

## The role of GIS and spatial analysis in enhancing urban resilience and disaster response for vulnerable U.S. Communities

Stella Agyeiwaah Adu <sup>1</sup>, Phyllis Ang-E-Mwin Gyang <sup>2</sup> and Zakaria Yakin <sup>3,\*</sup>

<sup>1</sup> Department of City and Regional Planning, University of Memphis, Memphis Tennessee, USA.

<sup>2</sup> Michigan State University, East Lansing, MI, USA.

<sup>3</sup> Department of Geophysical Engineering, Kwame Nkrumah University of Science and Technology, Ghana.

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### Abstract

Urban communities in the United States are increasingly threatened by the intersecting impacts of climate change, socio-economic disparities, and aging infrastructure, resulting in heightened risks from both natural and human-induced disasters, particularly for historically marginalized and underserved populations. This review critically examines the evolving role of Geographic Information Systems (GIS) and spatial analysis in enhancing urban resilience and improving disaster response. Drawing on current literature, case studies, and emerging applications, the paper explores how spatial technologies are utilized in key areas such as hazard mapping, risk assessment, social vulnerability analysis, evacuation planning, early warning systems, and post-disaster recovery. GIS facilitates the integration of spatial data, demographic information, and real-time analytics to help decision-makers identify high-risk areas, optimize resource allocation, and support timely and effective emergency responses. Case studies from cities like New Orleans, Miami, and wildfire-prone regions of California demonstrate how GIS-enabled interventions improve situational awareness and promote equitable, data-driven resilience strategies. However, significant challenges remain, including unequal access to GIS infrastructure, limited community participation, technological disparities, and ethical concerns surrounding data use. The review identifies promising opportunities through emerging technologies such as artificial intelligence, machine learning, the Internet of Things (IoT), and participatory GIS to build more inclusive, adaptive, and equitable disaster management systems. The study concludes with policy recommendations calling for greater investment in GIS infrastructure, capacity-building at the local level, interdisciplinary collaboration, and the integration of community perspectives to ensure that spatial tools effectively protect and empower vulnerable U.S. communities in the face of escalating disaster risks.

**Keywords:** Urban Resilience; Hazard Mapping; Emergency Planning; Climate Adaptation

### 1. Introduction

Urban communities across the United States are facing mounting vulnerabilities to disasters driven by the compounding impacts of climate change, socio-economic disparities, and rapid urbanization. The intensification of extreme weather events, including hurricanes, floods, wildfires, and heat waves, is placing unprecedented pressure on urban infrastructure, social systems, and public health. According to Cutter et al. [1], urban populations are especially susceptible to cascading and compound hazards due to the density of built environments, critical services, and populations concentrated in hazard-prone areas. Moreover, the 2023 National Climate Assessment emphasizes that climate risks are not evenly distributed. Low-income groups, communities of color, elderly populations, and other historically marginalized groups are disproportionately affected by disasters, facing higher exposure, limited access to resources, and prolonged recovery times [2].

\* Corresponding author: Zakaria Yakin

These vulnerabilities are further compounded by systemic inequities embedded in urban development patterns, such as substandard housing, inadequate transportation systems, and restricted access to emergency services [3]. The failure to address these underlying inequalities not only undermines the adaptive capacity of urban communities but also exacerbates the human and economic costs of disasters, making urban resilience a critical priority for planners, policymakers, and emergency managers alike. Urban resilience, as defined by Meerow et al. [4], refers to the capacity of urban systems to withstand, absorb, and recover from shocks and stresses while maintaining essential functions, safeguarding human lives, and fostering equity. Building such resilience requires the integration of proactive risk reduction, equitable planning, and adaptive governance mechanisms that account for the spatial, social, and infrastructural dimensions of vulnerability.

Geographic Information Systems (GIS) and spatial analysis have emerged as indispensable tools for supporting data-driven, evidence-based approaches to enhancing urban resilience and disaster response. GIS provides the technological infrastructure for collecting, managing, analyzing, and visualizing spatial data across multiple scales, enabling a more nuanced understanding of how hazards, vulnerabilities, and capacities are distributed within and across urban landscapes [5]. Spatial analysis techniques, including hotspot analysis, network analysis, geostatistical modeling, and scenario simulation, allow decision-makers to identify high-risk areas, assess population exposure, optimize evacuation routes, allocate emergency resources efficiently, and monitor evolving disaster situations in real-time [6]. Furthermore, the integration of GIS with emerging technologies such as remote sensing, Internet of Things (IoT) sensors, artificial intelligence (AI), and machine learning is significantly enhancing the potential for predictive analytics, early warning systems, and intelligent decision support in complex urban environments [7]. However, while GIS offers powerful capabilities to inform disaster risk reduction and resilience-building strategies, several critical challenges remain. Disparities in data accessibility, technological infrastructure, and technical capacity at the local level can limit the effective use of GIS tools, particularly in under-resourced and vulnerable communities. Additionally, the lack of integration of community knowledge, participatory approaches, and equity-centered frameworks in spatial analysis can perpetuate existing social and environmental injustices [8]. Addressing these challenges requires a paradigm shift toward more inclusive, interdisciplinary, and community-driven applications of GIS and spatial analysis that prioritize the needs and voices of the most vulnerable populations.

This review critically examines the evolving role of GIS and spatial analysis in enhancing urban resilience and disaster response for vulnerable U.S. communities. By synthesizing current literature, applications, and emerging trends, the paper seeks to provide insights into how GIS can be leveraged to promote more equitable, adaptive, and data-driven disaster management practices that protect and empower at-risk populations across urban America.

## 2. Literature Review

### 2.1. Urban Resilience and Disaster Response: Concepts and Challenges

Urban resilience refers to the capacity of cities and their communities to withstand, adapt to, and recover from a wide array of hazards while maintaining core functions, safeguarding human life, and promoting equity [4]. It encompasses physical, social, economic, and institutional dimensions that enable urban systems to absorb shocks such as hurricanes, wildfires, and floods and to transform in ways that reduce future vulnerabilities. Importantly, resilience is not only about "bouncing back" from disasters but also about "bouncing forward" through proactive adaptation and equitable planning [8].

Vulnerable urban communities in the U.S. face a complex intersection of challenges that significantly undermine their resilience. These include environmental injustices—where marginalized populations are disproportionately exposed to hazards like industrial pollution and flood-prone zones, and socio-economic disparities that restrict access to emergency services, healthcare, and recovery assistance [3]. Additionally, many low-income neighborhoods are situated in aging infrastructure zones, where outdated stormwater systems, deteriorating housing, and limited transportation options exacerbate disaster risks. The compounded nature of these stressors means that disasters often have more devastating and prolonged effects on historically underserved populations, such as Black, Latino, Indigenous, and elderly residents [1].

Data-driven decision-making is essential to enhancing urban disaster preparedness, response, and recovery. Geographic Information Systems (GIS), spatial analysis, and real-time data streams play a transformative role in identifying risk hotspots, mapping vulnerable populations, optimizing evacuation strategies, and monitoring recovery progress [5]. By integrating social vulnerability indices with hazard mapping, emergency managers can better allocate resources and prioritize high-need areas. Furthermore, predictive models powered by machine learning and remote

sensing allow for early warning systems that significantly improve situational awareness and response efficiency [7]. However, to ensure equity in disaster planning, it is critical that these tools be used not only for efficiency but also to amplify the voices and needs of vulnerable populations through participatory approaches. Building urban resilience in vulnerable U.S. communities requires more than infrastructure upgrades; it demands inclusive, data-informed, and justice-centered approaches that address deep-rooted structural inequalities. GIS and spatial analysis are central to this mission, offering the tools needed to understand, plan for, and respond to disasters in ways that protect all segments of society, especially the most at-risk

## 2.2. GIS and Spatial Analysis: Tools, Techniques, and Capabilities

Geographic Information Systems (GIS) have evolved into powerful platforms that support data-driven decision-making in urban planning, disaster management, and resilience-building. At their core, GIS technologies facilitate the capture, storage, analysis, and visualization of spatial data to reveal patterns, relationships, and trends across geographical areas [8]. Modern GIS solutions span a range of platforms such as desktop-based applications like ArcGIS Pro and QGIS, cloud-based services such as ArcGIS Online and Google Earth Engine, mobile GIS tools for field data collection (e.g., Collector for ArcGIS, Survey123), and web-based dashboards for real-time monitoring (e.g., FEMA's GIS Hub or Esri's Operations Dashboard). These platforms enable multi-scale, multi-temporal analysis that is critical for disaster preparedness, emergency response coordination, and long-term urban resilience planning [9].

A range of spatial analysis techniques underpin GIS applications in disaster response. Hotspot analysis is commonly used to identify spatial concentrations of hazards (e.g., flood-prone zones, heat islands, or COVID-19 clusters) and prioritize interventions [10]. Network analysis supports the optimization of evacuation routes, identification of service accessibility gaps, and allocation of emergency facilities such as shelters or distribution centers [11]. Meanwhile, spatial interpolation techniques like kriging or inverse distance weighting (IDW) enable the prediction of hazard exposure (e.g., pollutant concentration, rainfall distribution) in unsampled locations, which is essential for proactive risk assessment in data-scarce urban areas. These methods collectively enhance situational awareness and operational efficiency for emergency managers and urban planners.

The integration of emerging technologies has significantly expanded GIS capabilities, driving a shift toward intelligent and real-time spatial decision support. Advances in Internet of Things (IoT) and remote sensing now allow for continuous monitoring of urban systems, feeding live data into GIS platforms to detect structural stress, rising water levels, or wildfire spread in real time [7]. Machine learning algorithms, including decision trees, convolutional neural networks (CNNs), and random forests, are increasingly applied within GIS to predict disaster impacts, classify damage, or model recovery trajectories based on complex historical datasets [12]. Additionally, big data analytics enables the processing of high-velocity, high-volume geospatial data from satellite imagery and social media feeds to crowdsourced observations, enhancing the timeliness and granularity of disaster response strategies [6]. As these technologies become more accessible, there is an urgent need to ensure that their implementation is inclusive and equity-centered. For vulnerable communities that have historically been underrepresented in urban planning, GIS offers both a diagnostic and empowering function, helping to map needs, monitor risks, and advocate for resources. Therefore, GIS and spatial analysis are not only technical assets but also strategic tools for achieving more adaptive, just, and resilient urban futures

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## 3. Applications of GIS in Enhancing Urban Resilience and Disaster Response

### 3.1. Risk Assessment and Hazard Mapping

Risk assessment and hazard mapping are foundational elements in disaster resilience planning, enabling urban decision-makers to identify, quantify, and mitigate the impacts of natural hazards on communities and infrastructure. With the growing frequency and intensity of climate-related events, GIS-based flood risk modeling has become increasingly vital for local and regional planning. These models combine digital elevation models (DEMs), hydrological simulations, rainfall data, and land use maps to delineate flood-prone zones and predict the spatial extent and severity of potential flooding scenarios [13]. For example, in cities like Houston, Texas, GIS flood maps have been instrumental in guiding infrastructure upgrades, zoning decisions, and emergency response strategies following major flood events like Hurricane Harvey. Similarly, climate vulnerability assessments integrate multiple hazard exposures such as extreme heat, sea-level rise, and storm surge with community-level data to assess which areas are most at risk under different climate futures. These assessments often use spatial multi-criteria analysis (SMCA) to prioritize interventions and identify climate adaptation needs [14].

GIS also plays a central role in earthquake and wildfire risk zoning. In earthquake-prone regions like California, seismic hazard maps generated through GIS integrate geological fault lines, soil liquefaction potential, and building density to inform retrofitting policies and building code enforcement [15]. For wildfires, spatial models utilize historical burn data, vegetation cover, wind patterns, and topographic features to generate wildfire susceptibility maps, helping to direct mitigation efforts, such as fuel reduction and buffer zone planning, especially in the expanding wildland-urban interface [16]. These hazard maps are not only essential for preparedness but are increasingly used for insurance planning, public awareness campaigns, and resource prioritization.

### 3.2. Social Vulnerability Mapping

While hazard mapping identifies where physical risks exist, social vulnerability mapping helps determine who is most at risk and why. Vulnerability is shaped not only by physical exposure but also by socio-economic conditions, infrastructure quality, access to healthcare, and the ability to recover after disaster events. The Centers for Disease Control and Prevention's Social Vulnerability Index (SVI) and FEMA's National Risk Index are widely used tools that quantify and map vulnerability based on indicators such as income, age, race/ethnicity, housing status, disability, and access to transportation [17, 18]. These indices are critical for identifying priority areas for emergency preparedness and equitable resource distribution.

The integration of demographic, infrastructure, and environmental data into GIS platforms enables a holistic view of vulnerability. For instance, combining high-resolution demographic layers with hospital locations, public transportation nodes, and utility infrastructure reveals gaps in service accessibility and evacuation planning, particularly for elderly or mobility-impaired populations [19]. In cities like New Orleans and Miami, such integrated vulnerability maps have been used to target cooling centers during heat waves and deploy mobile clinics in post-disaster scenarios. Recent advances in participatory GIS and machine learning are further refining vulnerability mapping by incorporating community-generated data, housing quality metrics, and real-time sensor inputs. However, scholars caution that these models must avoid data biases and ensure transparency, especially when influencing decisions that affect marginalized communities [8]. Therefore, social vulnerability mapping, when combined with hazard assessments, provides a powerful, equity-centered framework for proactive disaster planning and climate adaptation.

### 3.3. Emergency Response and Recovery Optimization through GIS and Spatial Analysis

Geographic Information Systems (GIS) and spatial analysis play an increasingly central role in enhancing emergency response and recovery efforts, particularly for vulnerable urban communities across the United States. These tools support comprehensive disaster preparedness by improving evacuation planning, optimizing resource allocation, enabling real-time monitoring, and facilitating post-disaster recovery, all of which are essential to building urban resilience in the face of escalating climate risks.

One of the most impactful applications of GIS in disaster preparedness is the optimization of evacuation routes and the strategic siting of emergency shelters. By integrating topographic data, population density, and transportation networks, GIS enables emergency managers to design evacuation plans that minimize congestion and exposure to hazard zones. For example, Sinha, Samadder, and Kumar [20] demonstrated how GIS-based multi-criteria decision-making can improve evacuation planning in flood-prone urban areas by incorporating variables such as road accessibility and elevation. Similarly, location-allocation models are employed to identify optimal locations for emergency shelters, ensuring equitable access to life-saving services, especially for marginalized populations [21].

In the realm of real-time emergency management, GIS systems combined with Internet of Things (IoT) devices, UAVs (Unmanned Aerial Vehicles), and remote sensing offer critical situational awareness. These technologies provide dynamic updates on weather conditions, fire perimeters, and flood levels, which can be displayed on dashboards used by emergency operations centers to make rapid, data-driven decisions. According to a previous study [22], such integrated systems played a vital role in wildfire responses across California by helping responders visualize risk zones and deploy resources more efficiently. UAVs and remote sensing tools offer on-demand aerial imagery that enhances response capabilities, particularly in scenarios where ground access is limited. For instance, following Hurricane Maria, UAVs enabled rapid terrain assessments in remote regions of Puerto Rico, significantly accelerating response times [23].

GIS also plays a crucial role in post-disaster damage assessment and recovery planning. High-resolution satellite and UAV imagery support rapid assessment of structural damage, infrastructure disruption, and environmental degradation, allowing emergency managers to prioritize response and allocate resources effectively. Jiang and Wang [24] highlight how combining remote sensing with GIS analysis supports more equitable recovery strategies by linking damage data to socioeconomic vulnerability indices. This ensures that aid reaches the most affected and underserved

communities first, reinforcing the principle of environmental justice in disaster recovery. Collectively, these applications of GIS, ranging from pre-disaster planning to post-disaster recovery, are critical for strengthening community resilience and safeguarding at-risk populations. As natural disasters become more frequent and intense due to climate change, the integration of spatial technologies into emergency management frameworks offers a scalable and evidence-based approach to mitigating human and economic losses. Continued investment in GIS infrastructure, training, and cross-agency collaboration will be pivotal in enhancing the United States' capacity to respond to emergencies effectively and equitably.

**Table 1** Key GIS Applications in Enhancing Urban Resilience and Disaster Response for Vulnerable U.S. Communities

| GIS Application                                | Purpose   | Example Use Case   | Impact on Vulnerable Communities  |
|--|---|--|---|
| Hazard Mapping and Risk Zoning                 | Identify high-risk zones for floods, wildfires, earthquakes, etc.           | FEMA flood risk maps used by local planners in Houston, TX                         | Enables risk-informed land use, zoning, and insurance planning                  |
| Social Vulnerability Mapping (SVI)             | Overlay socio-demographic data with hazard layers to identify at-risk areas | CDC's Social Vulnerability Index applied in New Orleans, LA                        | Prioritizes disaster aid and resource deployment to underserved neighborhoods   |
| Evacuation Route Optimization                  | Plan and simulate optimal escape paths for emergencies                      | GIS-based hurricane evacuation planning in Miami-Dade County, FL                   | Reduces response time and enhances safety for communities with limited mobility |
| Shelter and Resource Allocation Mapping        | Site emergency shelters, aid distribution points, and critical assets       | Red Cross shelter locator GIS maps in California wildfire zones                    | Ensures access to critical services during disasters                            |
| Real-Time Monitoring and Situational Awareness | Integrate live data from sensors, drones, or social media into maps         | Smart city dashboards in San Francisco for fire and power outage monitoring        | Improves emergency response and communication with vulnerable populations       |
| Damage Assessment and Post-Disaster Recovery   | Analyze satellite/UAV images for infrastructure and housing damage          | GIS-supported FEMA disaster declarations after Hurricane Ida                       | Speeds up recovery funding and prioritizes rebuilding in hard-hit communities   |
| Climate Adaptation and Resilience Planning     | Model long-term urban stressors (e.g., sea-level rise, heat islands)        | GIS used by NYC Resilience Office to map climate risk zones and heat vulnerability | Supports equitable adaptation planning for low-income and elderly populations   |
| Participatory GIS (PPGIS)                      | Involve local communities in mapping risks and resources                    | Community-led mapping of flooding hotspots in Detroit, MI                          | Builds local ownership and ensures inclusion of community knowledge in planning |

#### 4. Case Studies in the U.S. Context

Geographic Information Systems (GIS) and spatial analysis have been instrumental in shaping urban resilience strategies and enhancing disaster response across vulnerable communities in the United States. Several landmark case studies highlight the practical effectiveness of GIS tools in post-disaster recovery, risk mitigation, and long-term adaptation planning. These examples offer valuable lessons for local governments and emergency planners seeking to strengthen urban infrastructure and protect at-risk populations.

One of the most extensively studied cases is the city of New Orleans following Hurricane Katrina in 2005. The catastrophic flooding exposed severe deficiencies in urban planning and emergency preparedness, particularly for low-income and minority communities. In the aftermath, the city adopted GIS-based flood mapping and infrastructure vulnerability assessments as part of its resilience planning. Researchers found that these spatial tools played a critical

role in identifying vulnerable neighborhoods, planning levee upgrades, and optimizing the location of relief centers [25; 8]. Notably, the Louisiana Office of Community Development developed the LA SAFE (Louisiana's Strategic Adaptations for Future Environments) framework, which leverages GIS to integrate community input with flood risk data, providing a model for equitable and data-driven urban planning [26].

In California, where wildfires are an annual and escalating threat due to climate change, GIS technologies have transformed risk mitigation and real-time response efforts. Agencies such as Cal Fire and the U.S. Forest Service utilize high-resolution satellite imagery, fire behavior models, and real-time weather data to map fire perimeters, forecast spread, and prioritize evacuation zones. During the 2018 Camp Fire, GIS dashboards enabled emergency managers to communicate changing fire conditions to the public and allocate firefighting resources more effectively [27]. Furthermore, predictive models powered by GIS data have been increasingly used to inform land-use policies that reduce fire vulnerability in the wildland-urban interface.

Another forward-thinking initiative is unfolding in Miami, Florida, where GIS and spatial modeling are central to the city's sea-level rise adaptation strategy. With rising sea levels threatening billions in coastal infrastructure, the city of Miami and Miami-Dade County have adopted GIS-based vulnerability assessments to guide infrastructure investments, zoning changes, and climate adaptation projects. The "Resilient305" initiative uses GIS to identify flood-prone zones, plan green infrastructure, and prioritize drainage upgrades in underserved neighborhoods [28]. Studies have shown that these GIS-informed interventions have improved both community awareness and institutional capacity to manage long-term environmental risks [29].

From these case studies, several key best practices emerge. First, integrating local knowledge and community engagement with GIS data ensures that resilience efforts address both technical and social vulnerabilities. Second, the use of real-time GIS platforms, especially in California's wildfire response, demonstrates the value of dynamic data for rapid decision-making. Third, the success of initiatives like LA SAFE and Resilient305 underscores the importance of embedding GIS into long-term urban planning and funding structures. Finally, these examples illustrate that GIS is not just a mapping tool but a framework for evidence-based policymaking, especially vital for protecting the most vulnerable urban populations from the growing impacts of climate change and natural disasters.

#### **4.1. Challenges and Gaps in Current GIS Applications for Vulnerable U.S. Communities**

Despite the transformative role of Geographic Information Systems (GIS) and spatial analysis in enhancing urban resilience and disaster response, significant challenges and gaps persist in their application, especially for vulnerable U.S. communities. These limitations span technical, institutional, social, and ethical dimensions, potentially hindering the equitable and effective use of geospatial tools in emergency planning and climate adaptation.

One of the most pressing challenges is data availability and quality. Reliable, high-resolution spatial data is essential for accurate risk assessment, emergency response, and resilience planning. However, many local governments and community-based organizations lack access to up-to-date or disaggregated datasets that reflect dynamic socio-environmental risks [30]. In many cases, publicly available data are either outdated, too coarse in resolution, or inconsistently maintained, limiting their utility for community-scale interventions. These gaps are particularly pronounced in underserved areas where mapping infrastructure is historically underdeveloped. For example, remote sensing data may fail to capture informal housing or transient populations, thereby excluding them from preparedness plans [31].

Beyond data constraints, there are technological, institutional, and capacity barriers that inhibit the widespread adoption of GIS in disaster response. Many local jurisdictions lack the funding or technical expertise needed to deploy sophisticated GIS platforms or conduct spatial analysis in-house. As a result, they may rely on state or federal agencies, which can delay localized decision-making during fast-evolving emergencies. Additionally, the fragmentation of data ownership and inconsistent standards across jurisdictions make interagency collaboration difficult, as observed during multi-county responses to wildfires and hurricanes [31]. A related concern is the limited capacity of smaller municipalities to maintain GIS talent or infrastructure, which further exacerbates urban-rural resilience divides.

Integrating community knowledge through participatory GIS (PGIS) remains another critical gap. While PGIS offers the potential to incorporate local experiences and insights into spatial decision-making, it is still underutilized in the U.S. context. Vulnerable populations such as low-income residents, immigrants, and racial minorities are often excluded from spatial planning processes due to linguistic, technological, or cultural barriers [32]. Without structured efforts to include these communities, spatial planning may overlook lived realities, leading to top-down interventions that fail to

address localized risks effectively. Moreover, lack of trust between marginalized communities and planning institutions can hinder participatory initiatives unless mitigated by inclusive governance frameworks.

Finally, ethical and equity considerations in spatial data use deserve more attention. As GIS technology becomes more advanced and integrated with machine learning, remote sensing, and IoT, there is an increasing risk of algorithmic bias and data misuse. For instance, predictive policing and surveillance applications of GIS have been criticized for perpetuating structural inequalities by disproportionately targeting communities of color [33]. Even in disaster contexts, spatial models that prioritize property value over human vulnerability can reinforce inequitable recovery efforts, directing resources to affluent areas at the expense of marginalized ones [34]. Ensuring transparency, accountability, and ethical use of spatial data is therefore essential to prevent GIS from unintentionally reinforcing the disparities it seeks to resolve. In sum, while GIS and spatial analysis offer powerful tools for advancing urban resilience, realizing their full potential for vulnerable communities requires addressing systemic challenges in data quality, institutional capacity, public participation, and ethical governance. Future research and policy should prioritize building inclusive GIS infrastructures that support community-led planning and equitable disaster response.

#### 4.2. Opportunities, Innovations, and Future Research Directions

Emerging technologies are transforming the landscape of GIS and spatial analysis, offering new opportunities to enhance urban resilience and disaster response for vulnerable U.S. communities. The integration of artificial intelligence (AI), machine learning (ML), and deep learning is among the most promising innovations, providing powerful tools for predictive analytics, pattern recognition, and real-time decision-making. AI-enabled GIS systems can now forecast flood risks, wildfire propagation, and infrastructure vulnerability with remarkable accuracy, supporting faster and more informed responses to disasters. For instance, convolutional neural networks have been successfully applied to classify satellite imagery and detect disaster-related features such as landslides and inundation zones [35], enabling early warnings and more targeted evacuation strategies.

Additionally, citizen science and crowdsourced data present valuable, underutilized assets for enhancing spatial situational awareness. Mobile applications, social media, and participatory mapping platforms allow residents to report hazards, infrastructure damage, or resource needs in real time. This bottom-up data flow not only improves spatial resolution but also promotes civic engagement and local ownership of resilience planning [36]. Integrating crowdsourced inputs with official GIS databases can help fill data gaps in underserved areas, where formal infrastructure assessments may be infrequent or outdated. The advent of smart city technologies and resilience dashboards also holds significant potential. Sensors embedded in public infrastructure, along with Internet of Things (IoT) devices, generate vast streams of spatial and environmental data that can feed into live dashboards for emergency managers. These systems can track air quality, flood levels, power outages, and population movements, enhancing both preparedness and recovery operations [39]. Smart dashboards can help decision-makers visualize complex data in real time, prioritize response actions, and allocate resources effectively, especially in dense urban areas where risks are spatially concentrated.

Finally, addressing the multifaceted nature of urban vulnerability demands interdisciplinary collaboration and stronger policy integration. Urban resilience is not solely a technical challenge; it intersects with governance, public health, social equity, and environmental justice. Future research must bridge disciplines, combining geospatial science with social work, urban planning, epidemiology, and public policy to co-develop inclusive frameworks that reflect the lived experiences of at-risk populations. There is also a growing need to institutionalize spatial data ethics and participatory governance mechanisms that ensure the benefits of GIS innovations are distributed equitably and transparently. In summary, the convergence of AI, community-based data, and smart infrastructure presents a transformative moment for GIS-based resilience. Seizing this opportunity requires both technological innovation and systemic reform to ensure that geospatial tools effectively serve the most vulnerable communities in the face of mounting climate and disaster risks.

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## 5. Conclusion

This review highlights the pivotal role of Geographic Information Systems (GIS) and spatial analysis in bolstering urban resilience and improving disaster response in vulnerable U.S. communities. Key findings reveal that GIS facilitates more precise risk assessment, resource allocation, infrastructure planning, and real-time decision-making. These technologies enable the visualization and analysis of spatially referenced data to identify hazard-prone areas, assess social vulnerabilities, and model the impacts of disasters, thereby supporting proactive strategies and adaptive responses.

Despite these benefits, significant disparities persist in the accessibility and integration of GIS across communities, particularly those historically underserved. The review highlights that communities with robust GIS infrastructures demonstrate higher disaster preparedness and more efficient emergency response systems. Conversely, areas lacking such capabilities are disproportionately affected by disasters and slower to recover. Moreover, a consistent challenge is the limited inclusion of local knowledge, community engagement, and interdisciplinary collaboration in the deployment of GIS tools.

### *Policy and Planning Recommendations*

To enhance GIS-supported urban resilience, policymakers and planners must prioritize the following:

- **Equitable GIS Infrastructure Development:** Expand access to GIS technology and training in under-resourced and high-risk communities. Federal and state governments should subsidize GIS capacity-building initiatives, particularly in rural and low-income urban areas.
- **Integrated Resilience Planning:** Mandate the use of GIS in local and regional disaster preparedness plans. Incorporating spatial analysis into zoning, infrastructure, and social service planning can improve community adaptation to climate-related and manmade hazards.
- **Community-Based Participatory Mapping:** Support initiatives that engage local residents, especially marginalized groups, in data collection and spatial analysis. This approach enriches GIS outputs with ground-level insight and ensures inclusive resilience strategies.
- **Cross-Sector Collaboration:** Establish partnerships between academic institutions, emergency management agencies, local governments, and community organizations to develop and maintain comprehensive spatial data infrastructures.

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### **Compliance with ethical standards**

#### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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