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A vulnerability research framework for the development of early warning systems for floods

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Institute for Advanced Development Studies



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A Vulnerability Research Framework for the Development of Early Warning Systems for Floods

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La Paz, September 2017

Abstract

Flood risk is increasing in urban areas due to increased population and urban development, a changing climate, coastal subsidence, and deforestation. To reduce people's exposure to floods, many countries have identified the need for Early Warning Systems for Floods (EWSFs). In the United Nations Climate Change COP15, sixteen of the 21 Latin American countries listed the improvement and establishment of early warning systems as a priority need. In this paper, we present a multi-scalar operational research framework that is being used to investigate EWSFs across three countries in Latin America. This novel framework can be applied to institutions or flood-prone communities, providing a standardized and integrative analysis at local and national levels. By analyzing interventions before, during and after flooding events, this generalizable assessment tool provides decision makers with information to evaluate the resource requirements for improving EWSFs.

Keywords: Early warning systems, flooding, vulnerability, risk management, Latin America.

JEF classification: D63, D81, I31, Q54.

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1. Introduction

The impact of flooding is increasing in urban areas (Hanson et al. 2011, De Sherbinin et al. 2007) due to increased population and assets, a changing climate (Nicholls 2007), coastal subsidence (Nicholls 1995, Dixon et al. 2006, World Bank 2010), and deforestation (Bradshaw et al. 2007, Gentry and Lopez-Parodi 1980). Extreme El Niño events, associated with flooding in regions such as southern Ecuador (Serrano Vicenti et al. 2016, Rossel, Le Goulven, and Cadier 1999), are projected to double in frequency as greenhouse-gas emissions continue to rise this century (Cai et al. 2014). Optimistic scenarios of sea level rising due to climate change are estimated at 20 cm by 2050 (Hallengate et al. 2013). With increased flooding, losses to human health and community assets are also expected to increase, making it critical to prepare for larger flooding disasters (Hallengate et al. 2013). Flooding events are exceedingly costly, due to damages to infrastructure and housing, income fluctuations, damages to crops and livestock, and increased human morbidity and mortality (i.e., injuries, infectious diseases, dietary problems, exposure to pollutants and mental trauma) (Hallengate et al. 2013, Rosales 2014, and Few et al. 2004).

Many countries have identified the need to implement Early Warning Systems for Floods (EWSFs) to reduce people's vulnerability to flooding at the community level (Charvériat 2000, United Nations 2006). When implemented effectively as part of a comprehensive risk management plan, an EWSF increases community and ecosystem resilience, reduces vulnerability and reduces damages to economies, health, property, infrastructure, and other assets of people, communities, nations, and the private sector. Globally, there exists a need to increase access to early warning systems and assessments of disaster risk through improved disaster mapping and assessments, modeling and monitoring, dissemination strategies, and public education surrounding multi-hazards risk (United Nations Global Survey of Early Warning Systems 2006; United Nations Sendai Framework for Disaster Risk Reduction 2015). In the United Nations Climate Change COP15, sixteen of the 21 Latin American countries listed the improvement and establishment of early warning systems as a priority need. Early warning systems were also included in many countries' (Intended) National Determined Contributions, (I)NDCs, as part of their adaptation measures.

In this context, we present an operational research framework to inform policymakers, practitioners and communities interested in developing EWSFs. This framework is based on a systematic synthesis of flood risk attributes, sub-attributes, and example indicators identified through a review of the literature and validation with key local and national-level stakeholders from Bolivia, Ecuador and the Dominican Republic, as described previously (del Granado et al. 2016).

2. Multi-scalar flood vulnerability framework

2.1. Risk management

The flood vulnerability framework presented here fits within a risk management context (Figure 1). Risk is described as a measure of the probability and severity of a given hazard and the consequences of those hazards on the normal functioning of the community (Haimes 2009, Lavell 2012, Renn 1992). Risk analysis has a history of being highly quantitative and consequently has overlooked broader, and often more qualitative, social, cultural and historic dimensions (Renn 1992, Merz 2010a, Few et al. 2004, Haimes 2009). In response to this critique, researchers have called for increased systems-based thinking (e.g. Haimes 2009), as

well as “qualitative” normative risk characteristics within localized social, cultural and historical contexts (Renn 1992). Previous authors have suggested combining indicators of hazard and social vulnerability as determinants of risk in order to overcome the limitations of narrowly focused risk analyses (Haimes 2009, Lavell 2012). This framework is designed to bring localized information into broader-scale risk or hazard analysis (e.g. the Global Natural Disaster Hotspot framework by Dilley et al. 2005). We draw from concepts and definitions from previously proposed and more generalized frameworks (i.e. Turner et al. 2003, Füssel and Klein 2006; Metzger et al. 2006; Uyttendaele et al. 2011), and present a novel adaptation of these frameworks to include indicators more usable in a context of flooding in Latin America.

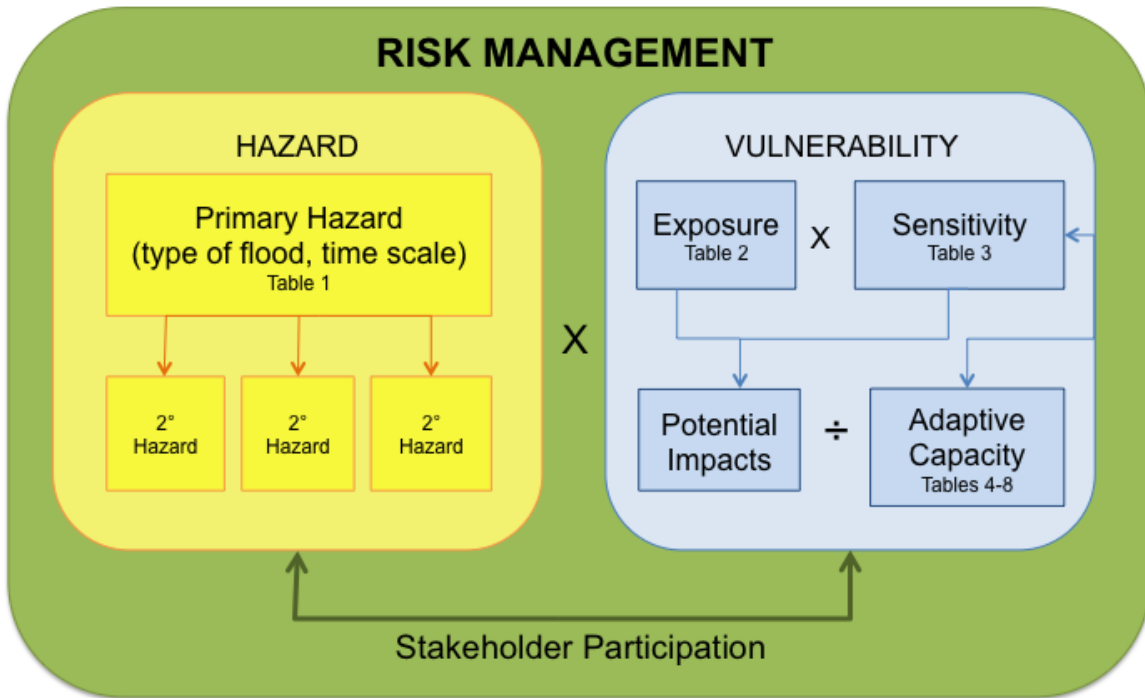


Figure 1. Conceptual framework for flood vulnerability analysis in the context of risk management (adapted from Füssel and Klein 2006, Metzger et al. 2006, Wilhelmi and Hayden 2010).

In the following section, we present measurement models for this framework, with attributes, sub-attributes and example indicators listed for each component. The primary attributes are hazard and vulnerability. The sub-attributes of vulnerability include exposure, sensitivity and adaptive capacity, as well as their applicable spatial scale. Below we summarize each attribute as well as their potential contribution to the development of localized EWSFs.

2.2. Hazards

Hazard assessment is an initial step in developing EWSFs. Hazards are conditions or physical situations with a potential for an undesirable consequence, such as a flooding event (Lavell 2012). We present various characteristics used to describe or measure flood hazard (Table 1). The first attribute to consider is the type of flood, as determined by the local geography, the

built urban environment, and hydro-meteorological conditions. The time-scale of the flood is a second sub-attribute of hazards. Floods may be seasonal, occurring each year during the rainy season, or episodic, occurring every twenty years during strong El Niño events. Frequency can be measured quantitatively by meteorological reports and reports by the risk management institution (for example, Serrano Vicenti et al. 2016) and qualitatively through community memories (traditional knowledge) of seasonality and extreme climate events (Nyakundi et al. 2010).

Table 1. Flooding hazards

Sub-Attributes of Hazards		Examples
Primary Hazard: Floods	Type of flood event	<ul style="list-style-type: none"> • Sewer/canal flood • Riverine flood • Hurricanes/tropical storms • Tidal flood
	Time scale occurrence of flood event	<ul style="list-style-type: none"> • Episodic: El Niño extreme events or hurricanes • Seasonal: Annual/interannual rainfall events
Secondary hazards		<ul style="list-style-type: none"> • Road erosion • Drain/canal blockages from trash • Mass landslides • Salinization of water supply • Infrastructure and property damages • Water-borne disease outbreaks (cholera, typhoid, leptospirosis, fungal skin infections) • Vector-borne disease outbreaks (dengue fever, chikungunya, zika) • Venomous snake bites and/or zoonotic diseases • Drowning and loss of life

Common primary flood hazards in Latin American include sewer flooding, riverine flooding, tidal and hurricane flooding, based on the varying hydrological systems (del Granado et al. 2016). Sewer/canal floods occur within hours following heavy rain and are caused by over-saturation of the sewer and canal systems. Riverine floods in delta communities are caused by rain events in the mountains or broader riparian areas, sometimes over an hour's distance by automobile or bus. Hurricane floods, common in Caribbean countries, occur due to storm surges and lack of drainage in low-lying areas. Tidal floods can compound the effects of other types of flooding events, preventing floodwaters from receding quickly, as commonly occurs in coastal Ecuador (Figure 2).

From these primary flooding hazards, stem secondary hazards created by the flooding events. For instance, secondary hazards associated with a riverine or tidal flood include erosion and associated sicknesses from exposed sewage. Secondary hazards associated with annual rainfall events and storm drain blockages within the urban core may lead to pools of standing water that trigger vector-borne disease outbreaks, like dengue, chikungunya, and zika. Both primary and secondary hazards are generally socioecological, since natural occurrences or processes both impact and are impacted by human actions, manifesting as flood hazards (e.g. Merz et al. 2010a and Merz et al. 2010b).



Figure 2. A family is shown evacuating during a major flood on February 26, 2016, when over 170 mm of rain fell in the coastal city of Machala, Ecuador, in 10 hours and coincided with high tides (Machala Soportó La Lluvia Más Fuerte Del Año | El Comercio n.d.). Machala is typical of cities in Latin America, which lack structured urban planning. Low-income neighborhoods in the urban periphery are exposed to flooding during extreme rainfall events in El Niño years, as shown here, and experience loss of property and livelihoods. Photo credits: Dany Krom.

The hazard analysis provides the foundation for the development of an EWSF, allowing practitioners to strengthen surveillance of flood events in key places and at the appropriate timescales. This analysis also allows the risk management sector to identify other sectors associated with the management of secondary hazards, such as the health sector.

2.3. Vulnerability

Vulnerability describes the potential impacts of the flood on the affected community and the capacity of the community to adapt to a flood. Broadly, vulnerability is defined as the state of sensitivity to harm due to exposure to stresses associated with environmental and social change and due to the inability to adapt (Adger 2006). People's vulnerabilities to flooding and other disasters vary across spatial, temporal and organizational scales (Wilhelmi and Hayden 2010). In this context, we define vulnerability as a function of *exposure*, *sensitivity*, and *adaptive capacity*, similar to more generalized frameworks (Turner et al. 2003, Eakin and Luers 2006) and problem-specific frameworks (Wilhelmi and Hayden 2010). Exposure refers to the physical threat, sensitivity is the extent to which a system or population can absorb impacts without suffering long-term harm, and adaptive capacity is the potential of a system or population to modify its features and behavior so as to better cope with existing and anticipated stresses (Figure 1).

Table 2. Exposure to Flood Events

Sub-Attributes of Exposure	Example Indicators
Proximity to hazard	<ul style="list-style-type: none"> • Proximity to rivers/canals, low lying areas or stagnant pools of water
Duration	<ul style="list-style-type: none"> • Hours to months • Depends on rain persistence, lingering of stagnant water
Timing	<ul style="list-style-type: none"> • Nighttime events vs. daytime events
Elevation	<ul style="list-style-type: none"> • Low lying neighborhoods
Land use	<ul style="list-style-type: none"> • Impacts of impervious/vegetated surfaces to runoff • Deforestation • Enforcement of zoning/land use regulations and building codes • Drainage systems

Exposure to flooding describes the presence of communities in places that could be adversely affected by hazard events (Table 2, Figure 2). These communities are subject to potential future harm, loss, or damage (Lavell et al. 2012). Exposure can be described by the aerial extent and the severity of the flood in relation to affected communities. The attributes of exposure are from the perspective of affected communities, rather than descriptive elements of the event, and include: proximity to hazard, duration, timing, elevation and land use. Example indicators are presented in Table 2. EWSFs can target the key local attributes of exposure in warning and flood management interventions. Identification of high-risk communities based on exposure indicators, like drainage impediments in specific zones, can assist in the prioritization of areas during evacuations and aid in the development of detailed flood-risk maps to inform zoning decisions

Sensitivity, also called “susceptibility,” refers to the physical predisposition of exposed individuals or communities to be negatively affected by a flood event due to lack of resistance or predisposition to suffer harm as a consequence of a flood event (Gallopín 2006, Adelekan and Asiyambi 2016, IPCC 2012) (Table 3). As with exposure, the higher the sensitivity, the higher the overall vulnerability may be (Füssel and Klein 2006, Metzger et al. 2006, Wilhelmi and Hayden 2010). Greater exposure and greater sensitivity interact to increase the impact of flooding on a community. Sensitivity is determined by the socio-cultural and structural factors that leave some individuals more affected by flooding than others. Examples of structural aspects of flood sensitivity include the characteristics of the building structure. Homes constructed with bamboo siding, typical in the urban periphery in coastal Ecuador, are more likely to fall apart during flood events than homes made of concrete blocks or homes made of wood. Examples of cultural aspects include age of the population (younger versus older people), physical ability (mobility issues), and other health considerations (Table 3). People whose livelihoods are dependent on the land or sea may also be more sensitive to flood events, such as indigenous groups that cultivate in riparian zones, as the Ese Ejja in the Bolivian Amazon (M. Romero, *pers. comm.*) or artisanal fishermen who require certain water levels for gathering clams and harvesting shrimp, as in coastal Ecuador (Figure 3). EWSFs can deliver information on prevention or post-disaster recovery programs to sensitive groups, such as customized information about health-risk prevention to families with children and elderly members within flood risk areas. Economic preparation or recovery programs can be targeted to the most sensitive economic groups, such as those in the

agricultural or fisheries sector.

Table 3. Sensitivity to Flood Events

Sub-Attributes of Sensitivity	Indicators
Building instability	<ul style="list-style-type: none">• Buildings made from unstable housing materials (e.g. walls made of bamboo siding or plywood versus concrete blocks)
Lack of access to dry areas	<ul style="list-style-type: none">• Single-story buildings• Lack of family or friends to provide dry refuge during floods
Demographic groups with low immunity to flood-related diseases	<ul style="list-style-type: none">• Age (children under 5 years of age and elderly)• Individuals with compromised immune systems
Demographic groups lacking psychological/ physical abilities	<ul style="list-style-type: none">• Individuals who do not know how to swim• Individuals with physical or mental disabilities• Individuals who have endured extreme emotional trauma
Demographic groups with specific land-use needs	<ul style="list-style-type: none">• Artisanal fishermen of crabs, shrimp and clams• Farmers• Indigenous riparian cultures

Adaptive capacity refers to the ability of the system to respond or adjust to a flooding event, to moderate potential damage, to take advantage of opportunities, and to cope with the transformations that occur as a result of the flooding (Gallopín 2006). Thresholds and “coping ranges” are the conditions that a system can deal with, accommodate, adapt to, and recover from while maintaining the baseline state of the system (Smit and Wandel 2006). This coping range, or capacity to respond, is also contingent upon the community’s overall resiliency and ability to return to normal conditions (Gallopín 2006). Resilience is defined as the amount of disruption needed to transform a system from one domain of stability to another (Gunderson and Holling 2002, Holling 1973). Most communities can cope with (or adapt to) normal climatic conditions and moderate deviations from the norm (i.e. domains of stability), but extreme events that lie outside the coping range will exceed the adaptive capacity of the community (Smit and Wandel 2006). As a community’s adaptive capacity increases, the impact of flooding, as determined by exposure and sensitivity, will decrease.

Adaptive capacity is also determined by community characteristics that facilitate response and coping mechanisms to both a specific flood event and to multiple generic stressors (e.g. economic poverty, health, or discrimination). Lemos et al. (2011) distinguish between generic and specific adaptive capacities, which are impacted by specific factors (e.g. coastal protection initiatives and other flood management actions or infrastructure) and generic factors (e.g. lack of income, education, health, political power) (Lemos et al. 2011).



Figure 3. People whose livelihoods depend on small-scale artisanal fisheries in flood-prone coastal regions, such as the man shown here, are highly sensitive to the impacts of flooding (Machala, Ecuador, February 2016). Floods may reduce their financial capital and their adaptive capacity. Photo credits: Dany Krom.

2.4. A livelihoods-based approach to adaptive capacity

In this framework, adaptive capacity is described by livelihood resources, as indicated by various forms of capitals, including social, human, physical, financial and natural capitals (Eakin and Lemos 2006, Smit et al. 2001 and Yohe and Tol 2002, Lemos et al. 2011). In assessing these capitals in relation to individual impacts, we can begin to understand the various capacities to adapt to generic stressors (e.g. poverty) and to specific stressors related to flooding events. The economic metaphor used here, livelihood *resources*, refers to the capital base that produces adaptive capacity (Scoones 1998). Higher and/or more robust capitals suggest a higher and more robust adaptive capacity. Both measurements of adaptive capacity, degree (i.e. the amount of a single capital) and robustness (i.e. the diversity of multiple capitals), act to decrease overall vulnerability.

Social capital includes the social resources (e.g. networks, social claims, social relations, affiliations, associations) that people leverage when pursuing livelihood strategies that require coordinated action during the various stages of flooding (Table 4). Community level indicators include social cohesion (Stewart Ibarra et al. 2014), leadership, social equity, and community surveillance systems (Abon, David and Tabios 2012) (Figure 4). Institutional indicators include management structures and the degree of communication and trust between impacted communities and institutions involved in flood risk management efforts (del Granado et al. 2016). In areas with high social capital, effective strategies may include community flood response simulations, inter-institutional coordination efforts, and community-based efforts to rebuild homes (del Granado et al. 2016). For example, strong

family relations may allow communities to self-organize evacuations and to provide continuous emotional support, while government institutions intervene to provide aid at specific time points. Social capital can also facilitate the development of small-scale “artisanal” warning systems that use existing communication networks in small communities in coordination with formal early warning systems. In contrast, in areas where community members and local governments have strained relationships marked by historically distrust, it may be difficult to mobilize community members to respond to flood warnings or to adopt preventative measures (Fatti and Patel 2013).

Table 4. Adaptive Capacity to Floods as Measured by Social Capital

Social Capital Sub-Attributes	Example Indicators
Effective multi-scale flood management structure	<ul style="list-style-type: none"> • Establishment of flood management committees or flood response community brigade and neighborhood cleanup crews • Functional emergency response systems • Number and quality of relationships between flood authorities and local neighborhoods to deliver assistance to affected communities
Public participation	<ul style="list-style-type: none"> • Pathways for affected individuals to provide input institutional management decisions • Access to and ability to share quality social media information related to flooding
Cohesion	<ul style="list-style-type: none"> • Ability of neighborhood to self-organize around local issues • Effective working relationships between communities and institutions
Collective memory	<ul style="list-style-type: none"> • Communication between long-time residents/staff and more recently arrived residents/staff
Surveillance	<ul style="list-style-type: none"> • Ability to protect personal property against looting during evacuations • Functional monitoring systems
Social equity	<ul style="list-style-type: none"> • Sense of empowerment across stakeholder group • Stigmatization of affected areas/communities (inverse metric)
Self-initiative to prepare	<ul style="list-style-type: none"> • Preparation of individual homes and institutions for flood risks (e.g. stored food, water and evacuation materials)
Social support	<ul style="list-style-type: none"> • % of households with single parent household (inverse metric) or retirees • Knowledge of and access to shelters/undamaged homes of relatives • Inclusion of comprehensive health care in flood response/preparation stages • Access to food and water deliveries
Leadership	<ul style="list-style-type: none"> • Champions for flood risk prevention/management • Respect across local community or institutions



Figure 4. Community members work together to remove debris from a blocked canal on the urban periphery of Machala, during a major flood in 2016. Community leadership and social cohesion are key aspects of social capital, which affects their adaptive capacity. Photo credits: Dany Krom.

Human capital includes the skills, knowledge, ability to labor and good health and physical capability important for the successful pursuit of different livelihood strategies (Lemos et al. 2011) (Table 5). Human capital indicators reflect the degree of knowledge about particular topics related to flooding and amount of people available to work on flood risk management efforts. At a community level, knowledge can be indicated by comprehension of flood risk maps or warnings. In institutional settings, knowledge refers to particular skill sets available for flood risk management, such as economic analyses or spatial analyses. At both a community and institutional level, human capital can be improved through leveraging resources to adequately staff or train individuals (del Granado et al. 2016). An assessment of human capital can inform the development of EWSFs, such as the material included in alert messaging or the tools used to disseminate information. For example, in multicultural and multilingual settings, such as border regions, word of mouth by trusted leaders may be the most effective communication strategy. Human capital should also be considered when analyzing the institutional capacity needed for an EWSF. Due to politically appointed leadership within emergency management committees, there may be frequent transitions in membership, which can result in knowledge gaps and lack of awareness needed to make context-sensitive decisions. Corruption, funding shortages and lack of accountability, especially during crises, can decrease overall financial capital and therefore human capital (del Granado et al. 2016).

Table 5. Adaptive Capacity to Floods as Measured by Human Capital

Human Capital Sub-Attributes	Example Indicators
Knowledge of flood management systems	<ul style="list-style-type: none"> • Access to television/radio warnings • Comprehension of monitoring outputs and warnings • Engineering expertise needed for adequate planning and recovery efforts • Understanding of flood management emergency response processes • Previous experience with EWSFs
Training for flood response	<ul style="list-style-type: none"> • Training and experience of staff • Community education with flood response drills
Adequate number of individuals dedicated to flood response efforts and risk management	<ul style="list-style-type: none"> • Quantity of trained staff • Number of individuals involved with community brigades or community cleanup efforts
System-wide accountability	<ul style="list-style-type: none"> • Yearly evaluation and debrief sessions after flooding
Population density	<ul style="list-style-type: none"> • People per household X number of households • Home vacancy rate (N) (inverse metric) • Percent of homes with more than 4 people per bedroom
Education	<ul style="list-style-type: none"> • Number of people with secondary or post-secondary education • Continuation of child education due to shelters occurring in non-school areas, flood resilient schools and access to dry roads
Literacy	<ul style="list-style-type: none"> • Number of people who are literate
Diversity of skills	<ul style="list-style-type: none"> • Diversity of professions/backgrounds • Diversity of age groups and gender

Physical capital includes the physical items (including material, basic infrastructure, equipment and technologies) that assist in the pursuit of livelihood strategies during a flood (Lemos et al. 2011, del Granado et al. 2016) (Table 6). Physical capital for flood risk management includes the materials and equipment needed at both a household level, such as potable water, and institutional level, such as adequate trash collection systems to avoid storm water blockages. By understanding community resources available for flood response, such as local construction materials or local community gathering spaces, flood practitioners can design appropriate flood risk reduction interventions. Analyses of physical capital should consider the long-term impacts of a project. Low-quality materials, justified by short-term savings, will ultimately compromise the ability of infrastructure to withstand floods in the long-term. Infrastructure investments, if not carefully planned, can also create perverse development incentives. For example, infrastructure built to divert floodwater to formerly unflooded areas, can result in the gentrification of the newly a dry area and the growth of low-income housing projects in flood prone areas (del Granado et al. 2016).

Table 6. Adaptive Capacity to Floods as Measured by Physical Capital

Physical Capital Sub-Attributes	Example Indicators
Equipment	<ul style="list-style-type: none"> • Access to flood protection/recuperation equipment, such as sand bags, pumps, shovels and medical equipment • Quality of material to fill-in property parcels
Physical meeting space	<ul style="list-style-type: none"> • Appropriate amenities for planning meetings
Food and potable water access	<ul style="list-style-type: none"> • Access to grocery stores or other sources of food and bottled water
Access to effective transportation	<ul style="list-style-type: none"> • Access to effective transportation options
Communication infrastructure	<ul style="list-style-type: none"> • Ownership of or access to TV/radio/internet devices
Monitoring equipment	<ul style="list-style-type: none"> • Ownership of or access to monitoring equipment
Potable water	<ul style="list-style-type: none"> • Rooftop cisterns • Bottled water supply
Connection to public services	<ul style="list-style-type: none"> • Access to sewerage, piped water, paved streets and garbage collection
Housing/property type	<ul style="list-style-type: none"> • Durable housing material (e.g. cement) • Two+ stories to store personal belongings • Fill material used to elevate home higher than adjacent areas

Financial capital includes the monetary base essential for the pursuit of livelihood strategies related to floods, including cash, credit/debt, savings, and other economic assets, including home ownership and other demonstrations of financial stability (Lemos et al. 2011) (Table 7). The financial capitals relevant to flooding at an institutional level include adequate budget reserves for floods during extreme weather events and efficiency in releasing those funds during times of crisis (del Granado et al. 2016). At an individual household level, the level of income impacts the recovery period needed for homeowners to recover from floods, along with the flexibility of work hours from their source of employment. Assessing financial capital informs the development of EWSFs by providing insight on the financial characteristics that may shape the ability to implement and sustain nearly every aspect of the EWSF, from purchasing equipment to hiring staff members. It is also important to consider the mechanisms for the disbursement of flood management funding and innovative funding solutions for communities impacted heavily by flooding. These insights may be helpful in implementing programs to fund flood recovery actions, such as flood insurance programs, which are not commonly available in countries in Latin America (Charvériat 2000, Surminski and Oramas-Dorta 2014).

Natural capital is the natural resource stocks (soil, water, air, genetic resources, etc.) and environmental services (hydrological cycle, pollution sinks, etc.) from which resources and services useful for livelihoods are derived (Lemos et al. 2011). (Table 8). Measures of natural capital indicate the health and quality of surrounding natural resources, such as water or soil contamination and vegetated buffer areas around canal ways. Natural capital indicators play a fundamental role when planning for flood risk prevention, such as installing green infrastructure or conducting garbage clean-up days in areas near sewerage canals. The presence of garbage in natural areas can be a key contributor of flooding, and floods can be prevented by community cleanup crews. The use of natural buffer areas along waterways is an effective means of reducing flood exposure and mitigating floods by increasing the porosity of waterways. EWSFs can be used as education tools to promote these green infrastructure solutions as part of integrated flood prevention efforts.

Table 7. Adaptive Capacity to Floods as Measured by Financial Capital

Financial Capital Sub-Attributes	Example Indicators
Sufficient budget resources available or dedicated for flood actions	<ul style="list-style-type: none"> • Ratio of available funds for flood actions to previous flood-related expenses • Household income
Effectiveness in allocating resources	<ul style="list-style-type: none"> • Quickness in dedicating necessary funds during flood events • Efficiency of fund allocation (% required for overhead expenditures)
Insurance	<ul style="list-style-type: none"> • Percentage of flood-risk homes holding flood insurance • % of monthly income being paid for insurance plan • Insurance coverage
Flood-Independent Financial Assets	<ul style="list-style-type: none"> • Independence from livestock or agriculture lost due to floods • Independence from tourism or other sectors impacted by floods
Consistent Income/ Funding Source	<ul style="list-style-type: none"> • Percentage of homes with unemployed head of household • Hourly wage vs. salary • Percentage of homes receiving remittances from relatives abroad • Reliable and consistent budget for flood expenditures • Savings/budget reserves available for flood recovery efforts

Table 8. Adaptive Capacity to Floods as Measured by Natural Capital

Natural Capital Sub-Attributes	Example Indicators
Functioning hydrologic systems	<ul style="list-style-type: none"> • Clear canal ways • Vegetated or natural buffers (e.g. mangroves, sand dunes, wetlands) • Permeable surfaces to decentralize runoff
Pollution sinks	<ul style="list-style-type: none"> • Use of non-toxic materials • Storage of toxic chemicals in areas protected from flood water • Healthy plant and microbe communities in soil and water
Clean air	<ul style="list-style-type: none"> • Smog and other airborne particulate concentration near populations
Precipitation	<ul style="list-style-type: none"> • Predictable weather patterns

3. Discussion

This framework is intended to provide a set of specific, locally adaptable indicators useful for integrative research, community dialogue and decision-making on flood risk management, particularly the development of EWSFs. The framework is integrative in not only the diverse array of vulnerability and hazard attributes and their nested relationships, but also in the multiple spatial scales and data sources needed to measure these components. Application of this framework may assist in localizing vulnerability or flood risk maps, evaluation of flood risk management actions for policy-makers and facilitation of communication at the local level (e.g., community and municipal leaders) to build civic capacity.

Challenges in using this approach include limited and incomplete data records, mixed quantitative and qualitative information, as well as spatial and temporal discrepancies in the data. For example, there may be differences between the spatial scales in problem areas and areas of existing data coverage. As true of any complex post-normal science approach, there exists the need to triangulate through a mixed methods approach while acknowledging specific data gaps (Norgaard 1989; Funtowicz and Ravetz 1993). Here we explore the opportunities and challenges associated with the key contributions of the framework.

3.1. Novel framing of flood risk management

This framework is novel in its multi-scalar applicability as well as its integrative risk management approach. Risk analysis has a history of disregarding broader, and often more qualitative, social, cultural and historic dimensions (Renn 1992, Merz 2010a, Few et al. 2004, Haimes 2009) in addition to a lack of acknowledgement of the various stakeholder perceptions of risk (Adelkan and Asiyani 2016, Merz 2010a). We hope that the use of this framework spurs creative thinking about risk through some of the localized indicators presented here. This framework presents a process of developing attributes and their sub-attributes using diverse stakeholder perceptions to customize indicators to fit local conditions, in turn making vulnerability assessment more relevant and robust for risk management institutions. This is an important contribution to the increasing literature that discusses risk management in terms of damage reduction as opposed to focusing solely on hazard reduction.

This framework also synthesizes new ways of thinking about adaptive capacity, along with other elements of vulnerability. First, it brings together adaptive capacities, which are impacted by specific factors (e.g. coastal protection initiatives and other flood management actions or infrastructure) and generic adaptive capacities (e.g. lack of income, education, health, political power) (Lemos et al. 2011). Furthermore, it provides a set of measurement indicators for adaptive capacity using multiple capitals or assets, specifically human, social, financial, physical and natural capitals (Eakin and Lemos 2006, based on Smit et al. 2001 and Yohe and Tol 2002). This provides a consistent and robust set of measurements that can fit within a socioecological frame, and thus become usable to in changing climatic and social systems.

3.2. Integrative insights into hazards and vulnerability

In implementing this framework, it is important to maintain an integrative perspective of all components of the framework in order to understand relationships within and between the attributes. The adaptive capacity component, in particular, includes relationships between multiple capitals. For example, availability of financial resources had a direct relationship to social and human capital. An increase in financial capital could directly influence the hiring of additional staff (human capital) and the ability to hold the necessary meetings with community brigades (social capital). These relationships could include single directional relationships (e.g., monitoring equipment to inform warnings), negative feedback loops (e.g. floods increasing ecological productivity, which in turn decreases the spread of flood waters) or positive feedback loops (e.g. ever-increasing poverty in poverty-trapped, flood-prone communities where recovery and preparation is hindered by lack of municipal aid).

Relationships between vulnerabilities and hazards are also nuanced and complex. Defining the type of hazard is essential to defining what kinds of exposures and sensitivities will occur, as well as addressing who within a community may be affected. For instance, floods occurring in urban centers with well-draining sewers may cause transportation-related

hazards and sensitivities, yet not the degree of public health hazards and sensitivities caused by floods occurring in non-drainable areas near residential areas.

It is essential to include multiple perspectives of vulnerability when defining the problem areas and in developing risk management strategies. Stakeholder perceptions are influenced by values, social status, economic resources, and personal experiences during floods, along with many other factors. Using this framework as a guide to navigate the diverse viewpoints not only creates a more comprehensive measurement of flood vulnerability, but it may also help in communicating results across communities and institutions involved in the development of flood risk reduction strategies, such as EWSFs.

3.3. Methodological considerations

Selecting the appropriate methods and tools to gather stakeholder insights on the framework is an especially important consideration when applying this framework. Selection of meeting venues, study recruitment techniques and question structure may depend on aspects like target population size, demographics, and scale. An awareness and understanding of local and institutional context will assist in recruiting research participants and structuring dialogue on controversial topics that occur within framework, such as issues related to financial resources or strained community/institutional relations.

It is important to assess exposure, sensitivity and adaptive capacity over a range of spatial and temporal scales in order to understand the drivers of local vulnerability to flooding. Vulnerabilities can occur at the household level (e.g. Vincent 2007), in local communities (Smit and Wandel 2006, Nelson et al. 2009), in institutions (Gupta 2010, Engle and Lemos 2010) and at the level of nations (e.g. Yohe and Tol 2002). Each spatial scale has its own set of interdependent vulnerability components (Haase 2013). These vulnerability components can be studied during a specific time-point in a flood event (e.g. during the recuperation phase) or can be studied over long periods of time, such as exposure to flood events over decades. For this reason, we include temporal and spatial specifications of vulnerability indicators in this framework

3.4. Using this framework for EWSF planning

This framework is designed to inform the development of EWSFs by ground-truthing existing datasets (e.g. hydrological monitoring), evaluating flood risk management actions for policy-makers (e.g. effectiveness of community flood brigades) and facilitating communication between and within communities and flood authorities. In each of these applications, participation of flood-impacted community members throughout the research process is a central element of the framework.

A fundamental component of EWSFs is hydrological data and other physical datasets that inform overall vulnerability (e.g. precipitation levels, elevation, river flows, tidal cycles). While attention to these components is critical for the diagnosis of flood hazards and accurate warning systems, this framework also calls for awareness of the various vulnerabilities to floods. In understanding the community vulnerability in addition to hazard typology, flood practitioners may better prepare and respond to floods of varying magnitudes, frequencies and sources.

Finally, this framework promotes cross-scale dialogue. Doing so, although at times difficult to work through, can elicit improved understanding of flood-related issues. By acknowledging how perceptions inform the comments of both practitioners and community members, researchers can develop nuanced problem definitions. For example, in Machala,

Ecuador, some flood practitioners referred to settlements on the outer edges of the city as invasions into the mangroves, whereas community members referred to their situation as economic marginalization of the working poor. This tension highlights two important components of flooding that get compartmentalized according to perspectives: ecological factors influencing site porosity and economic systems that drive settlement into flood prone areas.

While these approaches are more complex than simple hazard analysis, efforts towards understanding these diverse perspectives may generate integral and more effective solutions.

4. Conclusions

This framework provides options to those who wish to launch community dialogue and planning at the local level, while incorporating systematic hazard and vulnerability metrics that can be relevant at an institutional level. In applying this operational framework, we have developed a set of recommendations to use for practitioners and researchers to use in localizing the framework to their own areas of study. Throughout each recommendation, we emphasize the underlying need to balance pragmatism with the flexibility and openness in order to adequately capture local perspectives.

- *Develop framework indicators by identifying existing institutional actions that involve impacted communities to reduce flood vulnerability.* Initiating the use of this framework may start with one specific program or campaign that has been implemented in communities, such as community flood response simulations or brigades. However, rewarding and robust insights will most likely occur when researchers or practitioners allow for the flexibility needed to reach out to non-traditional stakeholders involved with related yet distinct actions, such as public health initiatives or building recovery programs.
- *Use a mixed method approach that considers data gaps.* Because of the high diversity of potential data sources associated with the indicators presented in this framework, researchers and practitioners should aim to utilize methods that are best suited to the data sources and purposes of the study. When developing this framework, researchers and practitioners should be in communication early in the process to understand these sources and any data gaps that may exist. Additional consideration may examine the usefulness of these indicators in relation to those data gaps. For example, the use of this study may generate much needed geographic data to practitioners at an institutional level for purposes beyond the scope of the study. Additionally, creative thinking should be used when collaborating across institutions. Both formal and informal forums, workshops or administrative processes may create opportunities to co-produce information and training resources useful for multiple interest groups (e.g. building permit data, grant applications and community programming).
- *Identify key stakeholder groups.* Efforts to create robust measurements of vulnerability often require a diverse array of stakeholder groups. In efforts to decrease the bias in stakeholder insights while working within time and funding constraints, researchers should monitor the ways that each indicator relates to stakeholders in efforts to track gaps and overlaps in contributing insights from participating stakeholders. It is important for researchers from universities and research institutions to recognize their leadership role and ability to serve as third-party “articulators” between local governments and communities.

- *Balance institutional insights with community insights.* This framework is useful in its applicability to both local scales and broader institutional scales. When working between these two scales, researchers can use this framework to provide dialogue opportunities between the two scales, such as program evaluation questions to communities on the effectiveness of existing institutional programs or offering institutional information to communities on flood resources. Throughout this process, it is important for researchers to maintain their role as a third party in efforts to effectively navigate differences in perceptions between these two scales. It is also important to maintain care when using this framework as an evaluative tool, as community level insights may vary across jurisdictions or geographic scales. Community cultural factors and observance of local regulations/ national policies that shape this dialogue are not always easy or obvious upon initial interactions, thus time and trust building with participating stakeholders is important.
- *Insights may be applied to tools beyond early warning systems.* The focus of this study was to use multi-scalar insights to generate thinking on the development of EWSFs. However, components of this framework may also be relevant and useful to the improvement or development of other flood risk reduction measures, such as insurance programs or recovery programs. Additionally, researchers and practitioners applying this framework to flooding issues should also consider non-flood specific risks within risk flood management efforts to increase the overall resilience of the communities.

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