Correction

OPINION

Correction for "Opinion: Urban resilience efforts must consider social and political forces," by Hallie Eakin, Luis A. Bojórquez-Tapia, Marco A. Janssen, Matei Georgescu, David Manuel-Navarrete, Enrique R. Vivoni, Ana E. Escalante, Andres Baeza-Castro, M. Mazari-Hiriart, and Amy M. Lerner, which appeared in issue 2, January 10, 2017, of *Proc Natl Acad Sci USA* (114:186–189; 10.1073/pnas.1620081114).

The authors note that the affiliation for Luis A. Bojórquez-Tapia, Ana E. Escalante, M. Mazari-Hiriart, and Amy M. Lerner should instead appear as Laboratorio Nacional de Ciencias de la Sostenibilidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Mexico City 04510, Mexico. The corrected author and affiliation lines appear below. The online version has been corrected.

Hallie Eakin[a,1], Luis A. Bojórquez-Tapia[b], Marco A. Janssen[a], Matei Georgescu[c], David Manuel-Navarrete[a], Enrique R. Vivoni[d,e], Ana E. Escalante[b], Andres Baeza-Castro[a], M. Mazari-Hiriart[b], and Amy M. Lerner[b]

[a]School of Sustainability, Arizona State University, Tempe, AZ 85287; [b]Laboratorio Nacional de Ciencias de la Sostenibilidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Mexico City 04510, Mexico; [c]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ 85287; [d]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287; and [e]School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287

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OPINION

Urban resilience efforts must consider social and political forces

Hallie Eakin[a,1], Luis A. Bojórquez-Tapia[b], Marco A. Janssen[a], Matei Georgescu[c], David Manuel-Navarrete[a], Enrique R. Vivoni[d,e], Ana E. Escalante[b], Andres Baeza-Castro[a], M. Mazari-Hiriart[b], and Amy M. Lerner[b]

Environmental disasters, ranging from catastrophic floods to extreme temperatures, have caused more than 30,000 deaths per year and more than US$ 250–300 billion a year in economic losses, globally, between 1995 and 2015 (1). Improved infrastructure and planning for extreme events is essential in urban areas, where an increasingly greater fraction of the world's inhabitants reside. In response, international governmental and private initiatives have placed the goal of resilience at the center stage of urban planning. [For example, The 100 Resilient Cities Initiative (www.100resilientcities.org/); the Global Covenant of Mayors (https://www.compactofmayors.org/globalcovenantofmayors/); and the recent UN Habitat III (https://habitat3.org/the-new-urban-agenda)]. In addition, scientific and policy communities alike now recognize the need for "safe-to-fail" infrastructural design, and the potential role of green and blue infrastructure in mediating hydrological and climatic risks in cities (2).

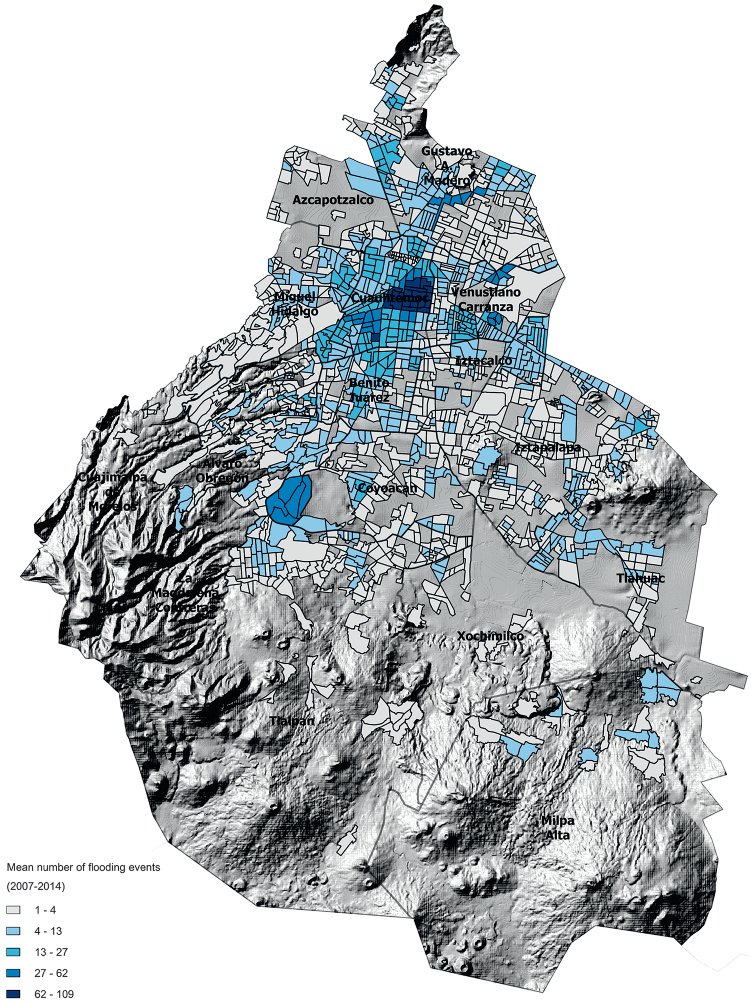

Fig. 1. Improving urban resilience could help cities better cope with natural disasters, such as neighborhood flood events in Mexico City pictured here. Data source: Unidad Tormenta, Sistema de Aguas de la Ciudad de México.

Nevertheless, the social and political norms, values, rules, and relationships that undergird and structure the myriad decisions made by public and private actors—what we call "socio-political infrastructure"—are likely to be as influential in urban vulnerability dynamics as "hard" infrastructure and environmental management. Urban planning for enhanced resilience and sustainability is ultimately a complex social and political process. Socio-political infrastructure creates patterns of behavior and action that shape the built environment. Developing more sustainable pathways of urban development hinges on making this socio-political infrastructure transparent and legible in the tools and approaches available for risk management. We argue that sustainability science is in the position to create the tools, methods, and strategies to identify, represent, and communicate the significance of these social and political processes to decision makers at all levels. In doing so, we can help ensure that these underlying drivers of urban vulnerability become subject to policy intervention.

Resilience and Sustainability

Sustainability science highlights the essential role of socio-political infrastructure in urban resilience. Sustainability is fundamentally about the normative decision process involved in steering a system to a preferred state, whereas resilience emphasizes a

[a]School of Sustainability, Arizona State University, Tempe, AZ 85287; [b]Laboratorio Nacional de Ciencias de la Sostenibilidad, Instituto de Ecología, Universidad Nacional Autónoma de México, Mexico City 04510, Mexico; [c]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ 85287; [d]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287; and [e]School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287

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[1]To whom correspondence should be addressed. Email: Hallie.Eakin@asu.edu.

system's capacity to resist disturbance and shocks. Efforts to integrate both resilience and sustainability into urban planning require tools that capture, quantify, and visualize how stakeholders' preferences, social relations, and political influence interact to affect urban vulnerabilities, which enable such processes to become tangible objects for public policy and citizen action.

As yet, decision-support tools and approaches have tended to focus on the social, cultural, and material vulnerabilities in cities (3). Although stakeholder participation in urban socio-hydrological vulnerability assessment is increasingly common, urban risk-management tools and support systems, such as US Environmental Protection Agency's Climate Resilience Toolkit (https://toolkit.climate.gov/), tend to emphasize the biophysical and technical determinants of risk. Increasing the salience of risk-management decision support requires further steps, which implies moving beyond risk assessment per se to evaluate the diverse socio-political influences on decisions (such as election cycles, constituent preferences, public relations, knowledge biases, organizational cultures, rents, and party politics) that ultimately condition urban vulnerability.

By pinpointing socio-political sources of vulnerability, risk management decision-support systems help city administrators and residents intervene appropriately. This means making explicit the spatial distribution and temporal dynamics of such social-political drivers, as well as their relationships with "hard" infrastructure and hydrological processes. In doing so, decision-makers can better evaluate how efforts to reduce vulnerability through costly hard-infrastructure investments may be derailed, for example, by the politics of water resource access or inequities in access to land for housing development.

Emerging fields, such as social-hydrology and urban ecology, are highlighting the coupled nature of biophysical and social processes in urban dynamics. Nevertheless, these fields have failed to capture the complexity of interacting formal and informal social and political influences, such as electoral politics, land-tenure insecurity, or the dominant role of special interests in water-resource distribution and access, and how these affect urban risk and resilience. In contrast, political-economic approaches, which aim to explain the nature and causes of differential vulnerability, have long argued that socio-political infrastructure often constitutes the most important determinant of differential vulnerability outcomes in cities. However, scholars from these perspectives may overemphasize the role of power and inequity, neglecting technological and ecological factors.

Hence, researchers must integrate an understanding of socio-political infrastructure into state-of-the-art models of the biophysical and technical drivers of urban vulnerability. This means recognizing that the political factors that are often considered obstacles to achieving sustainable cities are part and parcel of the dynamics of any urban space (4). However, doing so requires methods that can reveal the conflicting motivations, disparate values, and hidden preferences of urban actors whose actions have substantive consequences for the built environment, for natural resources, and for vulnerability.

Tools and Approaches

In contrast to more conventional vulnerability analysis in use today, assessments of urban resilience should not begin with vulnerability outcomes in the urban landscape (e.g., Fig. 1). Rather, these assessments should begin with the characterization of the actors' preferences in relation to risk. The aim should be to create a process model of social vulnerability based on the interaction of actors' priorities, the alternatives they envision, and—most importantly—the implicit and explicit criteria they use in making decisions.

Capturing the decision criteria that drive vulnerability is no small feat. Most of the "rules in use" and social norms that constitute socio-political infrastructure are well understood by city residents and administrators. The political party affiliation of a borough-level administrator, for example, may affect which neighborhoods are supplied with water or where investments in infrastructure are made (5). Socio-political infrastructure is thus often associated with informal and unsanctioned economic and political transactions: clientelism, corruption, or the need for decision makers to respond expeditiously to specific interest groups with disproportionate economic influence. Assessing decision processes thus depends on creating partnerships, and is therefore a delicate and political endeavor, requiring transparency and establishing legitimacy through nonjudgmental representation of stakeholders' perspectives. This outcome can only be achieved through transdisciplinary inquiry.

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A variety of social science techniques can help elicit the influence of socio-political infrastructure by identifying the real criteria that determine the decisions of key actors in the city. In our own work, for example, we have used mental models—elicited in interviews, focus groups, and participatory workshops with city managers, civil society groups, and residents—to identify the disparate problem framings and criteria they use as they confront problems of water scarcity and flooding in Mexico City. We ask participants to describe the problem as they see it: is the concern over water primarily about flooding or scarcity? What do they see as the primary causes? What actions do they take, and how do they perceive the effectiveness of their actions?

This work is not only revealing important disparities in how different groups view the causes of these threats—for example, the relative role played by natural factors, such as rainfall or topography compared with more endogenous factors such as poor maintenance of hard infrastructure—it also reveals differences in what solutions governments and citizens prefer and which solutions get enacted. For example, strategies for addressing water scarcity will differ dramatically depending on whether authorities view illegal settlements as the primary driver of unsatisfied water demand, or whether they see infrastructure inefficiencies and leakage as the primary cause of water shortages.

Although there are numerous possible mental models of urban dynamics, our initial analysis suggests that there is likely to be a parsimonious suite of such conceptualizations that can have a significant influence on urban development.

Urban space is created unevenly by those who inhabit it, through asymmetric relationships of influence and control. Residents experience and respond to flooding or water scarcity in relation to their homes, workplaces, and transportation. In aggregate, these responses—whether inadequate or successful in managing risk—affect where and how scarcity and flooding occurs and is experienced in the city. Neighborhoods that create makeshift barriers to stormwater run-off can channel water into lower elevation intersections; households who elevate the entrances to their homes may be less likely to complain to authorities of sewage in their streets. The challenge is thus to situate stakeholders' values, preferences, and decision criteria in space and place, so that scientists, residents, and city managers can evaluate the influence of such dispersed decisions on vulnerability outcomes. Essentially, the subjective elements of the mental models must be translated into objective measures salient for geospatial representation.

One approach to this challenge is to use geographic information science and multicriteria decision analysis theories, methods, and technologies (GIS-MCDA) to link stakeholders' values to map layers representing geographic attributes (6). Fuzzy cognitive maps (a graphic technique that employs fuzzy logic to calculate the strength of the relations between elements of a mental model) can be used as an initial step to capture how stakeholders differentially view the factors affecting their vulnerability. Participatory MCDA allows stakeholders to validate and weigh the different elements represented in the fuzzy cognitive maps according to which elements they perceive as instrumental in their decision making. These elements may be tangible geographic attributes (such as infrastructure conditions, flood frequency, or neighborhoods marred by water conflict) or intangible (such as trust or administrative efficiency).

If a condition in the landscape changes—for example, increased incidents of failure in drainage infrastructure—this may alter how a stakeholder weighs the importance of drainage infrastructure in relation to other elements in the system, thus affecting their response strategies. These responses—for example, investing in water infrastructure, altering home construction, or even moving homes to escape risk—in turn alter conditions in the landscape and vulnerability outcomes in the city (as represented in the GIS), creating feedbacks into the stakeholders' decision criteria (as captured in the MCDA). The resulting spatial representation of decisions then allows an exploration of how the mental models of different actors, each with different positions of influence and authority in the city, can affect distinct solution pathways, and thus patterns of vulnerability.

Case Study: Water Management

A demonstration of this concept transpired in 2015. One of Mexico City's boroughs erupted in protest, claiming the city's hosting of the Grand Prix had exacerbated their water insecurity. Even though authorities refuted any connection between the Grand Prix and the neighborhood's water supply, the high visibility of the event and the citizens' mobilization resulted in an expedient response from the public sector: the city government dispatched fleets of water tankers to the area, and allocated resources for well reparations and a water-supply facility (7). By making changes to the system of pipes and drains in the city, biophysical parameters of vulnerability—groundwater extractions drainage networks, water supply distribution—also changed. Through GIS-MCDA, we can thus understand the relative importance of such criteria as "social pressure" on public-sector action, and thus make visible the cumulative influence of social-political infrastructure on vulnerability.

Cumulatively, agents' actions are also linked to environmental dynamics at broader scales, and can be represented in geospatial models of land-use change,

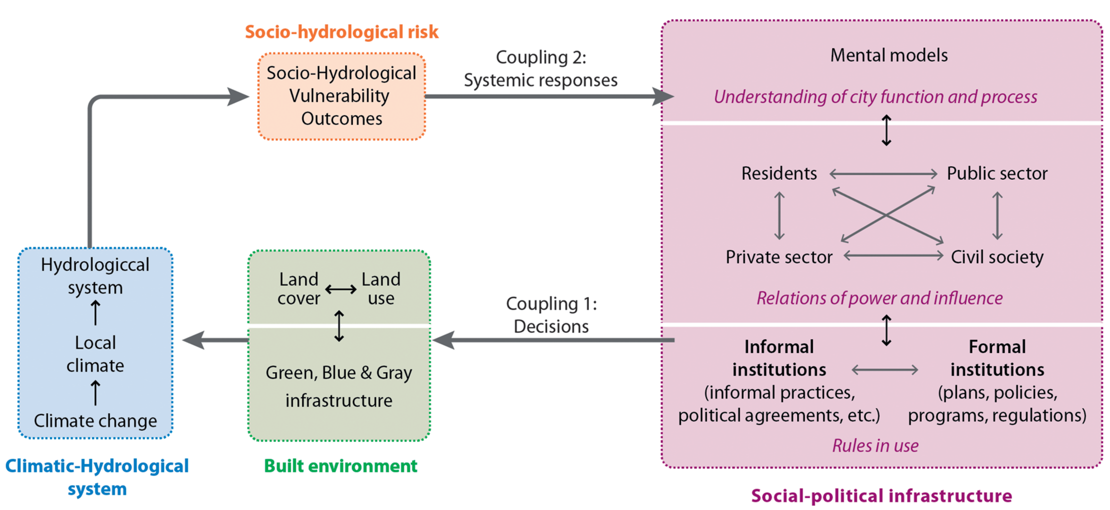

Fig. 2. The coupling of social-political infrastructure, the built environment, and the climate-hydrological system help shape urban resilience.

hydrologic flows, water-resources infrastructure, and urban climate variability (Fig. 2). For example, 600 years of urbanization has led to substantial increases in rainfall over large portions of Mexico City (8). This alone has likely exacerbated overall flood risk in the city during the rainy season.

The spatial and temporal incidence of flooding is expected to increase with continued urbanization and climatic change; city managers and residents will respond to changing flood risk according to their mental models. These responses generate feedbacks from the biophysical-infrastructure system into the GIS-MCDA. As critical values in biophysical variables are surpassed (such as a threshold of run-off volume as an outcome of urban sprawl), the relative weights of elements in stakeholders' mental models also change (for example, the relative importance of flooding over water scarcity), completing a two-way coupling of the social–environmental–technical system (Fig. 2). Agent-based modeling informed by GIS-MCDA can be a particularly useful tool to represent these dynamics.

There are significant opportunities now to represent cities in terms of scenarios that reflect these dynamics of vulnerability. Complexity researchers and others are starting to represent systems as evolving parallel processes that react to the internal states that they are perpetually creating. The methodological approaches now available provide new opportunities to depict socio-political realities and the biophysical setting as parallel-process models to capture the full complexity of cities. The two-way coupling of socio-biophysical models is essential for depicting how beliefs, strategies, and actions implicit in the mental models of actors are constantly recreating the decision-making context, leading to biophysical changes in the system and, in turn, adjustments in the actors' mental models as a result of experience, preferences, and learning.

The computational challenges of two-way coupling of socio-biophysical models are considerable. The spatial and temporal resolution of analysis that is appropriate for a watershed model to produce a flood forecast, for example, may lack saliency in terms of the intra-annual decision making of water authorities represented in an agent-based model. Decision makers themselves may operate with other units of analysis: for example, administrative units corresponding to programmatic mandates. Balancing what is meaningful and operational for science versus what is salient to decision makers is a complex process, but here again appropriate tools can help. MCDA techniques, such as the analytic network process, allow scientists to capture the continual effect of social-political processes on the biophysical, and vice versa, in a single integrated model. Fuzzy classification can be used to categorize the spatial outputs of such models into sets that are meaningful to specific audiences (6).

Making the social and political processes that undergird urban risk dynamics tractable and transparent is a political act as much as a research challenge, and one that may not be welcome in all spheres of decision making. Nevertheless, the increasing burden of managing risk and the urgency of finding more sustainable pathways of urban development provide opportunities for more transparent and democratic decision making. Sustainability science can and should help meet this challenge, using new methods that incorporate the complexities of social-hydrological risk in vulnerability assessment and planning.

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