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Factors Affecting Disaster Resilience in Oman: Integrating Stakeholder Analysis and Fuzzy Cognitive Mapping

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Planning for community resilience to disasters is a process that involves co-ordinated action within and between relevant organizations and stakeholders, with the goal of reducing disaster risk. The effectiveness of this process is influenced by a range of factors, both positively and negatively, that need to be identified and understood so as to develop organizational capacity to build community resilience to disaster. This study investigates disaster planning and management in Oman, a country facing significant natural hazards, and with a relatively new system of institutional disaster management. Fuzzy cognitive mapping integrated with stakeholder analysis is used to identify relevant factors and their inter-relationships, and hence provides an improved understanding of disaster governance. Developing an improved understanding of the complexity of this institutional behavior allows identification of opportunities to build greater resilience to disaster through improved planning and emergency response. We make recommendations for improved disaster management in Oman relating to governance (including improved plan dissemination and closer working with community organizations), risk assessment, public education, built environment development, and financing for disaster resilience.

KEY WORDS: Oman, organizational performance, resilience, fuzzy cognitive mapping, disaster management, cyclone

摘要

社区灾害复原力规划是一个涉及相关机构和利益攸关方内部及之间协调行动的过程， 其目的是减少灾害风险。该过程的有效性受一系列积极和消极因素影响, 需要识别并理解这些因素, 以期发展组织能力, 进而建立社区灾害复原力。本研究调查了阿曼的灾害规划及管理, 该国正面临重大自然灾害， 其机构灾害管理体系相对较新。使用了融合利益攸关方分析的模糊认知图(*FCM*), 以期识别相关因素及其相互关系， 进而提升对灾害治理的理解。对该机构行为的复杂性进行进一步理解, 则允许识别相关机遇, 后者通过改善的规划和应急响应以建立更强的灾害复原力。我们就以下几点对阿曼灾害管理提升提出相关建议：治理(包括提升规划传播、进一步与社区组织进行合作)、风险评估、公共教育、建成环境发展、以及灾害复原力融资。

关键词: 组织表现, 复原力, 模糊认知图, 灾害管理, 气旋

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Resumen

La planificación de la resiliencia de la comunidad ante los desastres es un proceso que implica una acción coordinada dentro y entre las organizaciones y las partes interesadas pertinentes, con el objetivo de reducir el riesgo de desastres. La efectividad de este proceso está influenciada por una variedad de factores, tanto positivos como negativos, que deben identificarse y comprenderse para desarrollar la capacidad organizativa para desarrollar la resiliencia de la comunidad ante los desastres. Este estudio investiga la planificación y gestión de desastres en Omán, un país que enfrenta importantes peligros naturales y con un sistema relativamente nuevo de gestión institucional de desastres. El mapeo cognitivo difuso (MFC) integrado con el análisis de las partes interesadas se utiliza para identificar los factores relevantes y sus interrelaciones y, por lo tanto, proporciona una mejor comprensión de la gobernanza de desastres. Desarrollar una mejor comprensión de la complejidad de este comportamiento institucional permite identificar oportunidades para desarrollar una mayor resiliencia ante desastres a través de una mejor planificación y respuesta a emergencias. Hacemos recomendaciones para mejorar la gestión de desastres en Omán relacionadas con: gobernanza (incluida una mejor difusión del plan y un trabajo más estrecho con las organizaciones comunitarias), evaluación de riesgos, educación pública, desarrollo de entornos construidos y financiación para la resiliencia a los desastres.

PALABRAS CLAVES: Desempeño organizacional, resiliencia, mapeo cognitivo difuso, manejo de desastres, ciclón

Introduction

This paper explores the development of disaster resilience in Oman, and the factors affecting that resilience. The research, which focusses on natural hazard, particularly cyclones, assesses how natural, human, and organizational factors contribute, positively or negatively, to resilience against disasters. In doing so the research seeks to identify opportunities to improve planning and regulation relevant to disaster management. Such solutions may be simple to implement as effective emergency management need not be reliant on costly high technology measures, but rather the establishment of an effective integrated system focussed on ensuring the "basics of life" including water, food, and shelter are met (Al-Shaqsi, 2015). However, while emergency management legislation has existed in Oman for many years, emergency management as a coherent system remains incomplete, and its integration into the development process has been neglected (Al-Shaqsi, 2015).

This study thus seeks to develop an improved understanding of disaster management in Oman. To do so, it applies fuzzy cognitive mapping (FCM) to the disaster management system, drawing on the knowledge and experience of those involved to develop a "causal map" of the complexity of organizational interaction. FCM is designed to represent structured knowledge and model complex systems and so has been applied across many fields, including medicine, education, business planning, engineering, and natural resource management (see reviews by Groumpos, 2010; Papageorgiou, 2013; Felix et al., 2019). Qiu, Gu, and Wang (2019) provide a review of FCM applications to industrial hazard. FCM has also been applied to assess hazard arising from climate change (Ahmed, Woulds, Drake, & Nawaz, 2018; Singh & Chudasama, 2017; Singh, Papageorgiou, Chudasama, & Papageorgiou, 2019).

The application of FCM enables us to identify the factors affecting the performance of organizations with disaster management roles in Oman, and reveals the dynamics of interactions between these organizations with respect to disaster management and building of community resilience. Following reviews of natural hazard resilience, and the disaster management system in Oman, we present the FCM methodology and data in detail (Section 3) followed by results and their discussion (Section 4), our conclusions (Section 5), and finally recommendations for building resilience to natural hazard in Oman (Section 6).

Background

Resilience

Ideas of resilience have long been addressed in engineering and ecological systems. Holling, Gunderson, and Light (1995) describes two facets of resilient systems, the first, "engineering resilience," focuses on efficiency, constancy, and predictability; and the second, "ecosystem resilience" focused on persistence in the face of change and unpredictability. Community resilience has most in common with ideas of ecological resilience, the capacity of an ecosystem to respond to a perturbation, such as fire, insect invasion or pollution, by resisting damage and recovering quickly. This conception of resilience has been particularly prevalent with respect to natural hazard management where for many years resilience has been seen as the ability of a community to resist and recover, or "bounce back," from a natural hazard event, such as flood, drought or earthquake.

With respect to natural hazard disasters, the goal of enhancing community resilience is seen as a necessity, essential for sustainability and improving environmental, social and economic capacity to manage disasters. As interactions between humans and hazards in natural systems are often complex, building resilience requires good understanding of the significant factors in disaster management and vulnerability (Twigg, 2015). In this context, the term resilience conventionally refers to the ability of a community to "cope successfully with substantial danger" (Timmerman, 1981; UNISDR, 2005; Wildavsky, 1991), and as resilient communities are less vulnerable to disasters, determining how resilience can be achieved has become an important task (Cutter & Finch, 2008).

Two components in planning for resilience are widely recognized: the desired outcome (a safe and resilient community); and the process leading to that outcome (enabling individuals and communities to adapt and move toward) (Twigg, 2015). The aim is to achieve a disaster-resilient community, which Djalante and Thomalla (2011) define as the safest possible community that we have the knowledge to design and build. This is widely seen as requiring co-operation across a wide range of systems and institutions (UNISDR, 2006, 2012). However, Zebrowski (2015) argues that resilience is not a concept with such stable and specific value and meaning, perceived either as positive, providing safety and security in an uncertain world; or negative, such as when governments offload security responsibility on to citizens. Rather, Zebrowski, whose work is set within the neo-liberal context of 21st-century security concerns, particularly conflict, envisages resilience in terms of values and meanings which are multiple and contested, and which evolve dynamically overtime via a politically mediated set of processes.

Consistent with this view of resilience as an evolving concept, Tiernan et al. (2018) review of disaster resilience practice and research since 2012, identifies the emergence of a new theme in resilience thinking. Here, resilience is still seen in the conventional sense, a community able to bounce back and recover ("ecological resilience"), but significantly, resilience is also seen as the ability to learn from the adverse event and so subsequently reach a new, higher level of resilience. Thus, resilience is increasingly seen as a continuing process of adaptive learning, involving both state actors and community-based organizations, who collectively experience natural hazards, recover from major crises, and learn from the experience to build greater resilience to threat. Core to this adaptive resilience is behavior in the community post-disaster, where strategies of resistance and adaptation to future threats are established, nurtured and grown. Thus, planning for community resilience is becoming a process both for the community, and from the community.

Disaster Management in Oman

In Oman, the National Committee for Civil Defence (NCCD) is responsible for emergency management via a disaster risk reduction system that has its origins in the co-operation of the Royal Oman Police, and Ministries of Interior, Health, and Social Affairs (NCCD, 2010). In 1989, these institutions established the National Committee of Natural Disasters, unique in the Gulf region at the time. However, although Oman had previously experienced a very damaging super cyclone that struck Masirah Island and southern Oman in 1977, no real emergency management activity occurred until 1999. Al-Shaqsi (2015) attributes this stalled progress in emergency management to the 1990–91 Gulf War and the ensuing financial crisis.

In 1999, the National Commission for Natural Disasters merged with the National Emergency Committee to become the NCCD under the leadership of the Inspector General of the Royal Oman Police, yet the NCCD remained relatively inactive because its remit was limited to reacting to national disasters and emergencies rather than engaging in disaster preparedness (Al-Shaqsi, 2015). In response to the 9/11 terrorist attacks of 2001 the NCCD became a separate executive office given a remit to coordinate efforts to strengthen national capacity in emergency management. By 2003 subcommittees had been established to build emergency preparedness at the regional level, with emergency reaction teams located within the Police force (Al-Shaqsi, 2015). The NCCD undertook its first national-level disaster management action in 2007 when super cyclone Guno, the most powerful recorded in the Arabian Sea in a century, hit the north coast of Oman, causing an estimated $4 billion in economic and infrastructure damage from the extreme rainfall and flash flooding. Guno was followed by a series of lesser, yet still extreme tropical cyclones including Chapala (2014), Mekunu (2018), and Luban (2018).

Today, the NCCD has permanent working groups, made up of government and non-government organizations, who are responsible for emergency planning, preparation and response. They comprise eight functional groups addressing: early warning, media, and public awareness, search and rescue, medical response and public health, relief and shelter, basic services (infrastructure), victims and missing people, and hazardous materials. We analyse the functioning of this system using.

Methods

Fuzzy Cognitive Mapping (FCM)

FCM is an approach for modeling complex systems using causal reasoning, derived from knowledge and experience (Groumpos, 2010, 2015; Kontogianni, Papageorgiou, & Tourkolias, 2012; Kosko, 1986; Papageorgiou & Stylios, 2008; Van Vliet, Kok, & Veldkamp, 2010; Wu, Liu, & Chi, 2017). Axelrod (1976) was the first to apply digraphs to show causal relationships between "concepts" (system components), producing cognitive maps, a formal way of representing knowledge, and a technique used in modeling decision making in the political system (Aguilar, 2005; Homenda & Jastrzebska, 2017). Kosko (1986) modified Axelrod's (1976) cognitive maps by adding fuzzy logic, which allows for degrees of truth not possible with a purely binary truth/false description, and so introduced the fuzzy cognitive map. Papageorgiou and Stylios (2008) describe the three key steps in building a FCM to describe a system: first, identifying the direction (positive/negative) of causal relationships between system concepts; second, using fuzzy logic to describe the strength of these causal relationships; and third, understanding the dynamics of the causal links, whereby a change affecting one concept can affect other concepts. Kosko (1986) thus describes the FCM as "fuzzy-graph structures for representing causal reasoning," and Papageorgiou and Stylios (2008) conclude that the FCM is a tool that is particularly well suited to gaining insight into otherwise complex systems.

Özesmi and Özesmi (2004) also point to the value of FCM in simulating complex and often opaque social systems, and hence in solving decision making problems. They identified four cases where FCM is particularly useful. First, is where hard to identify human behavior plays a significant role. Second, is where scientific data is missing, but local and traditional knowledge is available. Third, is the case of very complex questions, where no simple answer is available despite many different positions being included, and fourth, where public opinion is needed. Because of its applicability in such cases, FCM is widely considered a valuable tool in managing complex social systems with difficult decision making processes. FCMs address the dynamics of complex social systems, as feedback is incorporated in the FCM structure (Papageorgiou & Salmeron, 2013; van Vliet et al., 2010), yet they are relatively simple to build and use, making them understandable for use with the non-expert.

However, the FCM relies on several assumptions (Papageorgiou, 2013), including that causal relationships between concepts are always in effect, and the values denoting the strength of relationships are updated simultaneously at the same rate. Such assumptions may not always hold, hence the FCM is less powerful and robust when applied to model dynamic, evolving systems. A further restriction is that causal relations between concepts are assumed to be simple monotonic and symmetric, whereas this is not the case in many real-world systems. This has led to FCM being applied with an extended range of mathematical techniques so as to enhance the robustness and make FCMs more sensitive to system dynamics (see review in Papageorgiou, 2013).

Nevertheless, the core advantages of FCM mean it has been applied in many different fields to reflect on how a given situation is represented, to explain behavior, support decision making in complex situations, and so promote beneficial change (Papageorgiou & Salmeron, 2013). A sample of application areas includes the understanding of business performance (Kardaras & Mentzas, 1997) modeling of socioecological systems (Özesmi & Özesmi, 2004), medical diagnoses, such as of autism in children (Kannappan, Tamilarasi, & Papageorgiou, 2011) and military planning (Yaman & Polat, 2009). FCM applications with respect to hazards apply mostly to engineering resilience in high-risk environments such as petrochemical plants (e.g., Azadeh, Salehi, Arvan, & Dolatkhah, 2014) and nuclear installations (e.g., Park, Jung, & Yang, 2012). For natural hazards, applications address earthquake, including work to identify critical success factors in managing earthquake risk in China (Han & Deng, 2018), and risk to people in alpine environments from induced landslide and avalanche (Samarasinghe & Strickert, 2013). FCM has also recently been used in the Bay of Bengal, for assessing community perception of, and preparedness to, cyclone hazard (Singh & Chudasama, 2017; Singh et al., 2019), but FCM has not previously been applied to natural hazards in the Arabian region.

FCM gives a graphical presentation of the knowledge or perception of a given system (Kontogianni et al., 2012). It has nodes that represent system factors (concepts) and edges (vertices) that represent the relationships between factors. Where edges have direction, a directed graph (digraph) is used to present the results. Edges are also characterized by fuzzy values (also known as weights, in the range −1 to 1) or by linguistic values such as low, medium, and high. The resulting graph (map) is used to analyse the complex system of stakeholder relationships using matrix algebra, which provides a way to describe and explain the FCM structure (Özesmi & Özesmi, 2004). Thus when applied to disaster resilience FCM can analyse stakeholder opinions about the effectiveness of the disaster management system, including its strong and weak aspects, and hence identify opportunity for improvement.

In the FCM the connection is described by patterns of "out-degree" and "in-degree." Out-degree is the cumulative strength of relationships denoted by edges outgoing from a factor to other factors; in-degree for a factor is the cumulative strength of edges entering that factor (Abbas, 2014; Gray, Chan, Clark, & Jordan, 2012; Özesmi & Özesmi, 2004). Factors are also categorized as a transmitter, receiver, or ordinary. Transmitters are factors with positive out-degree, and no in-degree, and so are unaffected by any other factor. Receivers are factors with positive in-degree and no out-degree, and so do not influence other factors in the FCM. The ordinary factors are those factors that lie between receivers and transmitters and are characterized by positive in-degree and positive out-degree, and thus influence, and are influenced by, other factors (Abbas, 2014; Gray et al., 2012). This categorization denotes causal links within the network graph.

The more important factors in the system are those that have a high degree of centrality, as these are often a focal point for decision makers. Centrality is calculated from the total out-degree and in-degree for each factor. However, the variable can have a smaller number of edges but be more central if the edges have larger weights (Kosko, 1986; Özesmi & Özesmi, 2004).

A further network measure is factor density, which indicates the extent to which factors in the system are well connected (a "democratic system") or if a smaller number of factors dominate the system (a "hierarchical system") (Gray et al., 2012; Özesmi & Özesmi, 2004). A high-density score indicates the former position, a flexible adaptable system with more opportunity for change, while a low-density score represents the latter, more rigid system with less room for change (Özesmi & Özesmi, 2004). Density is calculated (Gray et al., 2012; Hage & Harary, 1983) as:

$$D = \frac{C}{N^2} \text{ or } D = \frac{C}{[N(N-1)]} \tag{1}$$

where D is the density of the FCM, *N* is number of factors, and *C* is the number of connections.

An alternative way of assessing system density is to use the hierarchy index (h), where the system is fully hierarchical when $h = 0$, and fully democratic when $h = 1$ (Özesmi & Özesmi, 2004). The h index is calculated as:

$$h = \frac{12}{(N-1)N(N+1)} \sum_i \left[\frac{\text{od}(\text{vi}) - \sum \text{od}(\text{vi})}{N} \right]^2 \tag{2}$$

where h is the hierarchy index, *N* is the number of factors, od is the number of out-degree factors, and od(vi) is the row sum of absolute values of a variable in the adjacency matrix.

Finally, FCM complexity is determined by calculating the ratio of receivers to transmitters (Gray et al., 2012). A complex map is indicated by a high ratio, reflecting a system with many possible outcomes and implications. In contrast, maps with a high frequency of transmitters indicate more forcing functions, and hence more top-down thinking, although, the consequences of these functions are not well articulated (Gray et al., 2012).

Simplifying the System (FCM)

A large complex system with many factors and connections can make the analysis of system function unclear and potentially counterproductive. An approach to deal with this complexity is to standardize and reduce the FCM data set so that component FCMs are produced, with a single aggregate FCM subsequently developed for the system as a whole (Abbas, 2014; Gray et al., 2012). Component maps can be merged using quantitative aggregation, where one draws a subgraph and visually identifies the active component in the cognitive map (Gray et al., 2012; Özesmi & Özesmi, 2004), or by qualitative aggregation, where factors are clustered by category (Gray et al., 2012).

The weight of edges connecting each cluster is calculated as an average of the weights of the connection between the factors in each cluster. Also, the value of each cluster is the average value of the factors in each group. The change in cluster value is then calculated as:

$$\text{new value}(xi) = \text{Tanh}\left(\sum_{\substack{j=1 \\ j\neq 1}} X(t-1)wij\right) \tag{3}$$

where x is the factor value, xi is the new factor value, and wij the new value weight. Tanh$(x/2)$ is used to normalize the data between −1 and 1.

Data Collection for Oman Disaster Management FC Mapping

Following an initial pilot the previous year, a workshop was conducted in Oman to identify the relevant factors from which the FCM's could be developed. A total of 16 stakeholders attended this workshop in April 2016, with stakeholders representing decision makers in the organizations relevant to disaster management performance. Participants represented the six sectors of the disaster management committee of Oman, addressing the key functional groups within the NCCD (Table 1). Participants

Table 1. Organizations Participating in the Fuzzy Cognitive Mapping Workshop

Sector	Organization	Number of Participants
National Committee of Civil Defence (NCCD)	–	2
General Authority of Civil Defence and Ambulance	–	1
Relief and shelter	Oman Authority of food security	1
Early warning center	General Authority of Civil Aviation and Meteorology	3
Infrastructure	The public authority of water and electricity	1
	Electricity company	1
	Transport	1
Public awareness	Media	1
	Ministry of Education (Curriculum Development Directorate)	1
NGO	Dar Al Atta'a (charity for underprivileged)	2
	Omani Women's Association	2
Total		16

represent the principle organizations in the state-led disaster management system, but because of the historical evolution of the NCCD, other stakeholders with potential roles to play in disaster management, most likely those from civil society, may be underrepresented. Therefore representatives from two national non-governmental organizations were included in the workshop. These were the Omani Women's Association, and Dar Al Atta'a, a large charitable body focussed on support for the underprivileged, and who have experience in disaster relief. Just two NGOs are not necessarily reflective of the wider body of NGOs in Oman, however, both work in support of wider government social policy goals, and have experience relevant to our goal of understanding how effective is the formal organizational structure for disaster resilience.

Participants were divided into three groups hazards, community, and organizations. This grouping helped the participants to be more specific about the factors affecting organizational performance based on the particular theme. For example, the hazards group focussed on factors specific to cyclones and their impact on disaster management performance in Oman, while the organizations group focussed on regulation and policy. The group discussions helped to identify and classify factors and collectively ensure a comprehensive coverage of relevant issues.

In each of the three groups, participants were prompted to identify and discuss factors using the five themes of the UN Hyogo Framework for disaster risk reduction: governance, risk assessment, knowledge and education, risk management and vulnerability reduction, and disaster preparedness and response (UNISDR, 2005). In each group an open discussion was first held to discuss the main factors (and later respective relationships, and values). Some initial differences of opinion were evident. These were then a specific focus of discussion facilitated by the researchers, who supported groups in exploring areas of disagreement, and ensured every individual contributed to areas where opinions diverged. This led to an improved collective understanding of participant viewpoints, allowing key reservations to be addressed, and consensus to be reached. The five themes were then used to merge and simplify a central FCM for each group. A final FCM was then created by combining the three FCMs (one per stakeholder group) into a single FCM representing the disaster management system in Oman.

Participants were next asked to use their judgement to subjectively score performance on factors in the five Hyogo theme areas, on a scale ranging from −3 for strong low (adverse) performance to +3 for strong high (beneficial) performance. This step reveals levels of performance for specific factors in the system. Participants were then asked to express their view on the relationship between factors, by first drawing edges between linked factors, and finally providing a quantitative value denoting the connection between the components (ranging from −1 for a strong negative influence to +1 for a strong positive influence). This step shows which factors contribute to, or detract from, the perceived level of performance for each factor. Collectively this process shows the relationship between factors and allows a determination of the strength of influence of factors. The factor value and edge weights (as group averages in the final overview FCM) were then used to calculate the contribution to change in each variable, whether positive or negative.

Table 2. Summary of the Structure and Function of the Three Group Fuzzy Cognitive Mappings (FCMs)

FCM Parameter	Community	Hazard	Organizations
Number of factors	33	20	25
Number of connections	43	36	47
Number of transmitters	9	5	7
Number of receivers	7	2	0
Number of ordinary	17	13	18
C/N	1.3	1.8	1.88
Complexity (R:T)	0.77	0.4	0
Density	0.039	0.09	0.075

Results and Discussion

Fuzzy Cognitive Map Structures and Functions

Data collected from the workshop resulted in four FCMs; three maps were focused on the thematic areas of the different groups, and the fourth was a composite map, used to understand how the three different systems work together and affect each other. This final FCM expresses the factors that influence the disaster management system as a whole, based on the interpretations offered by the three groups. Table 2 summarizes the structural and functional measurements of each groups' FCM. The values reflect the change in each map which allows for comparison of the different FCM models, and which factors are affecting the system.

Table 3 summarizes the values of the transmitters and receivers of each FCM, and the merged FCM. The values reflect the out-degree, the in-degree and the centrality of each factors in the FCMs. Appendix A shows a FCM for each of the stakeholder groups; community, hazards, and organizations. Each FCM thus represents different influences on Oman's disaster management system. These FCMs are then merged to examine the influence of the three-component systems on the system as a whole in Figure 1.

Community

The FCM for the community group shows a very complex system, indicated by many transmitter and receiver factors and a low-density index indicating a rigid system with less room for change. Table 3 shows the transmitters and receivers in the community FCM, and the centrality of each factor. The FCM has many transmitters showing how outside forces affect the function of the system, and a large number of receivers which indicates that these external forces can give rise to many possible outcomes. The transmitter factors seen as driving the system are financial support for organizations and the community, transport resilience, sewage effi-

Table 3. Fuzzy Cognitive Mapping (FCM) Transmitters and Receivers

Community FCM			Hazards FCM		
Transmitter	Out-degree	Centrality	Transmitter (5)	Out-degree	Centrality
Final evaluation of the process	0.5	0.5	Speed of data sharing	0.5	0.5
Electricity	0.75	0.75	Central data system	0.5	0.5
Regulations of civil institutions	0.75	0.75	Internal institutions training	0.75	0.75
Water availability	1	1	Early warning	1	1
Coordination between institutions (government and NGO)	1.25	1.25	Financial resources	2.25	2.25
Communication quality	1.5	1.5	Receiver (2)	In-degree	Centrality
Sewage	1.75	1.75	Food security	1.75	1.75
Transport (roads)	2	2	Emergency and evacuation plan	3.25	3.25
Financial support for institutions and community	2	2	Organizations FCM		
Receiver	In-degree	Centrality	Transmitter	Out-degree	Centrality
Waste management	0.5	0.5	Institutions' emergency plans	0.5	0.5
Data accessibility for the community	0.75	0.75	Knowledge of work	1.25	1.25
Hospital location	0.75	0.75	Absence of strict laws for misbehavior during the disaster	1.5	1.5
Rumors	0.75	0.75	Coordination between institutions during the emergency	1.5	1.5
Hazards awareness in schools and community	1	1	Absence of final evaluation of the committee work	2	2
Bank service (cash availability during the event)	1	1	Absence of Financial plan for disaster management	2.25	2.25
Shelter preparedness	2.5	2.5	Receiver (0)	In-degree	Centrality
Evacuation and relief	3.25	3.25	–	–	–

Figure 1. Merged Fuzzy Cognitive Mappings of Factors Influencing Disaster Management in Oman.

ciency, and communication quality. These values denote important influences on the system.

The result shows the impact of these factors in the system efficiency, and how weakness in specific factors can negatively influence the system and so reduce community resilience. For example, weakness in the surface water drainage and sewage system can adversely impact on resilience of the transport system. In the capital city Muscat, normal seasonal rains can cause pluvial flooding on roads and in urban areas. This situation can become much worse during severe weather such as tropical cyclones. These seasonal events are important for the decision maker and show them the hotspot affected areas and the type of risk.

Hazards

The FCM for the hazard group, shows a low complexity, low-density index system, indicating that this group perceives Oman's disaster management as dominated by top-down thinking with high chance of change. Table 3 presents the transmitter and receiver values for the hazards FCM. There are a high number of transmitter factors, with fewer receiving factors, thus the outside forces are seen as influential on the functioning of the system. Financial support for research, early warning of cyclones, private institutions training in disaster management, a central data system, and speed of data sharing are the transmitters driving the system; while two receiver factors averaged in the hazards map were the emergency and evacuation plan, and food security. These results demonstrate that community resilience can be enhanced through developing a better understanding of risk posed by cyclone hazard, which can be achieved via increasing financial support for research directed at improving disaster risk assessment and providing an improved early warning system.

Organizations

The organizations FCM is similar to the hazards FCM, with a high number of transmitters and no receiver factors (Table 3). This also suggests that the system functions under outside forces, with no influence itself. Transmitters are seen as forcing factors related to risk assessment and risk management and include the absence of financial plans for disaster management, and a lack of any final evaluation of the disaster committee's work.

Organizational performance is important in effective disaster management, yet a key finding is that the study reveals that emergency plans have low centrality. An element driving this result is that several institutions with a disaster management role in Oman had no emergency plan, and for others that did, stakeholders in the institutions did not know about them, which clearly has scope to adversely impact on community resilience to cyclone. A priority action to improve resilience against disaster is then the co-ordinated development and sharing of cyclone preparation and response plans, both within and across organizations. These plans should also be disseminated widely through community-based organizations, to raise awareness of the required actions under an event, and to enable these bottom-up organizations to feed in local knowledge to improve the emergency plans.

Merged FCM (The Oman Disaster Management System)

The composite FCM (Figure 1) is the outcome of merging the three groups FCMs developed in the workshop. Group FCMs were joined based on a judgement of similar factors in the group maps that could act as common linking factors. This composite FCM shows that the community accounts for 34.9 percent of the factors, organizations 25.4 percent, hazards 20.6 percent, with 19 percent of factors common to all three FCMs. It also shows that the community factors have a wide-ranging influence on the system.

Table 4. Transmitters and Receivers in the Merged Fuzzy Cognitive Mapping

Transmitters	Out-Degree	Centrality	Variable Value
Financial support for institutions and the community	4.25	4.25	1
Lack of knowledge on other institutions responsibilities	3.5	3.5	−1
Coordination between institutions (government and NGO)	2.75	2.75	2
Absence of financial plan for disaster management	2.25	2.25	−1
Lack of financial support for infrastructure projects	1.75	1.75	1
Sewage	1.75	1.75	−2
Absence of strict laws for misbehavior during the disaster	1.5	1.5	−3
Communication quality	1.5	1.5	−1
Final evaluation of the process	1.5	1.5	1
Transport (roads)	1.5	1.5	1
Early warning	1	1	2
Water availability	1	1	2
Electricity	0.75	0.75	2
Internal institutions training	0.75	0.75	−1
Regulations of civil institutions	0.75	0.75	1
Receivers	**In-Degree**	**Centrality**	**Variable Value**
Shelter preparedness	2.5	2.5	2
Training of target group	2	2	1
Bank service (availability of cash during the event)	1	1	−1
Hospital location	0.75	0.75	2
Response and evacuation	0.5	0.5	2
Waste management	0.5	0.5	1

Table 4 shows the transmitters and receivers of the merged FCM. Financial support for institutions and the community has a high centrality amongst transmitter factors. The positive value of this financial support for institutions and the community can increase the importance of other factors, like the health system and food security. The next highest centrality transmitters are lack of knowledge about other organizations' responsibilities, coordination between institutions (government and non-government), and the absence of a financial plan for disaster management. Five receivers are present in the map, of which shelter preparedness has the highest centrality, indicating the high degree of collaborative effort required to improve shelters.

Table 5 shows the results of the FCM function analysis. The density index is small, indicating a rigid system with little room for change. There are more transmitters than receivers, reflecting that outside factors are influential on the functioning of the system, and make it complex and inflexible. However, the hierarchy index is zero, which reveals a fully democratic system. Although the system is complex and currently relatively inflexible, its democratic nature means that interventions that are made to improve disaster resilience can be readily adopted across the system. The function analysis shows that a key route to effecting such change is to improve financial planning and support for disaster management, which is currently seen as a weakness. Such support should in particular focus on the enhancement of disaster mitigation training in

Table 5. Function Parameters of the Merged Fuzzy Cognitive Mapping (FCM)

FCM Parameters	Values
Number of factors	62
Number of connections	116
Number of transmitters	15
Number of receivers	6
Number of ordinary	41
C/N	1.85
Density = C/(N)2	0.03
Complexity index (R:T)	0.4
Hierarchy index, h	0

organizations, and on improving public awareness of health and safety risk posed by cyclones.

The aggregated map shows the mutual influence between different groups (community, hazard, and organization) and reveals how different systems are influential and hence that disaster management should focus on different factors for different systems. For example, the intensity of tropical cyclones increases the interest of the government in disaster management, which consonantly increase the health system performance during the catastrophic events. This is consistent with the findings of Singh and Chudasama (2017) who studied the impact of tropical cyclones in Ganjam and Puri, coastal towns in Odisha, India, on the Bay of Bengal. Their study, developed in the context of a rising incidence of cyclones in the region over the past decade, used a focus group to identify the major direct and indirect impacts of cyclones, and to determine associated preparedness measures. Sanitation was identified as a major public health issue with respect to cyclones as with no proper sanitation facilities, water supplies become readily contaminated, spreading disease. Also, losses related to livestock, agriculture, and fisheries impact significantly on the financial reserves of families and communities, which consequently affect education and health.

Clustering of FCM Factors

The merged FCM is evidently complex, presenting a challenge to understanding. Hence it was simplified using a clustering approach (see above) to aid interpretation. Figure 2 illustrates the five clusters of factors in the clustered FCM. The graph analysis (Table 6) reveals a flexible well-connected system. The factors are all ordinary (they influence, and are influenced by, other factors). Disaster preparedness and response is the most central (strongest) cluster, whilst risk management and vulnerability reduction, and knowledge and education are weak, as shown by their low centrality. The density index is high, and the complexity index is zero, which indicates that overall the system is flexible with a possibility for development to achieve goals. The hierarchy index is 0.45, which denotes that the system is both democratic and adaptive to the environment.

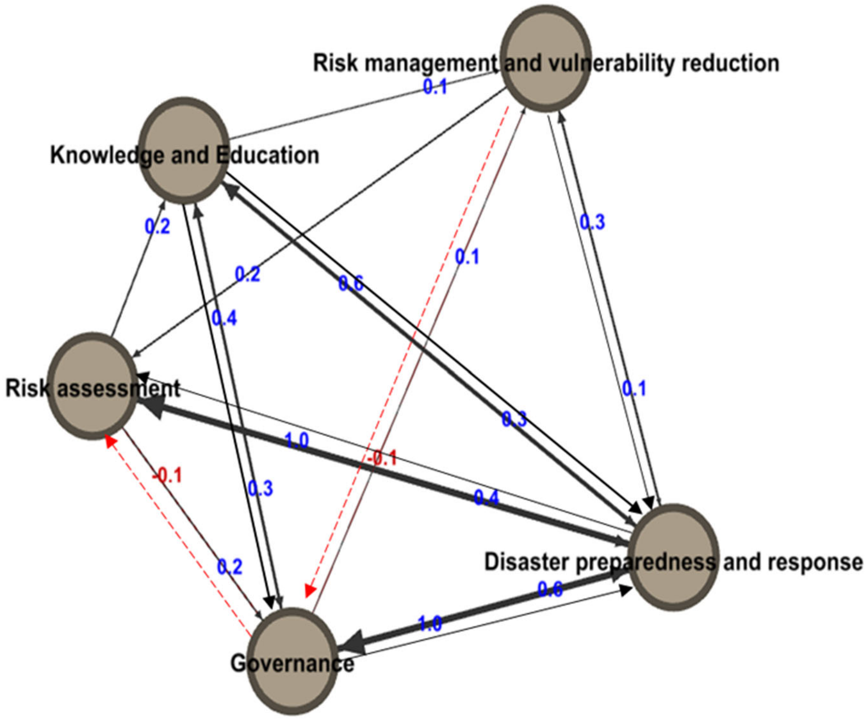

Figure 2. The Clustered Fuzzy Cognitive Mapping.

The clustered FCM show the institutions performance, and the mutual influence between the clusters. The result of clustered factors indicates the performance of each thematic area of community resilience provided by the Hyogo framework (HFW). It shows that the performance in disaster preparedness is high, and can improve other cluster performance like governance. However, the weakness in governance can cause a high negative influence on the risk assessment. This outcome helps decision makers to understand those parts of the system that are weak, and where interventions and investment can enhance and improve Oman's disaster management.

In Oman, disaster policies have historically focused on relief and response rather than prevention and recovery. However, a risk assessment for tsunami and storm surges is now carried out, by the early warning center (DGMAN, 2014), which identifies the social, economic, physical, and institutional factors contributing to vulnerability and risk. Additionally, progress is being made with respect to public awareness. For example, in 2016, the NCCD conducted training on tsunami evacuation in some schools in the coastal area; students were engaged with this exercise because it introduced them to new knowledge about disaster. Consequently, in 2018, a tsunami drill was extended to cover a larger area (Al Swadi) addressing about 5,000 people. Overall, Oman has established a comprehensive disaster management system, but it has some weaknesses where further attention must be focused to improve its effectiveness.

Table 6. Graph Indices for the Clustered Map

	Disaster Preparedness and Response	Governance	Knowledge and Education	Risk Assessment	Risk Management and Vulnerability Reduction
Disaster preparedness and response	0.00	1.00	0.56	1.00	0.31
Governance	0.56	0.00	0.44	0.13	0.13
Knowledge and education	0.31	0.31	0.00	0.00	0.00
Risk assessment	0.38	0.19	0.19	0.00	0.00
Risk management and vulnerability reduction	0.06	0.06	0.00	0.19	0.00
Total in degree	1.31	1.56	1.19	1.31	0.44
Total out-degree	2.88	1.00	0.63	0.75	0.19
Centrality (id + od)	4.19	2.56	1.82	2.06	0.63
Transmitters	0	0	0	0	0
Receivers	0	0	0	0	0
Ordinary	1	1	1	1	1
No. of factors	5				
No. of connections	16				
No. of transmitters	0				
No. of receivers	0				
No. of ordinary	5				
Connection/factors	3.2				
Density	0.64				
Complexity	0				
Hierarchy index, h	0.45				

Conclusions

This study sought to develop an improved understanding of the factors influencing the performance of those organization that constitute Oman's natural hazard disaster management system. The study examined the critical and dynamic influence of these factors within the organizational system, and provides a new and important perspective on the progress of these organization in building community resilience against cyclone induced disaster in Oman. The FCM study shows that the system in Oman is complex, with a high number of driving factors and a low-density index, which reduces the chance of change. However, the hierarchy index ratio was zero, indicating a fully democratic system and hence scope exists to develop a system better adapted to the risk environment. The study also shows the weakest and strongest parts in the system, knowledge of which will help us to focus on areas that need to be changed or improved to increase system performance, and build community resilience.

Overall, the stakeholders identified factors influencing the system positively or negatively. The most influential factors with negative impact are in the governance and disaster management and vulnerability reduction clusters. For example, the location of houses near the flood area negatively impacts on evacuation plans during an emergency, whilst such locational decision are themselves negatively affected by urban planning policies. Likewise, the absence of a comprehensive emergency and evacuation plan negatively impacts on emergency system performance.

Factors with a positive impact on the system are those in the areas of risk assessment, and knowledge and education, with the most positive factors in the preparedness and response cluster. For example, the availability of prepared shelters is particularly beneficial in terms of evacuation planning. The media also has a positive impact on public awareness and the emergency system.

Recommendations

Our findings enable us to make recommendations in the area of risk governance that can act to accelerate and improve the development of community resilience to disaster in Oman. First, is to strengthen the institutional system to ensure that disaster management has a more substantial basis, focusing on evident weaknesses in the disaster risk reduction system. Specifically, we find there is scope to develop and more effectively disseminate improved preparation and response plans, which will likely entail increasing financial support to risk management. However, a more fundamental aspect of an improved risk management system is to complement an improved state-led system, with a bottom-up perspective in which community-based organization can play a more overt role. Oman's response to cyclone risk has been very much a top-down state actor-led process, in contrast to recent risk management developments internationally, which Tiernan et al. (2018) show are increasingly involving grassroots community-based organizations. These organizations are increasingly seen as vital in natural hazard risk reduction, as they add an important new dimension in the adaptive learning cycle. They represent a move away from a pure command and control approach, and facilitate the harnessing of social capital within the community to build trust, a sense of community, and shared responsibility, and so establish cross-sector partnerships that co-operate to learn how to build resilience to disaster.

Our second recommendation is to improve the participation of all relevant organizations and stakeholders in risk assessment. Insufficient tools and statistical information about hazards and risk are currently available. Some information in international reports is based on estimates for the wider region (UNISDR, 2015a) and Oman-specific information is often absent. More comprehensive data about risk from natural hazards in Oman is essential to improve disaster risk assessment, evaluation, and management.

Our third recommendation is for Oman to develop an active program of public education. Too many lives are lost through poor decisions made by members of the public as a cyclone event unfolds (e.g., when faced with flash flooding, young men often take insufficient avoidance action, whilst vehicle drivers may attempt egress through waters which are too deep to traverse safely). It is essential to provide better information about the risk the public face, and how to take appropriate mitigating action. An education program must have the support of all organizations, and be adequately financed to support information collection, analyses, and dissemination, along with the necessary human resources such as technical and communication experts with the appropriate training. Public awareness programs should include information on the types of hazard, potential risks that arise, and the best ways to prevent and avoid such risks. The media and school system should work to develop better public awareness of the range of natural hazards that occur in Oman (cyclone, earthquake, flash flood, etc.) and commit to an ongoing educational program, not just information provision during an event.

Our fourth recommendation is to reduce risk in the community through building better public facilities, improving building codes, and developing land-use policies sensitive to the geographic distribution of natural hazards (e.g., restricting construction in wadis at risk from the flash flood). Other at-risk countries, like Japan, have well-prepared programs against earthquakes and most people across the country regularly participate in emergency training (UNISDR, 2005). A similar situation needs to be developed in Oman.

Finally, it is essential to provide appropriate financial support for disaster management, developing a clear financial system to support disaster management in all related organizations, with clear rules for the budget, financial management, and accountability. This will enhance disaster preparedness for effective response, and recovery—"build back better" rehabilitation and reconstruction (UNISDR, 2015b). Whilst support will be needed for physical infrastructure, great value can be had by further investment in "soft systems" such as risk assessment, education and planning, and by extending the reach of the rather rigid and top-down state-led disaster management structure to those community-based organization able to bring knowledge and capabilities that will help to accelerate the move into an era of adaptive learning in which everyone can play a role in reducing social vulnerability, and building Oman's resilience to natural hazard.

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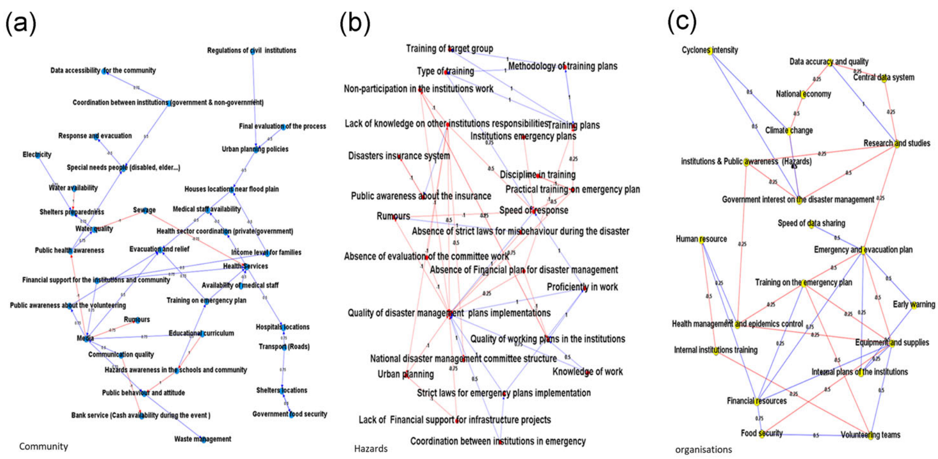
Appendix A



FCM for each of the stakeholder's groups; (a) community, (b) hazards, and (c) organizations. The relation between the points ranges from −1 for fully negative relations, to 1 for fully positive relations.