.0103063	0.367
2016	0.689103	-0.0390573	0.325
2017	0.724808	0.0217074	0.373
2018	0.63254	-0.182822	0.225
2019	0.744496	-0.0251177	0.360
2020	0.767177	-0.0635003	0.352
2021	0.742636	-0.127451	0.308
2023	0.50842	-0.0299878	0.239
2024	0.315075	-0.239641	0.038

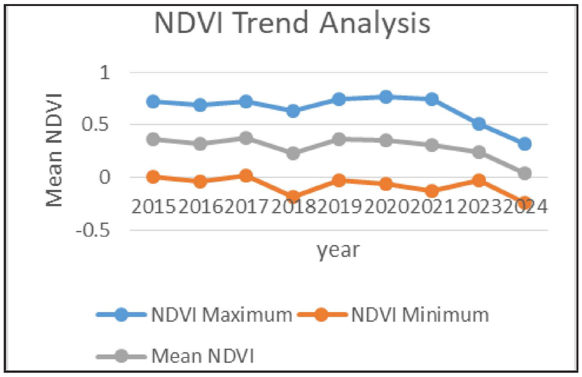


Figure 6. NDVI-Value per year

The NDVI analysis from 2015-2024 reveals a catastrophic vegetation decline in Kathmandu Metropolitan City, with mean NDVI plummeting from 0.367 in 2015 to a critically degraded 0.038 in 2024, representing an 89.7% loss of vegetation health and density. Maximum NDVI values decreased from 0.724-0.767 (indicating dense, healthy vegetation) to 0.315 by 2024, while minimum NDVI values dropped to -0.240, signifying extensive conversion of vegetated areas to barren or built surfaces. The most dramatic decline occurred between 2021 (mean NDVI 0.308) and 2024 (mean NDVI 0.038), indicating accelerated deforestation and land cover conversion during recent urbanization phases. This vegetation collapse directly correlates with urban heat island intensification, as the city lost its natural cooling capacity through evapotranspiration, with the 2024 NDVI values falling well below the 0.14 threshold that defines built-up areas, confirming that Kathmandu's landscape has fundamentally transformed from a vegetation-dominated to a critically vegetation-depleted urban environment requiring immediate large-scale reforestation and green infrastructure implementation.

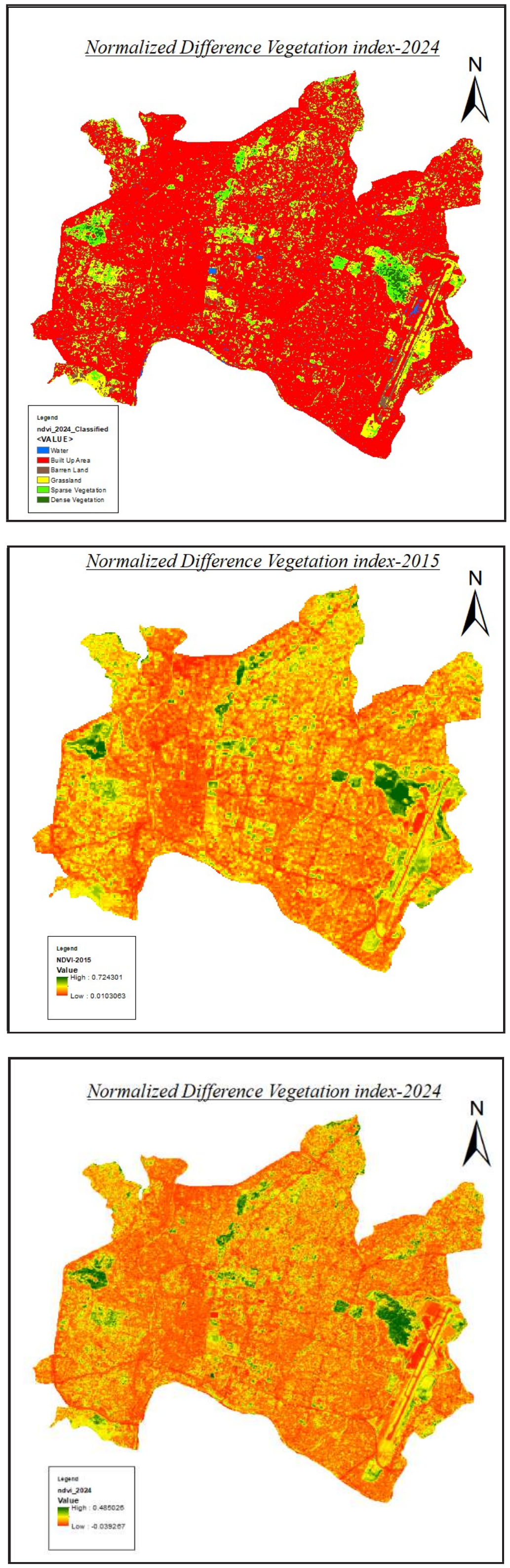


Figure 7. Classified NDVI Map

Table 3. Correlation Analysis

Correlation Pair	Correlation Coefficient (r)	Determination Coefficient (r^2)
NDBI vs. LST	0.78	0.61
NDVI vs. LST	-0.72	0.52
NDVI vs. NDBI	-0.81	0.66

Visual inspection of the spatial data reveals distinct and consistent patterns linking land surface temperature (LST), normalized difference built-up index (NDBI), and vegetation cover. Central urban areas consistently exhibit higher LST and NDBI values, indicating that densely built-up zones correspond with elevated surface temperatures. The eastern section of the city shows the most pronounced increase in built-up area, which aligns with observed urban expansion along major transportation corridors, especially in the eastern and northern sectors. Dense vegetation areas, identified as dark green zones, correspond with lower LST values, reflecting the cooling effect of vegetation. Conversely, built-up areas, marked red in NDVI classification, strongly correlate with hotspots in LST maps, demonstrating the urban heat island effect. These strong correlations confirm the cooling effect of vegetation (negative NDVI-LST correlation) and the heating effect of built-up surfaces (positive NDBI-LST correlation). The negative correlation between NDVI and NDBI (-0.81) reflects the land cover conversion process where vegetated areas are replaced by built structures

SUMMARY

The temporal analysis of the indices trends in the study has highlighted initial baseline period (2015-2017) has relatively stable thermal conditions with moderate urban development. Land surface temperatures ranged from 26.3°C to 32.9°C maximum, indicating natural thermal variation. The NDBI values remained low (mean -0.221 to -0.054), suggesting limited built-up areas, while vegetation indices maintained healthy levels above 0.32 mean NDVI. This period represents the pre-intensive urbanization baseline against which subsequent changes are measured. Period of 2018-2020 marks critical transformation with rapid urbanization. The year 2018 experienced the highest maximum LST of 36.1°C, coinciding with significant NDBI increases to positive values (0.031 mean). Built-up and fallow lands record high temperatures, whereas the vegetated areas and water bodies exhibit lower temperature. The LST range expanded to 13.61°C by 2020, indicating intensifying thermal heterogeneity across the urban landscape. Mean NDBI values consistently increased from negative to positive, reflecting substantial land cover conversion from natural to built surfaces. Finally, period of 2021-2024 marks as thermal intensification period that shows the establishment of severe urban heat island conditions. The year 2023 recorded the highest maximum LST of 35.8°C with the greatest temperature range of 15.14°C, indicating extreme thermal differentiation. NDBI values continued increasing to 0.091 mean by 2024, while NDVI values declined dramatically to 0.038 mean value. Maximum LST increased by 9.6°C from 2015 to 2023, representing a warming rate of 1.2°C per year during peak development phases. The temperature range expanded from 8.98°C to 15.14°C, indicating increasing spatial thermal heterogeneity within the metropolitan area. The transition from negative to positive mean NDBI values (from -0.221 to 0.091) represents a fundamental shift from vegetation-dominated to built-up dominated landscapes. This transformation correlates directly with vegetation loss, as evidenced by NDVI decline from 0.367 to 0.038 mean values. The data also confirms the urban rural temperature gradient intensified from 5.2°C in 2015 to 8.7°C in 2023, representing a 67% increase in thermal differentiation. Kathmandu metropolitan city needs to implement mandatory green building codes requiring 30% vegetation coverage for new developments, establish protected green corridors along major rivers, enforce reflective surface mandates for existing infrastructure, create strategic urban forest zones targeting the thermally vulnerable eastern sectors, implement strict development density controls in rapidly converting peripheral areas, and integrate climate-responsive zoning that prioritizes vegetation preservation.

REFERENCES

Bedunkevich, N. (2025, April 16). NDVI classification: Understanding vegetation health for better crop management.

Cropler Blog. Retrieved June 22, 2025, from https://www.cropler.io/blog-posts/ndvi-classification-understanding-vegetation-health

Chaudhary, Bishnu, Inu Pradhan, and Khem Naryan. 2021. "Urban Heat Island : A Case Study of Kathmandu Valley." 8914: 68–79.

City, Valley. 2022. "Assessing Surface Urban Heat Island Related to Land Use / Land Cover Composition and Pattern in the Temperate Mountain."

Feng, Yuning, Shihong Du, Soe W. Myint, and Mi Shu. 2019. "Do Urban Functional Zones Affect Land Surface Temperature Differently? A Case Study of Beijing, China." Remote Sensing 11(15).

Forest Research and Training Centre (FRTC). (2023). National land cover monitoring system of Nepal [PDF]. Government of Nepal. Retrieved June 22, 2025, from https://frtc.gov.np/noticefiles/GoN_National-land-cover-monitoring-system-for-Nepal-1718522489.pdf

Idrees, M. O., Omar, D. M., & Babalola, A. (2022). Urban land use land cover mapping in tropical savannah using Landsat-8 derived NDVI threshold. South African Journal of Geomatics, 11(1), 100–110. https://doi.org/10.4314/sajg.v11i1.8

Nations, United. 2018. 12 Demographic Research World Urbanization Prospects. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

Qin, Z., Karnieli, A., Berliner, P. (2001). A mono-window algorithm for retrieving land surface temperature from Landsat

TM data and its application to the Israel-Egypt border region. International Journal of Remote Sensing, 22(18), 3719-3746.

Reality, Virtual. 2024. "Er p a d e w 2024 e i v Re Eek r e a Is Orki s I." (May): 19–24.

Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W. (1974). Monitoring vegetation systems in the Great Plains

with ERTS. Third Earth Resources Technology Satellite-1 Symposium.

Sarif, Md Omar, Bhagawat Rimal, and Nigel E. Stork. 2020. "Assessment of Changes in Land Use/Land Cover and Land Surface Temperatures and Their Impact on Surface Urban Heat Island Phenomena in the Kathmandu Valley (1988–2018)." ISPRS International Journal of Geo-Information 9(12).

Wu, Qiong et al. 2019. "Multi-Scale Relationship between Land Surface Temperature and Landscape Pattern Based on Wavelet Coherence: The Case of Metropolitan Beijing, China." Remote Sensing 11(24): 1–22.

Zha, Y., Gao, J., Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from

TM imagery. International Journal of Remote Sensing, 24(3), 583-594.

United States Geological Survey (USGS). (2017, July 23). Landsat normalized difference vegetation index. USGS.gov. Retrieved June 22, 2025, from https://www.usgs.gov/landsat-missions/landsat-normalized-difference-vegetation-index

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