Keeping the Cartographer in the Loop: A Participatory Spatial Decision-Support System for Urban Heat Resilience Planning

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Keywords: urban heat resilience, spatial decision support system, participatory GIS, multi-criteria decision analysis, web GIS

Introduction

Automated geospatial analysis pipelines are now routinely used to generate urban vulnerability and susceptibility maps that inform resource allocation, emergency planning, and infrastructure investment. Yet these workflows conceal a critical governance problem: the value-laden assumptions embedded in composite indices—above all, criterion weighting—are rarely visible to the decision-makers and communities whose priorities they purport to represent (Malczewski, 2006; Sieber, 2006). When a single “official” heat susceptibility map is handed to planners, the implicit message is that neighborhood rankings are technically determined. In reality, they reflect choices about what matters most—choices that are political, ethical, and contextual rather than purely technical.

This problem is especially acute for urban heat risk, where susceptibility is shaped by interacting dimensions of environmental exposure, population sensitivity, and adaptive-capacity constraints (Eyni et al., 2025; Karanja et al., 2025; Qian & Liu, 2025). A map emphasizing health sensitivity may prioritize different neighborhoods than one emphasizing exposure or access barriers. Existing static heat indices therefore do more than summarize data; they institutionalize hidden preferences (Jankowski, 2009).

We argue that the cartographer and GIS practitioner should remain in the loop not merely as technical operators, but as facilitators of structured deliberation—surfacing trade-offs, eliciting stakeholder values, and ensuring that maps reflect explicit, auditable choices rather than hidden defaults. To operationalize this role, we develop a participatory web-based spatial decision-support system (SDSS) for urban heat resilience planning. The system’s core innovation is an interactive human-in-the-loop geovisual analytics workflow: stakeholder knowledge is elicited and encoded as machine-readable weights, which drive a responsive multi-criteria analysis engine that updates maps in real time as priorities are adjusted. This positions the SDSS not as a replacement for expert and community judgment, but as a structured medium through which that judgment becomes transparent, comparable, and analytically consequential.

Data and Methods

Conceptual framing

We organize susceptibility criteria into three domains—exposure, sensitivity, and adaptive capacity—to make trade-offs structurally explicit. Exposure captures the intensity and spatial pattern of hazardous heat conditions. Sensitivity reflects how strongly different populations are likely to be affected, including age structure, chronic disease, and disability. Adaptive capacity represents the resources available to avoid or mitigate harm, such as transportation, insurance, digital access, and access to cooling infrastructure.

Participatory criteria elicitation and default weights

To ground both the criteria set and the default weights in stakeholder perspectives, we organized a one-day workshop in Oklahoma City with local residents, local and regional governments, non-governmental organizations, and researchers. A central premise of our approach is that the selection of criteria—including which heat-exposure measures represent locally meaningful risk—is itself a value-laden decision that should be made with, rather than for, the affected community. Accordingly, the candidate criteria and the specific heat-exposure indicators were not imposed by the analysts but were deliberated and agreed upon collaboratively during the workshop, reflecting participants' lived experience of local heat conditions alongside data availability and transferability. This treats the choice of what to measure as an explicit, auditable stakeholder input rather than a hidden analyst convention.

Participants then rated 23 candidate criteria on a 1–10 importance scale. These criteria span exposure (heat exposure, green/blue-space deficit, vegetation condition, paved-road density, and building density), sensitivity (children, elders, female population, living alone, disability, and chronic disease), and adaptive capacity (low income, low education, minority status, language barrier, unemployment, rental housing, no vehicle, no insurance, no internet, no computer, no phone, and distance to cooling opportunities). A pilot yielded 31 complete responses. Mean ratings were normalized to sum to 1 and serve as the SDSS default weight vector—a transparent, stakeholder-derived baseline that users can inspect, challenge, and override. Heat exposure (M = 9.00), chronic disease (M = 8.75), elders (M = 8.71), and disability (M = 8.54) were rated highest, while no computer (M = 5.36) and language barrier (M = 5.46) ranked lowest. This study was reviewed and approved by the University of Oklahoma IRB, and all participants provided informed consent.

Spatial indicators and transferable design

The SDSS is designed to be transferable across urban contexts using widely available datasets. Social indicators can be derived from census and administrative sources, including age structure, disability prevalence, poverty proxies, insurance coverage, vehicle access, and digital-access variables. Environmental indicators can be derived from remote sensing and land-cover products, such as land surface temperature, vegetation indices, and greenness or blue-space proxies. Consistent with the participatory selection process above, the heat-exposure indicator used in the prototype reflects the measures prioritized by workshop participants and is operationalized from openly available remote-sensing sources to preserve transferability. Access to cooling opportunities can be represented by point-of-interest layers converted into distance or accessibility surfaces. Indicators are harmonized to a consistent planning unit, normalized, and directionally aligned so that higher values represent higher susceptibility or lower protection. The current prototype demonstrates a tract-level implementation using census-derived indicators while maintaining an extensible architecture for broader exposure and access layers.

MCDA scoring with WASPAS and interactive reweighting

We operationalize heat susceptibility ranking using the Weighted Aggregated Sum Product Assessment (WASPAS) method, which combines additive and multiplicative aggregation to balance compensatory and non-compensatory behavior in multi-criteria ranking (Karnatak et al., 2007; Malczewski, 2006). For each spatial unit i and criterion j, let x_{ij} be the normalized criterion value and w_{j} the user-specified weight with $\Sigma w_{\mathrm{j}} = 1$. We compute a weighted sum model score ${Q_{\mathrm{i}}}^{\mathrm{WsM}} = \Sigma w_{\mathrm{j}} x_{\mathrm{ij}}$ and a weighted product model score ${Q_{\mathrm{i}}}^{\mathrm{WPM}} = \prod (x_{\mathrm{ij}})^{\mathrm{wj}}$. The combined WASPAS score is $Q_{\mathrm{i}} = \lambda {Q_{\mathrm{i}}}^{\mathrm{WsM}} + (1 - \lambda) {Q_{\mathrm{i}}}^{\mathrm{WPM}}$, with λ set to 0.5 in the prototype as a neutral choice. The key design requirement is responsiveness: users edit weights and immediately examine how ranks and hotspots shift, enabling scenario exploration during participatory planning rather than as a post-hoc sensitivity exercise (Zhang et al., 2020)

Planned model extensions

Ongoing work will extend the SDSS with Monte Carlo weight sampling to quantify rank stability, group-specific weighting scenarios to visualize consensus and disagreement, and cross-method benchmarking using TOPSIS and VIKOR to identify priority areas robust across formulations. In parallel, we conceptualize the framework as a basis for LLM-assisted geospatial decision support, in which large language models would not replace the cartographer but function as a scenario-drafting and explanation assistant—for example, translating a prompt such as “prioritize elderly populations with poor access to cooling” into a candidate weighting scenario for human review.

Implementation and Preliminary Results

The SDSS is implemented as a web application coupling MCDA computation with interactive geovisualization to support live workshop use, deliberately lowering the barrier for non-GIS participants (MacEachren et al., 2004). The cartography-forward interface features a left-panel weight editor with on-hover descriptions and a choropleth map that updates after each submission. Crucially, it keeps the active weight vector visible, making the human choices driving the analysis legible at all times. Scenario presets such as “health-driven,” “access-driven,” and “exposure-driven” let participants compare distinct planning objectives rather than debating a single authoritative map (Jankowski, 2009; Sieber, 2006).

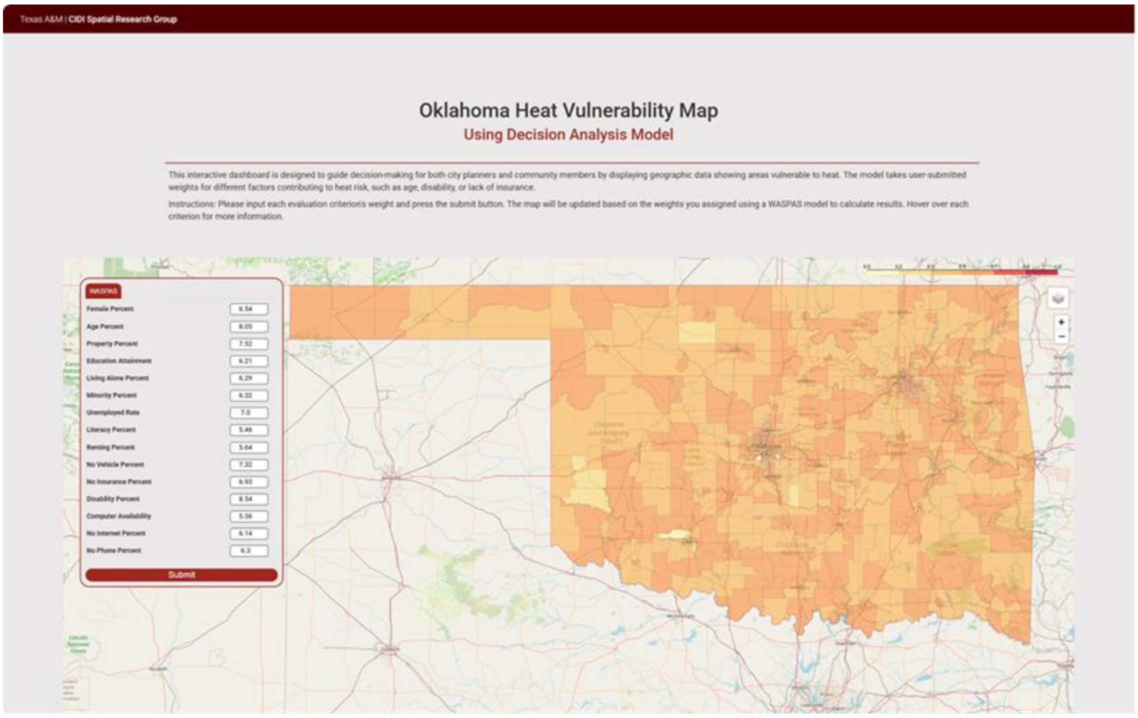

Figure 1: Prototype web interface for interactive heat susceptibility mapping. Users edit criterion weights in a left-side panel and update a tract-level choropleth map for scenario comparison.

Preliminary results illustrate why keeping stakeholders in the loop matters analytically. Under survey-derived default weights, priority areas concentrate where high thermal exposure co-occurs with health-sensitive populations and constrained coping options. When users shift weights toward access-related constraints—such as vehicle availability and insurance—priority areas migrate toward neighborhoods that may not be the most physically exposed but face stronger barriers to adaptation. These are not errors; they are the legitimate expression of different planning values. By rendering such shifts immediate and comparable, the SDSS transforms an implicit analyst choice into an explicit stakeholder deliberation.

Discussion and Conclusion

This work directly engages the conference theme by asking what the cartographer's role should be when automation can generate a susceptibility map in seconds. We argue for a threefold answer. First, the cartographer acts as an elicitor, designing structured processes that surface the community values that should drive criterion weighting. Second, the cartographer serves as a transparency architect, building interfaces that keep weight vectors, scenario assumptions, and model behavior visible so that maps can be read as arguments rather than facts (MacEachren et al., 2004). Third, the cartographer serves as a deliberation facilitator, using the SDSS not merely as a visualization tool but as a medium for structured disagreement, helping stakeholders articulate what they mean by "highest need" and evaluate whether the implied spatial prioritization aligns with local knowledge and feasible intervention.

More broadly, this prototype suggests one way geospatial automation can remain accountable to human expertise and explicit value judgments rather than presenting authoritative-looking outputs as purely technical results. The architecture demonstrated here—where stakeholder-elicited knowledge is encoded as machine-usable parameters, computationally propagated, and rendered cartographically legible—offers a template for keeping human expertise embedded in automated geospatial workflows rather than displaced by them.

Limitations remain. Data availability and modifiable areal unit effects can influence results, and correlated indicators can risk double-counting (Openshaw, 1984). Participatory weights from a pilot workshop may not be fully representative, and susceptibility rankings should not be treated as deterministic truth (Belton & Stewart, 2012). The system is best understood as decision-support and communication infrastructure: it structures multi-criteria reasoning, makes uncertainty in "what matters most" a participatory input rather than a hidden assumption, and complements contextual expertise rather than replacing it.

In sum, MCDA methods embedded in an interactive geovisual analytics environment can keep the cartographer meaningfully in the loop during urban heat resilience planning—transforming automation from a tool that obscures value choices into one that makes them visible, negotiable, and accountable.

Acknowledgements

Funding. This work was supported by the National Science Foundation under grants 2339174, 2526748, 2321069, and 2519476, and by NASA ROSES.

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