Reducing Social Vulnerability to Environmental Change: Building Trust through Social Collaboration on Environmental Monitoring

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(Manuscript received 4 August 2015, in final form 17 November 2015)

ABSTRACT

The occurrence of natural and socially driven catastrophic events has increased in the last few decades in response to global environmental changes. One of the most societally relevant challenges in managing the effects of these events is the establishment of risk management strategies that focus on managing vulnerability, particularly in disfavored countries, and communities among them. Most cases of enhanced vulnerability occur in, but are not limited to, developing countries, where the combination of social inequity, inappropriate use of natural resources, population displacement, and institutional mistrust, among other factors, make risk management particularly challenging. This paper presents a vulnerability-centered risk management framework based on social cohesion and integration principles that, combined with scientific, technical, and popular knowledge, lead to the development of social networks of risk reduction. This framework is intended as a strategy to strengthen early warning systems (EWS), where the human-related factor is among their most challenging components. Using water-related hazards as a case study, this paper describes the experience of the conformation of a social network for environmental monitoring using this model example on vulnerability reduction in the rural areas of the central Andes in Colombia. This experience allowed the effective conformation of a social network for environmental monitoring in 80 municipalities of Colombia, where communities developed a sense of ownership with the instrumentation and the network, strengthening links with local authorities and contributing to more efficient EWS. More generally, the authors highlight the need to develop vulnerability-centered risk management via community-building strategies, particularly for areas where little can be done to decrease the occurrence of catastrophic events.

1. Introduction

The complex interactions between global- and local-scale environmental changes (mainly related to land use and human activities) are tightly related to the potential occurrence of natural disasters affecting ecosystems, communities, and their interactions. Current and expected environmental changes lead to a higher level of uncertainty in the occurrence of potentially catastrophic events, posing a challenge to current disaster management strategies. On top of climate and environmental variability, current socioeconomic development models enhance social vulnerability, particularly in less favored regions of the world and in countries and regions within them where resource management and availability are precarious (e.g., Huppert and Sparks 2006; Mertz et al. 2009). The marked increase of social vulnerability in regions such as South American and Caribbean countries is generally associated with social inequity, conflict, population displacement, poverty, lack of opportunities, excessive and inappropriate use of natural resources, among others (e.g., Basher 2006). Particularly, Latin America is recognized as one of the most vulnerable regions to be affected by climate change, not only because of its increasing exposure to climate hazards but also because of its increasing social vulnerability (e.g., Basher 2006; Marengo et al. 2009; Hartmann et al. 2013;

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DOI: 10.1175/WCAS-D-15-0049.1

Magrin et al. 2014). This imposes an urgent necessity to formulate prevention, mitigation, and adaptation strategies involving the participation of communities in these regions.

Among the diverse prevention, mitigation, and adaptation strategies for climate change—or more generally environmental change—early warning systems (EWS) have been widely used, mainly after the Indian Ocean tsunami occurred in December 2004 (e.g., de León et al. 2006). For an effective and adequate operation of EWS, four key interrelated aspects need to be considered: 1) risk assessment, 2) monitoring and warning service, 3) dissemination and communication, and 4) response capability (UN 2006; Basher 2006). In this sense, EWS should include different subsets of participants that are not always considered part of these systems, such as political/administrative supporting entities, community actors, the research community, local authorities, and media, among others.

Monitoring and warning services are the most well-known elements of EWS and are typically related to large instrumental monitoring networks, which receive the most visibility and governmental investment. However, the human-related component has been shown to be very important in these systems, especially in aspects related to communication and preparedness (Twigg 2002); in fact, it might determine the potential success (or failure) and effectiveness of any EWS. Current failures in EWS appear to be related to inadequate political commitment; weak coordination among the involved actors; lack of an appropriate understanding of cultural processes by authorities, as well as their general perception on predominance of physical criteria in risk configuration regardless of social and political aspects; and lack of public awareness and public participation in the development and operation of these systems (UN 2006). Hence, an effective EWS requires local community participation to ensure that inhabitants at risk are adequately informed and alerted (Collins and Kapucu 2008). Thus, although effective EWS require strong technical foundations and adequate knowledge of the natural hazards, they must be people-centered (ISDR 2004; de León et al. 2006). However, one current difficulty in EWS is that the role of research and knowledge from outside the core area of expertise related to the specific warning system is often not acknowledged (Basher 2006).

If the technical elements of EWS are not tightly related to the social aspects, the main goals of these systems are often not accomplished. Therefore, a second important challenge in establishing and operating EWS, especially in developing countries, is the lack of ownership and commitment of the participants to autonomously maintain the network operation. The latter is related to multiple reasons: lack of institutional support, absence of risk events (or lack of communities remembrance of such events), lack of intrinsic motivation toward disasters prevention, and reduced response capabilities (e.g., UNISDR 2011). This is particularly critical in countries like Colombia, where a long history of internal conflict, political instability, and numerous unresolved basic social needs have enhanced mistrust relations between members of society, mainly between communities and governmental institutions/authorities. Therefore, people-centered EWS in these countries should serve not only to empower communities to prepare for and confront the power of natural hazards (de León et al. 2006), but also to provide a path to build trust through social collaboration on environmental monitoring.

A third current difficulty in EWS is the fact that their focus still tends to remain on the hazard, with less emphasis on the vulnerabilities, risks, and response capabilities (Basher 2006). Therefore, to conform and operate an efficient EWS it is necessary to consider an integral risk management framework that includes not only the technical aspects of the risk (e.g., complete hazard diagnostics, appropriate technology for monitoring) but also its social aspects, generally related to vulnerability. The latter highlights the need for including social and communication sciences knowledge during the conception and operation of EWS.

This paper describes an initiative that integrated scientific, technical, and popular knowledge to provide basic tools to adapt to and mitigate the possible impacts of global and local environmental change. The risk management framework intended in this research especially focuses on vulnerability as a determinant factor toward risk reduction, as hazards associated with global phenomena are largely unmanageable (and perhaps somewhat unpredictable). Particularly, this research is centered in the conformation of a social network for environmental monitoring of rainfall and water stream stages as a strategy to reduce vulnerability to environmental change in rural communities in Colombia. Our research emerges from the context of the extreme rainy seasons occurred in Colombia during 2010–12, which led to a nationwide crisis (CEPAL 2012; Hoyos et al. 2013) and constituted a novel experience in Colombia. However, the vulnerability approach intended here could be applied to any other country or natural hazard.

This document contains the following sections: section 2 presents the vulnerability approach for risk reduction addressed in this research; section 3 presents the particular case study in Colombia where this approach was applied; finally, section 4 discusses the main learning and conclusions from this experience.

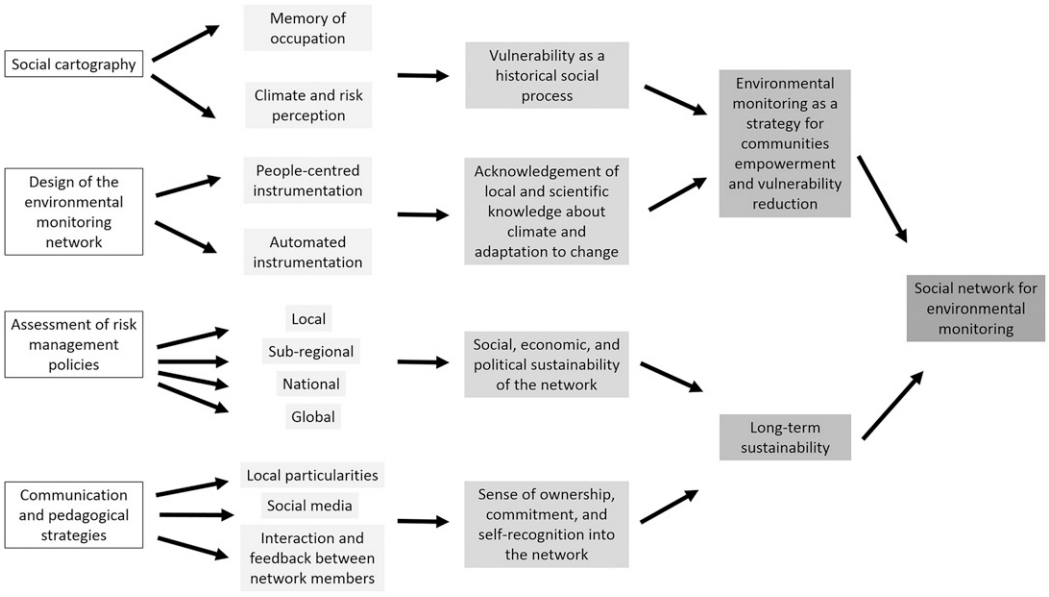

FIG. 1. Conceptual scheme of the risk management framework suggested around social networks for environmental monitoring, as a strategy for prevention, mitigation, and adaptation to environmental change.

2. A vulnerability approach for risk reduction

Our key focus relies on the recognition that the conformation and implementation of any EWS is a participatory process, where communities and governments are the main actors, and the research community catalyzes their interactions. Moreover, the success of this type of strategies largely depends on dialogue, interaction between the different participants involved, and consensus on matters of public interest. In this sense, we propose a reflection-based approach that aims to acknowledge the necessity to build trust between people. Consequently, the risk management framework intended in this research is supported on four pillars: 1) the development of social cartography to collect and socialize proper understanding of local risk conditions based on local knowledge and collective risk management strategies, 2) the design of a people-centered environmental monitoring network, assisted by manual and automated instrumentation, 3) the assessment of current risk management policies at local and subregional levels, and 4) the communication and pedagogical strategy emerged and implemented during the process, in order to articulate the different members and sources of knowledge involved. Figure 1 shows a scheme with the main elements of this framework, which are described in the following subsections.

a. Social cartography

The risk management framework suggested here considers the inclusion of vulnerability as a reflective path into disaster prevention, through seeking a suitable integrated risk management policy in developing countries. In this approach, we address vulnerability from a historical perspective, through the processes that have configured vulnerable scenarios (Vidal 2007; García Acosta 2008; Blaikie et al. 1996). With this objective, we focus on the inquiry of memory of occupation as well as climate and risk perception by communities and institutional members. We aim to articulate scientific and popular knowledge, allowing us to configure a social network for environmental monitoring consistent with the real context and necessities of each specific community. To collectively reflect and discuss about risk management in our territory, we introduce the social cartography technique (e.g., Liebman and Paulston 1994) to motivate an open dialog between participants around leading questions and reflections about two necessary actions: 1) the development of a social process, focused on the memory of livelihood and climate and risk perception of communities, and 2) the installation of environmental monitoring equipment as a catalyzer and conveyor for interactions between the different participants in the network. In this sense, our path for social cartography is formulated from the need of strengthening ties between local inhabitants. Such dialog not only provides valuable elements for a more integrated understanding of local vulnerability that could help to formulate reduction strategies, but also helps to identify the particular locations where monitoring instruments would provide the most relevant information about the specific hazards, according to communities' and authorities' perceptions. The latter is especially important to

achieve a greater sense of ownership in the network from the participants involved.

b. *Instrumental monitoring network*

The social network for environmental monitoring constitutes a pedagogical tool for prevention awareness by identifying and appropriating elements of the territory, recognizing the processes that have enhanced social vulnerability, based on local knowledge of the space–time dynamics of each territory, and understanding the natural phenomena that take place in such territory. Such network is the basis of a short- to long-term process in the public scenario, which aims to acknowledge the importance of climate as a catalyzer of socionatural phenomena and, therefore, the importance of environmental monitoring as a strategy for vulnerability and risk reduction. Thus, as a second element in our framework, we consider the design of an instrumental monitoring network where both popular and scientific knowledge are recognized. Hence, the design of this instrumental network should consider not only technical requirements for an adequate installation and operation of these instruments, but also elements of the climate and risk perceptions from inhabitants and local authorities, which clearly identify the locations in their own territory where socionatural hazards represent a greater risk for their communities and livelihoods. To further promote interaction between network participants and articulation between different knowledge sources, we consider the use of automated and people-operated instrumentation for environmental monitoring. Although the most common perception among people is that automated instrumentation is more reliable and effective than manual and people-operated instrumentation, an adequate training in using these instruments, as well as an integral understanding of the phenomenon that is being monitored, would promote a much better preparedness of communities and risk management institutions to confront environmental hazards, reducing their vulnerability. Additionally, the knowledge acquired by communities and authorities from their self-recorded environmental data would also promote reconciliation between local and scientific knowledge and a sense of ownership of each member as an integral part of the network. In this sense, the goal with our approach is to transcend a set of automated monitoring instruments, so communities are empowered by monitoring using manual and easy-to-manufacture instruments, turning a monitoring network into a social network for environmental monitoring.

c. *Assessment of risk management policy*

A social network for environmental monitoring is a political challenge, where, as a result of a public problem called ''risk,'' all devices, mechanisms, methods, and modes of action are activated in order to identify joint solutions between institutions and civil society to develop and implement public decisions to achieve risk reduction. Therefore, this type of strategy should not only be inserted into public policy but should also effectively include elements of public policy. Thus, we consider necessary to complement our risk management framework with a third element, constituted by a complete assessment of the current risk management policies at local and subregional levels. Such assessment would provide insights on how current policies include vulnerability reduction strategies, suggesting how a social network for environmental monitoring could be inserted into such policies. Conversely, an adequate comprehension of local and regional policies by communities and institution members would promote a more effective inclusion of these risk management policies into the network, which in turn would provide more possibilities and mechanisms for institutional and economical sustainability of the network. Moreover, a better understanding of these policies by local communities would empower their leaders, building a more effective communication between communities and authorities, enhancing their possibilities to collectively build and participate in public policy. On the other hand, the social network itself could provide new elements to contextualize current risk management policies with social needs.

d. *Communication and pedagogical strategy*

The motivation awakened in communities and local governments/institutions during the conformation process of a social monitoring network is key to its permanence, sustainability, and usefulness in the territory. To promote this motivation, we seek to engage the different communities and institutions through the use of appropriate pedagogical and communication approaches, developed from the particularities of each territory. Thus, as a fourth element, our framework considers the development of communication and pedagogical strategies directed to the communities and participants involved into the network, as a step to achieve a greater impact and appropriation by communities and institutions, and to pursue its continuity and significant presence in the territories. Our communication approach considers that the appropriation of public speech empowers communities and contributes to the consolidation of public areas within the scope of plurality and diversity, helping to build collective identity and respect about differences. This, in addition to the appropriation of the media, may contribute to strengthen social ties, enhancing the participation of communities in public and collective decisions, and in turn building trust among communities

and institutions. On the other hand, our pedagogical approach sought for a systemic understanding of ecological and social interconnections in order to address any discussion about socionatural hazards, vulnerability, and risk. In this sense, a people-centered environmental network takes value only when inhabitants understand the processes that have configured their vulnerabilities and how an adequate understanding of natural phenomena could increase their preparedness to confront socionatural hazards.

In summary, the reflection-based approach suggested here aims to acknowledge the necessity to build trust between people through environmental monitoring, based in four fundamental pillars: social cartography, monitoring instruments, policy assessment, and pedagogical and communication strategies. Next section describes a particular experience in Colombia, where this framework was applied during the conformation of a social network for environmental monitoring of rainfall and stream stages, as a strategy to prevent and mitigate the effects of water-related hazards.

3. Case study: 2010–12 floods in Colombia

a. *The 2010–12 flood emergency*

Because of its geographic location and topographic features, weather and climate in Colombia show large variability at different spatial and temporal scales. The presence of the three mountain ranges of the Andes, the resulting changes of topography and vegetation throughout Colombian territory, and the proximity to the Amazon rain forest, the Caribbean Sea, and the Pacific Ocean lead to high complexity in local weather and climate (e.g., Snow 1976; Poveda et al. 2006). In climatological terms, rainfall in Colombia is characterized by different annual cycles in different regions across the country (e.g., Eslava 1993; IDEAM 2005). These climatological rainfall annual cycles are strongly modulated by the anomalous interannual variations of sea surface temperatures over the equatorial Pacific Ocean, known as El Niño–Southern Oscillation (ENSO), whose influence on Colombian hydrometeorology has been observed at diverse temporal scales (e.g., Pabón and Torres 2007; Poveda et al. 2011, and references therein). As a result, reductions of precipitation, runoff, soil moisture, and vegetation cover are observed in Colombia during the warm phase of ENSO (El Niño), while its cold phase (La Niña) is associated with increases in these variables (e.g., Poveda et al. 2011).

In particular, the two consecutive La Niña events that occurred in 2010/11 and 2011/12 were associated with anomalously enhanced precipitation and flood regimes in Colombia, even during the dry seasons (Arias et al. 2015). Consequently, 2010 is the wettest year in Colombia since the beginning of instrumental records in the country (Martínez et al. 2011), consistent with an anomalously strong La Niña event in 2010/11, recognized as one of the strongest La Niña episodes in recent decades (Australian Bureau of Meteorology 2012). The 2010–12 flood regimes in Colombia caused a high amount of emergencies and disasters in many regions of the country, affecting around 4 million people, with significant socioeconomic losses estimated to be about US $7.8 billion (CEPAL 2012; Hoyos et al. 2013). During this period, widespread flooding occurred, while many lakes and wetlands recovered their former areas of influence that were currently colonized and populated by local communities, displacing large populations. These emergencies made evident the increasing inappropriate use of floodplains in Colombia. Furthermore, one of the most notable impacts of these floods was the demonstration of poor preparedness in local communities, as well as in local, regional, and national authorities and risk management institutions in the country (formally established over two decades ago), triggering a nationwide socioeconomic crisis (CEPAL 2012). Such institutional crises made clear the lack of a comprehensive policy for risk management in Colombia, suggesting the need for reformulating local policies on these matters and adjusting the current system to new socionatural realities. The latter is particularly important since these types of emergencies will continue to occur, and may even increase in number and magnitude, given the significantly increased vulnerability of local communities (CORANTIOQUIA 2011).

b. *Implementation of a social network for environmental monitoring*

After the events observed in 2010–12, we implemented the approach described in section 2 in 80 municipalities of Colombia (Fig. 2), along a three-stage field campaign developed during two years (2011–13). To convene and commit communities and institutions to the monitoring network, we developed a set of activities (meetings, workshops, interviews) that allowed us to get in touch with people, media, and public sectors related to risk management (both inhabitants and institutions) in each particular municipality. In the next subsections, we describe the implementation process of the four pillars of our risk management framework during the conformation of an environmental monitoring network to water-related hazards in Colombia.

1) SOCIAL CARTOGRAPHY

To develop social cartography, we promoted individual and group activities intended to reconstruct individual and collective memory to understand the sociohistorical

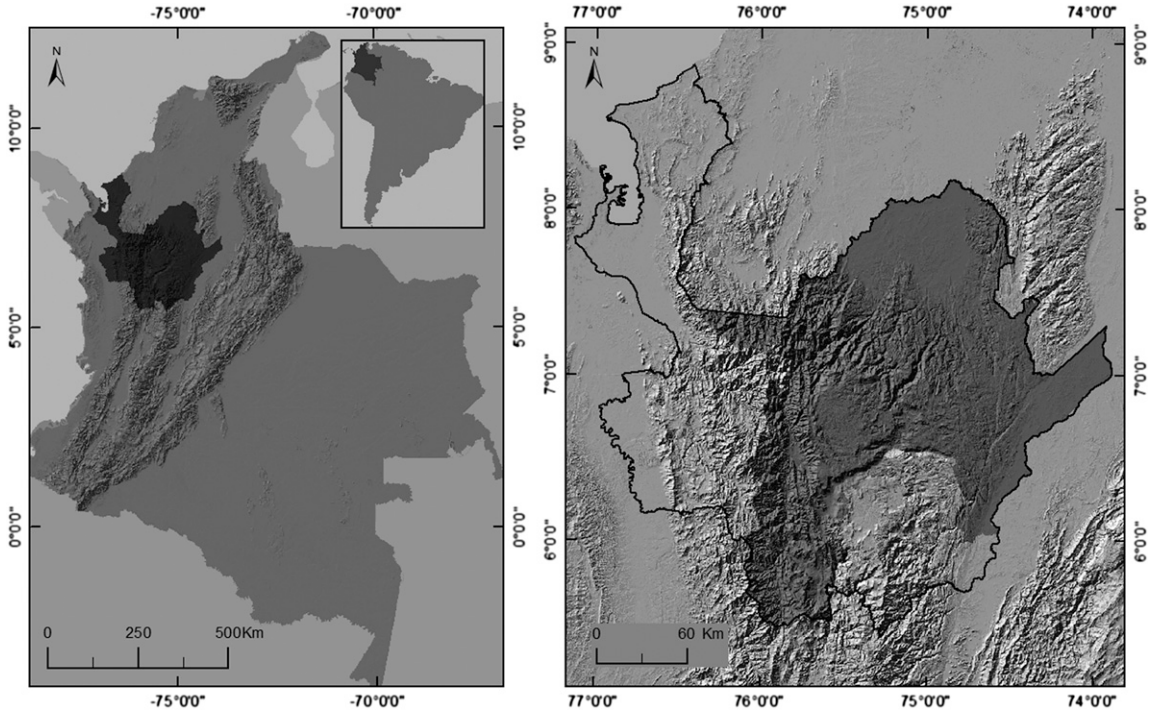

FIG. 2. Region of interest during the conformation of a social network for environmental monitoring in 80 municipalities of Colombia.

changes that have contributed to increase vulnerability in each municipality. The communication and pedagogical strategies developed during this process were always tangential to these activities, which took place during the entire field campaign. Particularly, during the first stage, the social cartography allowed us to identify risk perception from inhabitants and institutions. One of the main results from this first cartography exercise with inhabitants was the identification of critical zones, where monitoring of rainfall and streams is considered as necessary by communities as it is by authorities. This identification of critical areas from social cartography exercises, was complemented with geological, hydrological, and land use criteria. Thus, the final selection of the pilot area to conform the monitoring network in each municipality was based on the combination of social and technical factors, as well as considerations related to safety and access restrictions in each area.

During the second stage, we continued implementing the social cartography methodology, where reflection was addressed toward the perception of communities about climate and risk. These perceptions and the local knowledge about disasters related to climate and environmental conditions, and their link to sociocultural aspects, lead inhabitants to understand the importance of acknowledging environmental monitoring as a powerful mechanism for risk and disaster reduction.

2) INSTRUMENTAL MONITORING NETWORK

During the design of this monitoring network of water-related hazards, we considered two types of instruments: rain and stream stage gauges. Therefore, during the first and second stages of fieldwork, we advanced in the design and manufacture of automated and manual instruments. The automated instruments were based on cell-phone technology to transmit their records to an institutional server at the regional environmental authority (CORANTIOQUIA), where data are processed and stored for public access. On the other hand, the manual instruments were designed considering the World Meteorological Organization standards. Both the automated and manual instrumentation were designed and manufactured from local technology.

The third stage of fieldwork included a main activity focused on the installation of manual and automated rain and stream stage gauges in the different locations identified with local inhabitants and institution members. Our methodological strategy was always addressed to both communities and local governments, seeking for interaction between these two participants and generating a sense of ownership in the social network. For this reason, both audiences were involved not only during the development of the different activities through workshops and meetings, but also during the instrumentation installation process. Our strategy

sought to encourage communities and local governments to take an active role in monitoring activities, leading to responsibilities for an adequate treatment and care of manual and automated instrumentation. Thus, during the installation process in each location, we developed a cultural activity that emerged from community and institutional motivation, which sought to generate commitment among the different participants involved. This activity varied between the different municipalities and allowed the network members to interact between them and get familiarized with the instruments. The cultural activities developed during this process include the creation of mural paintings or collective artworks, photography contests, and music shows focused on the importance of monitoring and understanding our environment to reduce our vulnerability to socionatural hazards and strengthen community ties.

3) Assessment of risk management policies

To achieve an adequate assessment of the current risk management policies, we considered a careful revision of the different local land use plans in each locality. This review allowed us to identify how the municipality considers the reduction of vulnerability through environmental networks and, if so, how the monitoring network pursued during this process could be part of the current local strategies. Additionally, we developed different interviews with members of local risk management institutions to inquiry their risk perception as well as their motivation and commitment with this monitoring network. This assessment obtained from local policies was complemented with a revision of national and global risk management policies, such as those addressed in the Colombian National Development Plan and international risk management authorities. On the other hand, we socialized the main conclusions from this assessment through different meetings in each municipality, for the sake of strengthening community leaders as key participants in the formulation of public policies. Moreover, during the different activities throughout the field campaign, we encourage communities and their institutions to formulate individual and collective agreements and commitments to participate in and maintain the social network as a mechanism to build trust between both parts and collectively identify strategies for risk reduction.

4) Communication and pedagogical strategy

The different activities developed during the three-stage field campaign fed from the communication and pedagogical strategy that emerged from this research. The social cartography developed during the first stage allowed us to identify strengths, possibilities, difficulties, and challenges in each municipality. During the transition between the first and second field campaign stages (between 4 and 6 months), we made a dedicated effort to contextualize our framework with the features and particularities of each municipality. Considering the synthesis from this exercise, we formulated a methodological articulation to integrate the four components of our framework through a set of different activities. This articulation was implemented during the next two stages of fieldwork with communities and institutions. The process of introducing communities to monitoring activities and instruments was guided by the pedagogical strategy. During these activities, we interacted with inhabitants around the meaning and use of instruments to monitor rainfall and stream gauges, and their role in vulnerability reduction. To achieve this goal, we used videos, animations, calendars, and other didactic tools to learn how to use the instruments, interpret their measurements, and recognize their importance in risk reduction. Additionally, during the period between the first and second stages, we pursued continuous contact with the communities linked to the process, developing different communication strategies. Particularly, in most of the rural areas where we focused our research, radio is still the most important communication channel. We took advantage of this and implemented sketches, interviews, and special programs that were broadcasted by local community radio and TV stations. To ensure reaching all kinds of audiences, we also used modern channels like Facebook, Twitter, and a blog feed with the different local experiences during the process. More specifically, these channels constituted a very useful way to reach contact with the younger members of the network (Facebook) and institutional actors (Twitter). The use of community radio and TV stations and modern communication channels allowed us to keep a constant feedback from the network members, and to approach different participants not directly involved with the monitoring network. The use of these media was key to promoting a sense of ownership among the network members, as well as to acquiring recognition from other local and national parts.

4. Learning and concluding remarks

The risk management framework presented here proposes a space for reflection and participatory research in our inquiry to identify social and environmental processes that have led to increased social vulnerability to environmental change. This research was addressed in association with local communities,

governments, and risk management institutions, under the consideration that risk should be viewed as a process induced by both vulnerability and hazards. The particular implementation of this approach in 80 municipalities of Colombia has contributed to build a social network for the monitoring of floods, torrential floods, and landslides. To achieve this goal, we worked with communities and local authorities in order to promote a greater sense of ownership in the social network from all the involved participants, acknowledging the importance of people-centered environmental monitoring as a powerful mechanism to acquire autonomy, response capability, and preparedness to water-related hazards. The latter will reduce the impacts of local and global environmental change in developing countries, even more when these impacts can aggravate in a scenario of increasing vulnerability and adverse weather and climate conditions over the region.

Previous studies address the social impacts of global and local environmental change in small Latin American communities, with especial emphasis on adaptation strategies and policies, as intended in our framework (e.g., Conrad and Hilchey 2011; Carey et al. 2012; Wrathall et al. 2014; Huggel et al. 2015). However, in this study we explored a different route through the hands-on construction of bottom-up adaptation strategies, derived from community empowerment and organization. We anticipate that this approach should lead to stronger and potentially more stable community networks in and otherwise socially unstable territory.

Our experience is not the first citizen-oriented weather observation network. We found similar social networks in Chile and the United States aimed at rainfall monitoring by communities. These networks are ''Pluviómetro Ciudadano,'' a network created by Dirección General de Aguas (DGA) in Chile (http://milluvia.dga.cl/), and ''Rainlog.org,'' a cooperative rainfall monitoring network for Arizona developed at The University of Arizona by Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) and the school's cooperative extension (http://rainlog.org/usprn/html/main/maps.jsp). Although these networks promote people-centered monitoring, they are conceived more from the perspective of providing denser measurement coverage to improve climatological rainfall estimations than becoming a strategy to reduce social vulnerability of the communities involved. Additionally, a third initiative developed in the European Union (particularly in Italy, the United Kingdom, and the Netherlands) considers the participation of communities in a citizen observatory of floods, water storage, and quality and quantity of water resources (http://wesenseit.eu/). This initiative aims to engage citizens in directly interacting with authorities and other stakeholders and provide services for viewing, requesting, and feeding back information.

Although similar initiatives have been developed in other countries, our framework highlights the role of community monitoring not only as a mean to improve existent environmental monitoring networks, but also to provide communities with tools to reach a stronger understanding of climate variability/change and its influence on their geographic and socioeconomic environment. Furthermore, this framework is aimed to identify the sociocultural particularities of each municipality where it is applied, providing a context in order to provide a suitable social context where this strategy for vulnerability reduction can be inserted. This is probably the most innovative feature of our framework.

During this two-year experience, we could reach 80 municipalities in Colombia, convene more than 1300 inhabitants, install 80 automated rain gauges and 25 automated stream stage gauges, and provide communities with 630 manual rain gauges and 230 manual stream stage gauges. The engagement of local communities and authorities to this monitoring network was the result of a participatory process that sought for the integration of popular and scientific knowledge and recognized the importance of public policy for its sustainability. The learning acquired during our contact with communities and authorities allows us to draw four important conclusions: 1) the current global and local economic development models have configured strong vulnerability scenarios in developing countries like Colombia, exposing their communities to adverse conditions that may aggravate in a context of increased environmental change; 2) the conformation of the social network for environmental monitoring is just the beginning of a long-term process of monitoring environmental variables related to hydroclimate variability in our watersheds, as a strategy to reduce the vulnerability of the communities within them; 3) a people-centered environmental monitoring network is especially important in Colombia, where the lack of hydroclimatological data at local scale and the limited access to current existent environmental information (generally provided by automated networks) by communities and local governments place an even higher value on environmental monitoring; and 4) the knowledge of local climate and hydrology in Colombia acquired from the social network for environmental monitoring should help to further improve our monitoring networks (manual and automated) since hydroclimate variability is large and complex across Colombian territory, due to its diverse topographical and land use conditions.

In addition, the agreements and commitments between the members of the network established during the entire process, as well as the local and subregional policy assessment, allowed us to propose a first protocol for the sustainability of the monitoring network. This protocol proposal considers the existent normative context on risk management in Colombia (at local, subregional, and national scales) but also provides different possibilities to pursue international financial aid to sustain the network, according to current international risk management policies and strategies. In fact, as a path toward sustainability, the social monitoring network conformed during this process is currently part of the PIRAGUA program at CORANTIOQUIA, where environmental monitoring is continuously addressed in conjunction with local communities and authorities (http://suyay.corantioquia.gov.co/piragua/).

The risk management framework suggested here is a starting point toward the establishment of more effective EWS and the collective formulation of public policies in developing countries. Particularly, this constitutes a novel experience in Colombia aimed for social vulnerability reduction.

In summary, we present an experience focused on the process of implementation of a social network building, such that social response to extreme events, supported by the instrumentation, can lead to a reduction in vulnerability and further reduction in risk. To date there have been no well-documented cases of extreme events leading to social episodes in our network. However, for a recent flash flood at the municipality of Salgar there has been anecdotal evidence of early warning in response to sudden increase of water levels in a secondary creek. These are long-term goals that require the continuous commitment of both institutions and communities in order to achieve an effective reduction of social vulnerability and risk to socionatural hazards associated with global and local environmental change in these countries.

Acknowledgments. This work was supported by CORANTIOQUIA Contract 9063, as part of its 2007–2011 Action Plan. This participative research was possible thanks to the multidisciplinary team presented in the appendix. We sincerely thank the supervision of Luz Marina Betancur, Adriana Molina, Diana Montoya, Ángela Peña, Yesidh Quintero, Juan David Ramírez, and Marta Salazar from CORANTIOQUIA, who helped us to improve this research. We also thank the strong support from Carlos Palacio, Natalia Gaviria, Ricardo Moreno, and Miguel Velásquez, at Universidad de Antioquia for facilitating the development of this complex project. We deeply thank all communities, local authorities, school teachers, volunteers, and members of this social network for their support and contributions that made this work possible. Finally, we acknowledge the insightful comments from WCAS Editor Henry Huntington, three anonymous reviewers, and Ángel Muñoz at International Research Institute for Climate and Society (IRI). This paper is part of the program "Estrategia de Sostenibilidad 2014–2015" at Universidad de Antioquia, Colombia.

APPENDIX

Work Team

This participative research was possible thanks to the hard work performed by Diana Raigoza, Olga Ossa, Natalia Sánchez, Juan Pablo Marín, Sergio Vásquez, Juan Carlos Ríos, Jayson Mejía, Hernán Méndez, Alba Delgado, Isabel Gutiérrez, Lina Velásquez, Santiago Uribe, Agustín Cárdenas, Amanda Delgado, Ana Taborda, Angelly Saldarriaga, Carolina Mejía, Cristian Abad, Diego Aguirre, Diego Chaves, Diego Peña, Ferney Jurado, Hernán Vélez, Jenni Perdomo, John Zapata, Jorge Castro, Juan Sánchez, Kelly Dunlap, Liliana Hurtado, Liliana Salas, Lina López, Lorena Zapata, Manuela Arango, Santiago Díaz, Isabel Alzate, Alexander Agudelo, Ángela Uribe, Sonia Niebles, Olga Monsalve, Lucas Arboleda, Carlos Arenas, Osfredilian Gallo, Alejandro Henao, Luis Hernández, Guillermo Lora, Esteban Medina, Miguel Ruiz, Mario Jiménez, Cristian Ortiz, Juan Álvarez, Ana Gallo, Albert Usma, Juana Arroyo, Alejandro Montealegre, Julián Pardo, Samuel Restrepo, Juan Delgado, Ferney Hernández, Juan Vega, Carolina García, Clara Grisales, Amalia Pérez, and Marlon Gutiérrez.

REFERENCES

Arias, P. A., J. A. Martínez, and S. C. Vieira, 2015: Moisture sources to the 2010–2012 anomalous wet season in northern South America. *Climate Dyn.*, **45**, 2861–2884, doi:10.1007/s00382-015-2511-7.

Australian Bureau of Meteorology, 2012: Record-breaking La Niña events: An analysis of the La Niña life cycle and the impacts and significance of the 2010–11 and 2011–12 La Niña events in Australia. Bureau of Meteorology, Melbourne, 28 pp.

Basher, R., 2006: Global early warning systems for natural hazards: Systematic and people-centred. *Philos. Trans. Roy. Soc.*, **364A**, 2167–2182, doi:10.1098/rsta.2006.1819.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner, 1996: Vulnerabilidad: El entorno social, político y económico de los desastres. *La Red: Red de Estudios Sociales en Prevención de Desastres en América Latina*, Tercer Mundo Editores, 290 pp.

Carey, M., C. Huggel, J. Bury, C. Portocarrero, and W. Haeberli, 2012: An integrated socio-environmental framework for glacier hazard management and climate change adaptation: Lessons from Lake 513, Cordillera Blanca, Peru. *Climatic Change*, **112**, 733–767, doi:10.1007/s10584-011-0249-8.

CEPAL, 2012: Valoración de daños y pérdidas: Ola invernal en Colombia 2010–2011. Comisión Económica para América Latina y el Caribe, Misión BID, 240 pp.

Collins, M. L., and N. Kapucu, 2008: Early warning systems and disaster preparedness and response in local government. *Disaster Prev. Manage.*, **17**, 587–600, doi:10.1108/09653560810918621.

Conrad, C. C., and K. G. Hilchey, 2011: A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environ. Monit. Assess.*, **176**, 273–291, doi:10.1007/s10661-010-1582-5.

CORANTIOQUIA, 2011: Plan de acción para la atención y mitigación de la emergencia invernal en la jurisdicción de CORANTIOQUIA. CORANTIOQUIA, 80 pp.

de León, J. C. V., J. Bogardi, S. Dannenmann, and R. Basher, 2006: Early warning systems in the context of disaster risk management. *Entwickl. Ländlicher Raum*, **2**, 23–25.

Eslava, J., 1993: Some climatic particularities of Colombia's Pacific region (in Spanish) *Atmósfera*, **17**, 45–63.

García Acosta, V., 2008: Historia y desastres en América Latina. Vol. III. Centro de Investigaciones y Estudios Superiores en Antropología Social de México, LA RED: Red de Estudios Sociales en Prevención de Desastres en América Latina, Publicaciones de la Casa Chata, 358 pp. [Available online at http://www.la-red.org/public/libros/2008/hyd/Historia_y_Desastres_VolumenIII.pdf.]

Hartmann, D. L., and Coauthors, 2013: Observations: Atmosphere and surface. *Climate Change 2013: The Physical Science Basis*, T. F. Stocker et al., Eds., Cambridge University Press, 159–254.

Hoyos, N., J. Escobar, J. C. Restrepo, A. M. Arango, and J. C. Ortiz, 2013: Impact of the 2010–2011 La Niña phenomenon in Colombia, South America: The human toll of an extreme weather event. *Appl. Geogr.*, **39**, 16–25, doi:10.1016/j.apgeog.2012.11.018.

Huggel, C., and Coauthors, 2015: A framework for the science contribution in climate adaptation: Experiences from science-policy processes in the Andes. *Environ. Sci. Policy*, **47**, 80–94, doi:10.1016/j.envsci.2014.11.007.

Huppert, H. E., and R. S. J. Sparks, 2006: Extreme natural hazards: Population growth, globalization and environmental change. *Philos. Trans. Roy. Soc.*, **364A**, 1875–1888, doi:10.1098/rsta.2006.1803.

IDEAM, 2005: *Atlas Climatológico de Colombia*. Instituto de Hidrología, Meteorología y Estudios Ambientales, 219 pp.

ISDR, 2004: Early warning as a matter of policy: The conclusions of the Second International Conference on Early Warning. United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR) and the German Disaster Reduction Committee (DKKV), 28 pp. [Available online at http://www.unisdr.org/files/8290_earlywarningasamatterofpolicy.pdf.]

Liebman, M., and R. G. Paulston, 1994: Social cartography: A new methodology for comparative studies. *Compare*, **24**, 233–245, doi:10.1080/0305792940240304.

Magrin, G., J. Marengo, J.-P. Boulanger, M. S. Buckeridge, E. Castellanos, G. Poveda, F. R. Scarano, and S. Vicuña, 2014: Regional aspects: Central and South America. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, Cambridge University Press, 1499–1566.

Marengo, J. A., R. Jones, L. M. Alves, and M. C. Valverde, 2009: Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. *Int. J. Climatol.*, **29**, 2241–2255, doi:10.1002/joc.1863.

Martínez, R., C. Euscátegui, E. Jaimes, G. León, and A. Quintero, 2011: Northern South America and the tropical Andes [in "State of the Climate in 2010"]. *Bull. Amer. Meteor. Soc.*, **92**, S186–S187, doi:10.1175/1520-0477-92.6.S1.

Mertz, O., K. Halsnæs, J. E. Olesen, and K. Rasmussen, 2009: Adaptation to climate change in developing countries. *Environ. Manage.*, **43**, 743–752, doi:10.1007/s00267-008-9259-3.

Pabón, J. D., and G. Torres, 2007: Socioeconomic impacts of El Niño and La Niña phenomena in Bogota during the 20th century (in Spanish). *Rev. Colomb. Geogr.*, **16**, 81–94.

Poveda, G., P. R. Waylen, and R. S. Pulwarty, 2006: Annual and inter-annual variability of the present climate in northern South America and southern Mesoamerica. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **234**, 3–27, doi:10.1016/j.palaeo.2005.10.031.

——, D. M. Álvarez, and O. A. Rueda, 2011: Hydro-climatic variability over the Andes of Colombia associated with ENSO: A review of climatic processes and their impact on one of the Earth's most important biodiversity hotspots. *Climate Dyn.*, **36**, 2233–2249, doi:10.1007/s00382-010-0931-y.

Snow, J. W., 1976: The climate of northern South America. *Climates of Central and South America*, W. Scwerdtfeger et al., Eds., World Survey of Climatology Series, Vol. 12, Elsevier, 295–403.

Twigg, J., 2002: The human factor in early warnings: Risk perception and appropriate communications. *Early Warning Systems for Natural Disaster Reduction*, J. Zschau and A. N. Kuppers, Eds., Springer, 19–26.

UN, 2006: Global survey of early warning systems: An assessment of capacities, gaps and opportunities towards building a comprehensive global early warning system for all natural hazards. United Nations, 46 pp. [Available online at http://www.unisdr.org/2006/ppew/info-resources/ewc3/Global-Survey-of-Early-Warning-Systems.pdf.]

UNISDR, 2011: Global assessment report on disaster risk reduction: 2011. United Nations International Strategy for Disaster Reduction, 178 pp. [Available online at http://www.unisdr.org/we/inform/publications/19846.]

Vidal, L. M., 2007: Evolución de la vulnerabilidad frente a fenómenos asociados con deslizamientos e inundaciones. Caso Zona Nororiental de Medellín, 1960–1990. *Rev. Gestión Ambiente*, **10** (2), 53–71.

Wrathall, D., J. Bury, M. Carey, B. Mark, J. McKenzie, K. Young, M. Baraer, A. French, and C. Rampini, 2014: Migration amidst climate rigidity traps: Resource Politics and social–ecological possibilism in Honduras and Peru. *Ann. Assoc. Amer. Geogr.*, **104**, 292–304, doi:10.1080/00045608.2013.873326.