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Understanding the dissemination and adoption of innovations through social network analysis: geospatial solutions for disaster management in Nepal and Kenya

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Vulnerable areas of the world, including many developing countries, are increasingly exposed to natural disasters. New technologies, such as geospatial technologies, could help them manage the risks of extreme events and cope with disaster aftershock. However, new technologies are often disseminated slowly among the relevant stakeholders. Assuming that knowledge exchange through stakeholder networks can effectively enhance the uptake of innovation, this research applied a social network approach focussing on the structural patterns of communication and collaboration networks regarding landslide-related disasters in Nepal and floods in Kenya. Using methods of formal social network analysis, we reveal centrally positioned stakeholders and discuss their actual and potential roles in outscaling innovations between the different sectors and upscaling them to different levels within the disaster management communities under study. In doing so, this case study demonstrates the potential of social network analysis for improving the dissemination of innovations for disaster risk management.

Keywords: landslide; flood; earth observation; social network analysis; disaster risk reduction

1. Introduction

Natural disasters and, in particular, extreme climatic events are occurring with growing intensity and frequency, most probably driven by climate change (IPCC 2012; Min *et al*. 2011). Many developing areas of the world have been increasingly exposed to natural disasters over the past few decades (Arnold and Kreimer 2004; Dilley 2006; Klomp and Valckx 2014; Toya and Skidmore 2007). Low-income areas of the world have greater difficulties in coping with extreme weather in a timely and effective manner due to their financial constraints and less-developed infrastructures (Becerra, Noy, and Cavallo 2012; Fankhauser and McDermott 2014; Mirza and Monirul 2003; Yohe and Tol 2002). These regions also suffer from gaps in access to climate data, forecasts and knowledge in general (Vitart *et al*. 2017).

Managing the risks of extreme events before they become disasters and coping with disaster aftershock is known as "disaster management". Disaster management comprises both disaster risk reduction (DRR), i.e. reducing disaster risk by analysing

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and managing disaster causes, addressing exposure and vulnerability to hazards (UNISDR 2009), and disaster response, including relief and recovery (IFRC 2015).

Different procedures and techniques can enhance disaster management by reducing or eliminating risks and corresponding losses. These procedures and techniques include geospatial data analysis and tools (Hodgson *et al*. 2014). The increasing accessibility, reliability and effectiveness of geospatial technologies in providing accurate models and simulations of real-world phenomena, as well as visualisations of geospatial data, are further improving their applicability for disaster risk reduction and disaster response (Abdalla and Li 2010). Access to geospatial data to support decision-making in developing countries is an ongoing challenge for the disaster management community.

The Regional Visualization and Monitoring System (SERVIR)[1] is one of the programmes that provide developing nations with access to Earth observation data and geospatial technologies. The programme also provides training to strengthen the capacity of decision-makers to use these technologies and to facilitate improved decision-making related to disaster management and other environmental problems. However, simply providing more and better information, knowledge and tools for managing environmental problems, including disaster events, does not necessarily or immediately provide positive impacts on the business-as-usual approaches (Fazey *et al*. 2014; Spiekermann *et al*. 2015). A performance evaluation of SERVIR has been conducted to ascertain whether the products and services it provides have resulted in usable knowledge, how they have been distributed and whether the use of the new information has resulted in any changes in policy or management practices by affecting the decision-making process.[2] This paper presents the results of two of the case studies within this larger performance evaluation study: (1) natural disaster management in Nepal and the role of SERVIR's Rapid Response Mapping (RRM) service and (2) flood management in Kenya and the role of SERVIR's Coupled Routing and Excess Storage (CREST) products. We undertook these case studies to answer the following questions related to SERVIR performance evaluation: in which ways, and by whom, have these innovative services and information been adopted, and how can the innovation dissemination process be enhanced?

When analysing the adoption of innovations, it is important to address how the innovations are spread beyond the community of developers and produce a broader impact. An innovation system approach considers how different actors interact in the social system under consideration (Freeman 1987; Klein Woolthuis, Lankhuizen, and Gilsing 2005). From the diffusion of innovation perspective, individuals or organisations are exposed to new knowledge and technologies through their contacts with others in social networks (Gamboa, Barkmann, and Marggraf 2010; van der Valk, Chappin, and Gijsbers 2011). The transfer of information through social networks can result in a behavioural response, such as the implementation of disaster reduction measures (Kasperson *et al*. 1988; Haer, Wouter Botzen, and Aerts 2016). Hermans *et al*. (2013) took a network perspective when analysing the adoption of new technologies and practices within an innovation system. According to them, one of the functions necessary in integrating a local innovation into the broader innovation system is *upscaling*, i.e. providing hierarchical links between the different levels of the innovation system. *Outscaling*, meanwhile, is a horizontal process that allows knowledge transfer between different types of organisations. In outscaling, brokers, i.e. actors in positions to control the information flow (Freeman 1977), are particularly important for connecting different types of organisations or sectors (Hermans *et al*. 2013).

We applied a formal social network approach to examine the evaluation questions using social network analysis (SNA), a method for investigating social structures that looks beyond the attributes of individuals to focus on social relations between actors (Prell, Hubacek, and Reed 2009; Wasserman and Faust 1994). SNA has been used in environmental management, for example, by Bodin and Prell (2011), who provided an overview of SNA's contribution to the theoretical and methodological discussion on natural resource management. More recently, a formal social network approach has also been investigated in disaster research (Varda *et al*. 2009), because a community's resilience to disasters is dependent on the strength of its social networks (Magsino 2009). Moreover, SNA has been recommended as a tool for understanding communication in a social network (Comfort and Haase 2006) in order to support emergency management practitioners in improving situational awareness of who is communicating and working with whom and under what circumstances (Kapucu 2005, 2006).

However, to our knowledge, the social network approach has not been applied as a means for improving the understanding of the diffusion of innovative services and technologies for risk management. In this research, we performed SNA in order to analyse the social networks of potential innovation beneficiaries and understand how the dissemination and adoption of the SERVIR products happened, or could happen in the future. This involved analysing the communication and collaboration networks of the actors involved in the environmental issues of concern and understanding the positions of these actors in the networks, i.e. who the central players and information brokers were and how they were connected to SERVIR and to other actors in the networks. This method could be adopted in the future to explore the potential for innovation adoption before its delivery or implementation.

2. Methodology

The methodologies applied in this research comprised stakeholder analysis, focus group discussion, interviews and SNA.

The data collection was conducted in two main steps:

1. Stakeholder analysis and identification of the main actors through documentation review and focus groups;
2. Data collection on social relations in the interviews conducted with selected stakeholders.

2.1. Stakeholder analysis

Stakeholder analysis is used to frame and analyse complex situations in natural resource management and other initiatives that influence a variety of actors and, hence, demand their participation (Grimble and Wellard 1997). In this research, stakeholder analysis was conducted as a first step towards understanding and characterising the main actors in the disaster management communities and for identifying entities for SNA. We determined the initial list of main stakeholders, including organisations and specific offices from a variety of sectors that affected, or were affected by, the issues of concern, through a literature review and consultation with the partner institutions in direct collaboration with SERVIR. The initial list also included those institutions that SERVIR, or its regional partner institutions, directly communicated with regarding the product under evaluation, for example, through providing training on the use of the product or the data provided by that service.

The selected stakeholders were invited to participate in a focus group in which we discussed the SERVIR products under evaluation, as well as the pertinent environmental issues and natural disasters. Most of the stakeholders were present, but some were unable to attend. The focus group was our initial direct interaction with the local stakeholders, which helped us learn about their first-hand experiences with environmental problems and, together, defined the problems for which the SERVIR service would be useful. In most cases, the participants had been designated by selected institutions or offices and, therefore, were expected to speak on their behalf. The focus group also served to illuminate the actors' relationships, which we then more profoundly analysed through SNA. In addition, the focus group discussion was aimed at identifying recent case studies that represent pertinent disaster management practices and needs in the country. The participants in the focus groups in Nepal and Kenya had been involved in the events' responses or were aware of them and, thus, provided valuable background information on the selected disaster events, as well as a broad overview of how the disaster response industry functions in local contexts. We then conducted the SNA in the context of these case studies.

At the end of the focus group meeting, we shared the list of actors identified in the stakeholder analysis and asked the participants to write down, or notify us later, if they thought of any other important and/or influential actors they considered relevant for the SNA. These additional inputs from experts served to complete the initial list of stakeholders, making it more robust and reliable and ensuring the involvement of all the relevant actors (Bryman 2001). The findings from the focus groups were combined with the findings from individual in-depth interviews that we subsequently conducted with both the focus group participants and all the other stakeholders identified by them. Interview guides were developed for each country. In this paper, we only focus on the last section of the interview, i.e. the evaluation matrix that was used as input for SNA (Supplemental Material, Fig. A1). In a few cases, when focus group participants stated they could not take part in the interviews, we conducted the evaluation exercise with them after the focus group.

2.2. Data collection and analysis of social relations

The analysis of social relations was conducted using the evaluation matrix (Supplemental Material, Fig. A1) that allowed the interviewees to quantify their relations with other stakeholders. The interviewees ranked the relations on a Likert scale from 1 to 5.

In particular, we asked about two types of relations:

1. Communication: the participants ranked communications about disaster management between their organisations and other listed actors from the disaster management community. The ranking was done according to the frequency of communication;
2. Collaboration: the participants ranked collaboration in response to natural disasters (e.g. landslides and floods) between their organisations and the other listed actors

from the disaster management community. The ranking was done according to the frequency of collaboration.

A formal social network approach studies the structural relationships between interacting network members (Varda *et al*. 2009; Newman 2010). The focus of the formal social network approach is on network characteristics, including network structure and tie characteristics, rather than on the attributes of its actors (Wetherell, Plakans, and Wellman 1994). SNA is a method that uses mathematical algorithms to assess to what degree network members are connected to one another in terms of different relationships. A graphical representation of a social network contains ties (edges) that connect actors (nodes). The network nodes may be individuals, groups, institutions or other types of actors. Ties indicate linkages between pairs of actors and could be assigned values to represent the strength of the relations (Scott 2011), e.g. based on the frequency of communication or strength of collaboration.

The first step in SNA is to specify the unit of observation (Varda *et al*. 2009). This involves determining the entity that will represent the nodes of the social network and specifying the types of relations investigated. In this research, we analysed the relations between the different institutions involved in disaster risk management, with *relations* here denoting the communication on disaster risk management in general and the collaboration in disaster response in particular.

The data analysis comprised the computation of the social network metrics and the development of a graphical representation of the network. Social network metrics, such as centrality or density, provide the basic properties of social networks. At this stage, we wanted to identify the position of the individual nodes within the analysed networks. We were looking into the possibility for individual actors to influence the communication between, and the collaboration among, network members. The aim was to single out those actors who were in a "central" position in the network.

Centrality measures provide the actors' properties relating to their structural importance or prominence in the network (Borgatti *et al*. 2009; Hansen, Shneiderman, and Smith 2011), which we considered a good proxy for their potential roles in innovation adoption. We considered two types of centrality measures:

- **Degree centrality** is the total number of edges connected to a particular node (Freeman 1978, Newman 2010, Das, Samanta, and Pal 2018). Actors with a high degree centrality have important roles in transferring information due to their ability to communicate directly with others in the network (Koschutzki *et al* 2005). We assumed that actors with high degree centrality could more easily transfer information related to a disaster and to the use of the service/product under evaluation. Degree centrality gives only "local" information of a node and does not consider global structure (Das, Samanta, and Pal 2018). Therefore, we applied this measure to analyse the flow of communication in the network;
- **Betweenness centrality** denotes how often a given node lies on the shortest path between two other nodes (Freeman 1977). A node high in betweenness centrality has the power to connect disconnected groups, to broker opinions and to control information flow (Bodin, Crona, and Ernstson 2006; Stuetzer *et al*. 2013). This type of actor has control over connections, including the ability to restrict connections in the network (Das, Samanta, and Pal 2018). Unlike degree centrality, betweenness is a global measure, i.e. it studies the characteristics of

the network as a whole. We used this measure when analysing collaboration in disaster response. Since actors with high betweenness centrality could improve or hinder information flow, we also considered this measure when analysing communication in the studied networks.

Besides centrality measures, we also calculated the networks' densities. The density of a network considers both local and global measures and is a good indicator of its cohesion (Bandyopadhyay, Rao, and Sinha 2011). Density shows the presence of ties in relation to all the possible ties in the analysed network and is calculated as the number of registered connections divided by the number of all possible connections (Burt, Kilduff, and Tasselli 2013). Density can range from 0 to 1 and can be used to compare different networks.

A graphical representation of the network provides an immediate understanding of the structure of interactions and relationships within the network. We performed a graph analysis with the SNA software, NodeXL Pro, a template for Excel that can calculate a core set of network metrics and scores (Hansen, Shneiderman, and Smith 2011). We revised the graphical representation of the network by editing the shapes and colours of the symbols according to the findings from both the interviews and from the computational analysis. For better visualisation, we placed the key stakeholders – those with the highest centrality values in the analysed network – at the centre of the graph and others around them according to their respective centrality values.

2.3. Case studies

2.3.1. Nepal

Located in the Hindu Kush-Himalayan region, Nepal is exposed to a wide range of natural disasters, including landslides, floods and earthquakes, as evidenced by the devastating earthquake of 2015. The Hyogo Framework for Action established internationally agreed-upon guidelines for coordination between the sectors and actors of participating countries in order to reduce disaster losses and to strengthen disaster resilience (ISDR 2007). Pursuant to the Hyogo Framework for Action, in 2009, Nepal established a National Strategy for Disaster Risk Management that serves as the principal set of guidelines for disaster management. Since successfully implementing the Hyogo Framework of Action, Nepal has also committed to a tangible contribution to the implementation of the Sendai Framework of Action (2015–2030).

The SERVIR-Himalaya initiative was launched in 2010 at the International Centre for Integrated Mountain Development (ICIMOD). Its aim is to improve environmental decision-making in Nepal and the rest of the Hindu Kush-Himalayan region through the dissemination and analysis of Earth observation data. This research analyses the RRM service that provides map products, mainly based on satellite data, for disaster situations such as landslides, particularly in remote areas. The SERVIR-ICIMOD partnership increased the ICIMOD's access to data and enabled the expansion of the RRM. The generation and dissemination of RRM products is event-based, i.e. it depends on the nature, location and context of the disaster in question. In the case of a larger disaster, ICIMOD can activate the International Charter on Space and Natural Disasters to obtain high-quality satellite data for a particular area. ICIMOD can then process, analyse and share these data in the form of detailed maps and other products. Significant natural disaster events that occurred prior to this investigation in November

2014 included the 2012 flash flood of the River Seti in the Western Development Region of Nepal and the 2014 landslide disaster on the River Sunkoshi in Nepal's Central Development Region. Consequently, the RRM performance evaluation and the SNA of the Nepali disaster management community were conducted in the context of these two events.

2.3.2. Kenya

Flooding is a major issue in some parts of Kenya, including Western Kenya, with severe impacts on human lives, food and agricultural security, infrastructure and other sectors. Flood monitoring, disaster response and flood management infrastructures all demand significant capacity and financial resources from the responsible institutions. The need for a flood coordination centre was expressed both in the focus group discussions and in the interviews. The participants raised concerns that most of the activities were project-based and that these activities were not sustainable unless a more institutional approach was established. SERVIR and its Eastern and Southern Africa partner, the Regional Centre for Mapping of Resources for Development (RCMRD), developed the CREST services to support water management in Kenya. CREST integrates NASA's Tropical Rainfall Measuring Mission, satellite data and local rainfall information, including meteorological forecasts, to produce streamflow estimates and predictions of the likelihood of flooding in various catchments within the RCMRD member states. The objective of the CREST products is to provide water managers with information about precipitation and streamflow amounts and the resulting likelihood of flooding for the selected watersheds. The CREST Streamflow Viewer presents recent precipitation and resulting streamflow information in three-hour increments. The CREST hydrologic model needs to be calibrated for particular watersheds, and this work has already been done for the Nzoia River basin in Western Kenya. In this case study, conducted in April 2015, we approached the general issue of floods in the lower Nzoia River basin rather than focussing on a specific event.

3. Results

3.1. The Nepal case study

3.1.1. The stakeholder network

The stakeholder analysis and characterisation were obtained through a literature review, focus group discussions and 31 interviews with actors who have a stake in disaster management in Nepal.

The lead agency in disaster response is the National Emergency Operations Centre (NEOC) within the Ministry of Home Affairs (MOHA). The NEOC coordinates disaster response, activating operations for the Nepalese Army, the Nepal Police and the Armed Police Force. The Nepalese Ministry of Urban Development assumes the lead in disaster reconstruction, while the Ministry of Federal Affairs and Local Development and the Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) lead risk reduction activities in the medium to long term.

Apart from disaster management coordination at the level of central government, operations remain largely decentralised. The NEOC's district-level operation centres (DEOC) are chaired by a chief district officer (CDO). Similarly, many ministries, such as the Ministry of Urban Development and the Ministry of Federal Affairs and Local Development, have district "line" agencies.

The government of Nepal also works closely with international organisations on disaster management and contingency planning for humanitarian responses. The government and humanitarian organisations represent the core of the Nepalese disaster management network, although there are also many other organisations that participate in DRR and disaster response, particularly through the Disaster Preparedness Network (DPNet), a coalition of NGOs, private sector institutions, professional associations and related groups.

In the event of a disaster, and in order to conduct a situational analysis, the CDO and DEOC work with district line agency representatives, the Red Cross and relevant political party leaders. In the case of a larger disaster, the CDO notifies the NEOC, which activates the humanitarian cluster system (Supplemental Material, Fig. A2). Once the government has declared a disaster, there is an international appeal to the Red Cross Office.

Although the system is well structured, there is no centralised database that establishes a baseline for natural disaster data in Nepal. Data collection, therefore, tends to be event specific and/or region specific. Data are primarily drawn from eye-witness accounts, ground-based observation and army-led reconnaissance.

The disaster response chain in Nepal was confirmed in the two analysed events, i.e. the River Seti flash flood and the River Sunkoshi disaster. The disasters were reported by the local police to the district police and further to the CDO and the Nepalese state police. The CDO contacted the NEOC who, in turn, activated the police, armed police and the army, as well as external experts. The police informed the office of the Ministry of Home Affairs, which informed the minister and the secretary. In addition, the MOHA informed other relevant ministries (Supplemental Material, Fig. A2).

In the case of a disaster where remote sensing images are available, the ICIMOD provides SERVIR's RRM service with satellite maps of the disaster area. In the River Seti and River Sunkoshi events, the ICIMOD reported that the primary recipient of the RRM products was the NEOC. Hence, the NEOC was perceived as the distribution vector for receiving RRM products (from the ICIMOD) and passing them on to the Nepalese Police, the Armed Police Force, the National Army and the United Nations Development Programme (UNDP). The results from the focus group discussion and the interviews show limited awareness of the RRM product, however, and, hence, little awareness of its use. We could not confirm that the actors placed further down the chain received the RRM maps in the case of the two analysed events.

In addition to understanding the formal plan of action in the case of a disaster, revealing the informal relationships and the working environment helped to understand the factors that can improve or hinder the adoption of the SERVIR's RRM. One example is the frequent rotation of technical staff within the government, which could be a limiting factor in spreading new knowledge both within and beyond individual offices and departments. This further highlights the importance of involving different stakeholders in the dissemination of the new service.

3.1.2. *Social network analysis*

In the 31 interviews conducted for this case study, we identified 25 actors involved in communications about disaster management, 15 of which were active in disaster response (Supplemental Material, Table A1). We applied SNA to the results obtained from the social relations evaluation exercise conducted by these stakeholders.

The communication network is composed of $N = 25$ stakeholders who are involved to varying degrees in disaster management. Figure 1 presents the network of stakeholders frequently communicating about disaster management. We focussed only on strong ties (marked with 4 and 5) and discarded communication marked as some and episodic (marked with 3 and 2), as not sufficiently significant. The stakeholders with the highest degree centralities are, in decreasing order, the Red Cross, CDO and NEOC. Out of the three best connected actors, only the NEOC used RRM, while the other two actors were not aware of it. Other stakeholders with a relatively high number of connections are the Ministry of Urban Development, Armed Police Force, Nepal Police, Department of Geology and World Wide Fund (WWF) for Nature Nepal. The latter three were aware of RRM, but had not used it. Looking into the betweenness centrality measure, the Department of Geology is in third place, after the Red Cross and the CDO (Degree and betweenness centrality values for the communication network are available in Table A2, Supplemental Material). The density of the communication network is 0.26.

Table 1 presents egocentric networks of the three stakeholders with the highest degree centralities and the ICIMOD. Here, we wanted to investigate the potential of innovation dissemination through best connected actors, who can have good access to information. The width of each edge is related to the frequency of communication. A

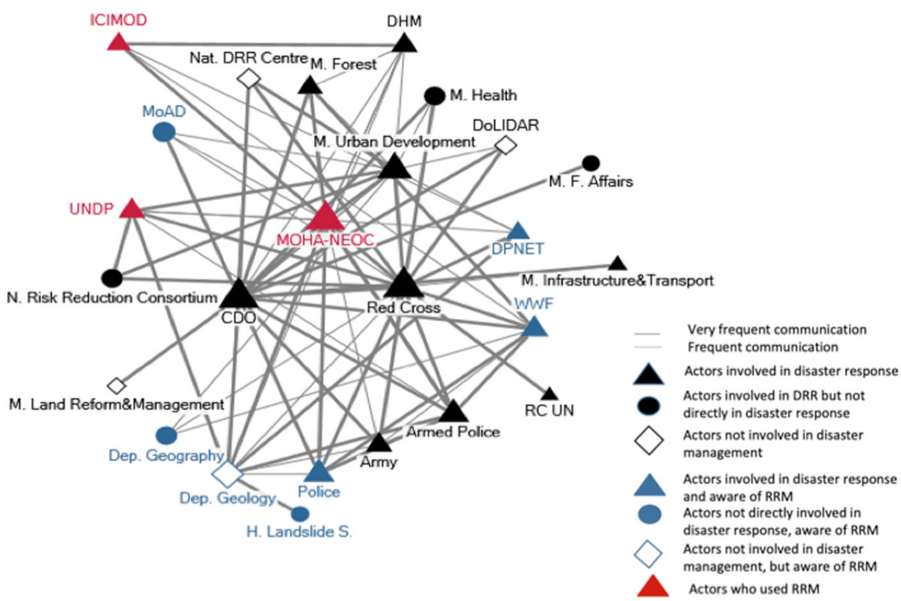
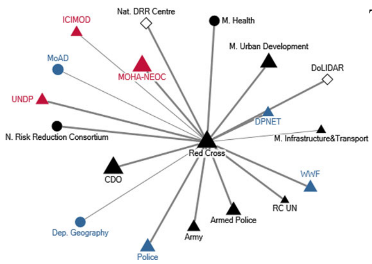
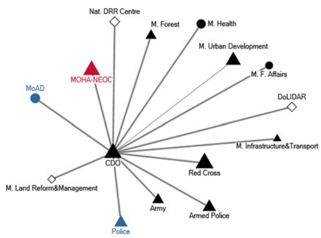
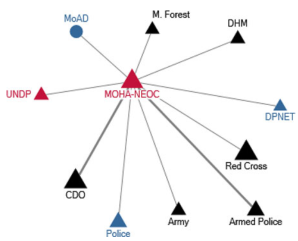
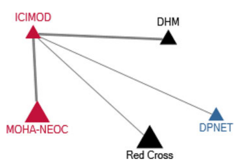


Figure 1. Social network of the Nepalese disaster management community, based on frequent communication. Node size is determined by the stakeholders' degree centrality. Edge thickness is determined by the frequency of communication, with the thickest edges representing very frequent communication (5), compared to frequent communication (4). Triangles represent stakeholders involved in disaster response. Circles represent those stakeholders involved in DRR but not directly involved in disaster response. Diamonds represent participants who were not involved in disaster management in the two analysed cases. The colour blue indicates awareness of the RRM service and red indicates those stakeholders who used RRM.

Table 1. Key stakeholders' communication relationships (egocentric networks) in the Nepalese disaster management community.

<table>
<tr><th></th><th>Individual stakeholder</th><th>Description</th></tr>
<tr><td>RED CROSS</td><td>
</td><td>The Nepal Red Cross Society has the highest degree centrality, totalling 23. This means they communicate with a broad group of stakeholders involved in the issue of disaster management in different ways. The Red Cross communicates to all three actors that use the RRM service, although it was not aware of it, as declared in the interview. However, the Red Cross showed a strong interest in learning about this service.</td></tr>
<tr><td>CDO</td><td>
</td><td>The CDO has a high degree centrality value of 22. This office communicates with stakeholders involved in disaster response and also with other ministries, such as the Ministry of Land Reform and Management and the Ministry of Agricultural Development (MoAD), as well as DoLIDAR, which leads risk reduction activities in the medium to long term.</td></tr>
<tr><td>MOHA-NEOC</td><td>
</td><td>The NEOC of the MOHA is the central institution responsible for coordinating disaster response. It has good communication with other stakeholders involved in disaster response (triangles). The NEOC has a relatively high degree centrality, with a total of 20 connections marked as frequent communication.</td></tr>
<tr><td>ICIMOD</td><td>
</td><td>The ICIMOD has strong communication with the Department of Hydrology and Meteorology (DHM), who is a stakeholder with relatively high betweenness and degree centrality. Also, the ICIMOD has strong communication with the NEOC, to whom they send RRM, and with the DPNET, which was aware of the service.</td></tr>
</table>

thicker edge denotes very frequent communication (5), as compared to frequent communication (4). In the case of the ICIMOD, as the analysis showed only few connections with this institution, we also considered occasional communication, marked with *3*. (Social network of the Nepalese disaster management community, based on communication frequency marked with 3–5 is available in Fig. A3, Supplemental Material).

The Nepalese disaster response collaboration network is composed of $N = 15$ stakeholders. In Figure 2, the stakeholders that have the most important roles in connecting other stakeholders (the highest betweenness centrality), i.e. the Red Cross, CDO, NEOC and WWF, in decreasing order, are vertically placed in the centre of the matrix. Another stakeholder with relatively high betweenness centrality is the Armed Police.

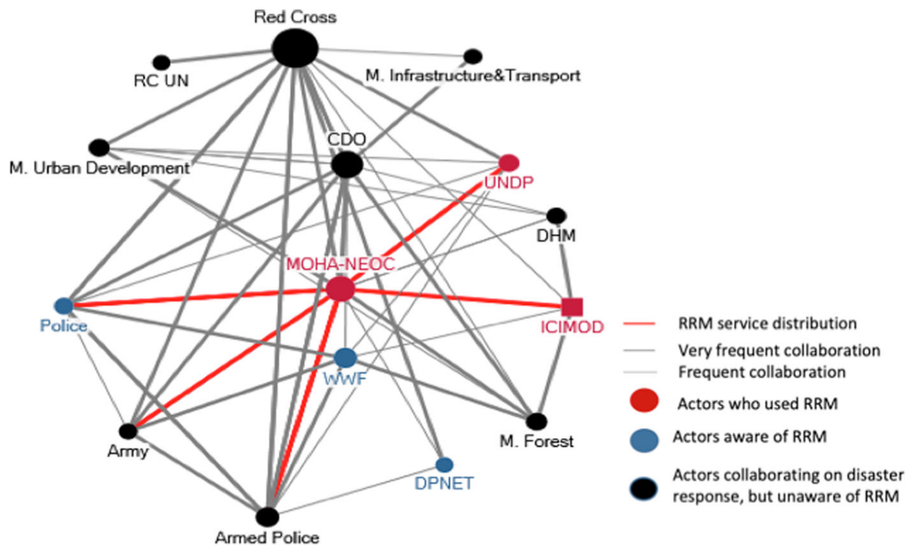


Figure 2. Social network of stakeholders collaborating on natural disaster response in Nepal. Node size is determined by the stakeholders' betweenness centrality. The thickness of the edges denotes the intensity of collaboration, with the thickest edges representing very frequent collaboration (5), compared to frequent collaboration (4). Stakeholders who used RRM are coloured red, while those that are merely aware of the service are coloured blue. Red edges present RRM service distribution, as reported in interviews with the ICIMOD and an NEOC representative.

(Betweenness centrality values are available in Table A3, Supplemental Material.) Apart from the ICIMOD, there were only two other stakeholders who used RRM. However, one of them – the NEOC – has a high potential to improve information flow about RRM. Figure 2 also shows how the RRM service was distributed from the ICIMOD to other stakeholders in the network. The density of the collaboration network is 0.44.

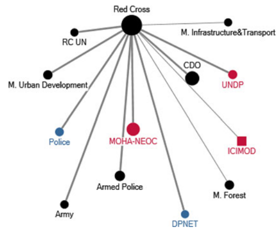
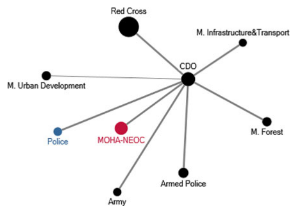
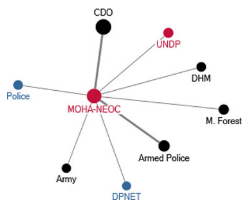
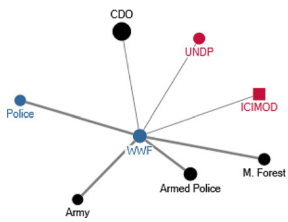
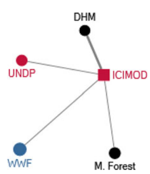
Table 2 zooms in on the collaborative relations of the four stakeholders with the highest betweenness centralities, as well as the ICIMOD, focusing on their ego networks. We wanted to understand who was connected with the key stakeholders in the collaborative network, as these have potential to improve information flow and, hence, disseminate innovation. The width of each edge is related to the frequency of collaboration. A thicker edge denotes very frequent collaboration (5), as compared to frequent collaboration (4). In the case of the ICIMOD, we also considered occasional collaborations, marked with 3, since this stakeholder reported only one very frequent and no frequent collaboration with other actors from the analysed social network. (See Fig. A4, Supplemental Material for the whole network of stakeholders collaborating on natural disasters in Nepal, based on collaboration frequency marked with 3–5.)

3.2. The Kenya case study

3.2.1. The stakeholder network

The identification of relevant stakeholders and the characterisation of their roles in flood management were obtained through a literature review, the focus group

Table 2. Collaborative relationships between key stakeholders (egocentric networks) in the Nepalese disaster response community.

<table>
<tr><th>Individual stakeholder</th><th></th><th>Description</th></tr>
<tr><td>RED CROSS</td><td>
</td><td>The Nepal Red Cross has the highest betweenness centrality. The Red Cross indicated having relatively frequent collaboration with the ICIMOD, although it was unaware of the RRM service.</td></tr>
<tr><td>CDO</td><td>
</td><td>The CDO is second in terms of its importance for connecting other stakeholders while responding to a disaster. The CDO interviewed for this research characterised their collaboration with other key actors, such the Red Cross and NEOC, as very frequent.</td></tr>
<tr><td>MOHA-NEOC</td><td>
</td><td>The NEOC is third in terms of its importance in connecting other stakeholders in the collaborative network. The NEOC representatives interviewed did not indicate they frequently communicated (Table 1) or collaborated with the ICIMOD.</td></tr>
<tr><td>WWF</td><td>
</td><td>The WWF is in the fourth position in terms of its importance in the operational network during a disaster response. However, this only applies when a disaster takes place in a protected area. Apart from the Red Cross, the WWF is the only other stakeholder within the group of four stakeholders with important positions that described its collaboration with the ICIMOD as frequent.</td></tr>
<tr><td>ICIMOD</td><td>
</td><td>The ICIMOD reported strong collaboration only with the Department of Hydrology and Meteorology (DHM) within the disaster management network. Other connections presented in the graph are based on less frequent, i.e. some, collaboration (marked with 3) (see supplementary material Fig. A3).</td></tr>
</table>

discussion and 39 interviews conducted with actors interested in, or affected by, floods in Kenya.

Formally, the lead agency for flood monitoring and disaster response in Kenya is the National Disaster Operations Centre (NDOC). In practice, however, a number of government institutions and NGOs work to respond to this threat in an effort to mitigate the negative effects of flooding on vulnerable communities. These efforts include water resource management, the provision of meteorological and hydrological data, disaster preparedness and an alert system, as well as infrastructural measures, such as the construction of dams and dikes.

The Water Resource Management Authority (WARMA) and the Ministry of Environment, Water and Natural Resources (Ministry of Water) are separate institutions with significantly different mandates and areas of responsibility, although both have a role in water management. The WARMA, through its regional offices, focusses on water permitting and tracking the usage of water resources by different sectors (e.g. agriculture, energy, industry, households). The Ministry of Water, meanwhile, is in charge of water quality and watershed protection. The Kenya Meteorological Service (KMS), more specifically its local office, the Western Kenya Flood Mitigation Office, also has a mandate in flood management in this region.

The findings from the focus group discussion and interviews in Kenya suggest that the SERVIR-RCMRD CREST products were being used in diverse contexts and by diverse stakeholders from government institutions, academia, NGOs and international organisations. The reported uses of the service were as follows: filling in missing data in the streamflow using CREST historical runs, remote monitoring of rivers for potential flooding situations, flood forecasting and prediction, assessing the extent of floods, academic research and the design of water infrastructure.

The focus group discussion, drawing together representatives from the main government institutions with a stake in water management, confirmed collaboration between these institutions. One example of this collaboration is through the Kenya Food Security Steering Group. The participants in the focus group highlighted data sharing as an important matter. The sharing of environmental data, including weather, climate and hydrological information, is, in theory, supported by all the stakeholders. There are, indeed, positive examples of such data sharing, including the flood bulletin for the Nzoia River basin with a three-day forecast for river discharge, as well as an early warning system operated through a radio station. However, the participants from the focus group and the follow-up interviews also expressed concerns that the sharing of data between ministries was limited in some cases. The WARMA, for example, only shares processed products; due to security concerns, raw data are only shared to a limited extent and on request. Similarly, the KMS charges for certain data uses. The participants agreed that having access to the free and easily available CREST products would provide an alternative to reliance on government data, which is sometimes costly and hard to obtain. This would benefit government actors as well as stakeholders from academia and the NGO sector.

The frequent restructuring of ministries was found to be another possible barrier to data sharing and more profound collaboration. For example, the WARMA and the Ministry of Water drifted into two separate institutions. These frequent transitions within institutions, together with a high turnover of staff, can hinder smooth communication and disrupt established collaboration practices between different institutions.

In addition, frequent employee turnover limits the effectiveness of the staff training provided by the RCMRD and slows down the establishment of the critical mass of users required for broader product uptake within the organisations. According to the interviewees from academia, this situation is further exacerbated by the way in which the awareness and potential adoption of the new services is driven by personal connections. Since the SERVIR project in Kenya has also witnessed staff changes and restructuring in the past, this presented yet another barrier to the broader adoption of the product. Drawing from experience with other well-established and broadly used

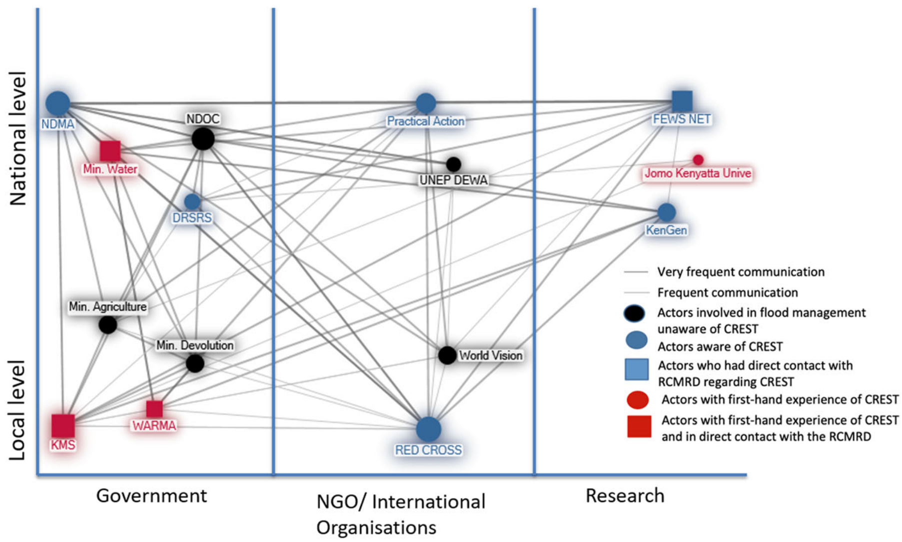


Figure 3. Social network of actors involved in water and flood management in Kenya, based on frequent communication. The network is organized based on the types of stakeholders (x axis) and their territorial influence (y axis). Node size is determined by the stakeholders' degree centrality. Edge thickness is determined by the frequency of communication, with the thickest edges representing very frequent communication (5), compared to frequent communication (4). Blue nodes denote stakeholders aware of CREST. Red nodes denote stakeholders who used CREST. Square nodes represent stakeholders who had direct contact with the RCMRD regarding CREST.

hydrology models, the representatives of academia emphasised the importance of establishing a "community of practice" of model users who could support dissemination and increase the uptake of the CREST model, ultimately leading to its more substantial role in decision-making.

3.2.2. Social network analysis

The SNA in Kenya covered communication and collaboration between $N = 15$ stakeholders from different sectors regarding water, flood and drought management and the awareness and use of the CREST products (Supplemental Material, Table A4). Along with these 15 stakeholders, the RCMRD also took part in this evaluation exercise. Since this stakeholder is not active in disaster response, the RCMRD is not included in the graphical network presentation (Figures 3 and 4). Table 3, instead, focuses on the RCMRD.

Figure 3 presents the network of stakeholders frequently communicating regarding water and flood management. The stakeholders with the highest degree centralities, in descending order, are the Red Cross, National Drought Management Authority (NDMA), KMS and NDOC. Other stakeholders with a relatively high number of connections are the Ministry of Water and the Famine Early Warning Systems Network (FEWS Net). Aside from the NDOC, other stakeholders with high degree centrality were aware of the CREST products. The KMS, Ministry of Water and FEWS Net had direct contact with the RCMRD regarding CREST and, except for the FEWS Net, had

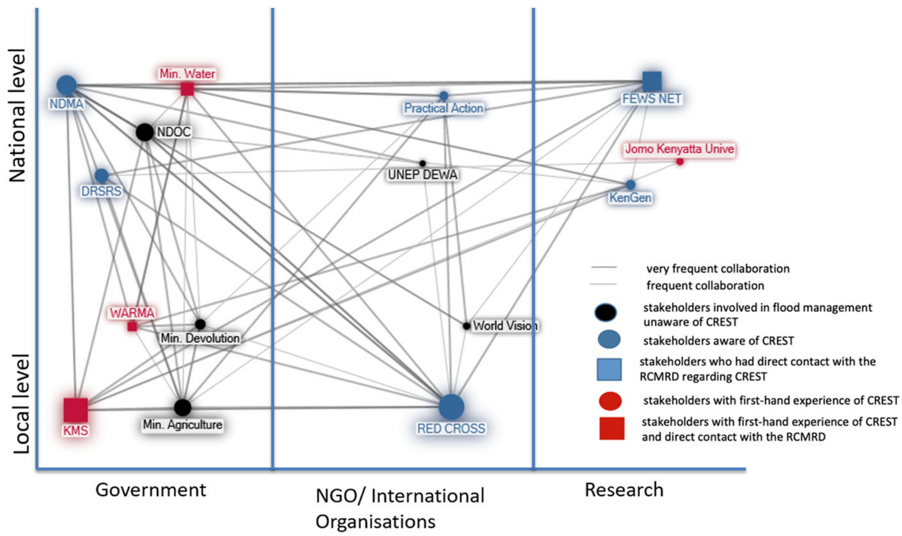
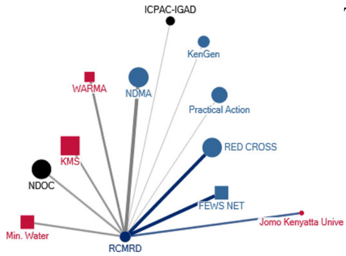
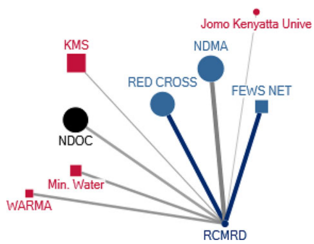


Figure 4. Social network of stakeholders collaborating on water and flood management in Kenya, based on frequent collaboration. The network is organized based on types of stakeholders (*x* axis) and their territorial influence (*y* axis). Node size is determined by the stakeholders' betweenness centrality. Edge thickness is determined by the frequency of collaboration, with the thickest edges representing very frequent collaboration (5), compared to frequent collaboration (4). Blue nodes represent stakeholders aware of CREST. Red nodes represent stakeholders who used CREST. Square nodes represent stakeholders who had direct contact with the RCMRD regarding CREST.

also used the products. In addition, all the stakeholders with high degree centralities reported that they communicated with the RCMRD regarding water monitoring or management (Table 3). The KMS reported frequent communication, while communication between the Red Cross and the RCMRD was very frequent (Table 3). Looking into betweenness centrality values in the communication network, the RCMRD appears as one of the important stakeholders for affecting the information flow. (Degree and betweeness centrality values from the communication network are presented in Table A5, Supplemental Material.) The density of the communication network is 0.55.

The social network evaluation exercise included stakeholders from different sectors, including government institutions, NGOs, international organisations and the research sector. In addition, we interviewed stakeholders at the national-level working more generally on the issue of water, flood and drought management, as well as stakeholders from regional offices working on local issues. The majority of stakeholders were from the government sector. In Figure 3, the key stakeholders in the communication network are located in different domains – quadrants of the graph representing the stakeholder's type versus influence. Within the government sector, the NDMA is the best-connected stakeholder at the national level, and the KMS is the best connected at the local level. Aside from the KMS, other key local stakeholders have a modest number of connections with which they frequently communicate within the institutional network under analysis. Nevertheless, the WARMA had direct contact with the RCMRD and experience of CREST, while the key actor, the Red Cross, reported frequent communication with all four stakeholders from the governmental sector at the local level (light grey lines in Figure 3).

Table 3. Communication and collaboration between stakeholders involved in water and flood management in Kenya and the RCMRD.

<table>
<tr><th>RCMRD’ social network</th><th></th><th>Description</th></tr>
<tr><td>COMMUNICATION</td><td>
</td><td>The Red Cross, NDMA and FEWS Net have very frequent communication with the RCMRD, based on the degree centrality. Communication between the RCMRD and the NDOC, KMS, Ministry of Water, WARMA and Jomo Kenyatta University is frequent. Other stakeholders presented on the left, such as Practical Action, reported only occasional communication with the RCMRD (communication marked with 3–5 is presented in Fig. A6, Supplemental Material).</td></tr>
<tr><td>COLLABORATION</td><td>
</td><td>Among four stakeholders highest in betweenness centrality, three have very frequent collaboration with the RCMRD – the Red Cross, NDMA and FEWS Net. The collaboration between the RCMRD and the NDOC, Ministry of Water and WARMA is frequent. Communication between the KMS and the RCMRD is only occasional, which is surprising since the KMS is one of the actors who actually used the SERVIR products. (Collaboration marked with 3–5 is presented in Fig. A7, Supplemental Material).</td></tr>
</table>

With regard to collaboration on water and flood management in Kenya, the Red Cross is the stakeholder with the highest betweenness centrality. The KMS is in second place, while the NDMA and the FEWS Net share third place. (Betweenness centrality values are presented in Table A6, Supplemental Material.) All four stakeholders with the highest betweenness centralities were aware of CREST; however, only the KMS used the products, although the FEWS Net also had direct contact with the RCMRD on this issue (Figure 4). The density of the collaboration network is 0.19.

The Red Cross, which is the most powerful stakeholder according to its betweenness centrality, works at the local level. Although it belongs to the non-governmental sector, it has intensive collaboration with local governmental offices (Figure 4). In this domain, the local office of the KMS and the Ministry of Agriculture are the key stakeholders for collaboration on water and flood management. Although unaware of the RCMRD or its products, the Ministry of Agriculture has frequent collaboration with the KMS and the WARMA, which is another office operating at the local level and with first-hand experience of the CREST products.

The FEWS Net is the key stakeholder at the national level from the research sector for collaboration on water, flood and drought management. This actor had direct contact with the RCMRD regarding the CREST products.

Table 3 provides details on the relationships between the key stakeholders in Kenya’s network and the innovation provider – RCMRD. Unlike in the Nepalese case, actors in this case study were already familiar with the innovation under analysis. We were thus less interested in the potential innovation dissemination through the key actors and rather investigated the reported connections between the RCMRD and the key actors, which could explain how the dissemination took place. Edge thickness is determined by the frequency of communication and collaboration, with the thickest edges representing very frequent (5), midsize frequent (4) and the thinnest edges representing some communication/collaboration (3). Looking in Table 3, it is obvious that the key stakeholders in the network already have frequent or very frequent communication with the RCMRD. The two sides also have already established collaboration, often frequent, except in the case of the KMS, that only occasionally collaborates with the RCMRD.

4. Discussion

Disaster management typically involves numerous institutions, each playing a different role and acting on different scales at various stages in the "disaster cycle". Therefore, bringing about effective innovations to improve disaster management requires in-depth knowledge of the existing networks of key actors. We wanted to single out those actors who hold the most prominent positions in the social network of the disaster management community and who should be targeted in the innovation dissemination process to help spread new information. To do so, we conducted SNA to understand and assess the communication network of actors involved in disaster management and the collaboration network involved in response to natural disasters in Nepal and Kenya.

In Nepal, the stakeholder highest in degree and betweenness centrality, the Red Cross, could play an important role in service outscaling, since it communicates and collaborates with a broader group of stakeholders involved in DRR and disaster response. Even though its previous role has been limited, the Red Cross could significantly contribute to the broader use of the SERVIR service in the future, thanks to its pre-existing frequent communication with the ICIMOD on the issue of disaster management. The CDO is second in importance regarding its centrality value. With its many different communication and collaboration connections, as well as its influence at the local level in particular, the CDO could contribute significantly to service adoption at this level, if the connection with the service provider or other service users was established.

The SNA also showed that the NEOC, which is a primary recipient of the RRM product during a disaster event, has relatively high degree centrality and betweenness centrality, when it comes to collaboration. Since it is involved in Nepal's well-developed formal disaster management network (Supplemental Material, Fig. A2), this actor might have an interest in promoting the service and helping its distribution. Moreover, the NEOC could contribute to the upscaling of the new knowledge by serving as a distribution vector to the recipients at different hierarchical levels, such as the police, army and armed police (Figure 2). The NEOC has also contributed to the outscaling of the service, i.e. supporting horizontal knowledge transfer to different types of organisations by sending it to the UNDP. Other than the UNDP, however, we could not obtain confirmation that any of these actors used RRM. High degree centrality for this actor shows that it has access to, and could provide, information to many other actors in the network. However, its lower betweenness centrality value in the communication network (Supplemental Material, Table A2) suggests its more limited role in improving information flow and could explain why, so far, it has not contributed more to the promotion of RRM.

As mentioned above, the limited use of the service under evaluation in Nepal could be related to the fact that the key stakeholders in the network were not aware of it (e.g. the Red Cross, CDO, Ministry of Urban Development, Armed police, Police). Another important factor that could have affected the potential use and usability of RRM is the timeframe for product delivery. Data acquisition, analysis and processing often require at least three days. The reason for this delay is that, in many cases, the ICIMOD needs to activate the International Charter on Space and Natural Disasters, which provides relief organisations with free satellite data for charitable and humanitarian purposes in the event of a disaster. This limits the use of RRM for immediate response activities.

Nonetheless, RRM could be very useful for post-disaster activities, particularly if the service dissemination efforts were to include actors with a stake in the different stages of the disaster management process. For example, the Ministry of Urban Development could promote the service for post-disaster assessment, reconstruction and future planning. Likewise, DoLIDAR could use the service as an effective instrument for fundraising appeals: remote sensing images of an area affected by a landslide provide clear and communicable illustrations of the scale and severity of a given disaster.

Finally, the service should not be oriented only towards government agencies but should target all potential users within the disaster management community. RRM could also be an important tool for researchers, e.g. from the Department of Geology, helping to identify the causes of landslides in remote areas of the Himalayas. Another actor with high betweenness centrality, the WWF, was aware of the product and could, hence, support the adoption of the RRM service if the need was to emerge in a protected area in the future.

In Kenya, three of the four stakeholders with the highest degree centralities reported being aware of the CREST products. The KMS also reported having first-hand experience with CREST. This is not surprising, since all four stakeholders reported frequent communication with the SERVIR's partner institution, the RCMRD, regarding water management.

The density (0.51) of the communication network that involves stakeholders from the government, non-governmental actors and the research sector is highly promising for the prospects of success in outscaling the service. From the government sector, the NDMA has the second highest degree centrality and the NDOC the third highest betweenness centrality in the communication network (Supplemental Material, Table A5). These two actors could be important for transferring new knowledge about floods at the national level to other governmental institutions, as well as in transferring such knowledge horizontally to the non-governmental sector (Figures 3 and 4). The FEWS Net could serve as a significant bond to the research sector. For spreading the service at the local level, the Red Cross could play an important role, while the KMS and the WARMA could be important in sharing this new knowledge within the governmental sector.

The primary role of CREST is in monitoring target areas at high risk of floods and mitigating disaster risks at the pre-onset phase, but it could also play a role in other stages of the disaster management cycle. In the post-disaster period, CREST can help in assessing and communicating the extent of flooding through the use of their Streamflow Monitoring Application and, later, in providing better-informed decisions on the design of water infrastructure. The scientists interviewed for this research confirmed the usability of the CREST hydrology model for flood research and modelling if it manages to reach the critical mass of users that would enable the sharing of information about, and experience of, the model. Hence, even those stakeholders not directly involved in disaster management have an important role to play in spreading this new information and converting it into knowledge.

In the two case studies presented in this paper, the focus was on two different types of natural disasters and on the uptake of two different innovative products. Still, a similar pattern emerged in terms of the roles played by stakeholders in DRR communication and disaster response collaboration. The Red Cross emerged as the best-connected stakeholder in both communication and collaboration networks. This is not surprising, since the Nepal Red Cross Society, as well as the Kenya Red Cross, has already been in existence for more than 50 years. The Nepal Red Cross is the largest humanitarian organisation in Nepal, and its network spreads to all of the districts in the country, including many volunteers. In Kenya, the Red Cross has more than 100,000 volunteers. Disaster and emergency services are among the main activities of these two Red Cross societies.

Further down on the prominence scale are institutions from the government sector at the local level, i.e. the CDO in Nepal and the KMS in Kenya. Third in order of importance are the governmental institutions that operate at the national level, i.e. the NEOC in Nepal and the NDMA in Kenya. Interestingly, in analysing the collaboration network of stakeholders active in disaster response, and according to the betweenness centrality values, a fourth type of stakeholder joins the group of key stakeholders. In both case studies, these stakeholders – the WWF and the FEWS Net, respectively – are from the non-governmental sector and are active at the national level.

In some aspects, particularly regarding the characteristics of the communication and collaboration networks, the two case studies diverge. The collaboration network in Nepal is smaller but more coherent (density = 0.44) than the communication network (density = 0.26) and could, thus, be more effective in innovation dissemination. Then again, the larger communication network could better involve different actors. In Kenya, we focussed on the general issue of floods and analysed the network involved in flood management, for looking into both communication and collaboration. In this case, the density of the communication network is significantly higher (0.55) than the density of the collaboration network (0.19). This could signal that supporting the product dissemination through communication could be sufficient.

For more effective innovation dissemination, not only should the key actors in the disaster management community be recognised, but they should also be incentivised to promote the services. These incentives could include clear communication about how the services work and what added value they might bring compared to the tools currently in use. Long-lasting programmes of training and capacity building are an essential part of the effective use of the services, as reported in the interviews. Further, it should not be forgotten that, in both cases, two of the limiting factors for innovation diffusion were the frequent restructuring of institutions and employee turnover, which affect the efficiency of the communication network and disperse the skills gained in training. In addition, in both cases, it appeared evident that the ability to use the products was, to some extent, restricted by the limitations of computer power and Internet connectivity, which are obvious constraints to effective innovation dissemination. Finally, once the innovators understand the social network of interests and who the key stakeholders are, they should establish some degree of institutional sensitisation regarding the potential provision of these products in disaster situations.

5. Conclusions

Good communication and collaboration between the stakeholders involved in disaster management are crucial when hazardous events arise and when urgent decisions need to be made. New information and services, such as geospatial solutions or climate services, could be critical assets for decision-making in these situations, but it cannot be expected that they will be "automatically" adopted, even if they are freely available. Instead, the dissemination and adoption of innovations should be carefully planned and coordinated, with focus not only on the expected beneficiaries of the innovation process but also on those who hold the most prominent positions in the network of the disaster management community.

We applied SNA in order to analyse the structure of communication and collaboration networks related to disaster management in Nepal and Kenya. We were able to identify the central actors in the networks according to their degree centrality and betweenness centrality. Interestingly, the key stakeholder was found to be the same in both networks. In both case studies, it was easy to identify the Red Cross as the best-connected and most influential actor for the dissemination of innovation.

Although the two case studies do not allow for generalisation, they do provide indications of which groups of stakeholders are involved in disaster management communication and collaboration in disaster response. Large international NGOs active in the field of disaster management, in our case the Red Cross, emerged as the best connected and, hence, the most powerful stakeholders in the networks. National government institutions tasked with the responsibility for disaster management and response, together with their local and regional counterparts, were found to be among the most prominent stakeholders in terms of the number of actors who confirmed having frequent communication and collaboration with them. If the results of the SNA were available before the launch of the innovation services, they could have informed dissemination and implementation strategies, increasing their potential to achieve positive impacts on the quality of disaster management.

In this study, we analysed the social network structure to identify the key actors and pathways for enhancing the distribution and adoption of innovative services and information. However, the implemented approach showed several limitations. Limited time spent in the countries under investigation affected the robustness of the stakeholder analysis. Another consequence of the time limitation is the fact that it was not possible to interview many representatives of the same institution. Relying on only one or several answers increases the risk of obtaining biased evaluation results. Finally, we analysed the communication and the collaboration networks related to disaster management. The ideal case would be to analyse a network of communications regarding the innovations under research.

If applied in the future, this approach should allocate more time to conduct a more thorough social relations analysis, for example, through focus groups organised with each individual stakeholder institution. The change from ex post assessment to ex ante analysis and planning of innovation strategies should justify the allocation of the required resources.

Further developments could also go beyond the use of a single scale to assess communication and collaboration frequency, such as the Likert scale, and consider scales adjusted or weighted to each individual stakeholder based on their role in disaster management. Stakeholders influential at different levels were considered together in this analysis, but future research could analyse national and local/regional networks separately and then inquire into the strengths of the connections between the networks and the various actors at the national and local/regional levels. This would provide a more thorough understanding of the possibilities for outscaling innovations between different types of organisations and for their upscaling to different levels of the disaster management community.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Supplemental data

Supplemental data for this article can be accessed here.

Notes

1. SERVIR is a joint development initiative of the National Aeronautics and Space Administration (NASA) and the United States Agency for International Development (USAID) that works in partnership with regional organisations from Central America, East Africa and the Hindu Kush Himalaya region (https://www.servirglobal.net/#aboutservir).
2. The results of this evaluation are available in the "FY15 Evaluation Report – SERVIR Performance Evaluation" prepared by Management Systems International and Development and Training Services for the E3 Analytics and Evaluation Project.

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