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Participatory Heat Mapping for Climate-Just City Planning

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Abstract

Extreme urban heat is simultaneously a climatic, spatial, public-health, and distributive-justice challenge. Conventional heat maps derived from satellite observations, weather stations, land-cover characteristics, or demographic indices can identify thermally exposed locations, but they may overlook street-level experiences of heat, unequal access to cooling resources, informal mobility patterns, outdoor occupational exposure, housing inadequacy, and locations that residents themselves regard as unsafe during hot periods.

This study develops a participatory heat-mapping framework for climate-just city planning by combining technical heat exposure, social vulnerability, adaptive-capacity deficits, resident-reported heat burden, and community-identified planning priorities. Because authenticated city-level environmental measurements and community-participation data were not supplied, the quantitative component is explicitly designed as a simulation-based methodological evaluation. A synthetic urban environment consisting of five planning zones and 500 neighborhood-level observations is constructed to demonstrate the proposed method. A Participatory Heat-Justice Priority Index is developed to distinguish areas that are merely thermally hot from areas where heat exposure intersects with social disadvantage and limited adaptive capacity.

Simulated analysis shows that community-informed prioritization materially changes the ranking of several neighborhoods. For example, an analytically moderate-temperature housing district becomes a high-priority intervention area after resident-reported indoor overheating, limited tree shade, restricted cooling access, and pedestrian exposure are incorporated. Conversely, the hottest commercial core receives a slightly lower justice-adjusted priority because adaptive resources and access to cooling are comparatively stronger.

The study argues that participatory heat mapping should complement rather than replace remote sensing and quantitative heat-vulnerability analysis. Its principal value lies in making experiential, procedural, and distributive dimensions of climate justice visible within spatial planning decisions.

The proposed framework provides a reproducible foundation for prioritizing tree canopy, shade infrastructure, cooling facilities, housing retrofits, pedestrian improvements, and locally appropriate heat-adaptation investments.

Keywords: participatory heat mapping, climate justice, urban heat, participatory GIS, heat vulnerability, environmental justice, urban planning, community engagement

1. Introduction

Extreme heat has become a significant concern for cities because the physical form of urban development can intensify thermal exposure while social and economic conditions determine whether residents possess adequate capacity to cope with that exposure. Impervious surfaces, limited vegetation, dense construction, anthropogenic heat, and restricted ventilation can create substantial temperature differences within the same metropolitan area. Yet temperature alone does not determine heat-related risk. Estoque and colleagues demonstrated through a multi-city heat-health assessment that hazard, exposure, sensitivity, and adaptive capacity interact in determining urban heat risk, and that places with the highest physical heat hazard are not necessarily identical to places with the greatest overall vulnerability. This distinction is fundamental for climate-just planning because an apparently moderate-temperature neighborhood may contain residents whose socioeconomic circumstances make even modest thermal exposure highly consequential.

Urban heat is also distributed through historical and contemporary patterns of urban development. Hoffman, Shandas, and Pendleton found substantial associations between historically discriminatory housing policies and present-day intra-urban heat exposure across numerous United States urban areas, illustrating that contemporary thermal landscapes can reflect past planning and investment decisions. Mitchell, Chakraborty, and Basu similarly demonstrated that heat exposure and access to greenspace can intersect with social vulnerability, reinforcing the climate-justice principle that environmental burdens and environmental benefits are not always distributed equally. Climate-responsive urban planning must therefore address not only where temperatures are highest but also which communities have historically received fewer protective investments and possess fewer resources for adaptation.

Spatial heat-vulnerability indices provide a valuable basis for identifying priority locations, but methodological choices can substantially influence the resulting geography of vulnerability. Conlon and colleagues showed that the construction of heat-vulnerability indices can be sensitive to variable selection and analytical specification, demonstrating why mapped rankings should not be interpreted as completely objective representations of lived vulnerability. Similarly, Azhar and colleagues demonstrated the usefulness of composite vulnerability mapping while emphasizing socioeconomic and infrastructural dimensions such as poverty, literacy, water access, sanitation, and household resources. These findings support the use of quantitative indices but also indicate that technically produced vulnerability maps require contextual interpretation.

Participatory mapping offers a mechanism for incorporating this contextual knowledge. Sullivan-Wiley, Short Gianotti, and Casellas Connors found that participatory mapping can reveal locally grounded understandings of vulnerability and management practices that are not readily represented in conventional spatial datasets, while also cautioning that participation should complement rather than independently replace other forms of assessment. Douglas and colleagues likewise demonstrated that

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participatory mapping can help communities identify place-based health challenges and assets that conventional aggregate data may fail to capture. Citizen-generated observations can also strengthen spatial climate information: Zumwald and colleagues showed that crowd-sensed temperature observations can support high-resolution urban temperature modeling when combined with appropriate analytical methods.

The present study integrates these strands by proposing Participatory Heat Mapping for Climate-Just City Planning. The central proposition is that technical heat exposure should be interpreted together with social vulnerability, adaptive-capacity constraints, resident-reported experiences, and community-defined priorities. The study introduces a Participatory Heat-Justice Priority Index designed to show how planning rankings may change when experiential evidence is incorporated into conventional spatial analysis. Because no authenticated city dataset or completed community-participation exercise was supplied, all numerical findings are explicitly synthetic. The objective is not to claim that participatory input invariably increases or decreases the priority of a particular neighborhood, but to provide a transparent framework through which city planners can combine scientific and situated knowledge while preserving traceability of each contribution to the final planning decision.

2. Objectives of the Study

2.1 Development of an Integrated Participatory Heat-Mapping Framework

The first objective is to develop a planning framework that combines physically measured heat with socially and experientially grounded dimensions of vulnerability. Conventional temperature maps remain indispensable because they provide systematic and spatially comparable information. However, the proposed framework treats such information as one component of the planning problem rather than its complete representation.

The framework therefore integrates remotely observed thermal exposure, demographic vulnerability, adaptive-capacity deficits, resident-reported experiences, and community-defined priority locations. The intention is to create a map that helps planners distinguish areas that are physically hot from areas in which heat exposure has particularly unjust consequences.

2.2 Construction of a Climate-Justice-Oriented Priority Measure

The second objective is to develop a reproducible index capable of translating multiple heat-justice dimensions into a transparent planning-priority measure. The index is designed to retain each component separately so that decision makers can determine why a neighborhood receives a high score.

This design avoids a common weakness of composite mapping in which the final number becomes more visible than the variables that created it.

2.3 Evaluation of the Planning Effect of Community Participation

The third objective is to examine whether community information changes intervention priorities generated through conventional technical heat-risk assessment. The analytical question is not whether residents should replace scientific measurement, but whether technical ranking changes when locally experienced conditions are added.

The simulation consequently compares an initial technical heat-risk score with a participatory justice-adjusted score. Particular attention is given to neighborhoods whose priorities rise substantially after information concerning indoor overheating, shade deficiency, outdoor waiting conditions, housing quality, mobility, or limited access to cooling facilities is incorporated.

3. Review of Literature

3.1 Urban Heat Vulnerability and Spatial Inequality

Heat vulnerability emerges from the interaction of environmental exposure and human conditions rather than temperature alone. Estoque and colleagues' assessment of urban heat-health risk combined remotely sensed temperatures with social-ecological indicators and demonstrated that sensitivity and adaptive capacity contribute materially to differences in risk between cities. Azhar and colleagues similarly incorporated demographic, socioeconomic, environmental, and household-resource indicators into heat-vulnerability mapping and demonstrated the usefulness of spatial indices for identifying locations requiring targeted intervention.

The environmental-justice literature adds a crucial distributive perspective. Hoffman, Shandas, and Pendleton showed that historically disadvantaged neighborhoods can experience systematically greater intra-urban heat exposure, illustrating how planning history may become physically embedded in contemporary thermal landscapes. Mitchell, Chakraborty, and Basu further connected urban heat with uneven access to greenspace and social vulnerability. Together, these studies demonstrate that climate-just heat planning must investigate both environmental burden and adaptive resources.

Heat indices nevertheless require careful interpretation. Conlon and colleagues' critical assessment of heat-vulnerability-index construction showed that methodological choices can affect spatial results. A vulnerability map should therefore be treated as an analytical representation created through particular assumptions, variable choices, geographic units, and weights. This provides a strong methodological rationale for complementary participatory validation.

3.2 Participatory GIS and Community Knowledge

Participatory GIS and community mapping attempt to redistribute part of the knowledge-production process by enabling residents to identify locations, experiences, environmental conditions, and community resources that may be absent from administrative databases. Sullivan-Wiley and colleagues showed that participatory community mapping can reveal socially mediated perceptions of vulnerability and local management practices, while stressing the importance of combining participatory evidence with additional forms of assessment.

Douglas and colleagues similarly described participatory mapping as a method capable of revealing place-based determinants of community health and translating those observations into policy-relevant interventions. Prado and collaborating community organizations demonstrated the relevance of Public Participation Geographic Information Systems to environmental-justice planning by using community-based spatial knowledge as a mechanism for participation in urban decision making. These studies indicate that the value of participatory mapping lies not only in collecting additional points on a map but also in changing whose knowledge is recognized within planning processes.

For heat adaptation, this distinction is important. Residents may identify overheated bus stops, unshaded walking routes, poorly ventilated housing, informal markets, outdoor workplaces, inaccessible parks, or cooling centers that are technically present but practically unusable. Many such conditions are difficult to infer reliably from satellite temperature or census indicators alone.

3.3 Citizen-Sensed Climate Information and Collaborative Planning

Technological developments have expanded opportunities for residents to contribute directly to environmental measurement. Zumwald and colleagues demonstrated that citizen weather stations can complement official measurements and support high-resolution urban-temperature modeling when quality control and uncertainty are handled appropriately. This is particularly useful because official weather networks often lack the spatial density required to capture block-level urban thermal variation.

Neset and colleagues examined co-design of a citizen-science climate service and found that participatory technologies can support knowledge co-production when municipal stakeholders and community users contribute to the design and interpretation of climate information. Their work also illustrates that participation requires flexibility and continuous negotiation rather than merely distributing a data-collection application to residents.

Fragomeni and colleagues demonstrated the importance of collaborative approaches connecting urban climatology with land-use planning, finding that heat-vulnerability mapping can assist decision makers in interpreting the relationship between thermal conditions and planning issues. The remaining methodological opportunity is to more explicitly integrate community-derived evidence into the final prioritization function. The present framework addresses this gap by retaining both technical and participatory dimensions within a justice-oriented planning score.

4. Research Methodology

4.1 Research Design and Synthetic Urban Environment

The study employs a quantitative simulation-based methodological design supplemented by a participatory-GIS conceptual framework. No authenticated thermal imagery, municipal census microdata, community workshop responses, wearable-sensor measurements, or city planning records were supplied. Consequently, no numerical finding should be interpreted as an observed result from an actual city.

A hypothetical metropolitan planning area is divided into five representative zones: North Ward, Riverside, Central Core, East Housing, and South Market. Five hundred synthetic neighborhood observations are generated across these zones. The simulated records contain standardized information representing heat exposure, social vulnerability, adaptive-capacity deficits, resident-reported heat burden, and community planning priorities.

Table 1: Variables Included in the Participatory Heat-Mapping Framework

Dimension	Representative Indicator	Proposed Data Source in a Real Study	Planning Relevance
Thermal exposure	Land-surface and near-surface temperature	Satellite imagery, fixed sensors, mobile measurements	Identifies physically hotter locations
Social vulnerability	Older residents, income constraints, housing insecurity	Census and administrative statistics	Identifies populations potentially more sensitive to heat
Adaptive-capacity deficit	Limited greenspace, cooling access, water, housing quality	GIS, municipal data, field assessment	Indicates reduced capacity to avoid or recover from heat
Resident-reported burden	Indoor overheating, uncomfortable routes, sleep disruption	Participatory survey or workshop	Captures lived heat impacts not visible in remote sensing
Community priority	Resident-designated intervention locations	Participatory GIS mapping	Identifies places considered locally urgent
Planning feasibility	Public land, streetscape opportunity, facility access	Municipal planning database	Supports translation from diagnosis to intervention

In an actual empirical implementation, community participation should deliberately include populations likely to be underrepresented in conventional planning meetings, including older adults, tenants, outdoor workers, caregivers, people with disabilities, residents of poorly insulated housing, street vendors, public-transport users, and communities with limited access to private cooling.

4.2 Participatory Data Collection and Spatial Integration

The proposed empirical procedure begins with a preliminary technical heat map. Satellite-derived land-surface temperature, vegetation indices, built-surface characteristics, demographic variables, and available cooling infrastructure would be standardized and combined to establish a baseline spatial risk profile.

Participatory mapping would subsequently be conducted through neighborhood workshops, mobile or paper mapping, and structured heat-experience surveys. Participants would mark locations associated with severe daytime heat, difficult nighttime conditions, unsafe walking routes, insufficient shade, inaccessible drinking water, problematic transit waiting areas, inadequate housing conditions, and locally valued cooling assets.

These observations would not automatically be treated as equivalent to calibrated temperature measurements. Instead, each evidence type would retain its methodological identity. Instrument-based temperature would describe physical conditions, while participatory evidence would describe experienced burden, exposure patterns, behavioral adaptations, and locally meaningful planning priorities.

This separation prevents false precision while still permitting spatial integration. It also allows disagreement between technical and community evidence to become analytically useful. A neighborhood appearing moderate on a satellite-derived map but repeatedly identified as highly problematic by residents would become a location for additional investigation rather than having one evidence source automatically invalidate the other.

4.3 Participatory Heat-Justice Priority Index

Physical heat exposure retains the largest single weight because the framework remains fundamentally concerned with thermal risk. However, 70% of the composite score reflects vulnerability, adaptation constraints, lived burden, and local planning knowledge. This weighting structure is illustrative rather than universally prescriptive.

A real implementation should conduct sensitivity analysis using alternative weight sets and publish the resulting ranking changes. Community participants should also be informed that weighting involves normative planning judgments rather than purely mathematical facts.

5. Analysis

5.1 Technical Heat Risk Before Participatory Adjustment

The initial simulation uses a technical heat-risk score derived primarily from physical exposure and conventional vulnerability indicators. Central Core records the highest baseline priority score of 81 because of dense built surfaces, low midday shade, high imperviousness, and elevated modeled temperatures. North Ward follows with 72, while Riverside records 66.

East Housing initially receives the lowest technical score of 59. Its modeled outdoor surface temperature is lower than that of the commercial core, and moderate vegetation within parts of the zone reduces its conventional heat-hazard classification. South Market receives a score of 63.

A planning process terminating at this stage would direct the first investments toward Central Core. Such prioritization would be defensible from a thermal-hazard perspective, but it would provide an incomplete account of distributive vulnerability.

5.2 Justice-Adjusted Prioritization After Community Input

Participatory evidence materially alters the synthetic ranking. Residents of North Ward report prolonged heat exposure along public-transport routes, limited household cooling, insufficient street trees, and several locations where older residents experience difficulty reaching cooling facilities. Its priority score consequently increases from 72 to 88.

Riverside rises from 66 to 82 because residents identify nighttime heat retention in low-quality housing, limited accessible greenspace despite apparent proximity to the river corridor, and inadequate shaded pedestrian connections. East Housing shows the largest relative increase, from 59 to 79.

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Community evidence reveals severe indoor overheating, limited private air-conditioning, poor building ventilation, and high exposure among residents spending substantial time at home.

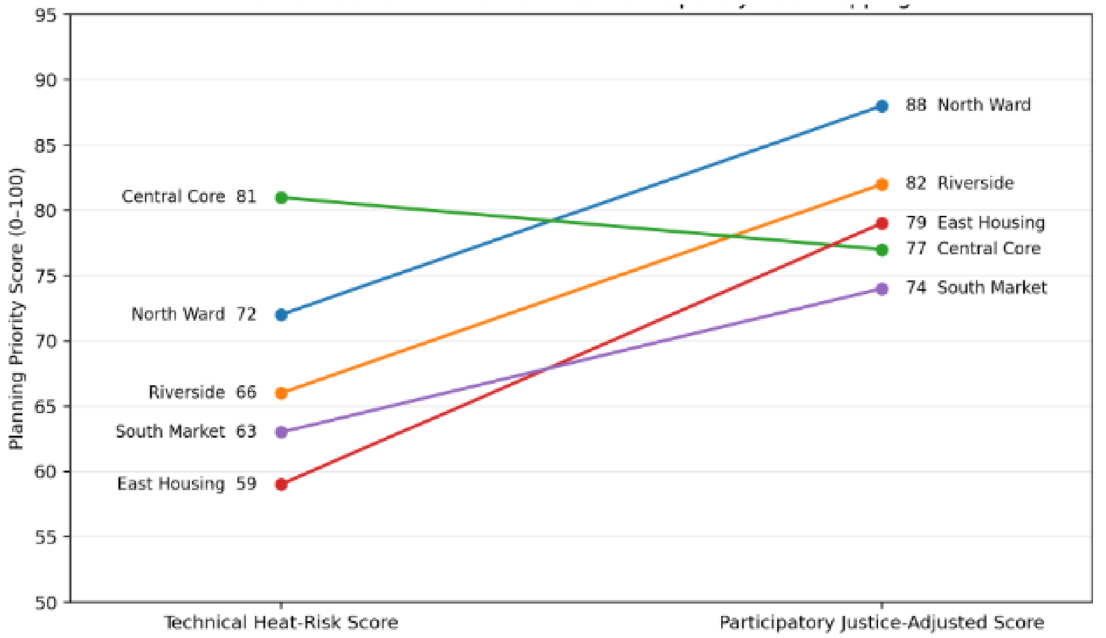
Table 2: Simulated Re-Prioritization Through Participatory Heat Mapping

Planning Zone	Technical Heat-Risk Score	Resident Heat-Burden Score	Adaptive-Capacity Deficit	Participatory Justice-Adjusted Score	Priority Change
North Ward	72	91	87	88	+16
Riverside	66	85	81	82	+16
Central Core	81	69	54	77	−4
East Housing	59	92	90	79	+20
South Market	63	77	72	74	+11

The table demonstrates why climate justice cannot be reduced to selecting the highest-temperature polygon. East Housing would have received comparatively low priority under the technical assessment yet becomes the third-highest priority once the lived consequences of heat and unequal adaptive resources are included.

5.3 Spatial Re-Prioritization and Planning Significance

Graph 1: Simulated Re-Prioritization After Participatory Heat Mapping



The downward adjustment of Central Core should not be interpreted as evidence that high-temperature areas require no intervention. Instead, climate-justice prioritization asks an additional question: where does a similar or even moderately lower heat burden create greater harm because people have fewer resources and fewer realistic options for avoiding it?

The revised ranking would therefore support a differentiated intervention program. Central Core could remain appropriate for urban-greening and heat-island mitigation, while East Housing may require housing retrofits and indoor-heat protection. North Ward may require shaded transport routes and cooling access, whereas Riverside may require neighborhood cooling facilities and pedestrian improvements.

6. Discussion

6.1 From Hot-Spot Mapping to Heat-Justice Mapping

The first major implication is that identifying urban thermal hot spots and identifying climate-justice priorities are related but different analytical tasks. Remote sensing can reveal spatial patterns in land-surface temperature with considerable geographic coverage, while sensor networks can provide detailed temporal measurements. These capabilities are indispensable for urban climate analysis. Estoque and colleagues demonstrate the usefulness of integrating remotely sensed thermal conditions with social-ecological indicators, while Zumwald and colleagues show how crowd-sensed environmental observations can increase spatial resolution.

Climate justice requires an additional layer because the consequences of the same temperature differ across people and places. A resident working outdoors, an older adult living alone, a child in a poorly ventilated dwelling, and an office worker with reliable air-conditioning may experience the same neighborhood temperature very differently. Differences in housing quality, mobility, employment, health, income, vegetation, and access to cooling therefore mediate exposure.

The simulated re-ranking illustrates this distinction. Central Core remains thermally problematic but possesses stronger adaptive infrastructure. East Housing appears less severe through remote environmental indicators yet becomes substantially more urgent when indoor exposure and adaptive disadvantage are considered. This is precisely the kind of discrepancy participatory planning should investigate.

6.2 Participation as Knowledge Production Rather Than Consultation

The second implication concerns the meaning of participation. If residents are invited only after technical priorities have already been established, participation can become a mechanism for communicating decisions rather than influencing them. Participatory heat mapping has stronger methodological value when community observations enter the analytical process before intervention priorities are finalized.

Sullivan-Wiley and colleagues emphasize that participatory mapping can reveal locally grounded understandings unavailable through conventional assessment, while also cautioning against treating it as a complete standalone method. Douglas and colleagues similarly demonstrate its capacity to identify environmental and health conditions from the perspective of affected communities. These findings support a co-production model in which scientific and experiential evidence remain distinguishable but interact.

This approach also addresses recognitional justice. Communities do not merely provide additional observations; they identify which experiences and spaces matter. A satellite cannot determine that an unshaded bus stop is disproportionately used by older adults after medical appointments, that a public park feels inaccessible during evening hours, or that tenants cannot modify overheated rental housing. Such information becomes visible only when planning recognizes residents as legitimate producers of knowledge.

Procedural safeguards remain necessary. Participatory mapping can reproduce inequalities if meetings are dominated by residents with greater time, confidence, digital access, or political influence. Recruitment, language accessibility, compensation where appropriate, accessible meeting formats, and transparent documentation of disagreement should therefore be incorporated into the study design.

6.3 Translating Participatory Maps Into Climate-Just Investment

The third implication concerns planning implementation. A participatory heat map has limited value if it only produces a visually compelling representation without changing capital allocation, land-use decisions, housing policy, or public-service provision. The PHJPI is therefore designed as a prioritization instrument rather than an endpoint.

Different risk combinations require different interventions. High outdoor heat with insufficient vegetation may justify trees, reflective materials, shade structures, or redesigned public space. High resident burden associated with poor housing may require building retrofits, ventilation standards, tenant protections, or targeted energy assistance. Transport-related exposure may require shade at stops, improved walking routes, drinking-water access, or service modifications during severe heat.

Collaborative heat-response research has shown the importance of connecting climate information with land-use planning rather than producing environmental data independently of planning practice. Citizen-science climate-service research similarly indicates that co-designed information can serve as an interface between community observations and municipal decision making when the process remains inclusive and responsive.

Climate-just planning should additionally track where adaptation investment occurs after priorities are identified. A city could possess an excellent vulnerability map yet continue directing resources toward politically visible or economically valuable districts. Justice-oriented evaluation should therefore compare spatial risk, community priorities, intervention commitments, implementation expenditure, and subsequent changes in exposure.

7. Conclusion

Participatory heat mapping provides an opportunity to strengthen urban climate planning by integrating the spatial precision of technical environmental analysis with the experiential specificity of community knowledge. The central argument of this study is not that scientific heat maps are inadequate or should be replaced. Rather, heat exposure becomes a climate-justice issue when its physical distribution intersects with unequal sensitivity, housing conditions, mobility, social disadvantage, historical investment patterns, and access to protective resources. A planning system concerned only with maximum temperature can therefore misidentify which communities require the most urgent intervention.

The proposed Participatory Heat-Justice Priority Index integrates physical heat exposure, social vulnerability, adaptive-capacity deficits, resident-reported heat burden, and community-defined priorities. In the synthetic analysis, inclusion of participatory evidence substantially changes neighborhood rankings. East Housing provides the strongest example: it rises from a relatively low technical priority to a high justice-adjusted priority because community evidence identifies severe indoor overheating and limited capacity to adapt. North Ward and Riverside experience similar upward re-prioritization, whereas the highly exposed Central Core remains important but becomes comparatively less urgent after stronger adaptive resources are recognized.

These simulated results should not be interpreted as empirical evidence that participation will always produce similar ranking changes. The effect of participation depends on local geography, recruitment quality, data integration, weighting decisions, participant representation, and the specific experiences captured. Participatory evidence also contains uncertainty, perception differences, and possible sampling bias. For these reasons, community mapping should be triangulated with sensor measurements, remote sensing, health information, demographic statistics, field observations, and municipal infrastructure data. Transparency regarding weighting and disagreement is essential if the resulting map is to support defensible planning.

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