FLOOD DISASTER RISK MANAGEMENT IN NSW TRANSPORT INFRASTRUCTURE: COUNCILS' APPROACHES

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Abstract

In Australia, mitigating the adverse impacts of flooding on transport infrastructure has increasingly become the responsibility of local decision makers. While floods cannot be eliminated, resilient roads and bridges are those where floods are effectively managed by stakeholders such as Road and Maritime Services, Local Government and Shires. However, there is a significant lack of attention on floodplain risk management in terms of stakeholders' proactive and/or reactive approaches. Furthermore, there has been little evaluation of why some stakeholders have a tendency to follow reactive rather than proactive approaches and vice versa. Focussing on Local Councils in NSW, this study examines the factors influencing their decision to adopt proactive and/or reactive approaches in managing floods. We use statistical models to measure the Local Councils' approaches based on a survey data of flood disaster management in transport infrastructure. Particular attention is paid to the role of Local Council's attributes to floodplain risk management in addition to various local meteorological, socio-economic and transport infrastructures characteristics. The resultant Stakeholder Flood Response Index (SFRI) measures the Local Councils' overall approaches against floods. Results indicate that Local Councils have chosen more reactive approaches than proactive tasks; moreover, stakeholder's attributes are significant factors contributing to the implementation of proactive and/or reactive approaches.

Introduction

Flood is likely to occur more often than many other types of disasters (Sohn, 2006). It is regarded as the most lethal disaster among all other disasters (Alexander, 1997). EM-DAT (2004) reported that during the past century, floods killed at least 8 million people all over the world. Approximately 800 million people are currently living in flood-prone areas across the world, and about 70 million people currently living in flood-prone areas are, on average, exposed to floods each year (UNISDR, 2011). Australia is one of the most susceptible countries to flood damages in the world. It has experienced approximately $13 billion in economic damages from floods over the past three decades (CRED, 2012). Furthermore, it is also reported that greater than $226 billion in residential, commercial and industrial buildings, and transport infrastructure are potentially exposed to inundation and erosion hazards at a sea level rise of 1.1 meters high end scenario for 2100 (Emergency Management Australia, 1999). Therefore, flooding remains the most costly natural disaster faced by Australia (Blong, 2004). This paper contributes to develop Stakeholder Flood Response Index (SFRI) to measure NSW Local Councils' approaches against flood.

The focal stakeholder in this study is Local government areas (LGAs) or Local Councils across NSW because they are responsible for providing infrastructure, preparing and responding to disasters, developing and enforcing planning, and connecting national government programs with local communities (Huq, Kovats, Reid, & Satterthwaite, 2007; UNISDR, 2011). Effective localised planning, mitigation, preparedness, response and recovery activities can minimise both the causes and consequences of natural disasters (Bulkeley, 2006). This study uses flood characteristics, socio-economic condition, transport infrastructure condition and stakeholder attributes to provide predictors of stakeholders' overall responses to flood disaster.

Conceptual framework

The conceptual framework for developing an overall stakeholder disaster response (Fig. 1) provides the rationale for the selection of indicators included in the SFRI, and the way in which they are combined. It suggests that six main factors contribute to a Council's overall flood approach: (1) flood characteristics; (2) socio-economic condition; (3) transport infrastructure condition; (4) stakeholders' attributes; (5) proactive approach; and (6) reactive approach. Each of these six main factors is broken down into more specific sub-factors or indicators. The arrows indicate the hypothesized interactions among the identified factors. Indicators for each single factor are illustrated in Appendix 1.

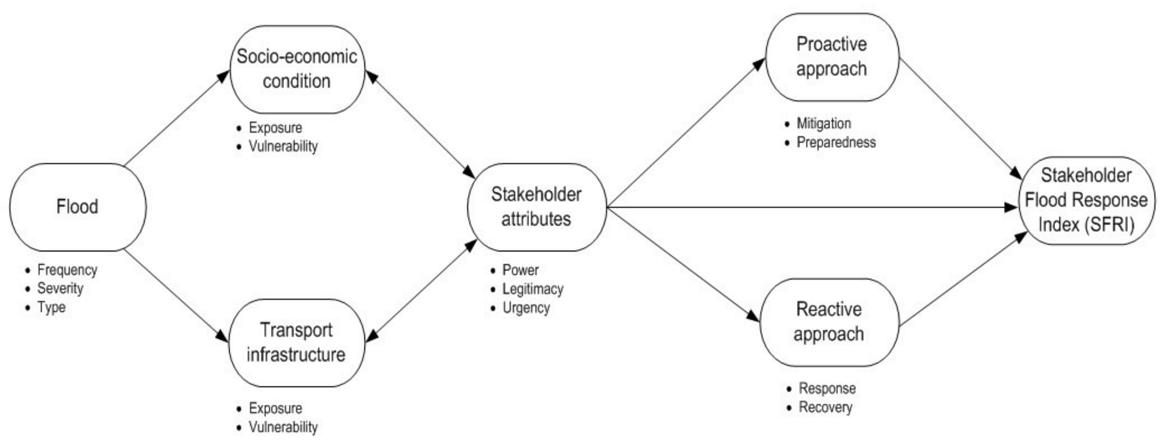

Figure 1: Conceptual framework of Stakeholder Flood Response Index

Flood disaster characteristics

Undoubtedly, flood characteristics are important components to measuring flood damage. Leroy (2006) defined that three factors, such as time, area and societal characteristics, play imperative roles in amplifying natural disasters. Merz and Blöschl (2004) proposed flood type, flood-generating process, region or zone and frequency are common characteristics of flood disaster. We have regarded flood frequency, severity and type as flood characteristics in this study for identifying hazards. Flood frequency refers to the average number of major floods per year and flood severity is classified as follows (Emergency Management Australia, 1999):

- **Minor flooding:** Causes inconvenience. Low-lying areas next to watercourses are inundated, which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.

- **Moderate flooding:** The evacuation of some houses may be required. Main traffic routes may be covered. The area of inundation is substantial in rural areas requiring the removal of stock.

- **Major flooding:** Extensive rural areas and/or urban areas are inundated. Properties are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood affected areas may be required.

Flood types include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake obstruct floods. In Australia, the most common form of flooding is river flooding. Overflow of drainage systems in urban areas can also be a major problem, particularly in heavily populated areas. Low lying coastal areas can be inundated by storm surges usually caused by tropical cyclones (Emergency Management Australia, 1999).

Socio-economic and transport infrastructure: Exposure and vulnerability

Hochrainer (2006) pointed out that for an effective disaster risk management, information is needed about: (i) the characteristics of the disaster, and (ii) the degree of exposure and vulnerability of the society, economy and the built environment. Therefore, exposure and vulnerability are key determinants of disaster risk (IPCC, 2012). In this study, we have focused on the relationships of flood characteristics, exposure and vulnerability of society, economic and transport infrastructure to flood damages.

- **Exposure** refers to the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by flood (IPCC, 2012).

- **Vulnerability** is the propensity or predisposition to be adversely affected. For instance, population vulnerability explains the characteristics of individuals and groups that make them more or less likely to be affected as the result of a flood (IPCC, 2012).

Exposure and vulnerability are dynamic and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors (IPCC, 2012). For example, the built environment exposure is the presence of physical assets and infrastructure, residential buildings, non-residential, commercial buildings and industrial buildings, public buildings, roads and bridges, and utilities, which can potentially be affected by natural disasters. Population, Gross Domestic Product (GDP) or Gross Regional Product (GRP), income level and age structure have been identified as major contributing factors for socio-economic exposure and vulnerability against natural disasters (Ibarrarán, Ruth, Ahmad, & London, 2007; Kahn et al., 2005; Skidmore & Toya, 2002).

Researchers have strongly argued that poor socio-economic conditions, in other words, society with higher exposure and vulnerability to natural disasters, are more likely to suffer more from the consequences of disasters (Haque, 2003). Natural disaster impacts not only vary among developing and developed countries, but also between and within countries, regions, local areas, sectors, systems, and individuals due to heterogeneity of exposure and vulnerability (IPCC, 2012). Some individuals, suburbs, regional areas and cities would be less affected than others in natural disasters. In accordance with previous studies, we investigate to find whether different regions and LGAs in Australia have different exposure and vulnerability to flood disasters.

Transport and associated infrastructure such as roads, railways, bridges, warehouses, airports, ports, and tunnels can be at risk of direct damage from climate events. Meyer (2008) pointed out that transport infrastructure is vulnerable to extremes in temperature, precipitation/river floods, and storm surges, which can lead to damage to road, rail, airports, and ports (Meyer, 2008). Although transport infrastructure is considered vulnerable to flooding, its' exposure and impacts of flood disasters will vary, for example, by region, location/ elevation, and condition of transport infrastructure. Bridges and culverts are the most vulnerable elements in transport infrastructure in areas with projected increases in flooding (IPCC, 2012; Meyer, 2008).

Stakeholder attributes

Freeman (1984) defined that a stakeholder is an entity without whose support the institution would not survive. Although there have been a few other stakeholder definitions, the latest describes a stakeholder as someone who has input in the decision-making as well as who benefits from the results of the decision-making (Phillips, Freeman, & Wicks, 2003). In disaster risk management, any kind of entity can be regarded as a stakeholder. Local people, groups, organisations, institutions, societies, and even the natural environment are generally thought to qualify as actual or potential stakeholders. Therefore, in disaster management, we can define the stakeholder as an organisation, any group or individual who can affect or be affected by the achievement of the disaster risk reduction. In this study, the focal stakeholder is LGA or Councils across NSW.

Stakeholder attributes play an important role in defining overall stakeholder disaster risk response (ref). The three distinctive stakeholder attributes in Freeman (1984) stakeholder theory were adopted in this study as below:

- **Power** is the probability that a stakeholder would be in a position to carry out its own will despite resistance. The power of a stakeholder allows them to mobilise social and political forces and to withdraw resources from an organisation (Olander, 2007; Post, Preston, & Sauter-Sachs, 2002).

- **Legitimacy** is a generalised perception that the actions of a stakeholder are desirable or appropriate. Legitimacy gives opportunity to a stakeholder to abide some sort of beneficial or harmful risk pertinent to an organisation. In disaster risk reduction, legitimacy is a generalised assumption that the behaviour of a stakeholder is proper within socially constructed systems of norms, mandates and procedures.

- **Urgency** is a degree to which a stakeholder claims call for immediate attention (Mitchell, Agle, & Wood, 1997; Olander, 2007). It is hence essential to investigate the role of stakeholder attributes in exacerbating or ameliorating the exposure and vulnerability of socio-economic conditions of a specific region. Furthermore, power, legitimacy and urgency could be leading attributes in reducing the devastating consequences of disasters.

Stakeholder proactive and reactive approaches

Stakeholders' approaches toward natural disaster management can be classified into: (1) proactive and (2) reactive approaches (Fig. 2). Moe and Pathranarakul (2006) described that proactive approach refers to those activities such as mitigation and preparedness that are planned and conducted before the natural disasters by stakeholders in order to tranquilise the adverse impacts of natural disasters effectively. In contrast, response and recovery activities which are conducted by stakeholders during and after natural disasters are called reactive approach.

- **Mitigation** refers to structural and non-structural activities aimed at eliminating and reducing the probability and consequences of disasters in the environment, society and infrastructure facilities before a disaster occurs.

- **Preparedness** activities include developing emergency procedures and stakeholder institutional capability taken in advance to ensure effective response to the impact of disasters.

- **Response** refers to the activities taken immediately during and following a disaster. The main aim of effective response to disaster is to save the community and minimise damages.

- **Recovery** activities involve rehabilitation (short-term) and reconstruction (long-term) endeavours aimed at restoring vital support systems and returning life to normal.

Although there are two approaches to tackling disasters - proactive and reactive - most studies have claimed that stakeholders often resolve the predicaments arisen in disasters by reactive approaches (Bosher, Dainty, Carrillo, Glass, & Price, 2009; Brilly & Polic, 2005; Loosemore & Hughes, 1998). As it is evident in Fig. 2, proactive approach covers both Flood Risk Reduction (FRR) and Flood Management (FM). However, reactive approach only refers to FM. Therefore, proactive approach covers overall perspective of Flood Risk Management (FRM).

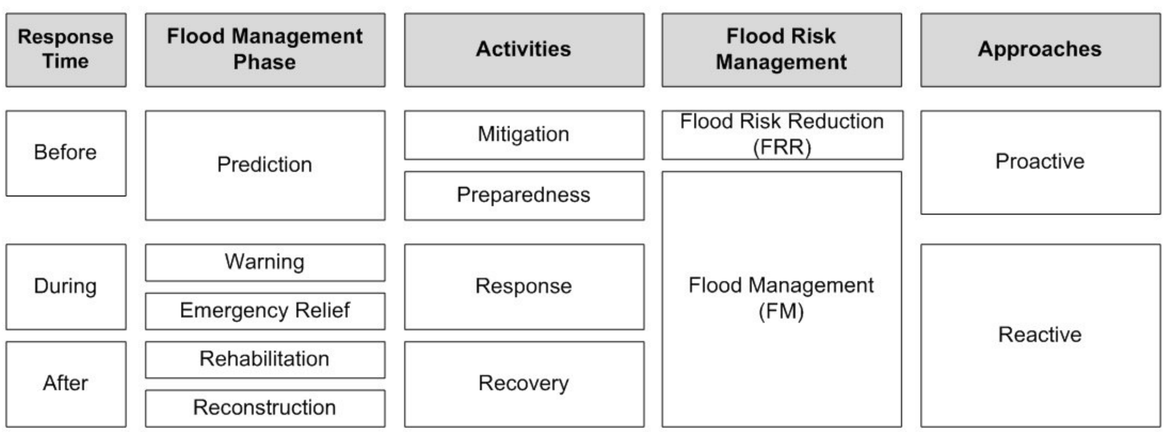

Figure 2: Flood risk management and approaches (adapted from Moe and Pathranarakul (2006)

Research method

Research design and data collection method

We collected our research data from three databases which are being maintained by (1) Road and Maritime Services (RMS), (2) Bureau of Meteorology (BOM), and (3) Australian Bureau of Statistics (ABS). RMS provided us with access to their post-disaster reconstruction projects database. This database includes a broad range of detailed information on the transport infrastructure recovery projects across NSW between the period of 1982 to 2012 for mainly flood, storm and bushfire disasters. Specifically, we have just focused on post-flood reconstruction projects. A part of flood characteristic information and socio-economic exposure and vulnerability were collected from databases provided by BOM and ABS, respectively. In addition, we collected remaining flood information and socio-economic data and all stakeholders' approaches information through a web-based structured survey among LGAs or local Councils across NSW. Since all LGAs are not susceptible to flood disaster, we have focused on Local Councils who are members of the Flood Management Associations (FMA). As of November 2005, it is noted that there are 152 LGAs in NSW, however, only 74 of them are members of FMA because they have been affected by flood disasters over the past decades. In order to facilitate the data collection process, FMA acknowledged distributing our survey questionnaire to its members, giving a response rate of 48% (36 out of 74). Local Councils' staffs who have been working in floodplain management such as floodplain engineers, planning and infrastructure engineers and emergency management officers filled the questionnaires. It is important to note that the designed questions have been related to Local Councils' experiences in managing flood disasters not staffs' experiences. Hence, a team might have filled a single questionnaire.

Data analysis techniques

We decided to use the Partial Least Squares Structural Equation Modelling (PLS-SEM) statistical approach. PLS-SEM is a powerful statistical method that can identify relationships in social research that probably would not otherwise be found. because this method: (1) predicts relationships among factors in an exploratory fashion: (2) achieves high levels of statistical power with small sample sizes; (3) does not require any distributional assumption; and (4) handles factors measured with single and multi-item measures. Factors are variables that are not directly measured and are sometimes called unobserved variables. For example, in this study, proactive approach, reactive approach and Local Councils' overall approach are factors that are not directly measured. There are, however, several limitations of PLS-SEM. Its application for theory testing and confirmation is limited, because it does not provide sufficient global goodness-of-model fit measures. Increasingly, PLS-SEM parameter estimates in terms of bias and consistency are not optimal (Hair Jr, Hult, Ringle, & Sarstedt, 2013).

We used SmartPLS 2.0 (Ringle, Wende, & Will, 2005) software to evaluate the structural model. In evaluating and reporting the results, we followed recent guidelines for PLS-SEM (e.g., Hair Jr et al., 2013; Wong, 2013) and assessed measurement models before the structural model. Measurement model in SEM specifies the variables for each factor and assesses the reliablility of each factor for estimating the casual relationships. However, structural model tests the hypotheses among factors (Hair, 2009).

An important property of the PLS-SEM method is the extraction of latent variable scores. Importance-performance matrix analysis (IPMA) is a useful tool in developing the latent variable scores (Hair Jr et al., 2013). IPMA contrasts the structural model's total effects (importance) and the average values of the latent variable scores (performance) to shed light on significant areas for the improvement of management activities. We have used the concept of IPMA to develop an index to measure the Council's overall response toward FRM in transport infrastructure. Hence, the general form of the SFRI is as follows:

$$\boldsymbol{SFRI} = \frac{\mathbf{E[\theta] - min[\theta]}}{\mathbf{max[\theta] - min[\theta]}} \times \mathbf{100} \qquad \text{Eq. 1}$$

Where θ is the latent variable for response index (SFRI), and $\mathrm{E}[.]$, $\min[\theta]$ and $\max[\theta]$ denote the expected, the minimum and the maximum value of the variable, respectively. The minimum and the maximum values are determined by those of the corresponding manifest variables.

$$\mathbf{Min}[\boldsymbol{\theta}] = \sum_{i=1}^{n} \boldsymbol{w_i} \, \mathbf{min}[\boldsymbol{x_i}] \ \ \boldsymbol{and} \ \mathbf{max}[\boldsymbol{\theta}] = \sum_{i=1}^{n} \boldsymbol{w_i} \, \mathbf{min}[\boldsymbol{x_i}] \qquad \text{Eq. 2}$$

Where x_i is the ith measurement variable of overall stakeholder response, w_i is the weight, and n is the number of measurement variables.

Characteristics of the Local Councils

Table 1 presents the characteristics of the Local Councils participated in our study. For the majority of the Local Councils (58.3%), only 1 to 2 staff in the respective organizations are currently involved in floodplain management. This can be partly explained by their low annual average capital work budget ($16 million for 2012-2013). It is noted that 5.6% of the Local Councils have 9 - 10 staff working in floodplain management, however, those Councils have a $51 million capital work budget on average for 2012-13.

Table 1 Characteristics of the Local Councils

Floodplain management staff	Number of councils (%)	Council's average capital work budget for 2012-13 (A$ million)
1-2	21 (58.3%)	16
3-4	7 (19.4%)	25
5-6	5 (13.9%)	31
7-8	1 (2.8%)	42
9-10	2 (5.6%)	51

Table 2 shows the Local Councils' priority for allocating their budget to different facilities in FRM. It can be seen that private residential buildings and transport infrastructure are of high priority in their assignment of annual work budget for flood disaster risk management.

Table 2 Councils' priority in floodplain risk management

Facility	Number of councils (%)	Rank
Private residential buildings	8 (18.55%)	1
Public roads and bridges	7 (18.31%)	2
Public buildings	7 (18.07%)	3
Utilities (water, sewerage, telecommunication, electricity etc.)	6 (16.88%)	4
Private commercial/industrial buildings	6 (16.65%)	5
Rural industries	4 (11.53%)	6

Results

Stakeholder Flood Response Index (SFRI)

Table 3 presents the results of the total effects (importance) and index value of SFRI (performance) used for IPMA. Table 3 represents the major factors in predicting SFRI. For example, reactive approach has the highest performance (68.055) among other factors and with highest effects (0.356) on defining SFRI. Increasingly, recovery activities such as post-flood reconstruction tasks have the imperative role in predicting Locals' Councils reactive approach.

Table 3 SFRI and total effects for the stakeholder overall flood response

Major factors	Total effects	SFRI
Stakeholder attributes	0.220	58.132
Mitigation	0.060	58.931
Preparedness	0.002	48.054
Response	0.092	47.766
Recovery	0.059	53.354
Proactive approach	0.107	61.111
Reactive approach	0.356	68.055

As shown in Fig.3, IPMA of SFRI reveals that the proactive approach is of primary importance in establishing SFRI. However, its importance is slightly low when compared with the other constructs. Stakeholder attributes has high importance and performance in defining SFRI compared with proactive approach and other constructs. Mitigation, preparedness, response and recovery activities have little relevance because they are of low importance even though they have relatively high performance. Finally, the reactive approach is the pivotal construct to define SFRI because it has high importance and performance compared with other constructs.

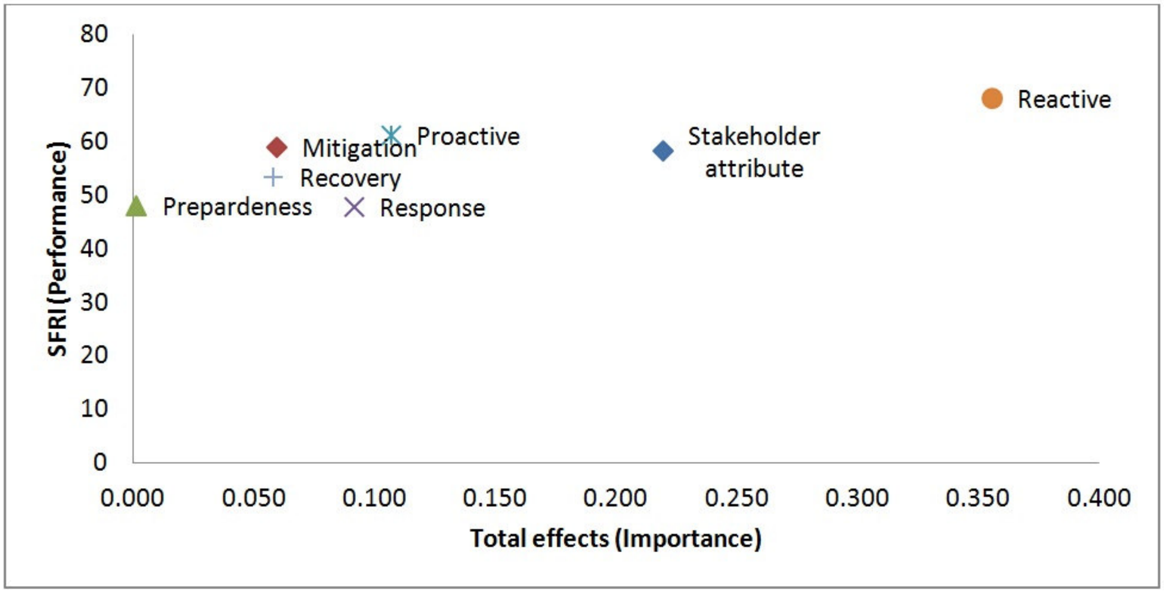

Figure 3: IPMA results of overall stakeholder response as target construct

Discussion

First, flood characteristics have substantial impacts on flood damages in Australia. Flood severity, flood frequency and flood type are the most contributing factors in the determination of flood losses. Australian transport infrastructure is very susceptible to major flooding and river floods. Therefore, stakeholders, in particular Local Councils, should take necessary measures in FRM for (1) zoning and land use controls to prevent construction of roads and bridges in river flood prone areas, (2) developing engineering design standards for resilient roads and bridges and (3) designing comprehensive, proactive flood disaster risk management procedures and mandates. In general, the observed or modelled relationship between socio-economic exposure and vulnerability, and flood impacts indicates that a wealthier Local Council is better equipped to manage the consequences of flood disasters by reducing the risk of impact and by managing the impacts when they occur. This is due to higher GRP per capita, higher income levels and lower population density.

Second, we found that a reactive approach has high importance and performance in denoting the Local Councils' overall response in flood risk management in NSW. We argue that a proactive approach should be the leading factor in defining SFRI. In this, Local Councils should take necessary measures in mitigation and preparedness activities in order to enhance the importance and performance of the proactive approach. Local Councils across NSW have shown high FM practices and activities, however, this is because of reactive approaches. Therefore, they need to show that they have high performance in FRR and consequently in FRM which this would most probably happen by practicing proactive approaches.

Third, stakeholder attributes have a significant role in SFRI as well. By increasing Council's power, legitimacy and urgency, we can improve Council's overall response to flood disasters, particularly in transport infrastructure across NSW. The power enables them to equip social and political forces and to benefit from FRM resources from their respective organisation. Legitimacy gives opportunity to LGAs to follow beneficial or harmful risks pertinent to floodplain risk management. In FRM, legitimacy is a generalised assumption that the behaviours of LGA are proper within socially constructed systems of norms, mandates and procedures. Finally, urgency enables LGAs to claim call for immediate response and recovery in the reactive approach. Improving stakeholders attributes would most likely result in decreasing the exposure and vulnerability of socio-economic and the built environment conditions.

Conclusion

The research presented in this paper establishes a novel approach to FRM. The development of the Stakeholder Flood Response Index brings together a body of knowledge about stakeholders' approaches to form a wide range of disciplines to provide three principal benefits. First, SFRI allows direct comparison of the relative overall stakeholders' responses to flood disaster. It indicates whether stakeholders have been proactive or reactive in their approaches. Many factors (e.g., flood frequency, type, severity, exposure and vulnerability of society, economy and built environment, stakeholder attributes) contribute to SFRI. A stakeholder may have a relatively high overall response to flood disaster, however, this high response could be because of more reactive approaches rather than proactive tasks. Such a comparison could be useful for governments as they allocate resources among various stakeholders. Insurance and reinsurance companies could employ it as they plan their portfolio diversification and establish premiums for flood insurance policies. Second, by monitoring and controlling the index periodically, stakeholders' responses over time could be monitored with the SFRI.
Future researches and FRM practitioners can repeat the process, altering the details to fit their specific goals and resources. With this methodology established, future researchers can create variations of the SFRI with relative ease. The interactions among mitigation, preparedness, response and recovery will have a major influence on resilient and sustainable pathways. Therefore, SFRI can open a new avenue for a resilient and sustainable future.

Acknowledgments

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Appendix 1: Indicators and constructs for SFRI

Factors/indicators
Flood Characteristics (FC)
FC1: Minor flooding
FC2: Moderate flooding
FC3: Major flooding
FC4: River flooding
FC5: Number of major floods over the past 20 years (1992-2012)
Socio-economic Condition (SE)
Exposure
SE1: Population
SE2: GRP per capita
Vulnerability
SE3: Population at risk to the flood disaster
SE4: Age structure
Transport Infrastructure Condition (TI)
Exposure
TI1: Local non-urban sealed roads (km)
TI2: Local non-urban unsealed roads (km)
TI3: Total bridge and culvert lengths on local roads
Vulnerability
TI4: Roads and bridges at risk to the flood disaster
TI5: Average response time for road reconstruction
Stakeholder Attributes (SA)
SA1: Power
SA2: Legitimacy
SA3: Urgency
Mitigation Activity (MI)
MI1: Analysing risks to measure the potential areas for floods
MI2: Training and education on flood risk management
MI3: Developing a master plan for flood disaster management
MI4: Developing flood disaster information systems among stakeholders
MI5: Providing timely and effective information related to flood disasters
MI6: Constructing flood retarding basins, barriers, culverts, levees, and drainage

Appendix 1. Continued

Factors/indicators
Preparedness Activity (PR)
PR1: Recruiting personnel for flood emergency services
PR2: Developing flood emergency management systems
PR3: Developing strategies for public education about flooding
PR4: Budgeting for and acquiring flood emergency vehicles and equipment
PR5: Locating places for flood emergency operation centres
PR6: Using technology to identify and assess floods and damaged roads
PR7: Developing coordination procedures with other stakeholders
Response Activity (RS)
RS1: Activating the flood emergency operations plans and operations centres
RS2: Evacuating threatened populations and vehicles
RS3: Operating shelters and provision of mass care
RS4: Estimating economic damages
RS5: Establishing procedures to prevent and suppress secondary hazards
RS6: Documenting lessons learned and best practices in response phase
RS7: Implementing effective coordination with other stakeholders (e.g., RMS)
RS8: Implementing effective logistics management (e.g., supply of equipment)
RS9: Implementing effective mobilisation and disbursement of resources
RS10: Providing information on flooded areas to public
Recovery Activity (RC)
RC1: Cleaning flood disaster debris
RC2: Considering sustainability in post-disaster reconstruction
RC3: Shortening reconstruction time by applying quick mobilisation
RC4: Selecting reconstruction contractors from a predetermined list of contractors
RC5: Constructing temporary roads and bridges
RC6: Implementing execution plan for post-disaster reconstruction
RC7: Documenting lessons learned and best practices in recovery phase
RC8: Applying lean construction in post-flood reconstruction
RC9: Realigning roads and relocating bridges to lower flood hazard locations
Proactive Approach (PA)
PA1: Stakeholder proactive approach in floodplain risk management
Reactive Approach (RA)
RA1: Stakeholder reactive approach in floodplain risk management

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