



URBAN HEAT, GREEN INEQUALITY, AND CLIMATE-RESPONSIVE PLANNING: A GEOSPATIAL FRAMEWORK FOR RAPIDLY GROWING PAKISTANI CITIES

Research Article

Rafey Konain

*BS English Literature, Institute of English Studies (IES), University of the Punjab
Lahore.*

Email: rafeykonain965@gmail.com

Abstract

Rapid urbanisation is reshaping land cover, local climate, and environmental inequality across South Asian cities. This article develops a geospatial framework for understanding how vegetation loss and expansion of impervious surfaces can contribute to urban heat exposure, and how spatial evidence can support more equitable regional planning in Pakistan. It synthesises recent published research on land-use/land-cover change, land surface temperature (LST), and urban heat islands, with particular attention to studies of Pakistani cities. The reviewed evidence consistently associates built-up and barren surfaces with higher daytime LST and vegetation and water with lower surface temperatures. However, satellite-derived LST is not equivalent to air temperature or direct human heat exposure, and spatial correlations alone do not establish causation. The article proposes a practical workflow combining multi-temporal Landsat imagery, vegetation and built-up indices, GIS-based hotspot mapping, demographic vulnerability indicators, and community validation. It recommends that planning agencies prioritise heat-risk mapping, protect existing green and blue infrastructure, expand shade and permeable surfaces in underserved neighbourhoods, and publish transparent monitoring indicators. As a conceptual synthesis rather than a new remote-sensing experiment, the article reports no original measurements; its contribution is an integrated framework that can be tested in future city-level studies.

Keywords: geography; regional studies; urban heat island; land surface temperature; GIS; remote sensing; vegetation; Pakistan; climate adaptation.

1. Introduction

Cities are both engines of economic opportunity and places where environmental pressures become concentrated. As urban areas expand, roads, roofs, parking areas, and other impervious surfaces replace vegetation and soil. These changes affect the surface energy balance by altering reflectivity, moisture availability, heat storage, and evapotranspiration. The resulting patterns of land surface temperature vary across neighbourhoods, creating spatial differences that matter for urban design, energy demand, and climate adaptation.

Pakistan provides an important context for examining these processes because its cities are growing under conditions of high summer temperatures, water stress, uneven access to public green space, and substantial variation in urban form. A 2024 study of Islamabad, Lahore, Multan, and Muzaffarabad reported increases in urban area between 2000 and 2020 and found that built-up and barren land had higher land surface temperatures than vegetation and water bodies (Irshad et al., 2024). A 2025 study of six major Pakistani cities also examined surface urban heat island intensity in relation to urban expansion and vegetation change (Spatiotemporal analysis..., 2025). These studies indicate that geospatial methods can help planners identify where land-cover change and thermal patterns coincide.

Yet a map of hot surfaces is not, by itself, a complete map of human risk. Satellite observations measure surface temperature at a particular time and spatial resolution; human heat exposure also depends on air temperature, humidity, wind, building design, work patterns, access to cooling, age, health, and socioeconomic conditions. A neighbourhood with high LST may not always have the highest health burden, and a neighbourhood with moderate LST may still be vulnerable if residents lack shade, reliable electricity, or cooling facilities.



This article asks: how can geospatial evidence on urban heat be translated into climate-responsive and socially equitable planning in Pakistani cities? It has three objectives: (1) synthesise recent evidence on land cover and urban heat; (2) outline a reproducible GIS and remote-sensing workflow for identifying heat hotspots and vulnerable populations; and (3) propose planning measures that link spatial analysis with regional governance and community needs. The article is a conceptual synthesis and methodological framework, not an original empirical analysis.

2. Literature Review and Conceptual Background

2.1 Urban heat islands and land cover

An urban heat island describes a temperature difference between an urban area and its less urbanised surroundings. The term may refer to near-surface air temperature or to land surface temperature observed remotely; these measures should not be conflated. Surface urban heat island analysis commonly uses thermal satellite data to compare the temperatures of different land-cover classes or urban and non-urban zones. The magnitude of the estimated difference depends on the season, time of satellite overpass, weather, spatial resolution, and definition of the reference area.

Land-cover change affects surface temperature through several interacting processes. Impervious materials can store heat and reduce evaporative cooling, while vegetation can shade surfaces and cool them through evapotranspiration when water is available. Water bodies may moderate local thermal conditions, although their effects depend on size, depth, season, and surrounding urban form. These mechanisms are well established, but their local strength should be measured rather than assumed to be identical across cities.

2.2 Evidence from Pakistani cities

Irshad et al. (2024) used geospatial techniques to assess land-use/land-cover changes and associated urban heat island patterns in Islamabad, Lahore, Multan, and Muzaffarabad over 2000–2020. The study reported urban expansion in all four study areas and higher land surface temperatures over built-up and barren classes than over vegetation and water. Its results support the value of comparing land-cover transitions with thermal patterns, while also underlining the need to inspect classification accuracy and seasonal comparability.

A study published in *Ecological Informatics* in 2025 examined spatiotemporal surface urban heat island intensity and vegetation in six major Pakistani cities (Spatiotemporal analysis..., 2025). A separate 2026 study of Karachi, Lahore, Faisalabad, and Islamabad linked thermal hazard analysis to vulnerability and disaster-risk reduction planning (Urban Heat Island Hazard..., 2026). These publications suggest a growing research direction: moving from mapping heat alone toward identifying who is exposed and how institutions can reduce risk.

International work also highlights the importance of local climate zones, high-resolution thermal observations, and spatial modelling. For example, a 2025 study in *Scientific Reports* combined unmanned aerial vehicle thermal imagery and GIS to examine microclimate patterns and found higher temperatures in zones with substantial impervious cover, while vegetated and water-rich zones showed cooling effects (Sütçüoğlu & Kalaycı, 2025). Such methods can complement satellite analysis, although UAV observations may cover smaller areas and require careful sampling design.

2.3 From spatial hazard to social vulnerability

Heat risk is shaped by the interaction of hazard, exposure, and vulnerability. Hazard concerns the intensity and duration of heat; exposure concerns people and assets located in affected places; vulnerability concerns the capacity to anticipate, withstand, and recover from heat. A geospatial assessment should therefore avoid treating LST as a direct proxy for mortality or illness. Instead, thermal maps can be overlaid with population density, age structure, housing conditions, land use, access to parks, health facilities, and other indicators, subject to data quality and privacy constraints.



The equity dimension is particularly important where green space is unevenly distributed. City-wide averages can conceal neighbourhoods with limited shade, poor-quality housing, outdoor labour, or unreliable access to cooling. Participatory mapping and community consultation can help reveal these conditions, while administrative data can provide broader spatial coverage. Neither data type is sufficient alone: satellite observations show physical patterns, while community evidence helps interpret how those patterns affect daily life.

3. Methodological Framework

This article uses a structured narrative synthesis of recent research and develops a reproducible workflow for future empirical studies. The literature discussed here includes multi-city Pakistani remote-sensing studies, a disaster-risk-oriented assessment, and an international GIS/UAV microclimate study. Because this article does not download and reprocess the underlying satellite imagery, it presents no new temperature estimates, classification metrics, or original maps. The recommendations below are a proposed study design that can be implemented and validated by a research team.

3.1 Study area and time period

A future empirical study could select Lahore, Karachi, Faisalabad, and Islamabad to represent different urban forms and climatic settings, while expanding to other cities where data and resources permit. A multi-year period should be chosen with comparable seasonal windows, cloud conditions, and sensor characteristics. The unit of analysis may be a pixel, neighbourhood, local climate zone, or administrative unit; the choice must match the research question and the scale of available demographic data.

3.2 Data sources and preprocessing

Landsat imagery can provide multi-decadal land-cover and thermal information, while Sentinel-2 can support more detailed land-cover classification for recent years. Researchers should document acquisition dates, cloud masks, atmospheric correction, sensor differences, spatial resolution, and any resampling. Meteorological observations should be used where available to contextualise satellite overpasses. Population and socioeconomic layers should come from credible official or openly licensed sources, with clear documentation of spatial and temporal limitations.

3.3 Indicators

- Land Use/Land Cover (LULC): classify built-up areas, vegetation, bare land, and water, and report classification accuracy.
- Land Surface Temperature (LST): retrieve surface temperature from thermal imagery using a documented method and comparable seasonal observations.
- Normalized Difference Vegetation Index (NDVI): use as an indicator of vegetation greenness, while recognising that it is not a direct measure of tree shade or plant health.
- Built-up indicators: use an index such as NDBI alongside visual checks and classification outputs, because spectral indices can confuse certain surface types.
- Heat hotspot measures: define thresholds or standardised scores in advance and test whether hotspot locations change under alternative definitions.
- Vulnerability indicators: where reliable data are available, consider population density, age, housing quality, outdoor employment, access to green space, and cooling resources.

3.4 Analysis and validation

The proposed workflow has five stages: (1) classify land cover for each selected period; (2) derive LST using consistent procedures; (3) compare thermal patterns across land-cover classes and years; (4) overlay heat hotspots with social vulnerability indicators; and (5) validate the maps. Validation should include classification accuracy assessment using reference samples, sensitivity analysis for hotspot thresholds, comparison with ground-based observations where available, and consultation



with local planners and residents. Statistical associations between vegetation and LST should not be described as causal effects unless the design supports causal inference.

Researchers should also test robustness to choices such as the urban boundary, reference area, season, pixel size, and method of defining hotspots. Spatial autocorrelation can make observations non-independent, so standard statistical tests may require spatial methods. Results should report uncertainty and avoid implying that a single city-wide index captures every dimension of heat risk.

4. Discussion

4.1 The value and limits of geospatial evidence

Remote sensing provides consistent spatial coverage and allows researchers to compare patterns across large areas and multiple years. GIS makes it possible to combine thermal observations with land cover, infrastructure, and demographic layers. These capabilities are useful for identifying locations that merit field investigation and for evaluating whether urban expansion coincides with loss of cooling surfaces.

However, satellite data have important limitations. LST represents the radiometric temperature of the observed surface, not the temperature experienced by a person at breathing height. Images capture specific times and may miss night-time heat, short heatwaves, indoor exposure, or microclimates beneath tree canopies. Cloud cover, sensor differences, mixed pixels, and land-cover classification errors can affect comparisons. A responsible study should state these limitations prominently and use multiple data sources where possible.

4.2 Planning for green and blue infrastructure

Protecting mature trees, parks, wetlands, and urban water bodies can support cooling, recreation, biodiversity, and stormwater management. New green infrastructure should be selected for local climate, water availability, maintenance capacity, and equitable access. Tree planting alone is not a complete policy: survival rates, canopy maturity, species selection, irrigation, soil conditions, and long-term maintenance influence results. In water-stressed areas, drought-tolerant vegetation, shade structures, reflective materials, and permeable surfaces may need to be combined.

4.3 Regional planning and environmental justice

Heat does not stop at municipal boundaries. Urban expansion can alter peri-urban agriculture, wetlands, drainage corridors, and regional land cover. Regional planning should therefore coordinate zoning, transport, housing, water management, and green-space networks across administrative jurisdictions. Development approvals can require heat-impact assessments for large projects and protect ecological corridors that provide multiple services.

Equity requires prioritising interventions according to both thermal conditions and social need. A neighbourhood with fewer private cooling options may warrant greater public investment than a wealthier area with similar surface temperatures. Public heat maps should be accompanied by transparent criteria for selecting interventions, accessible community consultation, and monitoring of who benefits. Personal or sensitive household data should not be exposed in public GIS layers.

5. Policy Recommendations

1. **Establish a city heat-monitoring programme.** Combine seasonal satellite analysis with weather-station data, ground checks, and documented uncertainty.
2. **Protect existing green and blue infrastructure.** Map mature tree canopy, parks, wetlands, and water corridors; integrate their protection into zoning and development review.
3. **Prioritise vulnerable neighbourhoods.** Use transparent, privacy-conscious overlays of heat, population, housing, and access-to-cooling indicators to target shade and cooling interventions.
4. **Use context-sensitive design.** Combine tree canopy, shade structures, cool roofs, permeable surfaces, and water-sensitive planning according to local ecology and maintenance capacity.



5. **Publish open and reproducible methods.** Document data sources, classification methods, model assumptions, accuracy measures, and revisions so other researchers can reproduce the analysis.
6. **Include residents in validation.** Use participatory mapping, accessible reporting, and feedback channels to compare mapped hotspots with lived experience.
7. **Evaluate outcomes over time.** Track canopy survival, surface temperature patterns, access to shade, and distribution of investment; revise interventions when results do not meet objectives.

6. Limitations and Future Research

This article is a conceptual synthesis and proposed methodological framework, not an original empirical remote-sensing study. It does not present newly processed imagery, a newly sampled population, or original statistical results. The literature discussed uses different study periods, sensors, spatial units, and definitions of urban heat; direct numerical comparisons across studies may therefore be inappropriate without harmonisation.

Future work should use a transparent protocol to select imagery and reference data, validate land-cover classifications, compare multiple hotspot definitions, and connect satellite observations with air temperature and community-reported exposure. Comparative studies across Pakistani cities could examine how urban form, water availability, socioeconomic inequality, and planning institutions modify heat risk. Researchers should also assess whether interventions produce measurable cooling and whether benefits reach the most vulnerable residents.

7. Conclusion

Geospatial analysis offers an important means of understanding the relationship between urban growth, land-cover change, and surface heat. Research in Pakistani cities has reported expansion of built-up areas and higher surface temperatures over built-up and barren land than over vegetated and water-covered areas. These patterns support the need for heat-sensitive planning, but they should not be interpreted as a complete measure of human exposure or as proof of causation on their own.

A more useful planning approach combines remote sensing, GIS, meteorological context, social vulnerability indicators, and community validation. Such a framework can help identify where interventions are needed, clarify uncertainty, and evaluate whether public investment is equitably distributed. Protecting existing green and blue infrastructure, expanding shade and permeable surfaces, improving regional coordination, and publishing reproducible monitoring methods are practical steps toward climate-responsive urban development. The central recommendation is to treat heat mapping not as an end in itself, but as one component of a transparent and socially accountable planning process.

References

- Irshad, Z., Hassan, M., Akbar, S., Farooq, M., & Chishtie, F. A. (2024). Spatiotemporal changes in LULC and associated impact on urban heat islands over Pakistan using geospatial techniques. *Urban Climate*, 57, Article 102112. <https://doi.org/10.1016/j.uclim.2024.102112>
- Spatiotemporal analysis of surface Urban Heat Island intensity and the role of vegetation in six major Pakistani cities. (2025). *Ecological Informatics*, 85, Article 102986. <https://doi.org/10.1016/j.ecoinf.2024.102986>
- Urban Heat Island Hazard and disaster risk in major Pakistani cities: Spatiotemporal analysis, vulnerability assessment, and risk reduction strategies. (2026). *Progress in Disaster Science*, 30, Article 100580. <https://doi.org/10.1016/j.pdisas.2026.100580>
- Sütçüoğlu, G. G., & Kalaycı, A. (2025). Planning cooler cities through integration of UAV thermal imagery and GIS in local climate zone studies. *Scientific Reports*, 15, Article 43424. <https://doi.org/10.1038/s41598-025-25178-y>
- Samad, N., Farnaghi, M., Ostermann, F. O., et al. (2026). A systematic literature review of machine learning and deep learning for urban heat island modelling. *Discover Cities*, 3, Article 43. <https://doi.org/10.1007/s44327-026-00223-1>