



# Mix Sustentável



## RESILIÊNCIA URBANA E A OCORRÊNCIA DE DESASTRES EM CLIMAS TROPICAIS: CONCEITOS, DEFINIÇÕES E INDICADORES

URBAN RESILIENCE AND THE DISASTER OCCURRENCE IN TROPICAL CLIMATES: CONCEPTS, DEFINITIONS, AND INDICATORS

RESILIENCIA URBANA Y LA OCURRENCIA DE DESASTRES EN CLIMAS TROPICALES: CONCEPTOS, DEFINICIONES E INDICADORES

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**Resumo:** Resiliência é um conceito complexo e multidimensional, geralmente observado e caracterizado após a ocorrência de um desastre. Para refinar sua compreensão, pesquisadores introduziram os conceitos de “resiliência adaptativa” e “resiliência inerente”, ambos relativamente recentes e desafiadores para definir. A resiliência adaptativa refere-se ao processo e aos resultados que ocorrem ex post desastres. Em contraste, a resiliência inerente abrange a capacidade de resiliência,

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resistência e recuperação ex ante, servindo como base para o fortalecimento da resiliência urbana. Estudos destacam consistentemente a associação entre resiliência e índices de vulnerabilidade social, ressaltando a necessidade de estruturar a resiliência urbana de acordo com os objetivos da pesquisa. Este estudo teve como objetivo analisar essas definições e relacioná-las a eventos adversos para mapear a resiliência urbana em nível internacional, contribuindo assim para a análise e mitigação de desastres em regiões tropicais. A revisão também examinou indicadores empregados em contextos tropicais para avaliar e identificar vulnerabilidades sociais, incluindo a relevância dos desastres mais frequentemente discutidos. Os resultados desta análise fornecem aos tomadores de decisão e gestores de mitigação de desastres evidências para subsidiar o desenvolvimento de estratégias que aumentem a resiliência, particularmente em regiões com climas tropicais. Abordar a resiliência como uma prática contínua e integrada contribui tanto para a adaptação às mudanças climáticas quanto para a mitigação de eventos de alto impacto nessas regiões.

**Palavras-chave:** Estratégias de prevenção; Resiliência adaptativa; Resiliência inerente; Vulnerabilidade social; Desastres.

**Abstract:** Resilience is a complex, multidimensional concept that is generally observed and characterized after the occurrence of a disaster. To refine its understanding, researchers have introduced the concepts of “adaptive resilience” and “inherent resilience,” both of which remain relatively recent and challenging to define. Adaptive resilience refers to the process and outcomes that occur ex post disaster. In contrast, inherent resilience encompasses the capacity for resilience, resistance, and ex ante recovery, serving as a foundation for strengthening urban resilience. Studies consistently highlight the association between resilience and social vulnerability indices, underscoring the need to structure urban resilience per research objectives. This study aimed to analyze these definitions and relate them to adverse events to map urban resilience at the international level, thereby contributing to disaster analysis and mitigation in tropical regions. The review also examined indicators employed in tropical contexts to assess and identify social vulnerabilities, including the relevance of the disasters most frequently discussed. The results of this analysis provide decision-makers and disaster mitigation managers with evidence to support the development of strategies that enhance resilience, particularly in regions with tropical climates. Addressing resilience as a continuous and integrated practice contributes to both climate change adaptation and mitigation of high-impact events in these regions.

permite o compartilhamento do trabalho com reconhecimento da autoria e publicação inicial nesta revista.

### **Contribuição dos autores segundo a Taxonomia CRediT**

LFLA: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing the Original Draft and Review and Editing, Visualization. AKA: Conceptualization, Methodology, Software, Writing the Original Draft and Review and Editing, Visualization. JAG: Conceptualization, Methodology, Writing the Original Draft. IKA: Conceptualization, Methodology, Validation, Formal analysis, Writing the Original Draft and Review and Editing, Visualization, Supervision, Funding acquisition.

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**Keywords:** Prevention strategies; Adaptive resilience; Inherent resilience; Social vulnerability; Hazards.

**Resumen:** La resiliencia es un concepto complejo y multidimensional que generalmente se observa y caracteriza tras la ocurrencia de un desastre. Para afinar su comprensión, los investigadores han introducido los conceptos de "resiliencia adaptativa" y "resiliencia inherente", ambos relativamente recientes y difíciles de definir. La resiliencia adaptativa se refiere al proceso y los resultados que ocurren ex post desastre. Por el contrario, la resiliencia inherente abarca la capacidad de resiliencia, resistencia y recuperación ex ante, sirviendo como base para el fortalecimiento de la resiliencia urbana. Los estudios destacan consistentemente la asociación entre la resiliencia y los índices de vulnerabilidad social, lo que subraya la necesidad de estructurar la resiliencia urbana según los objetivos de investigación. Este estudio tuvo como objetivo analizar estas definiciones y relacionarlas con eventos adversos para mapear la resiliencia urbana a nivel internacional, contribuyendo así al análisis y la mitigación de desastres en las regiones tropicales. La revisión también examinó los indicadores empleados en contextos tropicales para evaluar e identificar las vulnerabilidades sociales, incluyendo la relevancia de los desastres más frecuentemente discutidos. Los resultados de este análisis proporcionan a los responsables de la toma de decisiones y a los gestores de mitigación de desastres evidencia que respalda el desarrollo de estrategias que mejoren la resiliencia, especialmente en regiones con climas tropicales. Abordar la resiliencia como una práctica continua e integrada contribuye tanto a la adaptación al cambio climático como a la mitigación de eventos de alto impacto en estas regiones.

**Palabras clave:** Estrategias de prevención; Resiliencia adaptativa; Resiliencia inherente; Vulnerabilidad social; Desastres.

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## 1 INTRODUCTION

Urban ecosystems, characterized by high population densities and extensive built structures and infrastructure, host the majority of the world's population (Pickett *et al.*, 2011). As humans are the primary drivers of environmental change and catastrophic events are increasing globally, the introduction of new paradigms in urban planning has become a priority. These paradigms are intended not only to foster more livable, sustainable, and resilient cities but also to mitigate environmental and social impacts worldwide.

Accordingly, international interest in and emphasis on community resilience to disasters have intensified (Aldunce *et al.*, 2015). Timmerman (1981) defined resilience as “the measure of the capacity of a system or part of a system to absorb and recover from the occurrence of a hazardous event.”

By nature, resilience is typically analyzed and characterized after a disaster, which complicates efforts to measure or map it in advance. Nonetheless, decision-makers often require pre-disaster assessments to strengthen urban resilience. This challenge has led researchers (Cutter, 2016b; Cutter; Ash; Emrich, 2016; Cutter, 2016a; Rose, 2004; Rodríguez *et al.*, 2007) to propose two complementary approaches: adaptive resilience and inherent resilience.

Adaptive resilience refers to the processes and outcomes that occur following a disruptive event, meaning it can only be measured retrospectively. Inherent resilience, often described as resilience capacity, encompasses the inherent attributes that enable a community or territory to respond to and recover from shocks (Foster, 2007). In theory, inherent resilience can be assessed before an event and can serve as a foundation for strengthening urban resilience.

A disaster is defined as the result of adverse natural or anthropogenic events occurring in vulnerable settings, leading to severe disruptions in the functioning of a community or society. Such disruptions involve extensive human, material, economic, and environmental losses that exceed local coping capacity. The objective of this study was to analyze these definitions and relate them to adverse events to map urban resilience internationally, thereby contributing to disaster analysis and mitigation in tropical regions. The study also examined indicators commonly used in tropical contexts to measure social vulnerabilities and assessed the relevance of the disasters currently being discussed.

## 2 METHODOLOGY

### 2.1 Literature Review

The literature review was conducted according to the methodology described by Almeida *et al.* (2022) and Costa *et al.* (2019). Searches were carried out in major databases to identify methods for resilience analysis. Two combinations of search terms were used: the first with the term “adaptive resilience” and the second with “inherent resilience.” On November 10, 2023, a combined search for “adaptive resilience” AND “inherent

resilience” was conducted in SpringerLink, Web of Science, Scopus, and ScienceDirect. Only peer-reviewed scientific articles were included for analysis.

## **2.2 Database Analysis**

The data obtained from the searches were organized in a spreadsheet, and definitions of the terms, along with their scope of use by country and region, were analyzed. Publications were grouped according to their central theme, which yielded the following categories: (1) Topic 1 – Resilience: studies focusing primarily on resilience, including methods and conceptual development; (2) Topic 2 – Sustainability: studies emphasizing sustainable tactics and practices; (3) Topic 3 – Economics and Resource Management: studies on efficient planning and management of economic and material resources, including allocation, utilization, control, and monitoring practices; (4) Topic 4 – Vulnerability: studies analyzing factors that increase exposure to social, economic, and environmental risks and vulnerabilities; (5) Topic 5 – Indicators: studies focused on developing and applying metrics and indicators for performance evaluation and monitoring.

Duplicate records were removed, and the remaining publications were cataloged by title, database, abstract, publication title, keywords, authors, year, digital object identifier (DOI), link, and type of publication. While books, book chapters, and reference works were identified, only journal articles were retained for review, in accordance with the adopted methodology.

## **2.3 Relationship Between Urban Resilience and Tropical Climates**

Studies addressing resilience in tropical countries were identified, and the indicators used by international researchers to assess urban resilience in these regions were cataloged. The indicators included both Social Vulnerability Indexes (SoVI) reported in the literature and measures specific to tropical areas, as provided by national institutions.

# **3 RESULTS AND DISCUSSION**

## **3.1 Quantitative and Spatial Analysis of Study Distribution**

The initial database search yielded 102 publications: 60 from SpringerLink, six from Web of Science, 11 from Scopus, and 25 from ScienceDirect. After duplicates were removed, the working database contained 45 publications: 19 from SpringerLink, four from Web of Science, one from Scopus, and 21 from ScienceDirect.

The distribution and accumulation of publications over time are presented in Figure 1. In 2023, eight

publications were recorded, comprising six journal articles and two books or chapters. The earliest publication, Rose (2004), conceptualized resilience as an economic construct, emphasizing the ability of individuals, institutions, and communities to withstand adverse shocks and adapt or recover with perseverance. The study noted resilience in practices such as conserving scarce resources, resuming interrupted productive activities, and redistributing resources through markets. Cutter *et al.* (2008) examined resilience in the context of natural disasters and global change, highlighting the increasing concern with communities' capacity to recover from crises. The study also discussed the diverse perspectives on resilience, ranging from risk and disaster research to analyses of climate change impacts. Zhou *et al.* (2010) contributed models of disaster resilience, tracing the concept's origins in ecological, social, socio-environmental, and hazard sciences. Subsequent studies expanded the scope of resilience to include not only economic and disaster contexts but also urban systems and sustainable development.

**Figure 1 – Number of publications per year and cumulative publications for each category**

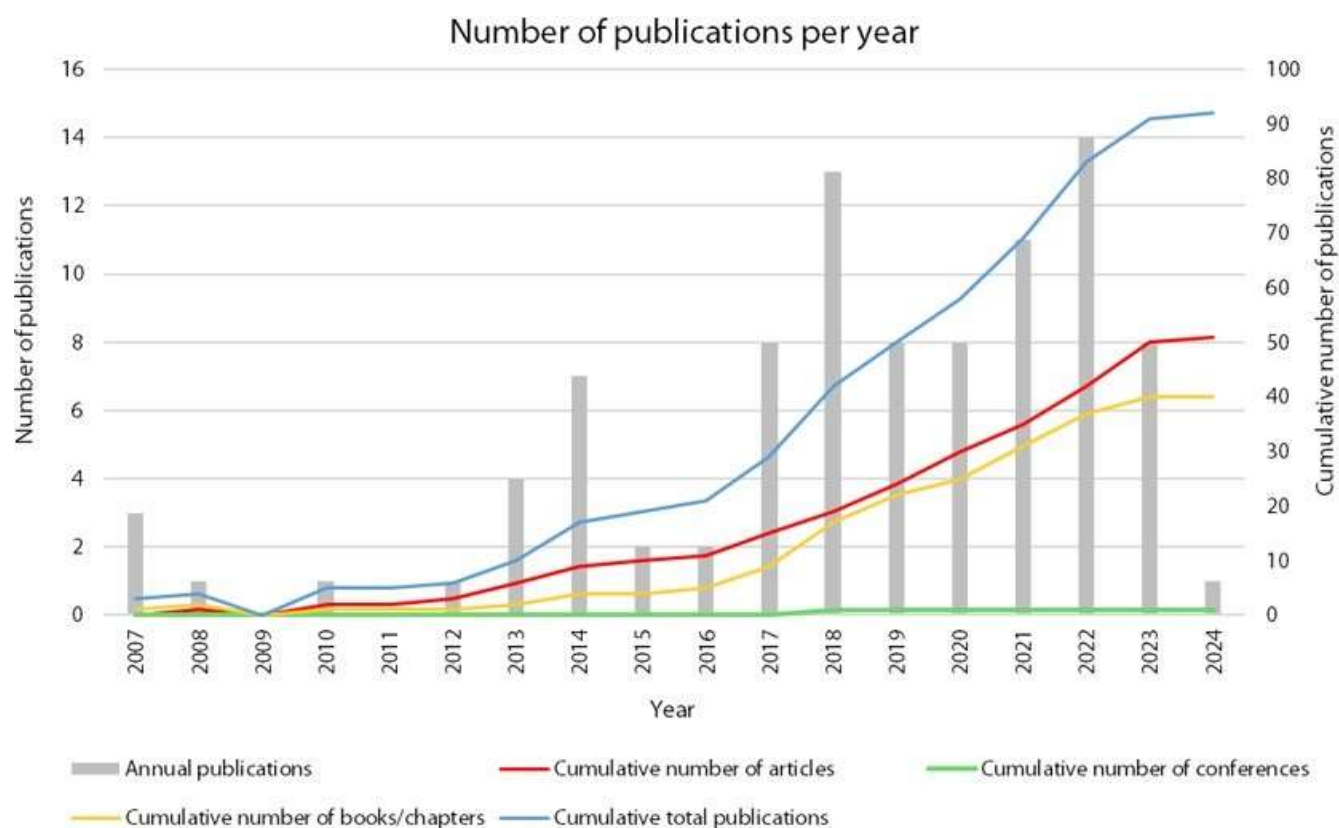
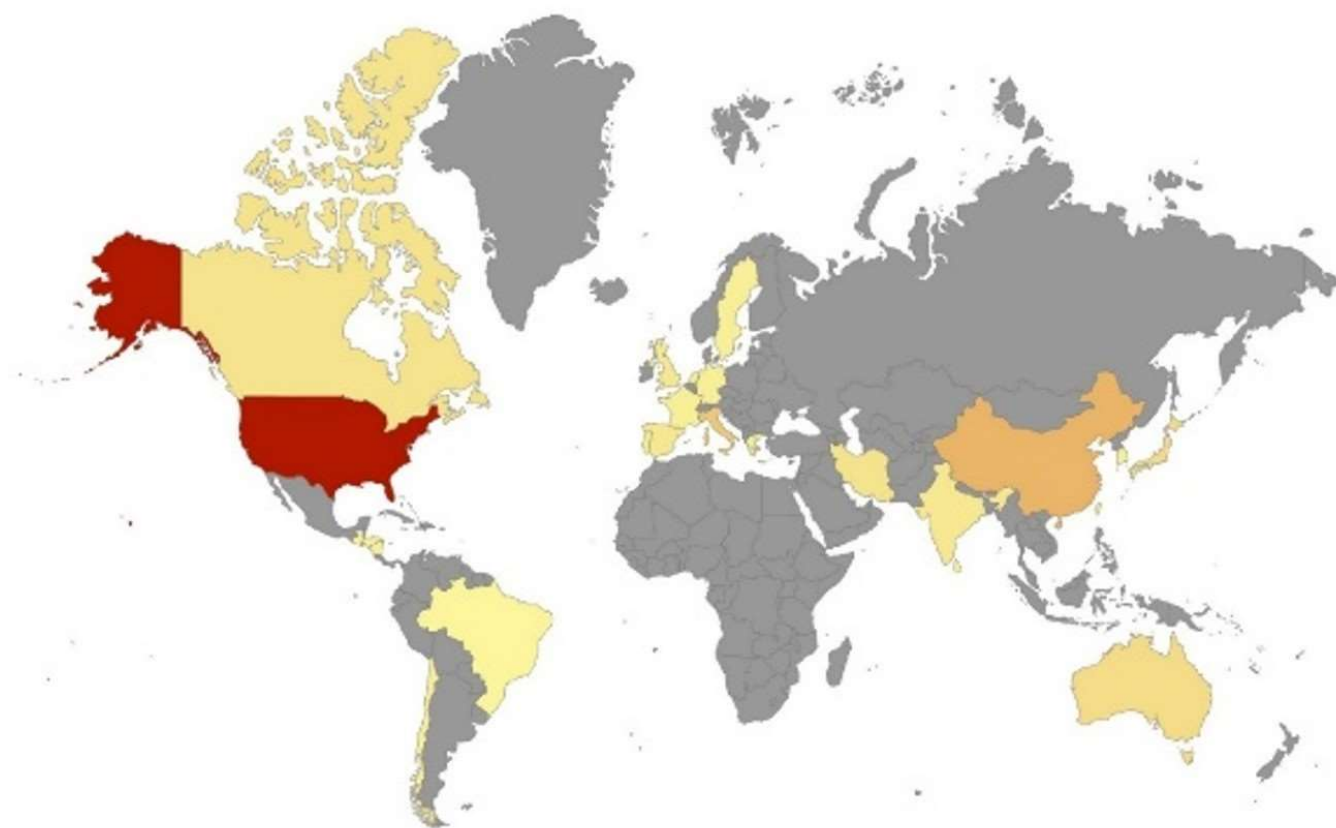


Figure 2 presents a map showing the number of publications recorded in the databases by country. The color scale ranges from 0 to 34 publications, including journal articles and conference papers. Yellow represents 1–9 publications, orange represents 10–20, gray indicates no publications, and red denotes 20 or more.

The majority of studies on resilience and disasters are concentrated in central North America, par-

**Figure 2 – Illustrative map of the distribution of publications worldwide**

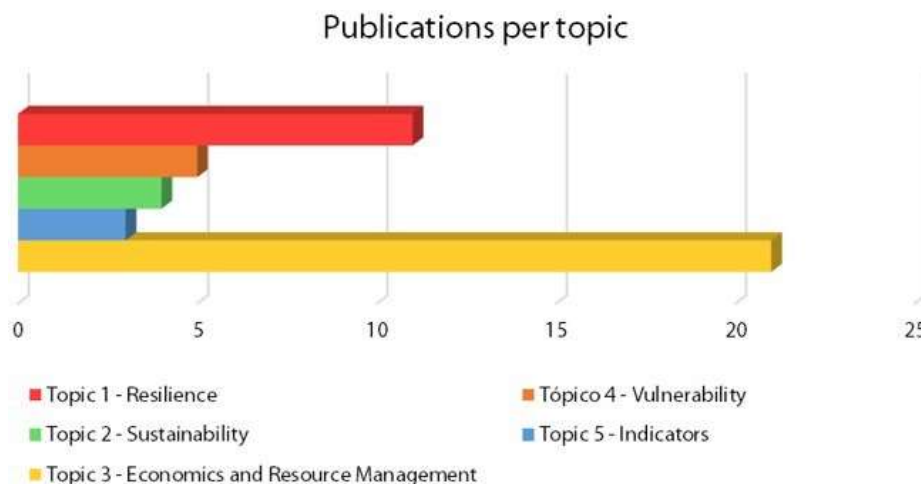


ticularly the United States, which recorded approximately 34 publications: 17 journal articles, 16 books or chapters, and one conference paper. Europe ranked second with 17 publications, comprising 10 journal articles and seven books or chapters. China followed with 11 publications (nine journal articles and two books or chapters), as did Asia overall with 11 publications (seven journal articles and four books or chapters). Australia contributed six publications, including one journal article and five books or chapters.

The United Kingdom, Canada, and Japan each produced three publications. Specifically, the United Kingdom published one journal article and two books or chapters, whereas both Canada and Japan published two journal articles and one book or chapter. South Korea and Jamaica each recorded one publication, the first a journal article and the second a book or chapter. South America contributed only one article, highlighting the limited attention disaster resilience in tropical regions has received compared with other parts of the world.

The reviewed publications were classified into five main topics (Figure 3), enabling a detailed analysis of research concentration. The largest cluster was in Topic 3 – Economics and Resource Management, comprising 21 studies, which indicates a strong academic interest in this area. Topic 1 – Resilience ranked second, with 11 publications focused on the conceptual development of resilience, underscoring its centrality. By contrast, Topics 2, 4, and 5 received comparatively limited attention, with only 4, 5, and 3 publications, respectively, reflecting lower levels of research concentration in these areas.

**Figure 3 – Number of publications per topic**



### 3.2 Inherent Resilience vs. Adaptive Resilience

Resilience is a broad and complex concept that spans multiple fields of knowledge, each with distinct applications. It comprises a wide array of definitions and interpretations, with little orthodoxy in its conceptualization and application. This lack of uniformity contributes to its appeal in policymaking (Cutter; Hummell; Emrich, 2016) and has facilitated its application across various fields, including disaster management and sustainability science.

The term originated in ecology, where Holling (1973) described resilience as the persistence of systems and their ability to absorb changes and disturbances while maintaining the same relationships among populations or state variables. From this foundation, the concept was subsequently adapted across disciplines. It has become central to understanding how natural, social, and technological systems respond to adverse events. For example, Cutter (2016b) noted that health sciences emphasize information that enables individuals and health systems to remain resilient before and after disasters. In engineering, resilience refers to the performance of buildings and infrastructure. In sociology, it addresses what makes social units resilient and their inherent capacities. In economics, it includes analyses such as business resilience. The biological and natural sciences focus on ecosystems, coastal areas, and floodplains, while spatial sciences (planning and geography) compare resilience processes from local to global scales (Cutter; Hummell; Emrich, 2016).

According to Tierney (2014), resilience manifests in both preexisting social arrangements (e.g., emergency planning, resident participation) and post-disaster adaptations (e.g., mobilization of support and resources). Inherent resilience refers to the conditions, characteristics, and properties that allow a social entity to withstand disasters. In contrast, adaptive resilience reflects the resource fulness and strategies through which a social entity recovers from disaster-induced disruptions. Cutter *et al.* (2008) expanded this view, defining resilience as the capacity of a social system to respond to and recover from disasters. This includes both inherent

conditions that allow systems to absorb shocks and post-event adaptive processes that enable reorganization, change, and learning. In geography and disaster studies, Zhou *et al.* (2010) similarly classified resilience into inherent (IR) and adaptive (AR) categories, making both essential for evaluating the capacity of entities to resist and adapt to disasters.

Despite the widespread use of the term, its definition remains fragmented and unclear. Lee and Basu (2018) observed that although disciplines emphasize different characteristics, they share the view that resilience is fundamentally about recovery. The authors identified five central aspects: resistance, speed of recovery, adaptability and transformability, resourcefulness, and redundancy.

The relationship between vulnerability and resilience further highlights the multidimensional nature of disaster studies. Cutter (1996) defined vulnerability as the pre-event characteristics of social systems that create the potential for harm. Vulnerability is a function of “exposure” (who or what is at risk) and “sensitivity” (the extent to which people and places can be harmed). Thus, vulnerability precedes an adverse event, while resilience reflects a system’s ability to respond, reorganize, and recover. Within this context, “adaptive capacity” refers to the ability of systems to adjust to change, mitigate impacts, and cope with disturbances. Adaptive capacity can be expressed in two ways: as inherent resilience, which prepares for future events, and as adaptive resilience, which addresses damage after it occurs. In disaster risk frameworks, the related concept of “mitigation” refers to proactive measures designed to reduce the impacts of events (Cutter *et al.*, 2008).

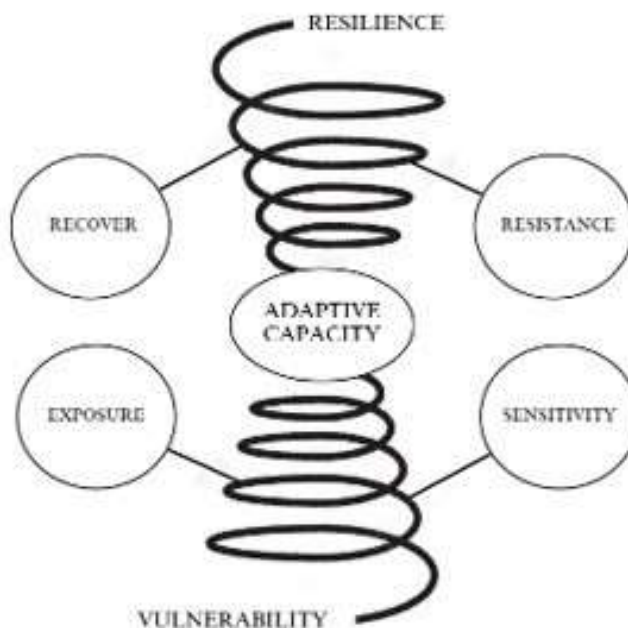
Cutter *et al.* (2008) also noted that the interplay between vulnerability, resilience, and adaptive capacity is not consistently articulated. Some researchers regard resilience as part of adaptive capacity, while others view adaptive capacity as a subset of vulnerability. Another perspective aligns both concepts within the concept of vulnerability. Risk scholars, however, often subsume adaptive capacity and mitigation under the concept of resilience. In this study, resilience and vulnerability are treated as distinct yet interconnected concepts, with their intersection resulting in adaptive capacity (Cutter *et al.*, 2008; Cutter; Ash; Emrich, 2014).

Disaster resilience emphasizes increasing the ability to withstand and recover from extreme events as quickly as possible, ideally with minimal external assistance. While exposure and sensitivity are key elements of vulnerability, these vary in relation to changes in the structures and functions of systems affected by hazards. Overall, vulnerability is generally considered a pre-disaster condition, helpful in anticipating future risks (Zhou *et al.*, 2010). Figure 4 illustrates the interrelationship among vulnerability, resilience, and adaptive capacity, emphasizing the importance of integrated approaches to risk management and disaster planning, where social systems are analyzed in terms of both their predisposition to risk and their capacity to respond.

### 3.2.1 Inherent Resilience

Inherent resilience refers to the preexisting capacity of a system, community, or individual to withstand and respond to challenges before they occur. Unlike adaptive resilience, which involves adjustments during and after a crisis, inherent resilience is developed *ex ante*. It is based on the resources and conditions already in place that enable systems to cope with adverse events. Rose and Eyer (2019) described inherent resilience

**Figure 4 – Relationship between vulnerability and resilience**



as a process through which resilience capacity can be cultivated in advance for later deployment. In contrast, adaptive resilience emerges from improvisations once a disruption begins.

In principle, inherent resilience can be measured before an event and can serve as a baseline for improving urban resilience (Cariolet; Vuillet; Diab, 2019). Graveline and Grémont (2017) emphasized that inherent resilience reflects capabilities embedded within systems before disasters occur—that is, resilience that has already been established. Inherent and adaptive resilience together enable communities to minimize potential losses by restoring equilibrium, whether stable or dynamic, as rapidly as possible. Jamali *et al.* (2023) further noted that inherent resilience is often used as a benchmark for assessing outcomes and changes over time. Cutter (2016b) observed, however, that the relationship between inherent and adaptive resilience remains theoretical mainly, as empirical testing of the concept has been limited.

Although primarily theoretical, the development of anticipatory resilience is essential for designing strategies to absorb shocks, preserve stability, and prepare for future disasters.

### **3.2.2 Adaptive Resilience**

Adaptive resilience refers to the capacity of individuals, stakeholders, or communities to learn from and respond to hazards during and after disruptive events. Unlike inherent resilience, which is anticipatory, adaptive resilience emerges *ex post* and often through processes of social learning. However, it may also be captured in measurable outcomes (Cutter; Hummell; Emrich, 2016).

Adaptive resilience extends beyond basic resilience, encompassing the ability to adapt and evolve in

response to crises and other challenges. Rose (2004) defined it as a dynamic construct associated with the speed of recovery to a desired state following a disaster. This framing positions resilience as a continuous cycle of recovery, adaptation, and transformation, directed toward achieving stability or improvement compared with pre-event conditions. Examples of adaptive resilience include adopting previously unconsidered conservation practices, introducing new technologies, creating market mechanisms, or designing government assistance programs in response to a disaster (Rose, 2018). Nevertheless, because adaptive resilience concerns post-event processes and outcomes, it can only be measured after disasters occur (Cariolet; Vuillet; Diab, 2019).

Saja *et al.* (2021) argued that both inherent and adaptive resilience are particularly relevant in contexts of disasters or ongoing crises. Yet resilience is often analyzed in relation to a single event, when it should instead be examined as a cycle spanning consecutive events. Lessons drawn from past experiences shape future responses, thereby strengthening urban resilience. Like inherent resilience, adaptive resilience remains theoretical mainly, but it is increasingly recognized as an essential tool for risk management and for interpreting outcomes generated by disasters.

### 3.3 Disaster Resilience

Disaster resilience has gained prominence across disciplines in response to the increasing frequency and intensity of catastrophic events. The concept encompasses not only the adaptive capacities of communities and infrastructure but also mitigation strategies aimed at reducing risks. Cutter (2016a) emphasized that disaster resilience spans multiple domains, each requiring distinct scientific contributions. This diversity underscores the importance of integrated, cross-disciplinary approaches to the challenges posed by natural and anthropogenic disasters.

Klein, Nicholls and Thomalla (2003) situated Timmerman (1981) definition of resilience within the context of natural hazards. They argued that after three decades of debate, the definition of disaster resilience had become so broad as to risk losing analytical utility. According to their analysis, early interpretations were ineffective in reducing vulnerability, whereas later formulations were more effective.

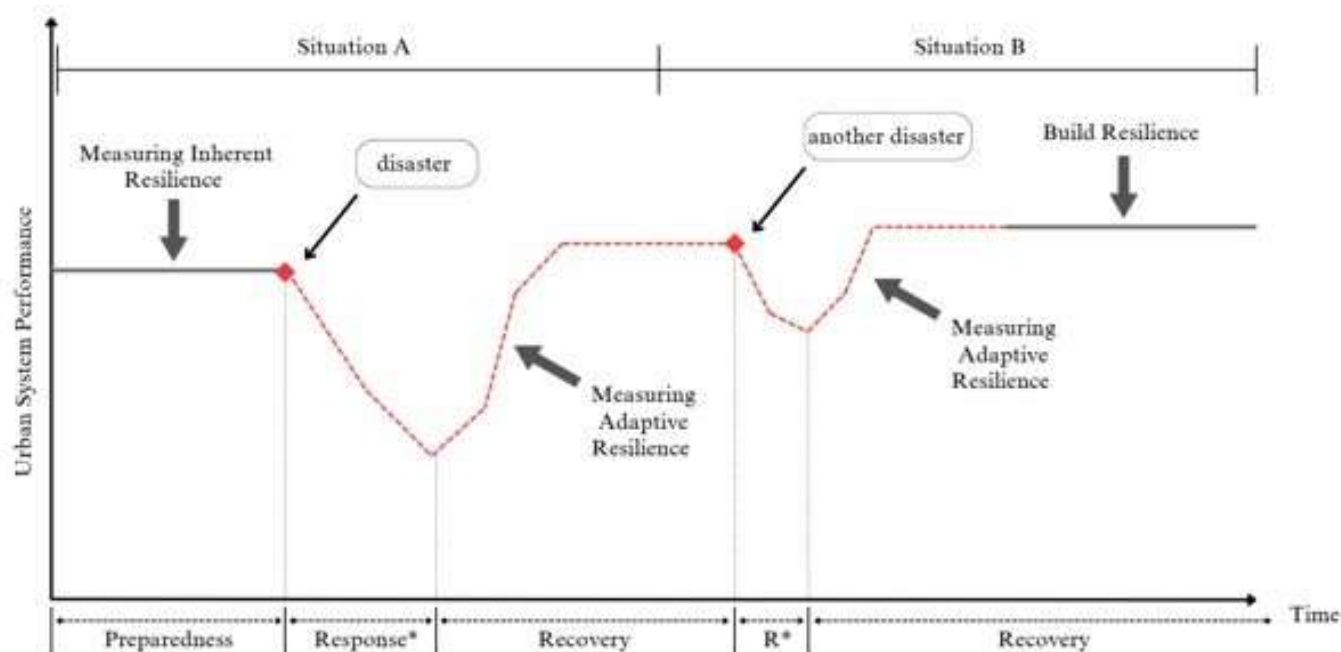
Preparedness is fundamental to reducing losses from disasters. Communities must proactively mitigate risks and build resilience to recover quickly (Saja *et al.*, 2021). This requires reinforcing infrastructure and developing effective policies that enable systems to cope with unexpected shocks. Relying on business-as-usual approaches is unsustainable, as human and material losses continue to escalate. Instead, policies must prioritize risk reduction and resilience-building at local, national, and international levels (Cutter; Hummell; Emrich, 2016).

Lee and Basu (2018) emphasized that disaster resilience is less about resisting all possible hazards than about recovering effectively from unforeseen ones. It entails preparing so that risks are mitigated, consequences minimized, and systems can evolve continuously through lessons learned from prior events. Disaster resilience should therefore be regarded as an ongoing practice.

Building on Yuan and Hu (2023), Figure 5 illustrates how inherent and adaptive resilience can be mea-

sured in different scenarios. Inherent resilience focuses on the pre-disaster stage and reflects the resources and capacities available for preparedness and response. Adaptive resilience, in contrast, focuses on post-disaster recovery and reflects the speed and effectiveness of a system's response to disasters. Because urban resilience can be meaningfully assessed only after disruptions, scholars often measure adaptive resilience by the time required for recovery, with shorter recovery periods indicating greater resilience (Yuan; Hu, 2023).

**Figure 5 – Measuring inherent resilience and measuring adaptive resilience in different situations**



As shown in Figure 5, situation (A) depicts an initial disaster that generates negative impacts and requires a system response. This event reveals vulnerabilities while initiating recovery and resilience-building measures. Subsequently, in situation (B), another disaster occurs, which may share characteristics with or differ from the first. Drawing on prior experience and strengthened adaptive capacity, the system responds and recovers more rapidly and effectively. The inherent resilience established during situation (A) also increases in situation (B), demonstrating the cumulative and evolutionary nature of resilience. Over time, communities become progressively better equipped to manage future events.

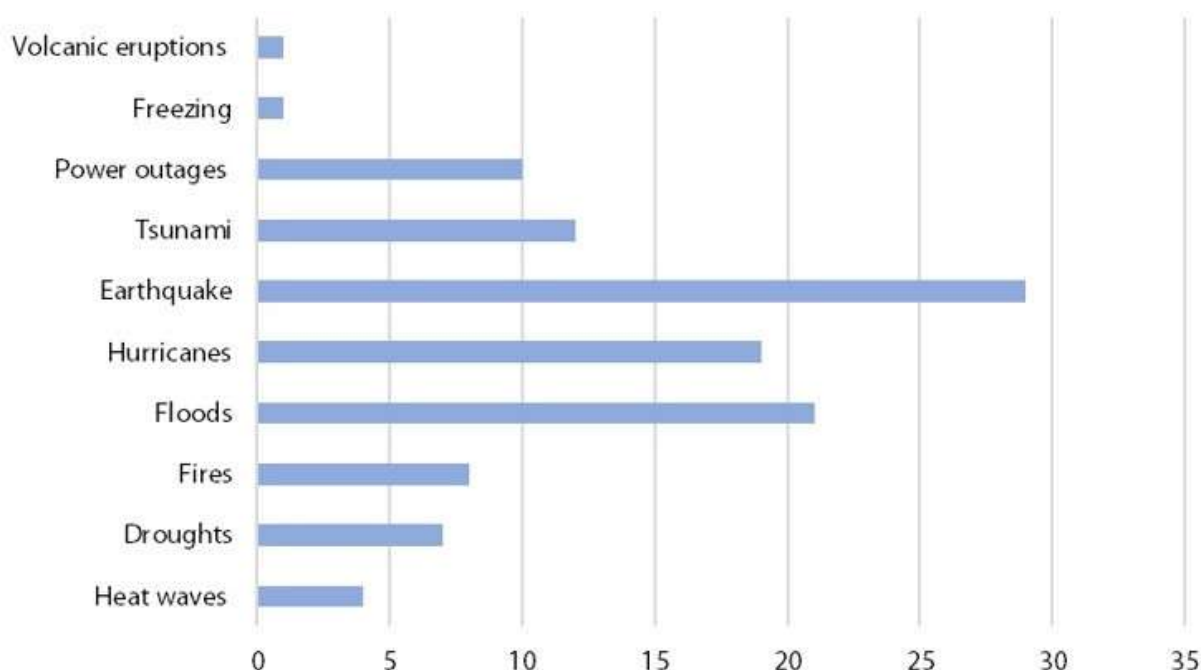
### 3.3.1 Disasters

Disasters, whether natural or anthropogenic, are disruptive events that significantly affect infrastructure, livelihoods, and the socioeconomic systems of communities. Within the context of disaster resilience, these events are analyzed regarding their magnitude and in relation to the ability of systems to resist, respond, and recover.

Cutter (2016b) emphasized that disaster resilience should be viewed as a dynamic process encompassing social, economic, and environmental factors. Unlike static classifications that label systems as simply resilient or vulnerable, resilience depends on the capacity to absorb shocks, reorganize, and overcome disruptions in ways that strengthen responses to future events. Disasters such as floods, earthquakes, hurricanes, and wildfires must therefore be understood not only by their physical intensity but also by the structural capacities of systems to defend against and adapt to their impacts.

Figure 6 presents the number of disaster mentions in the reviewed articles. Earthquakes were the most frequently cited, with 29 mentions. Notable cases included the 2008 Wenchuan earthquake in China, the 2011 earthquake in Japan, the 2010 earthquake in Haiti, the 2009 L'Aquila earthquake in Italy, the 1994 Northridge earthquake in the United States, and the 1960 Great Chile Earthquake, the largest earthquake ever recorded. Floods ranked second, with 21 mentions, including events in Pakistan (2010), Bangkok, Thailand (2011), the Dongting Lake dike collapse in Hunan Province, China, and flooding in São Paulo, Brazil. Hurricanes were third, with 19 mentions, featuring Hurricane Katrina in New Orleans (2005), Hurricane Sandy in New York (2012), and Hurricane Harvey in Texas (2017).

**Figure 6 – Number of Mentions of Disaster**



Tsunamis and power outages ranked fourth and fifth, with 12 and 10 mentions, respectively. Notable events included the 2004 tsunami in Sri Lanka, the 2011 catastrophe in Japan, and power outages in Southern California following the 2011 Tohoku earthquake. Fires ranked sixth, with eight mentions, including the forest fires in Southern Europe (2007) and Australia (2009). Droughts and heat waves followed, with seven and four

mentions, respectively. Droughts occurred in Russia (2010), East Africa (2011), and the United States (2012), while heat waves were highlighted by the 2003 European summer heat wave, one of the most intense in the Northern Hemisphere. Finally, disasters related to extreme cold (freezing) and volcanic eruptions were the least cited, with only one mention each.

Cutter *et al.* (2008) noted that rapid-onset events, such as hurricanes and earthquakes, require immediate responses that alter behaviors and practices during both preparedness (pre-event) and mitigation (post-event) phases. These events are frequently prioritized by risk management policies, as emphasized by Wilkinson *et al.* (2017) and Katsikopoulos (2021). Governments and communities, constrained by limited resources and attention, often focus on disaster risks that recur at national or local levels, assuming these to be of the highest priority.

For example, the 2008 Wenchuan earthquake in China devastated Heishui County, which was designated a central disaster area. Under strong reconstruction assistance policies, the county's economic and social development advanced significantly during the recovery phase (Tang *et al.*, 2021). According to the authors, the initial goal was rapid recovery, although resilience levels were initially low. In general, the shorter the recovery time, the higher the level of urban resilience. For instance, the speed of rebuilding damaged residential areas has been considered a measure of Los Angeles' resilience following the 1994 Northridge earthquake (Yuan; Hu, 2023).

Infrastructure fragility and community vulnerability often slow recovery. When a destructive earthquake occurs, resilient cities or communities can return to typical functioning more smoothly (Lei *et al.*, 2014). The 2004 tsunami in Sri Lanka, followed by severe flooding in 2011, further illustrates how hazard-prone areas amplify community exposure to risks. In such cases, adaptive capacity may involve preventive or mitigation strategies informed by past experiences, such as relocating populations from high-risk zones or constructing levees (Saja *et al.*, 2021). Vulnerability also fluctuates with exposure: when populations move into flood-prone areas, vulnerability rises, whereas relocation out of such regions lowers vulnerability (Zhou *et al.*, 2010).

Urbanization exacerbates these challenges. As Muzzio (2013) observed, continued expansion has led to the occupation of ecologically valuable areas, thereby increasing population exposure to hazards through overcrowding of flood-prone zones, particularly wetlands.

Events such as heat waves and droughts—especially in tropical regions—remain highly relevant, yet they often receive less attention compared to disasters with more immediate and visible impacts. The role of disaster resilience in reducing risks from these slower-onset events is less clearly understood (Cutter *et al.*, 2008; Miller, 2010; Zhou *et al.*, 2010). Currently, there is no widely accepted method for quantitatively characterizing community disaster resilience before adverse events occur, nor for clarifying how inherent resilience relates to pre-event vulnerability or response capacity. Similarly, methods for estimating adaptive resilience during or after events remain underdeveloped. The lack of reconciliation between resilience and vulnerability frameworks, along with the limited availability of quantitative indicators, constrains efforts to improve resilience at the community level (Cutter; Ash; Emrich, 2014).

In summary, disaster studies often focus on recurrent, high-impact events. Nonetheless, the complexity of disaster management consistently points to community resilience as a central factor (Norris *et al.*, 2008). Re-

silience strategies are increasingly emphasizing the role of performance indicators in evaluating interventions across the pre-event, event, and post-event phases. In disaster research, indicator-based assessment remains a widely used tool. Well-known examples include the Social Vulnerability Index (SoVI), the Disaster Risk Index (DRI), and the Earthquake Disaster Risk Index (EDRI) (Kim; Park, 2018).

### 3.4 Social Vulnerability to Disasters

In the context of disaster resilience, the concept of social vulnerability provides critical insight into population-level impacts. Factors such as socioeconomic inequality, infrastructure, access to resources, and geographic location can amplify adverse effects.

Although vulnerability and resilience are inherently dynamic, they are often treated as static for measurement purposes (Cutter *et al.*, 2008). Social vulnerability to disasters refers to the susceptibility of certain communities—due to socioeconomic and demographic characteristics—to greater harm during crises. Vulnerability relates directly to exposure and resilience to extreme events, whereas social vulnerability highlights structural inequalities that intensify risks and limit communities' ability to respond and recover.

Veen and Logtmeijer (2005) subdivided vulnerability into three components: dependence, redundancy, and susceptibility. Applied to social systems, these concepts clarify differential impacts during disasters. Dependence refers to reliance on infrastructure or economic systems that, when disrupted, disproportionately affect vulnerable groups. Redundancy refers to the ability to maintain function or compensate for disruptions. Susceptibility reflects the likelihood and severity of impact from extreme events.

Applying these categories underscores how inequality intersects with disaster risk. Disasters do not affect all populations equally; existing social structures determine who will be most severely impacted and who will face the most significant obstacles in recovery. Thus, risk reduction requires more than infrastructure interventions—it also demands social reforms that promote equity and strengthen social resilience.

#### 3.4.1 Vulnerability and Its Indicators

Indicators of social vulnerability are essential tools for assessing and monitoring community capacity to respond to disasters. These indicators measure diverse aspects of vulnerability and resilience by identifying risk factors across different contexts. Resilience indices have been developed across multiple disciplines, each constructed from varying definitions, constituents (indicators or variables), and intended purposes. Consequently, they capture different dimensions of resilience (Prior; Hagmann, 2013). By employing specific indicators, these indices help clarify challenges communities face in reducing vulnerability to disasters.

Social resilience indicators typically include variables such as income, education, access to services, infrastructure, and population density. These factors influence the capacity of individuals and groups to prepare for and recover from extreme events. Indicators also help identify priority needs, establish baselines for

monitoring progress, and evaluate the effectiveness of interventions. Furthermore, they inform cost–benefit analyses of resilience investments across scales (Cutter; Hummell; Emrich, 2016).

Social vulnerability indicators, meanwhile, focus on socioeconomic disadvantage and risk exposure. Among those developed by the United Nations (UN) is the Multidimensional Poverty Index (MPI), which measures acute poverty across more than 100 countries. First introduced in 2010 by the Oxford Poverty and Human Development Initiative and the UN Development Program (UNDP), the MPI supports Sustainable Development Goal 1: ending poverty in all its forms (United Nations Development Programme (UNDP); Oxford Poverty and Human Development Initiative (OPHI), 2022). Complementary to the MPI, the Human Development Index (HDI) measures long-term development across three key dimensions: income, education, and health. Created by Mahbub ul Haq in collaboration with Amartya Sen, the HDI offers a counterpoint to GDP per capita by incorporating social and human factors (United Nations Development Programme, 2023).

The UN's 2023 Annual Report for Brazil emphasized the importance of municipal-level support in strengthening disaster resilience. Strategies highlighted include risk monitoring, knowledge management, sustainable urban planning, and inter-municipal knowledge exchange. These initiatives prioritize vulnerable populations and employ holistic approaches, coordinated with governmental and nongovernmental partners (ONU Brasil, 2024). Social vulnerability indicators also align with the 17 Sustainable Development Goals (SDGs) and serve as benchmarks for monitoring progress and informing public policy.

### 3.5 Comparing Resilience by Indicators

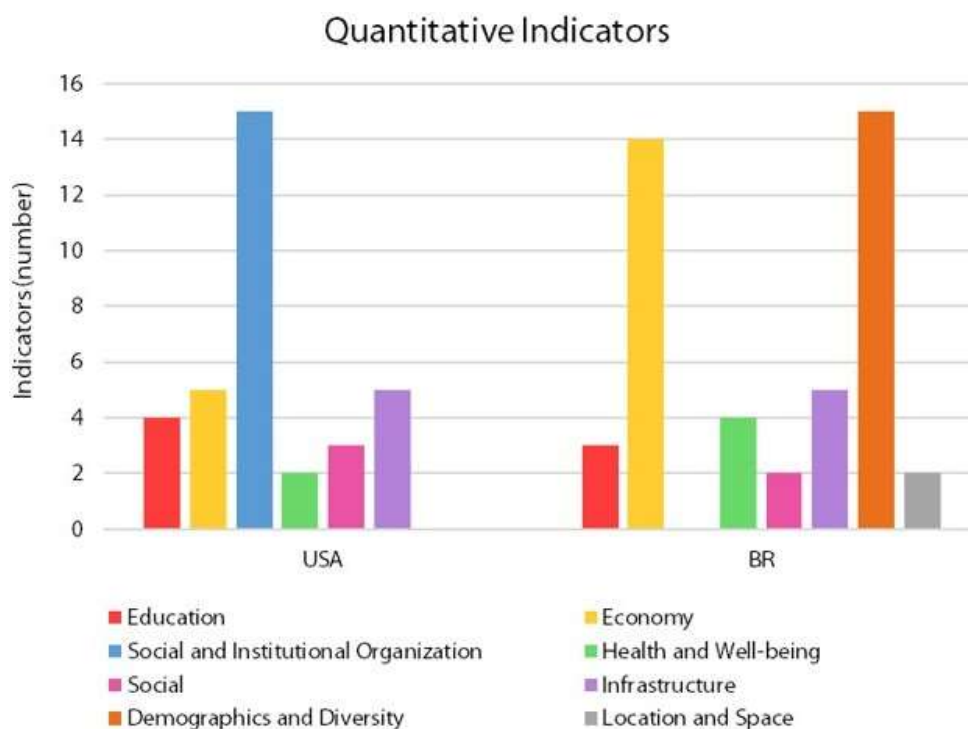
Cutter (2016b) and Cutter, Hummell e Emrich (2016) examined resilience indicators, utilizing the SoVI as a key tool for quantifying social vulnerability. These studies highlighted how regions and communities apply such metrics to evaluate their adaptive and recovery capacities, incorporating variables related to infrastructure, institutional strength, and economic resources.

Figure 7 compares the indicators used to measure resilience in the United States (USA) and Brazil (BR), classified into the following categories: Education, Social and Institutional Organization, Social, Demographics and Diversity, Economy, Health and Well-being, Infrastructure, and Location and Space.

The number of Education indicators is significantly higher in the United States, with approximately five, compared to three in Brazil. In the Social and Institutional Organization category, only the United States presents indicators, highlighting the absence of effective Brazilian measures for disaster mitigation through resilience. Both countries have relatively few indicators under the Social category; however, the United States shows a slight advantage, with three indicators compared to Brazil's two. Brazil stands out in Demographics and Diversity, with 15 indicators, reflecting the country's greater emphasis on social vulnerability and its implications for resilience within a context of entrenched inequality.

Regarding Economic indicators, Brazil leads with approximately 14, whereas the United States has only two. This suggests that economic resilience is prioritized in Brazil, where strengthening economic capacity is considered vital in light of existing vulnerabilities. For Health and Well-being, Brazil again leads, with

**Figure 7 – Number of Mentions of Disaster**



four indicators—twice as many as the United States—demonstrating greater concern with health as a pillar of resilience. Both countries have approximately five Infrastructure indicators, underscoring their shared recognition of this as an essential resilience element. Finally, in Location and Space, Brazil includes two indicators, reflecting the importance of geographic diversity and spatial factors in resilience analyses for tropical regions.

Altogether, these findings indicate that resilience indicators in the United States emphasize response and adaptation capacity. In contrast, those in Brazil highlight the need to address structural inequalities that exacerbate adaptation and recovery challenges during extreme events.

To contextualize these dimensions, resilience indicators identified in the literature review were grouped following the framework proposed by Prior and Hagmann (2013): social resilience (e.g., average age, health coverage), economic resilience (e.g., employment, income equality), institutional resilience (e.g., community mitigation actions, insurance), and infrastructure resilience (e.g., housing type, shelters). To these, sustainable resilience (e.g., planning and practices based on sustainability principles) was added as an additional dimension. Appendix 1 details the separation of indicators presented in Cutter (2016b) and Cutter, Hummell e Emrich (2016).

Figure 8 quantifies resilience using these dimensions. Based on Cutter (2016b) catalog of indicators, reorganized according to Prior and Hagmann (2013) framework, the quantitative results differ considerably. The analysis reveals that Brazil has more indicators for social, economic, and infrastructure resilience than the United States. However, Brazil is the only country with parameters for institutional resilience, and neither

country presents indicators explicitly tied to sustainable resilience.

Figure 8 – Quantitative Resilience

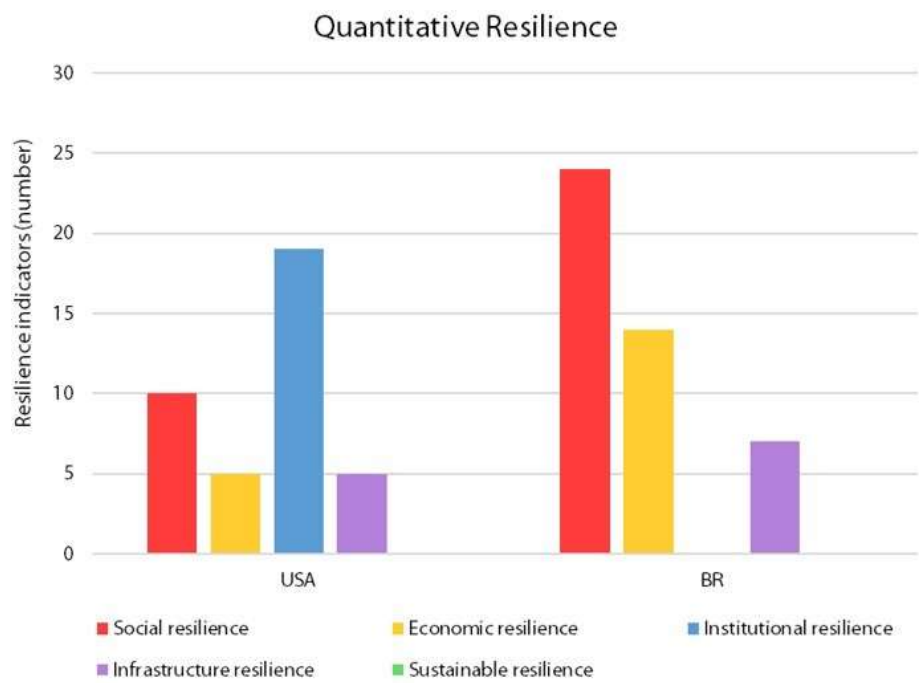


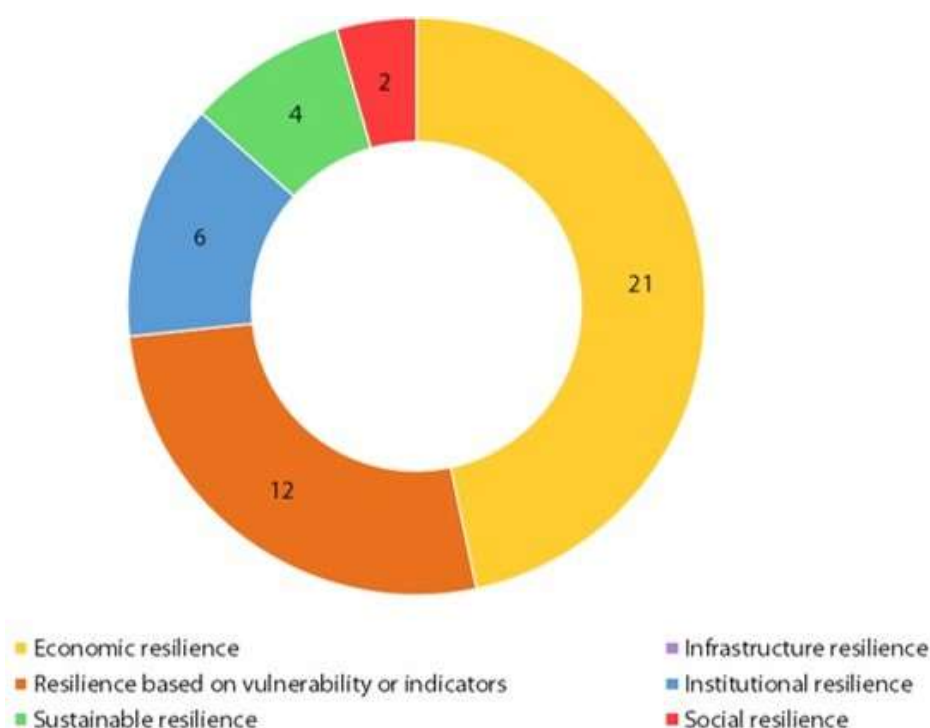
Figure 9 presents the number of resilience measures addressed in the publications reviewed. For this analysis, an additional dimension was introduced: resilience based on vulnerability or indicators. This dimension reflects cases in which the central focus was either the ability of individuals to cope with shocks by linking them to vulnerability contexts or the analysis of resilience through specific indicators. The inclusion of this measure expands the relevance of aspects emphasized in current publications.

In the Brazilian tropical context, social vulnerability indicators are critical for identifying and monitoring structural inequalities that shape disaster impacts. Brazil’s diverse geography exposes communities to a wide range of hazards, including droughts, floods, landslides, and storms. However, the severity of these impacts varies according to the level of social vulnerability in affected areas.

To assess vulnerability and design mitigation strategies, Brazil has developed several indicators, the most notable being the Social Vulnerability Index (SVI), created by the Institute of Applied Economic Research (IPEA). The SVI measures social exclusion across municipalities by considering factors such as access to education, health, infrastructure, gender equity, housing, and the labor market. It is widely used to identify high-risk municipalities that often lack adequate infrastructure or are situated in hazard-prone areas. Table A.2 in Appendix 1 provides a breakdown of the SVIs and their associated resilience classifications. Notably, sustainable resilience is absent from this framework, suggesting that sustainability-oriented methods are not yet incorporated into vulnerability and disaster analyses.

The use of vulnerability and resilience indicators in tropical regions not only facilitates the identification of fragile populations but also supports the implementation of disaster mitigation and prevention strategies.

**Figure 9 – Quantitative Resilience Measures Addressed in Publications**



These tools therefore contribute to more equitable and resilient patterns of development.

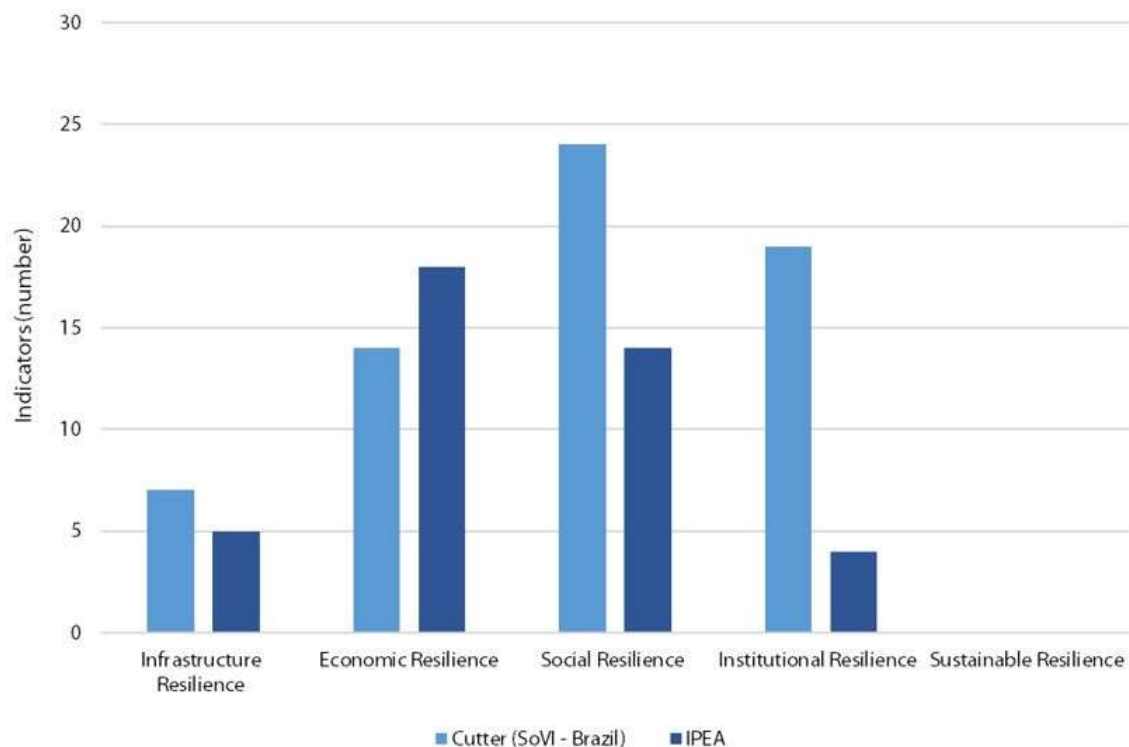
Figure 10 compares resilience indicators developed by IPEA with those proposed by Cutter, Hummell and Emrich (2016) for Brazil. The results show that, in most respects, the IPEA indices are less comprehensive than the internationally recognized SoVI-Brazil indicators. For example, Cutter's framework identifies 7 Infrastructure Resilience variables, 24 Social Resilience variables, and 19 Institutional Resilience variables, whereas the IPEA indices account for only 5, 14, and 4, respectively. This discrepancy highlights the need to integrate global assessment standards into national frameworks to improve accuracy and strengthen resilience development.

By contrast, IPEA performs better in the Economic Resilience category, presenting 18 indicators compared to SoVI's 14. This emphasis underscores Brazil's recognition of socioeconomic factors as central to disaster resilience. However, neither framework includes indicators that explicitly address Sustainable Resilience.

Overall, these findings suggest the need for consolidation between national and global measurement tools. Certain IPEA indicators are not represented in SoVI, while several global indices are absent in the Brazilian framework. Harmonizing these approaches would provide a more accurate and comprehensive picture of resilience, improving its applicability both domestically and for international comparison.

The Sustainable Development Goals (SDGs) developed by the United Nations—SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, In-

**Figure 10 – Comparison of IPEA and Cutter, Hummell e Emrich (2016) Resilience Indicators for Brazil**



novation, and Infrastructure), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 16 (Peace, Justice, and Strong Institutions)—address themes reflected in the indicators examined in this study. Table A.3 in Appendix 1 presents the relationships between the IPEA Social Vulnerability Index (SVI) and SoVI indicators in relation to the SDGs. The IPEA indices show strong correlations with SDG 5, SDG 8, and SDG 10, highlighting Brazil’s vulnerable context. The predominance of these indicators underscores the importance of measuring and addressing social inequalities and promoting economic growth, both of which represent areas of fragility in tropical regions. In contrast, the number of variables linked to other SDGs—such as SDG 3, SDG 9, SDG 11, SDG 13, and SDG 16—is lower or absent compared to international benchmarks.

## 4 CONCLUSION

The literature review revealed diverse terminologies for resilience. Despite a lack of harmonization, commonalities exist in defining resilience as the capacity for adaptation and recovery in the face of unexpected change. This conceptual framework has been applied to natural and anthropogenic disasters to better map and understand resilience in such contexts.

The analysis of urban resilience underscores both the complexity and the importance of distinguishing between inherent and adaptive resilience, as well as the ways these terms have emerged, been conceptualized,

and applied across published studies. Understanding these dimensions is essential for advancing disaster mitigation and climate change adaptation. Communities must build capacities both before and after disasters such as earthquakes, floods, and hurricanes.

Findings related to inherent resilience show that pre-existing community or system characteristics are critical for preparedness. In turn, adaptive resilience captures the capacity of communities to respond and recover after disasters, ensuring that lessons learned are integrated into future strategies.

The evidence also points to the need for an integrated approach that incorporates both vulnerability and social vulnerability indicators at national and international levels. Such integration enables more accurate assessments of community capacities to withstand disasters, despite socioeconomic or structural weaknesses. Yet, the review also highlights the relative scarcity of resilience studies focused on tropical regions.

This study further emphasizes the importance of using the SDGs as performance benchmarks, ensuring that countries monitor vulnerability and resilience-related goals when building sustainable and resilient cities.

Resilience must be viewed as a dynamic and ongoing process that requires cross-sectoral attention and cooperation, supported by effective institutions and public policies. Promoting social equity and sustainable development strengthens urban resilience, not only mitigating damages but also fostering fairer and more robust systems. A resilience-based perspective—whether adaptive or inherent—requires understanding both the physical impacts of natural phenomena and the underlying social and economic structures that shape communities' ability to protect, adapt, and recover.

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## 5 APPENDIX 1

**Table A.1 – Separation of resilience indicators present in publications**

| Resilience Dimen-<br>sion    | Variable/Indicator                                                                                  | Country |
|------------------------------|-----------------------------------------------------------------------------------------------------|---------|
| Infrastructure<br>Resilience | 1. Percentage of the urban population                                                               | Brazil  |
|                              | 2. Population density                                                                               | Brazil  |
|                              | 3. Percentage of households without access to piped water or well                                   | Brazil  |
|                              | 4. Percentage of households without access to sewage infrastructure                                 | Brazil  |
|                              | 5. Percentage of households without access to waste collection services                             | Brazil  |
|                              | 6. Percentage of households without access to electricity service                                   | Brazil  |
|                              | 7. Percentage of the population living in households with poor-quality exterior walls               | Brazil  |
|                              | 8. Emergency management buildings (fire stations, police departments, emergency operations centers) | USA     |
|                              | 9. Commercial establishments and businesses (all types listed)                                      | USA     |
|                              | 10. Governmental/institutional buildings (city halls, colleges, nursing homes)                      |         |
|                              | 11. Infrastructure systems (communications, power grid, bridges, wastew-                            |         |

USA

*Continued on next page*

| Resilience                | Dimen-<br>sion | Variable/Indicator                                                                                                 | Country |
|---------------------------|----------------|--------------------------------------------------------------------------------------------------------------------|---------|
| Economic<br>silience      | Re-            | 12. Others (recreational and arts centers)                                                                         | USA     |
|                           |                | 1. Percentage of the population living in households earning up to R\$70.00 per capita per month (extreme poverty) | Brazil  |
|                           |                | 2. Percentage of families living in multi-family households                                                        | Brazil  |
|                           |                | 3. Percentage of households without telephone (mobile or landline)                                                 | Brazil  |
|                           |                | 4. Percentage of the population employed in agriculture, fishing, forestry, livestock, and aquaculture             | Brazil  |
|                           |                | 5. Percentage of the population employed in extractive industries                                                  | Brazil  |
|                           |                | 6. Percentage of the population employed in transportation                                                         | Brazil  |
|                           |                | 7. Percentage of the population employed in accommodation services                                                 | Brazil  |
|                           |                | 8. Percentage of the population employed in food services                                                          | Brazil  |
|                           |                | 9. Percentage of the population employed in commerce                                                               | Brazil  |
|                           |                | 10. Percentage of the population employed in public administration, defense, and social security                   | Brazil  |
|                           |                | 11. Percentage of the population living in rented households                                                       | Brazil  |
|                           |                | 12. Percentage of the workforce with formal employment contracts                                                   | Brazil  |
|                           |                | 13. Percentage of the workforce without formal employment                                                          | Brazil  |
|                           |                | 14. Percentage of subsistence workers in the labor force                                                           | Brazil  |
|                           |                | 15. Annual income                                                                                                  | USA     |
|                           |                | 16. Per capita income                                                                                              | USA     |
|                           |                | 17. Wealthy retirees                                                                                               | USA     |
|                           |                | 18. Household per capita income                                                                                    | USA     |
|                           |                | 19. Median household income                                                                                        | USA     |
| Institutional<br>silience | Re-            | 1. Number of civic organizations per 10,000 inhabitants                                                            | USA     |
|                           |                | 2. Civic organizations (e.g., Kiwanis, Rotary) and political organizations                                         | USA     |
|                           |                | 3. Registered non-profit organizations                                                                             | USA     |
|                           |                | 4. Population (or %) covered by FEMA-approved hazard mitigation plan                                               | USA     |
|                           |                | 5. FEMA Community Rating System (CRS) scores                                                                       | USA     |
|                           |                | 6. 10-year average per capita mitigation expenditures                                                              | USA     |
|                           |                | 7. Number of religious adherents (or per 10,000 inhabitants)                                                       | USA     |
|                           |                | 8. Number of religious organizations (or per 10,000 inhabitants)                                                   | USA     |
|                           |                | 9. Faith-based networks                                                                                            | USA     |
|                           |                | 10. Direct experience with disaster recovery in the past 10 years                                                  | USA     |
|                           |                | 11. Preparedness                                                                                                   | USA     |

*Continued on next page*

| Resilience Dimen-<br>sion | Variable/Indicator                                                                               | Country |
|---------------------------|--------------------------------------------------------------------------------------------------|---------|
| Social Resilience         | 12. Learning from past events                                                                    | USA     |
|                           | 13. Frequency of loss-causing climate events                                                     | USA     |
|                           | 14. Number of Presidential Disaster Declarations per loss event                                  | USA     |
|                           | 15. Crop insurance policies per square mile                                                      | USA     |
|                           | 16. Coastal retreat, shoreline restoration                                                       | USA     |
|                           | 17. Acquisition of flood-prone properties, flood protection, flood early warning systems         | USA     |
|                           | 18. Authorities support vulnerability reduction                                                  | USA     |
|                           | 19. Building codes                                                                               | USA     |
|                           | 1. Percentage of women                                                                           | Brazil  |
|                           | 2. Percentage of women employed in the labor force                                               | Brazil  |
|                           | 3. Female-to-male average monthly income ratio                                                   | Brazil  |
|                           | 4. Percentage of the white population                                                            | Brazil  |
|                           | 5. Percentage of the Black population                                                            | Brazil  |
|                           | 6. Percentage of the Asian population                                                            | Brazil  |
|                           | 7. Percentage of the mixed-race (Pardo) population                                               | Brazil  |
|                           | 8. Percentage of the Indigenous population                                                       | Brazil  |
|                           | 9. Median age                                                                                    | Brazil  |
|                           | 10. Percentage of female-headed households without shared responsibility                         | Brazil  |
|                           | 11. Average number of people per household                                                       | Brazil  |
|                           | 12. Percentage of the population aged 15 or older who are illiterate                             | Brazil  |
|                           | 13. Percentage of the population who have completed or partially completed secondary education   | Brazil  |
|                           | 14. Percentage of the population with higher education degrees                                   | Brazil  |
|                           | 15. Population change between 2000–2010                                                          | Brazil  |
|                           | 16. Percentage of the workforce employed in human health and social care services                | Brazil  |
|                           | 17. Estimated population coverage by primary health care teams (2011)                            | Brazil  |
|                           | 18. Number of social security benefits granted per capita per year                               | Brazil  |
|                           | 19. Percentage of the population under age 14 and over age 60                                    | Brazil  |
|                           | 20. Percentage of the population with at least one type of disability                            | Brazil  |
|                           | 21. Percentage of the population with severe disability (visual, auditory, or motor impairments) | Brazil  |
|                           | 22. Percentage of the population born in other states                                            | Brazil  |

*Continued on next page*

| Resilience Dimen-<br>sion | Variable/Indicator                                                                                                 | Country |
|---------------------------|--------------------------------------------------------------------------------------------------------------------|---------|
|                           | 24. Percentage of residents who immigrated in the past 3 to 5 years                                                | Brazil  |
|                           | % of population with education beyond high school                                                                  | USA     |
|                           | Percentage point difference in educational attainment below high school between African Americans and Whites       | USA     |
|                           | % with high school diploma                                                                                         | USA     |
|                           | % with less than high school education                                                                             | USA     |
|                           | % with BA and % without high school diploma or GED                                                                 | USA     |
|                           | Physicians per 10,000 inhabitants (or per 1,000)                                                                   | USA     |
|                           | Total number of physicians                                                                                         | USA     |
|                           | Community services (or per 1,000 inhabitants)                                                                      | USA     |
|                           | Mutual support, hope for the future, sense of belonging, community col-<br>laboration, shared priorities and goals | USA     |
|                           | Access to essential services, emergency services, family and child support,<br>resources to address challenges     | USA     |

**Table A.2 – Separation of Social Vulnerability Indicators (SVI) and resilience classification**

| Resilience Dimen-<br>sion    | IVS Index                         | Variable/Indicator                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Infrastructure<br>Resilience | Housing/Urban In-<br>frastructure | 1. % of individuals in households with inadequate water supply and sanitation<br>2. % of the population living in urban households without waste collection services<br>3. % of individuals in households with per capita income below half the minimum wage (2010) and who spend more than one hour commuting to work<br>4. % of the population living in households with density >2 persons per room<br>5. % of the population in households with access to electricity |
| Economic<br>silience         | Re-<br>Income and Em-<br>ployment | 1. Per capita income<br>2. Average income of employed individuals aged 18 and over<br>3. % of income derived from employment<br>4. Per capita income of individuals vulnerable to poverty                                                                                                                                                                                                                                                                                 |

*Continued on next page*

| Resilience Dimen-<br>sion | IVS Index               | Variable/Indicator                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|---------------------------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Social Resilience         | Human Capital/Education | 5. Proportion of people with household per capita income at or below half the minimum wage (2010) and who spend more than one hour commuting to work<br>6. Gini Index<br>7. % of individuals in households with per capita income below half the minimum wage (2010) and dependent on elderly individuals<br>8. Unemployment rate among the population aged 18 and over<br>9. % of people aged 18 and over without complete primary education and in informal employment<br>10. Economic activity rate among individuals aged 10 to 14<br>11. Economically Active Population (EAP) – ages 10 to 14*<br>12. Economically Active Population (EAP) – ages 10 and over*<br>13. % of self-employed workers – ages 18 and over<br>14. % of employed individuals – ages 18 and over<br>15. Degree of employment formalization – ages 18 and over<br>16. % of employed individuals with completed primary education – ages 18 and over<br>17. % of employed individuals with completed secondary education – ages 18 and over |
|                           |                         | 1. Infant mortality (under 1 year of age)<br>2. % of children aged 0 to 5 not enrolled in school<br>3. % of individuals aged 6 to 14 not enrolled in school<br>4. % of females aged 10 to 17 who have had children<br>5. % of female heads of household without completed primary education and with children under 15<br>6. Illiteracy rate among the population aged 15 and over<br>7. Illiteracy rate – ages 18 and over<br>8. Illiteracy rate – ages 25 and over<br>9. % of children living in households where no member has completed primary education<br>10. % of individuals aged 15 to 24 who are not in school, not working, and whose per capita household income is at or below half the minimum wage (2010)                                                                                                                                                                                                                                                                                             |

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| Resilience Dimen-<br>sion | IVS Index            | Variable/Indicator                                                                           |
|---------------------------|----------------------|----------------------------------------------------------------------------------------------|
| Institutional<br>silience | Re-<br>Vulnerability | 11. % of individuals with 5 to 6 years of schooling                                          |
|                           |                      | 12. % of individuals aged 11 to 13 in final years of primary school or who have completed it |
|                           |                      | 13. % of individuals aged 15 to 17 with completed primary education                          |
|                           |                      | 14. % of individuals aged 18 to 20 with completed secondary education                        |
|                           |                      | 1. Vulnerable population aged 15 to 24                                                       |
|                           |                      | 2. Population living in vulnerable households with elderly individuals                       |
|                           |                      | 3. Female heads of household with children under 15 years of age                             |
|                           |                      | 4. Employed population vulnerable to poverty who commute daily from work                     |
|                           |                      |                                                                                              |
|                           |                      |                                                                                              |

**Table A.3 – List of national indicators (IPEA) and international indicators (SoVI - USA) in alignment with the SDGs**

| Sustainable<br>development<br>(SDG)   | De-<br>Goal | Technical Indicator / Variable                                                                                                                                 | Source |
|---------------------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| SDG 3 – Good Health<br>and Well-being |             | 1. Number of physicians per 10,000 inhabitants (or per 1,000)                                                                                                  | USA    |
|                                       |             | 2. Total count of licensed physicians                                                                                                                          | USA    |
|                                       |             | 3. Availability of community-based social and health services (per 1,000 inhabitants)                                                                          | USA    |
|                                       |             | 4. Access to essential services, emergency response coverage, child and family assistance, and availability of resources for addressing social vulnerabilities | USA    |
|                                       |             | 5. Infant mortality rate (deaths under 1 year of age per 1,000 live births)                                                                                    | IPEA   |
| SDG 5 – Gender<br>Equality            |             | 1. Proportion of females aged 10–17 who have experienced live births                                                                                           | IPEA   |
|                                       |             | 2. Percentage of female-headed households without complete primary education and with dependents under 15 years of age                                         | IPEA   |
|                                       |             | 3. Female heads of household with dependents under 15 years                                                                                                    | IPEA   |



| Sustainable Development (SDG)                   | De-Goal | Technical Indicator / Variable                                                                                                   | Source |
|-------------------------------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------|--------|
| SDG 8 – Decent Work and Economic Growth         |         | 1. Total number of formal economic establishments and business entities                                                          | IPEA   |
|                                                 |         | 2. Annual individual income                                                                                                      | USA    |
|                                                 |         | 3. Per capita income                                                                                                             | USA    |
|                                                 |         | 4. High-income retirees                                                                                                          | USA    |
|                                                 |         | 5. Per capita household income                                                                                                   | USA    |
|                                                 |         | 6. Median household income                                                                                                       | USA    |
|                                                 |         | 7. Per capita income (national methodology)                                                                                      | IPEA   |
|                                                 |         | 8. Mean earnings of employed individuals aged 18 and older                                                                       | IPEA   |
|                                                 |         | 9. Share of total income derived from labor earnings                                                                             | IPEA   |
|                                                 |         | 10. Per capita income among individuals at risk of poverty                                                                       | IPEA   |
|                                                 |         | 11. Proportion of individuals with household per capita income $\leq 0.5$ minimum wage (2010) and with commuting time $> 1$ hour | IPEA   |
|                                                 |         | 12. Proportion of low-income households ( $\leq 0.5$ minimum wage per capita, 2010) with elderly dependents                      | IPEA   |
|                                                 |         | 13. Labor force participation rate for individuals aged 10–14                                                                    | IPEA   |
|                                                 |         | 14. Economically Active Population (EAP) aged 10–14                                                                              | IPEA   |
|                                                 |         | 15. Economically Active Population (EAP) aged 10 and older                                                                       | IPEA   |
|                                                 |         | 16. Proportion of self-employed workers aged 18 and over                                                                         | IPEA   |
|                                                 |         | 17. Proportion of wage-employed individuals aged 18 and over                                                                     | IPEA   |
|                                                 |         | 18. Economically vulnerable employed population with daily commuting routines                                                    | IPEA   |
| SDG 9 – Industry, Innovation and Infrastructure |         | 1. Critical infrastructure systems (telecommunications, electricity grid, bridges, wastewater, water supply, dams)               | USA    |
|                                                 |         | 2. Availability of recreational and cultural facilities                                                                          | USA    |
|                                                 |         | 3. Agricultural insurance policies per square mile                                                                               | USA    |
|                                                 |         | 4. Coastal retreat strategies and shoreline restoration measures                                                                 | USA    |
|                                                 |         | 5. Enforced construction and building codes                                                                                      | USA    |
|                                                 |         | 6. Proportion of population in dwellings with inadequate water and sanitation infrastructure                                     | IPEA   |



| Sustainable<br>development<br>(SDG) | De-<br>Goal | Technical Indicator / Variable                                                                                                    | Source |
|-------------------------------------|-------------|-----------------------------------------------------------------------------------------------------------------------------------|--------|
| SDG 10 – Reduced<br>Inequalities    |             | 1. Governmental commitment to reducing vulnerability                                                                              | USA    |
|                                     |             | 2. Share of population with education beyond upper secondary level                                                                | USA    |
|                                     |             | 3. Disparity in educational attainment below high school between African American and White populations                           | USA    |
|                                     |             | 4. Proportion of population with completed secondary education                                                                    | USA    |
|                                     |             | 5. Proportion of population with less than secondary education                                                                    | USA    |
|                                     |             | 6. Proportion with a Bachelor's degree; proportion without secondary education or GED                                             | USA    |
|                                     |             | 7. Share of urban households without solid waste collection services                                                              | IPEA   |
|                                     |             | 8. % of individuals in households with per capita income $\leq 0.5$ minimum wage (2010) and commuting time $> 1$ hour             | IPEA   |
|                                     |             | 9. Household crowding index (population in households with $> 2$ persons per room)                                                | IPEA   |
|                                     |             | 10. Gini coefficient (income inequality)                                                                                          | IPEA   |
|                                     |             | 11. Unemployment rate (population aged 18 and over)                                                                               | IPEA   |
|                                     |             | 12. % of individuals aged 18+ without completed primary education and in informal employment                                      | IPEA   |
|                                     |             | 13. Degree of formalization of employment (aged 18 and over)                                                                      | IPEA   |
|                                     |             | 14. % of employed individuals aged 18+ with completed primary education                                                           | IPEA   |
|                                     |             | 15. % of employed individuals aged 18+ with completed secondary education                                                         | IPEA   |
|                                     |             | 16. % of children aged 0–5 not attending early childhood education                                                                | IPEA   |
|                                     |             | 17. % of children aged 6–14 not enrolled in school                                                                                | IPEA   |
|                                     |             | 18. Illiteracy rate among individuals aged 15 and over                                                                            | IPEA   |
|                                     |             | 19. Illiteracy rate among individuals aged 18 and over                                                                            | IPEA   |
|                                     |             | 20. Illiteracy rate among individuals aged 25 and over                                                                            | IPEA   |
|                                     |             | 21. % of children in households where no resident has completed primary education                                                 | IPEA   |
|                                     |             | 22. % of youth aged 15–24 not in education, employment, or training (NEET), with per capita income $\leq 0.5$ minimum wage (2010) | IPEA   |

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| Sustainable<br>development<br>(SDG)                       | De-<br>Goal | Technical Indicator / Variable                                                                                                            | Source |
|-----------------------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                                           |             | 25. % of youth aged 15–17 with completed primary education                                                                                | IPEA   |
|                                                           |             | 26. % of youth aged 18–20 with completed secondary education                                                                              | IPEA   |
|                                                           |             | 27. Vulnerable youth population aged 15–24                                                                                                | IPEA   |
|                                                           |             | 28. Population in socioeconomically vulnerable households with elderly residents                                                          | IPEA   |
| SDG 11 – Sustainable<br>Cities and Communi-<br>ties       |             | 1. Ratio of Presidential Disaster Declarations to total loss-inducing events                                                              | USA    |
|                                                           |             | 2. Social cohesion indicators: mutual aid, future outlook, community be-<br>longing, collaborative problem-solving, and shared priorities | USA    |
| SDG 13 – Climate<br>Action                                |             | 1. Frequency of climate-related hazard events resulting in loss                                                                           | USA    |
|                                                           |             | 2. Flood resilience measures: property acquisition, flood protection infras-<br>tructure, and early warning systems                       | USA    |
| SDG 16 – Peace, Jus-<br>tice and Strong Insti-<br>tutions |             | 1. Emergency response facilities (e.g., fire departments, law enforcement,<br>emergency operation centers)                                | USA    |
|                                                           |             | 2. Government and institutional buildings (e.g., city halls, universities,<br>long-term care facilities)                                  | USA    |
|                                                           |             | 3. Number of civic organizations per 10,000 inhabitants                                                                                   | USA    |
|                                                           |             | 4. Civic and political associations (e.g., Kiwanis, Rotary, political parties)                                                            | USA    |
|                                                           |             | 5. Registered nonprofit organizations                                                                                                     | USA    |
|                                                           |             | 6. Population (or %) covered by FEMA-certified risk mitigation plans                                                                      | USA    |
|                                                           |             | 7. FEMA Community Rating System (CRS) performance scores                                                                                  | USA    |
|                                                           |             | 8. Average per capita mitigation expenditure over 10 years                                                                                | USA    |
|                                                           |             | 9. Religious adherents (absolute number or per 10,000)                                                                                    | USA    |
|                                                           |             | 10. Religious organizations (absolute number or per 10,000 inhabitants)                                                                   | USA    |
|                                                           |             | 11. Faith-based support networks                                                                                                          | USA    |
|                                                           |             | 12. Direct experience with post-disaster recovery within the last decade                                                                  | USA    |
|                                                           |             | 13. Community preparedness for adverse events                                                                                             | USA    |
|                                                           |             | 14. Institutional memory and integration of past disaster experiences into                                                                |        |

