A Framework to Integrate Climate Risk and Resilience

A Case Study on Heat

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Risk Assessment Review & Existing Gaps

Review

Risk, as a concept, is measured by a combination of factors (indicators) aimed at identifying a population's *vulnerability to harm* and the *potential magnitude of the harm*. Table 1 is a list of important terms[1] from the risk assessment literature that are used throughout this report.

Two main equations circulate in the existing literature. The Risk Triangle, originated by Crichton (1999),

Table 1: Definitions and examples of commonly used risk terminology.

Term	Definition	Example
Hazard	An event or condition that may cause injury, illness, or death to people or damage to assets	An extreme heat event
Exposure	The presence of people, assets, and ecosystems in places where they could be adversely affected by hazards	People living in areas of a city with less shading are more exposed during an extreme heat event
Adaptive Capacity	The process of adjusting to new (climate) conditions in order to reduce risks to valued assets	Those living in building with air conditioning have a higher adaptive capacity when extreme heat occurs
Sensitivity	The degree to which a system, population, or resource is or might be affected by hazards	Those over 65 and under 5 years old are less able to adapt physiologically to heat, making them more sensitive to an extreme heat event
Vulnerability	The propensity or predisposition of assets to be adversely affected by hazards. A combination of sensitivity and adaptive capacity.	A combination of those over the age of 65 without access to AC would constitute a group with high vulnerability in an extreme heat event
Assets	People, resources, ecosystems, infrastructure, and the services they provide. Assets are the tangible and intangible things people or communities value	A community cooling center that people can access during an extreme heat event

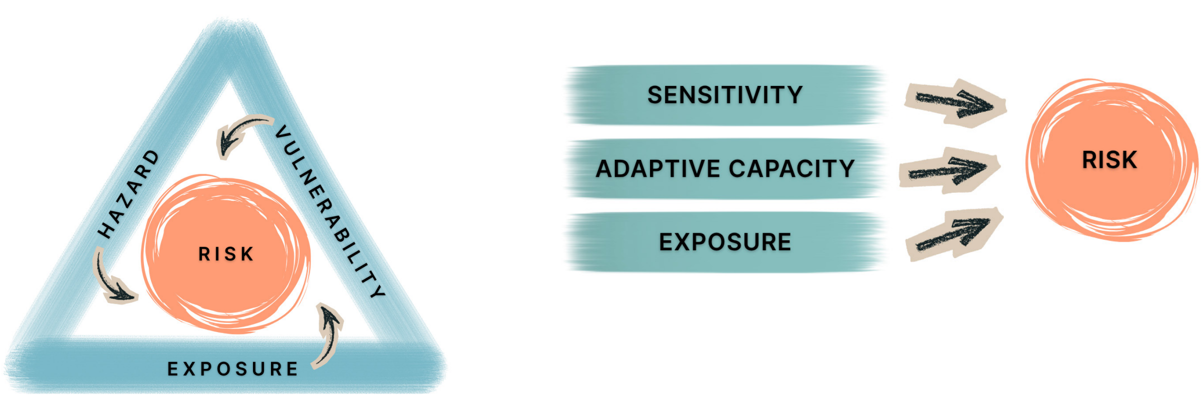

Figure 1. Pictorial representations of the two main risk equations used in the Heat Vulnerability Index literature.

1 Adapted from the US Climate Resilience Toolkit.

Table 2: The new most common risk equations used in the Heat Vulnerability Index literature, and example papers that use them.

Risk Equation Name	Risk Equation Indicators	Example Papers
Population Vulnerability Equation	Risk = Sensitivity + Exposure - Adaptive Capacity	Cutter et al., 2003; Inostroza et al., 2016; Kim et al., 2017; Rinner et al., 2010; Wilson & Chakraborty, 2019; Wolf & McGregor, 2013; Zuhra et al., 2019)
Risk Triangle	Risk = Hazard + Exposure + Vulnerability	Buscail et al., 2012; Ho et al., 2015; Hu et al., 2017

conceptualizes risk as a three-sided equation combining hazard, vulnerability, and exposure.[2] The Population Vulnerability Equation, which is more commonly used in the heat-risk specific literature, conceptualizes risk as a combination of sensitivity, exposure, and adaptive capacity.

Table 2 are the two equations, using the heat vulnerability index (HVI) literature to provide concrete examples of studies that employ each of these frameworks.

Existing Gaps

While almost all papers use one of these frameworks, the ways in which the study authors operationalize the variables used to indicate the different categories (i.e., vulnerability, hazard, etc.) differ considerably.[3] This leads to a lack of consistency both within and between studies. In addition to variability in how indicators are chosen and categorized, the methods of combining, scaling, and weighting variables also differ considerably from study to study (Cheng et al., 2021; Kim et al., 2017). Finally, vulnerability to heat depends on context specific factors, such as the availability of air conditioning, climate zones, and social/behavioral norms (Ebi et al., 2021; Hansen et al., 2013) . This variation presents a challenge in designing a one-size-fits-all framework for global cities with different climates, developmental stages, and sizes.

Despite the variety mentioned above, scholars largely agree on the categorization of some indicators. The most consistently categorized indicators are those that measure access and infrastructure, which are most often categorized as adaptive capacity (in the Population Vulnerability Equation) or rolled into vulnerability (in the Risk Triangle). For example, Buscail et al. (2012) use the Risk Triangle and include building age as a vulnerability indicator, while Inostroza et al. (2016) use the Population Vulnerability Equation and include access to water supply as an adaptive capacity indicator. Both because of the consistency of definition regarding this indicator, as well as its unique positioning within the risk equations,[4] adaptive capacity is a good place to examine more closely.

A new approach to integrating risk and resiliance

Why Adaptive Capacity?

Current measures of risk focus almost exclusively on the negative, identifying which areas will do most poorly when an adverse event occurs. While this is a necessary aspect of risk evaluation, researchers

2 The IPCC Sixth Assessment Report refers to this as the "Risk Propeller," see Fig. 1.4 of Working Group II report.

3 For examples of these inconsistencies, see Cheng et al. (2021), as well as the literature review document produced for DDL on this topic.

4 Asset management, the way in which adaptive capacity is often martialled, is perhaps the most tangible and straightforward way for communities and local governments to reduce risk. Altering hazard and exposure, while important, may not be under local control in a meaningful way (Kretzmann & Mcknight, 1993; Van Assche & Gruezmacher, 2022).

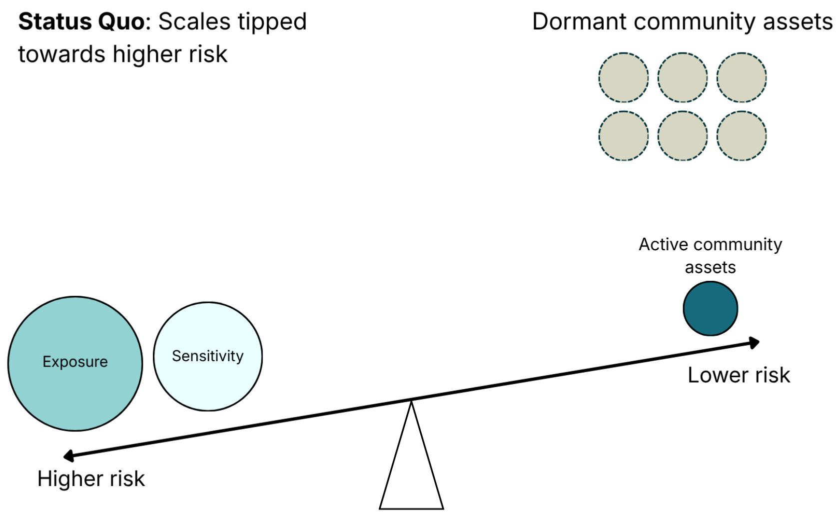

Figure 2. A pictorial representation of the traditional risk framework, with dormant community assets waiting to be activated. In this representation, the community depicted is at higher risk due to large exposure and sensitivity variables.

in the field of Asset Based Community Development (ABCD) emphasize the importance of reframing this approach to focus on the "mobilization of local assets and social capital" to solve existing problems (Maclure, 2023). Rather than proscriptive, top down approaches which focus on where communities are lacking, ABCD researchers advocate for inverting the framework to more explicitly include those assets – both physical and social – which allow for a bottom-up, community-centered approach (Mathie & Cunningham, 2003). Applying these same concepts to risk reduction leads naturally to a focus on adaptive capacity, the part of the traditional risk equations that describes community (and individual) assets.

The point is not to rate those areas with high potential as areas with lower risk, but rather to highlight those assets that already exist within a community, and to elucidate the potential pathways by which they can be leveraged to lower risk. This leads to the new conceptual framework proposed here.

Tipping the Scale: Integrating Untapped Community Assets into Risk Assessment

Take the traditional risk equation and reimagining it as a scale, weighted towards either higher or lower risk depending on the relative magnitude of the existing exposure, sensitivity, and adaptive capacity variables. Rather than focusing solely on existing community assets as the measure of adaptive capacity, the new framework splits them into **dormant** and **active community assets**. Active assets are those which are currently in play; for example, a cooling center that is open to the public whenever extreme heat warnings are issued within a community. Dormant assets, by contrast, are those tangible and intangible resources which, if leveraged by the proper policy, can become activated.

> A third way to tip the scale towards lower risk, which is not previously emphasized in the heat risk literature, is to activate those dormant community assets that already exist within a community, but are not currently being utilized in a way that reduces risk.

Ways to tip the scales in favor of lower risk traditionally include altering either the magnitude of the exposure (shifting the population away from high risk areas) or altering the magnitude of existing assets (in the cooling center example above, increasing the cooling center's hours of operation, or opening it at a lower heat threshold than before).

For instance, a densely populated urban area with majority black shingle roofs has significant potential

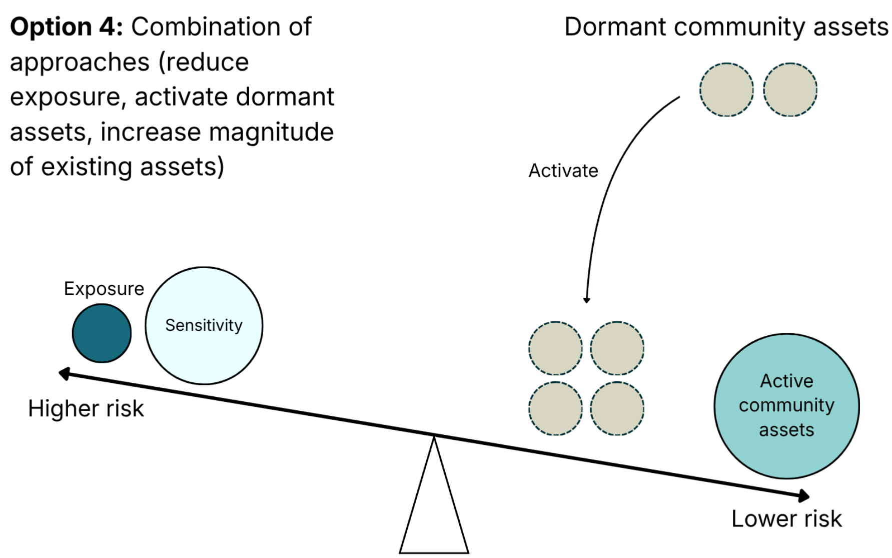

Figure 3. Using the same pictorial reference as before, our risk equation now involves the activation of dormant community assets. This approach, when combined with a decrease in exposure and increase in the magnitude of active community assets, substantially lowers the risk to the community.

(i.e., dormant community assets) to reduce exposure to the hazard by replacing those roofs with a higher albedo material, therefore reflecting more radiation and reducing heat in the area. The necessary element to activate this asset would be a policy that incentivizes cool roofing material (for example, a subsidy provided by the government for roof replacements if the new roofing material meets a certain albedo threshold, or a tax break for developers if new buildings meet certain albedo thresholds).

> By combining the traditional approaches to risk reduction with the new focus on activation of dormant community assets, a city can tip the scales towards lower risk.

Next Steps

The New Risk Equation – Weighting

One of the key challenges that needs to be solved for this framework to be rolled out effectively is to work out the actual risk equation that involves dormant community assets. Under this framework, a community with many dormant assets should score higher than a community with the same overall risk but lacking those dormant assets. However, we would not want the score to rise too high, as it would signal that the risk is substantially reduced, when in reality we are only saying that it is theoretically reduced. An example risk equation under this framework could be:

In this example, dormant assets are included, but scaled substantially lower than active assets. The exact weighting scheme under this approach would need to be determined. Possibilities for solving this problem include:

> Risk = hazard + exposure + sensitivity - activate community assets - (0.5 * dormant community assets)

1. Assigning an absolute scaling factor based on some arbitrary measure of importance (similar to how one might weight an unreliable data source to be less important to the overall equation)

Box 1: What is dimensionality reduction, and why does it matter?

Dimensionality reduction, commonly accomplished through a statistical technique called Principal Component Analysis (PCA), is a way of taking large, complex data sets and reducing them to their most important "components." This reduction makes it easier to see trends in the data by filtering out the "noise" and retaining those aspects of the data that contribute the most variance to the outcome. Why might we use this technique to understand heat risk? As explained in the Review and Existing Gaps sections, risk is an extremely complex concept to measure, being made up of a large number of components that contribute in varying degrees to the overall risk measurement. Applying dimensionality reduction techniques is one way to sift through these many variables and pull out those factors that contribute the most to the overall risk.

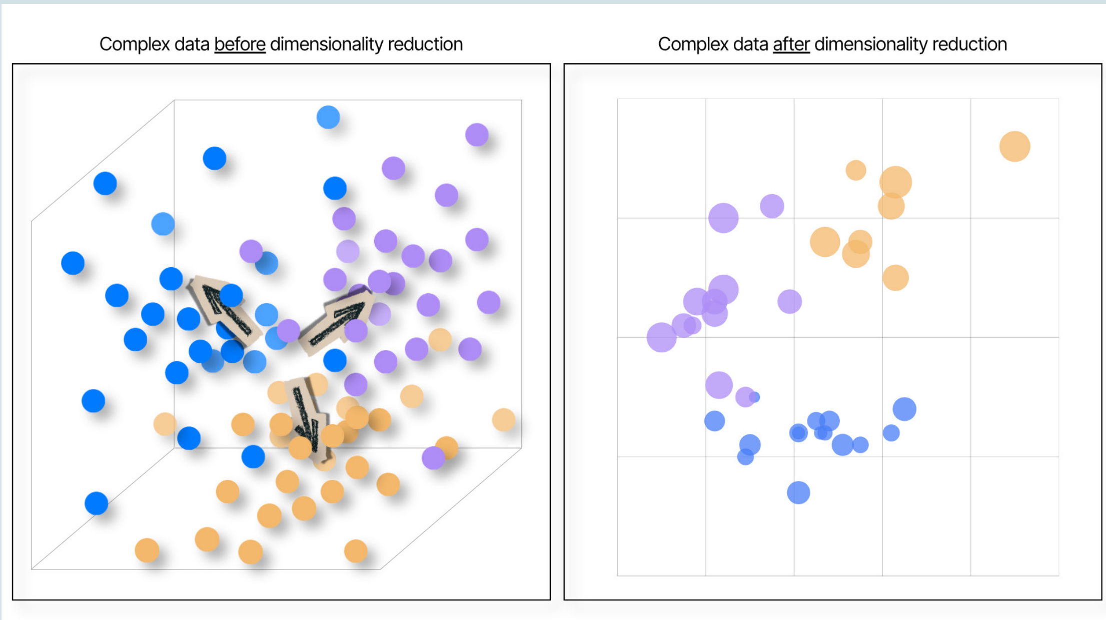

Figure 4. An example of how dimensionality reduction helps to simplify complex data, such as heat risk factors, in order to better observe trends.

2. An approach that takes into account the sensitivity of the variable weighting, and throws out those weighting schemes which cause too extreme a variance in the final risk score

3. A review of existing literature to make an informed guess based on importance (for instance, examining papers that apply principal components analysis (PCA) to heat risk indices to determine the most important factors)

Context Specific Indicators & Data Availability

As mentioned in the background section, a second challenge is defining the context specific nature of risk and of community. Defining what constitutes a "community asset," or "adaptive capacity" more generally, will be highly dependent on both the needs of and the challenges faced by local communities themselves. For the purposes of a globally relevant framework, we will likely have to

Box 2: Activating a dormant asset, or increasing the magnitude?

One possibility to solve this debate is to look to the analytical frameworks in existing literature. For instance, in the United States, administrative institutions are often called upon to define what constitutes a "new" policy when the question of unfunded mandates arises (Congressional Budget Office, 2023), and a similar logic model could be applied to determine if a policy is "new" or a merely a modification of an existing policy. For example, the Unfunded Mandates Reform Act (UMRA) of 1995 defines a "new" policy as one that is created from scratch or one that increases the stringency of an existing policy above a certain monetary threshold (ACUS *Information Interchange Bulletin No. 041*, 2025). Similarly, activating a dormant asset could involve either a completely unused asset, or changes to an existing asset that exceed a certain threshold of financial, administrative, or personnel expenditure.

make some judgement calls about which assets can be reliably measured and are widely applicable. Some community assets may be more relevant in some areas than others.

Deciding Between Active and Dormant

A third challenge will be determining what constitutes an active asset whose magnitude is being increased, versus what constitutes a dormant asset that is being activated. In the above example of cooling centers, would opening a new cooling center in a previously disused government building be adding to the magnitude of existing cooling center capacity, or activating a new asset that previously was not used? We suggest that communities consider the "activating arrow" in the above diagram (Figure 3). If the asset needs a new policy put in place in order to start working to reduce risk, then a dormant asset is being activated. If all that is being done is a tweak to an existing policy, then the asset is already active. Of course, this then leads to the question of what constitutes a "new" policy (is extending operating hours a new policy, or a change to an existing policy?). Some of these cases will be clear cut (a policy for cool roofing material where no policy has existed before), while others will be more murky. However, we suggest that these fine distinctions need not be figured out from the beginning. An iterative process involving practitioners, local government officials, and relevant stakeholders will most likely be necessary to make these determinations.

Conclusion

Under the novel conceptual framework proposed in this document, we put forth a bottom-up approach to risk reduction that emphasizes both existing and potential community assets. This new framework is designed to provide communities with a more practical and positivistic approach to risk reduction. Using examples from the Heat Vulnerability Research sphere, we propose a framework that can be widely applied across risk arenas and across global communities.

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