Charting the Urban Heat Archipelago: Delineating Data Islands Using Land Surface Temperature

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Abstract: Urban heat resilience is an increasingly critical issue, as extreme heat kills more people in the United States than any other weather-related disaster (BERKO 2014). The Intergovernmental Panel on Climate Change (IPCC 2022) warns of prolonged stretches of high temperatures, which pose greater health risks than isolated extreme heat events. Researchers now conceptualize the urban heat island as an "archipelago" of hot spots heterogeneously distributed across cities, with higher temperatures concentrated in areas dominated by concrete and asphalt, while cooler zones are found around trees, parks, and shaded open spaces (BORUNDA 2021). The growing intensity, duration, and frequency of heat waves have disproportionately impacted underserved populations, who face increased vulnerability. This paper investigates how mapping and visualization can uncover thermal disparities within urban environments. We developed a vulnerability assessment method in collaboration with the City of Omaha Planning Department, which is simultaneously creating a Climate Action Plan. Using Landsat 8 satellite imagery, we calculated and mapped Land Surface Temperature (LST) to identify Omaha, NE's most significant heat islands. To better understand heat disparities within these "islands," we mapped and compared environmental/health, social/economic, and physical infrastructure data against city-wide metrics. Our analysis focused on average surface temperature, total population, percentage of ethnic minorities, poverty rate, median household income, unemployment rate, and indicators of physical and mental health vulnerability. The results indicate that in all identified "islands," average surface temperature and poverty rates exceeded city averages. The areas of 75 North, Southside Terrace, and Downtown showed the highest vulnerability scores, with elevated surface temperatures, poverty rates, minority percentages, and unemployment rates, while household income, physical health, and mental health outcomes were lower than citywide averages.

Keywords: Heat, mapping, thermal disparity, Landsat

1 Introduction

Extreme heat is an increasingly urgent issue in urban environments, with rising temperatures exacerbating health risks, infrastructure vulnerabilities, and environmental degradation (IPCC 2022). The urban heat island (UHI) effect intensifies heat exposure, disproportionately affecting marginalized communities due to factors such as impervious surface concentration, limited vegetation, and socio-economic disparities (BENZ & BURNEY 2021, LIU et al. 2022).While traditional mitigation strategies – such as urban greening, reflective materials, and improved infrastructure – can help reduce urban heat, these interventions often fail to account for the spatial complexity of thermal disparities within cities (KLEEREKOPER et al. 2012). Understanding these disparities requires a more nuanced, data-driven approach that integrates environmental, social, and infrastructural factors (CHANG et al. 2021). In contemporary heat research, the urban heat island (UHI) phenomenon is increasingly conceptualized as an archipelago, where fragmented heat islands – hot spots across the urban landscape – contrast with cooler microclimates formed by green spaces, tree canopies, and shaded open areas (BORUNDA 2021, SHEPHERD 2013, OKE 1982).

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Landscape architects and urban planners are increasingly tasked with designing climate-responsive interventions to mitigate heat exposure, yet existing approaches lack the precision needed to target high-risk areas effectively (HIRSCHFELD 2024). The spatial heterogeneity of urban heat exposure necessitates interdisciplinary methods that merge remote sensing, GIS-based analysis, and socio-economic vulnerability assessment. Recent advancements in thermal mapping technologies have enhanced the ability to visualize and quantify urban heat variations, but gaps remain in the identification and assessment of urban heat islands (ALMEIDA et al. 2021).

Studies utilizing Landsat-derived land surface temperature (LST), UAV-based thermal imaging, and ground-based sensor networks have demonstrated the potential of high-resolution spatial analysis in identifying localized heat hotspots (AVDAN & JOVANOVSKA 2016, LI et al. 2021, LINDQUIST & GIBBONS 2024a). However, much of the existing research focuses on broad-scale UHI trends rather than high-resolution vulnerability assessments that integrate socio-economic and infrastructural data (ALMEIDA et al. 2021). The lack of interdisciplinary synthesis limits the applicability of heat mitigation strategies, as interventions often overlook the social dimensions of heat exposure (JOSHI et al. 2024).

Despite the increasing use of remote sensing in urban heat research, standardized methodologies for integrating environmental, social, and infrastructural data remain limited (VOOGT & OKE 2003, ALMEIDA et al. 2021). Many studies focus solely on thermal characteristics, omitting critical socio-economic indicators that shape heat vulnerability (KARANJA & KIAGE 2021). Additionally, while previous research has mapped generalized heat islands, few studies have developed an adaptive framework for identifying and classifying heat archipelagos based on multi-variable analysis (CHENG et al. 2021). There remains a need for fine-scale, spatially explicit assessments that not only map temperature variations but also contextualize them within broader urban systems.

This study addresses these gaps by refining heat archipelago identification through an integrated approach that combines LST mapping, socio-economic vulnerability assessment, and spatial clustering techniques. Using Omaha, Nebraska, as a case study, this research employs Landsat-8 remote sensing data, GIS-based spatial analysis, and Census demographic datasets to generate a heat vulnerability assessment. By merging climate science, landscape architecture, and urban analytics, this work advances the methodology for urban heat mapping and intervention planning. The findings contribute to both academic discourse and real-world policy applications, supporting the City of Omaha Planning Department’s ongoing efforts to develop a Heat Resilience Plan as part of its broader Climate Action Plan.

2 Methods

This research was conducted in collaboration with the City of Omaha Planning Department as part of its efforts to develop a Heat Resilience Plan alongside an ongoing Climate Action Plan. The study area includes Sarpy and Douglas Counties, encompassing Omaha’s municipal boundaries (Fig. 1). These counties were selected due to the availability of comprehensive Geographic Information Systems (GIS) data. Omaha's average high temperatures range from 0.5°C in January to 30.5°C in July (US CLIMATE DATA 2023). Within this context, the identification of Omaha’s heat archipelago serves as a core component of the vulnerability assessment, providing insights into areas most at risk and informing resilience strategies.

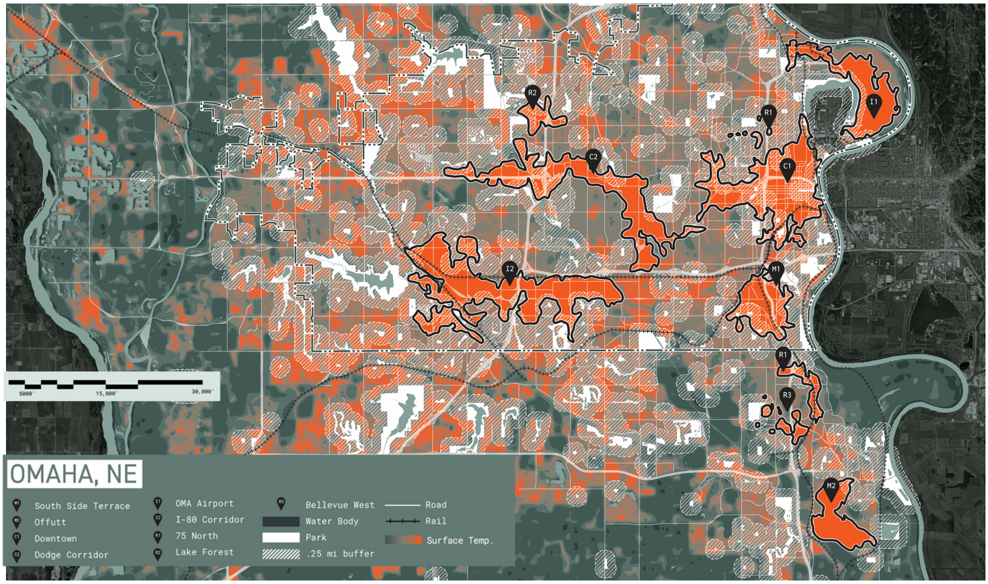

Fig. 1: City of Omaha area delineation with Landsat 8 Land Surface Temperature data overlaid with the city parks system. The black tags indicate selected heat islands.

2.1 Mapping the Heat Archipelago

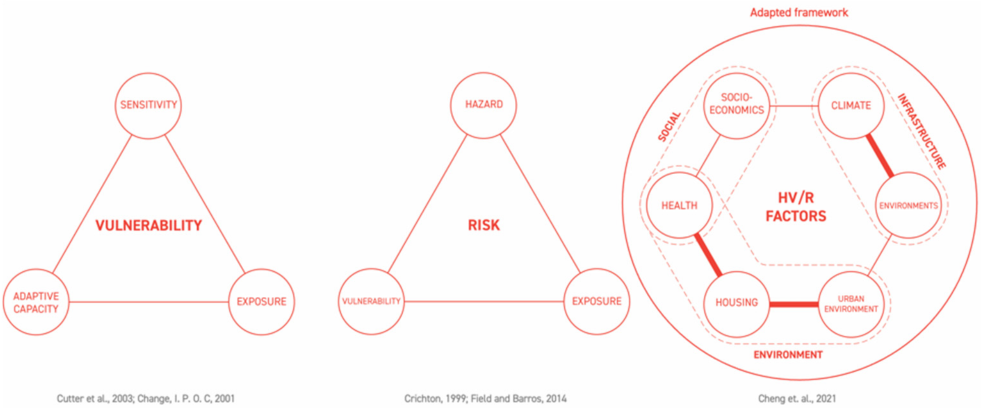

Fig. 2: Heat vulnerability/risk framework adapted from CHENG et al., which reviewed approaches for identifying heat-vulnerable populations and locations in current literature

To delineate the spatial distribution of heat islands we used Landsat 8 satellite imagery from August 3, 2022, obtained via USGS Earth Explorer. The dataset included thermal bands 4, 5, and 10, along with corresponding metadata. Various calculations were conducted using ArcGIS Pro to calculate Land surface temperature (LST) using Avdan and Jovanovska's "Algorithm for Automated Mapping of Land Surface Temperature" (AVDAN & JOVANOVSKA

2016). Before analysis, the Landsat imagery underwent several preprocessing steps to enhance accuracy. Atmospheric correction was applied to minimize interference, while radiometric calibration was performed to ensure consistency in thermal readings. Spatial alignment adjustments were made to match Omaha's urban extent, ensuring that all data sources corresponded to the same geographic reference.

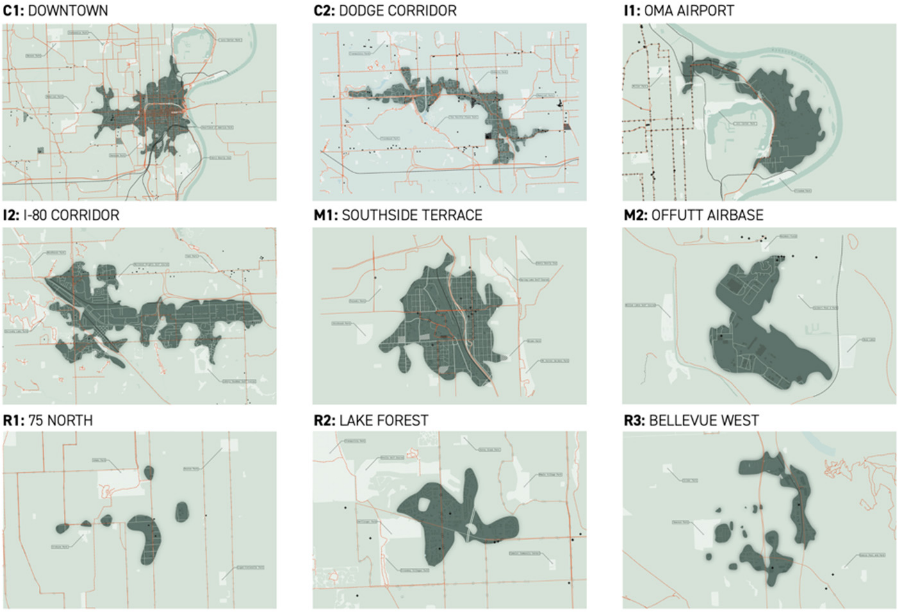

Fig. 3: Delineated heat islands (Landsat Data) coded by land use type

Table 1: Criteria for heat vulnerability assessment. Census data compiled at the block scale.

Categories	Criteria	Metric
Environment	Contamination Ecological systems Green amenities Land surface temperature (Landsat) Land cover Tree equity score	Incidents of lead contamination Proximity to water bodies Proximity to green space Average temperature Percent canopy coverage Tree equity score
Social	Age distribution Ethnic distribution Mental and physical health Poverty rate Population density Unemployment rate Wealth distribution	Average age Percent minority Health burden index (tree equity score) Poverty rate Population density Unemployment rate Household Median Income
Infrastructure	Health facilities Land use Public mobility Traffic volume Transportation infrastructure Zoning	Proximity to health facilities Majority land use Proximity to public transport Average daily vehicle count Proximity to high-volume roads Percent zoning distribution

2.2 Heat Vulnerability Assessment

To assess heat vulnerability, this study adapted CHENG et al.'s (2021) vulnerability framework, which categorizes relevant variables into environmental, social, and physical infrastructure factors (Fig. 2). The framework was modified to align with Omaha's specific urban and socio-economic characteristics. Environmental factors included land cover type, vegetation density, impervious surface area, and proximity to water bodies, drawing from national census databases and satellite imagery. Social factors incorporated demographic data, including age, race, and income, along with social vulnerability indices and Tree Equity Score data, sourced from the 2020 Census and related datasets. Physical infrastructure variables focused on aspects such as building density, transportation infrastructure, and access to green spaces, utilizing GIS data from state, county, and city sources.

While Table 1 outlines a broad framework for assessing heat vulnerability using environmental, social, and infrastructure-related criteria, the data presented in Table 2 focuses specifically on key socio-economic and environmental variables that are most relevant for drawing direct comparisons between the identified heat islands and the city-wide dataset. The selection of variables in Table 2 was guided by their direct influence on heat vulnerability at a localized scale and their availability at a consistent resolution across all identified heat islands. The broader criteria from Table 1 played a critical role in shaping the development of maps used throughout the study, helping to visualize factors such as land cover, tree canopy distribution, and transportation infrastructure. These spatial analyses provided important context for understanding heat disparities across Omaha. However, not all criteria were ultimately used in Table 2, as certain variables, such as contamination levels, proximity to health facilities, and traffic volume, either did not exhibit significant variability among the heat islands or were not available at a fine enough resolution for meaningful spatial comparisons.

Instead, Table 2 prioritizes factors such as population demographics, household income, unemployment rates, poverty rates, and health indicators, as these variables provide a more immediate understanding of socio-economic disparities and their correlation with extreme heat exposure. Additionally, while land use and zoning data were incorporated into the broader analysis, they were not included in Table 2, as the primary objective was to compare quantitative vulnerability scores rather than categorical land classifications. By focusing on these selected metrics, Table 2 provides a concise and comparable dataset that allows for the ranking of heat islands based on their overall vulnerability. This approach ensures that the results align with the study's primary goal of identifying priority areas for intervention while maintaining methodological rigor.

2.3 Isolating and Assessing the Heat "Islands"

Nine distinct heat islands were delineated from the land surface temperature (LST) data, representing areas with elevated temperatures relative to their surroundings. To achieve this, a combination of spatial analysis techniques, including thresholding and clustering algorithms, was applied to the LST raster dataset. The process involved defining thresholds for LST values indicative of heat island formation and applying spatial clustering algorithms to identify contiguous clusters of pixels with similar temperature characteristics. The resulting heat islands were then categorized into four predominant land use types: Commercial, Industrial, Mixed Use, and Residential. It is important to note that all data used in this portion of the methods section, including 2020 Census Data, 2020 Tree Equity Score Data, and LST data, were acquired at a consistent temporal resolution to ensure compatibility and minimize temporal discrepancies. Additionally, the spatial resolution of the data sources was carefully considered to align with the spatial scale of the analysis, with finer resolutions preferred for capturing localized variations in heat vulnerability.

To further investigate disparities within the heat archipelago, the heat vulnerability assessment was compared to land surface temperature distributions. Key socio-economic and environmental indicators were extracted from compiled datasets to analyze the characteristics of each heat island (Fig. 4). These indicators included population density, median income, minority population percentages, poverty rates, household income distribution, unemployment rates, and public health metrics related to physical and mental well-being. The relevant data was sourced from the United States Census Bureau, local government agencies, and public health databases to ensure accuracy and consistency.

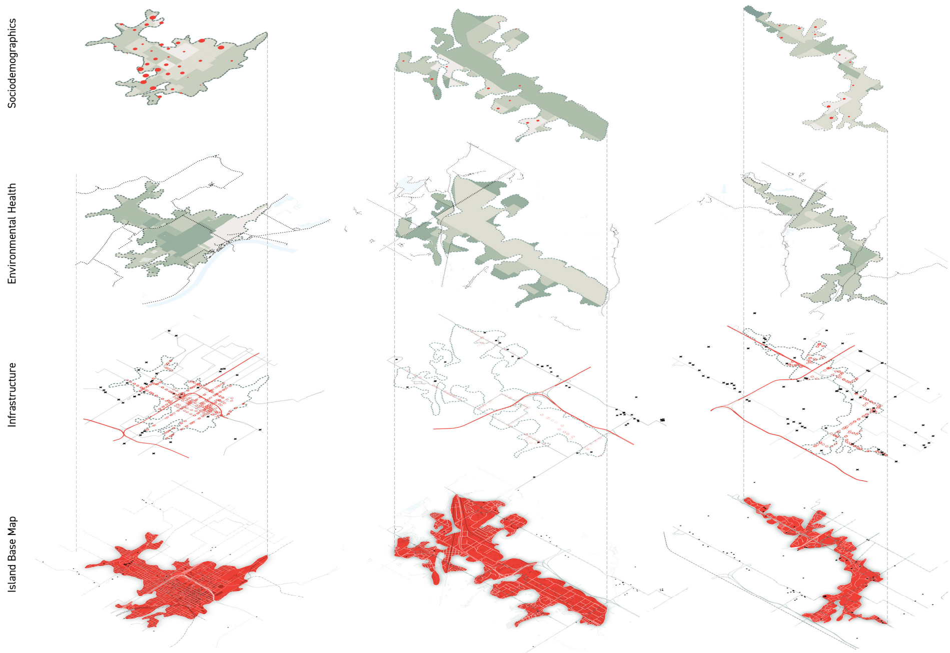

Fig. 4: Multi-criteria assessment of heat islands in Omaha, Nebraska. This visualization illustrates the spatial distribution of socio-demographic factors, environmental health variables, and infrastructure characteristics for three of the nine identified heat islands. These layers were analyzed to delineate and classify heat islands, highlighting the intersection of social and environmental vulnerabilities.

Once the quantitative data was extracted, it was clipped to the boundaries of the identified heat islands to facilitate spatial analysis at a localized scale. This allowed for a direct comparison of each heat island's socio-economic and environmental characteristics against city-wide averages for Omaha, Nebraska. Each criterion received equal weighting, and scores were assigned based on the relative rank of each heat island in comparison to the city-wide dataset. For instance, if a heat island exhibited higher poverty rates than the city average, it received a higher vulnerability score for that criterion. To establish a ranking from most to least vulnerable, the scores assigned to each criterion were totaled, providing a quantitative measure of vulnerability. This ranking enabled the identification of priority areas for intervention and resource allocation (Tab. 2). While equal weighting was applied in this study, alternative weighting schemes could be explored in future research to account for variations in the relative importance of different vulnerability indicators.

Table 2: Isolated island data compared and ranked against the City of Omaha dataset

Island	**Total Pop.**	**Avg. High Temp.**	**Minority Pct.**	**Pov. Rate**	**Household Inc.**	**Unempl. Rate**	**Phys. Health**	**Mental Health**	**Total Score**
75 North	731	89.34	86.1	73.92	22591	7.29	18.86	19.35	**54**
Southside Terrace	1259	92.71	73.65	60.78	42188	8.75	16.48	17.34	**53**
Downtown	1029	94.3	42.14	47.59	40364	6.48	11.86	14.55	**46**
OMA Airport	1439	89.25	47.3	61.69	36649	8.22	14.64	16.16	**46**
Lake Forest	1107	91.89	33.46	33.4	55566	4.16	9.69	12.42	**31**
Offutt Airbase	910	91.67	20.94	30.95	50949	5.86	8.83	11.39	**26**
Dodge Corridor	1151	92.51	19.67	26.84	68873	4.47	8.88	10.73	**21**
I-80 Corridor	970	92.88	14.87	18.87	69913	2.01	9.07	10.84	**19**
Bellevue West	1231	90.34	30.61	22.34	53803	2.83	8.9	10	**19**
City of Omaha	**491,168**	**87**	**34.2**	**11.6**	**65662**	**2.5**	**10.52**	**12.44**	

3 Results

Across all identified heat islands, both average surface temperature and poverty rates were consistently higher than city-wide averages. This pattern suggests that these areas experience heightened heat exposure and socio-economic vulnerability, likely due to factors such as a higher concentration of impervious surfaces, limited green spaces, and lower socio-economic status. Neighborhoods such as 75 North, Southside Terrace, and Downtown emerged as hotspots of vulnerability, exhibiting elevated surface temperatures and poverty rates that significantly exceed city-wide metrics.

In addition to economic disparities, the demographic composition of the heat islands revealed notable differences. The percentage of ethnic minority residents and unemployment rates were markedly higher in these areas, underscoring the intersectionality of heat vulnerability with social and economic inequities. These findings indicate that marginalized communities are disproportionately affected by extreme heat, compounding existing disparities in access to resources and adaptive capacity.

Further analysis revealed that heat islands exhibited lower household incomes and poorer physical and mental health outcomes compared to city-wide averages. Residents in these areas may face additional challenges in coping with heat stress, including limited access to healthcare services, inadequate housing conditions, and increased levels of chronic stress. These socio-economic and health disparities highlight the need for comprehensive interventions that address the broader determinants of heat vulnerability.

Overall, the findings emphasize the urgent need for holistic, transdisciplinary approaches to heat resilience planning that integrate social, economic, and environmental factors. Targeted investments in green infrastructure, affordable housing, social support systems, and community engagement are essential for mitigating heat-related risks and fostering more resilient and equitable urban environments. By prioritizing these strategies, policymakers and stakeholders can help reduce systemic inequities and enhance community resilience in the face of climate change.

4 Discussion

The findings of this study provide valuable insights into the identification and spatial distribution of urban heat islands in Omaha, Nebraska, using land surface temperature (LST) data derived from Landsat remote sensing imagery. This research moves beyond conventional UHI assessments by integrating LST data with socio-economic and infrastructural indicators to map urban heat archipelagos – a methodological approach that enhances the precision of heat vulnerability assessments. Without this interdisciplinary framework, the City of Omaha's heat mitigation strategies would likely have relied on broad-scale temperature models that fail to capture intra-urban disparities, limiting the ability to prioritize high-risk neighborhoods for intervention. By contrast, this study provides spatially explicit, data-driven insights that directly inform municipal decision-making on targeted cooling strategies and urban resilience planning. The impact of this approach is tangible – based on the findings, the City of Omaha was able to secure nearly $1 million in grant funding from a HUD Choice award to implement heat mitigation strategies in the South Omaha heat island, demonstrating how research-driven analysis can translate into actionable policy and investment.

While this study provided tangible contributions to the City of Omaha, certain limitations must be acknowledged. One key limitation is the use of equal weighting in the heat vulnerability assessment. While the selection criteria for identifying heat islands were clearly defined, the assumption that all indicators contribute equally to vulnerability may not accurately reflect the significance of each factor. Future research should explore systematic approaches for assigning differential weights to criteria using validation techniques, allowing for a more rigorous and objective assessment of high-risk areas.

Despite these challenges, the application of **LST data combined with socio-economic analysis** presents a critical opportunity for **evidence-based urban planning and public health interventions.** By leveraging advancements in **remote sensing technology, GIS-based analytics, and interdisciplinary collaboration**, this study refines methodologies for evaluating heat islands at finer spatial scales. Moreover, interdisciplinary collaborations between remote sensing specialists, urban planners, and public health experts are essential for advancing our understanding of urban heat disparities and developing targeted strategies to mitigate the adverse impacts of extreme heat events on vulnerable populations.

5 Conclusion

In conclusion, this study identifies Omaha's urban heat archipelago using land surface temperature analysis, revealing significant heat islands and their correlation with socio-economic vulnerability. Findings highlight the disproportionate heat exposure faced by marginalized communities, emphasizing the need for targeted interventions to address thermal disparities. By integrating remote sensing and spatial analysis with socio-economic data, this research provides valuable insights for urban planning and climate resilience. Moving forward, continued monitoring and collaborative efforts between researchers, policymakers, and community stakeholders will be essential for mitigating extreme heat impacts and promoting equitable urban resilience.

References

ALMEIDA, C. R., TEODORO, A. C. & GONÇALVES, A. (2021), Study of the urban heat island (UHI) using remote sensing data/techniques: A systematic review. Environments, 8 (10). https://doi.org/10.3390/environments8100105.

AVDAN, U. & JOVANOVSKA, G. (2016), Algorithm for automated mapping of land surface temperature using Landsat 8 satellite data. Journal of Sensors, 2016. https://doi.org/10.1155/2016/1480307.

BENZ, S. A. & BURNEY, J. A. (2021), Widespread race and class disparities in surface urban heat extremes across the United States. Earth's Future, 9, e2021EF002016. https://doi.org/10.1029/2021EF002016.

BORUNDA, A. & CHAMPINE, R. D. (2020), Racist housing policies have created some oppressively hot neighborhoods. National Geographic, 2 September. https://www.nationalgeographic.com/science/article/racist-housing-policies-created-some-oppressively-hot-neighborhoods.

CHAPMAN, L., AZEVEDO, J. A. & PRIETO-LOPEZ, T. (2013), Urban heat and critical infrastructure networks: A viewpoint. Urban Climate, 3, 7-12. https://doi.org/10.1016/j.uclim.2013.04.001.

CHENG, W., LI, D., LIU, Z. & BROWN, R. D. (2021), Approaches for identifying heat-vulnerable populations and locations: A systematic review. Science of The Total Environment, 799. Available at: https://doi.org/10.1016/j.scitotenv.2021.149417.

CHEVAL, S. et al. (2024), A systematic review of urban heat island and heat waves research (1991-2022). Climate Risk Management, 44, 100603. https://doi.org/10.1016/j.crm.2024.100603.

HIRSCHFELD, D. & GUENTHER, A. (2024), Landscape architecture solutions to extreme heat: Research study. American Society of Landscape Architects Fund (ASLA Fund), March. https://www.asla.org/evidence.

IPCC (2022), Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009325844.

JOSHI, K. et al. (2024), Understanding the synergy between heat waves and the built environment: A three-decade systematic review informing policies for mitigating urban heat island in cities. Sustainable Earth Reviews, 7 (1). https://doi.org/10.1186/s42055-024-00094-7.

KARANJA, J. & KIAGE, L. (2021), Perspectives on spatial representation of urban heat vulnerability. Science of The Total Environment, 774, 145634. https://doi.org/10.1016/j.scitotenv.2021.145634.

KLEEREKOPER, L., VAN ESCH, M. & SALCEDO, T. B. (2012), How to make a city climate-proof, addressing the urban heat island effect. Resources, Conservation and Recycling, 64, 30-38. https://doi.org/10.1016/j.resconrec.2011.06.004.

LINDQUIST, S. & GIBBONS, K. (2024a), Infrared chorographies: Visualizing thermal disparities. Journal of Digital Landscape Architecture (JoDLA), 9-2024.

LINDQUIST, S. & GIBBONS, K. (2024b), Thermal toolkit: Technologies and techniques for visualizing heat. Landscape Architecture Foundation Report, Washington D.C., 11-15.

LIU, J., VARGHESE, B. M., HANSEN, A., ZHANG, Y., DRISCOLL, T., MORGAN, G., DEAR, K., GOURLEY, M., CAPON, A. & BI, P. (2022), Heat exposure and cardiovascular health outcomes: A systematic review and meta-analysis. The Lancet Planetary Health, 6 (6). https://doi.org/10.1016/s2542-5196(22)00117-6.

OKE, T. R. (1982), The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society, 108 (455), 1-24. https://doi.org/10.1002/qj.49710845502.

SHEPHERD, J. M., ANDERSEN, T., STROTHER, C., HORST, A., BOUNOUA, L. & MITRA, C. (2013), Urban climate archipelagos: A new framework for urban impacts on climate. Earthzine, 29 November. http://www.earthzine.org/2013/11/29/urban-climate-archipelagos-a-new-framework-for-urban-impacts-on-climate.

TRAILL, L. W., LIM, M. L., SODHI, N. S. & BRADSHAW, C. J. (2010), Mechanisms driving change: Altered species interactions and ecosystem function through global warming. Journal of Animal Ecology, 79 (5), 937-947. https://doi.org/10.1111/j.1365-2656.2010.01695.x.

VOOGT, J. A. & OKE, T. R. (2003), Thermal remote sensing of urban climates. Remote Sensing of Environment, 86 (3), 370-384. https://doi.org/10.1016/s0034-4257(03)00079-8.