

Disaster community resilience assessment method: a consensus-based Delphi and AHP approach

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Received: 25 November 2014 / Accepted: 19 March 2015 / Published online: 28 March 2015
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Abstract Several studies have highlighted the importance of community resilience in disaster management. The paper focuses on Saudi Arabia and proposes a ‘community resilience to disaster’ framework. The dimensions of the framework have been developed using the consensus-based Delphi technique. A weighting system for each dimension and criteria is proposed using the analytic hierarchy process (AHP). Experts’ opinions were collected using pair-wise comparisons and then coded in AHP Expert Choice software to evaluate and give priorities to the possible outcomes of the process. The weighting system provides a quantitative and qualitative assessment tool to measure community resilience to disasters in Saudi Arabia and beyond. The findings emphasise the importance of a number of dimensions, including health and well-being (24.5 % of the total weight), governance (18 %), physical and environmental (17.4 %), economic (15.9 %), information and communication (14.3 %) and social (9.9 %).

Keywords Weighting system · Assessment · Community resilience · Delphi · AHP

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1 Introduction

Several studies highlight the importance of community resilience in disaster management (Joerin et al. 2012; Ainuddin and Routray 2012). Thus, greater importance is attributed to the capacity of affected communities to recover from disaster, with or without overseas aid (Bosher and Dainty 2011). This has brought about a change in the disaster risk reduction work culture, with a stronger emphasis being placed upon resilience, rather than vulnerability (Manyena 2006).

Dalziell and McManus (2004) point out that the concept of ‘resilience’ is used in different research fields with varying definitions (Dalziell and McManus 2004; Mayunga 2007; Engle et al. 2013). Recently, resilience has formed a key element of the United Nations International Strategy for Disaster Reduction (UNISDR) (Castleden 2011), and in this context is defined, as:

... the ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions (UNISDR 2009; p. 24).

Resilience operates at several interrelated levels, including individual, community and national (Longstaff et al. 2010; Wilson 2012). It is noted by Norris et al. (2008) that the resilience of communities is dependent upon the resilience of the individuals within the communities. The link between individual resilience and community activities has been described by numerous studies (Paton 2006).

A disaster-resilient community is a community that can resist disasters and that is able to take mitigating actions consistent with achieving the required level of protection (Cimellaro et al. 2010). Davis et al. (2005) stress the need for an assessment tool that can help communities identify and increase the criteria to build community resilience. However, there is a lack of instruments for assessing community resilience (Frankenberger et al. 2013). Nevertheless, Buckle (2006) highlights that components of resilience should be measured to assess the resilience of a community on the basis of how best to manage them (Buckle 2006), while Kirmayer et al. (2009) point out that measuring community resilience is important to indicate the weakness of the community. In that respect, different authors have established various frameworks and indicators of resilience (Tierney 2006; Cutter et al. 2003). However, there is no agreed framework or model to measure and monitor community resilience to disasters (Cimellaro et al. 2010; Jordan and Javernick-Will 2013; Ainuddin and Routray 2012). Measuring community resilience remains a real challenge (Cutter et al. 2008). For example, Kusel (1996) conducted an assessment of community well-being in the Sierra Nevada to establish the most important aspects affecting community ability and to rank the components of community resilience (Kusel 1996). Also, Colussi (1999) developed a framework of community resilience comprising four dimensions: people; organizations; resources; and community process (Colussi 1999).

Numerous authors indicate that assessing community resilience has become a difficult process due to several challenges (Mayunga 2007; Frankenberger et al. 2013; Cutter et al. 2008), including (a) the dynamic and complex interactions of people with their communities and (b) the local environment and their societies. An additional challenge is the lack of method to identify the resilience of a community due to the absence of shocks or stressors during the life of a project (Frankenberger et al. 2013). One of the most important

challenges highlighted by Frankengerger et al. (2013) is building a resilience index based on the weighting of each factor to reveal the impact of each on resilience.

In the past two decades, the rate of disasters has increased in Saudi Arabia, contributing to an increase in the exposure of the population to their impacts (Alshehri et al. 2013). Colussi (1999) notes that each community is unique, and the concept of community in the context of Saudi Arabia takes on a further dimension in view of the importance of religion, customs and traditions. Taking these factors into account, a community resilience to disaster framework is proposed, using the Delphi method, consisting of 62 criteria clustered into six dimensions: social; governance; health and well-being; and information and communication. In this paper, a new weighting system for each dimension and criterion is presented. This is derived using the analytic hierarchy process (AHP) and related equations to establish the priorities of community resilience framework. The weighting system provides an assessment tool that can be used for measuring community resilience to cope with disasters in Saudi Arabia. Section 2 provides a brief overview of the underpinning methodology. This is followed by a summary of the initial community resilience framework and expert survey consultation. Section 4 describes the proposed weighting system applied to the community resilience framework dimensions and criteria. Section 5 elaborates on the findings, analysis and discussion of the results. Finally, Sect. 6 provides concluding remarks and directions for future research.

2 Methodology to establish a community resilience framework (CRDSA)

This paper addresses the following research questions:

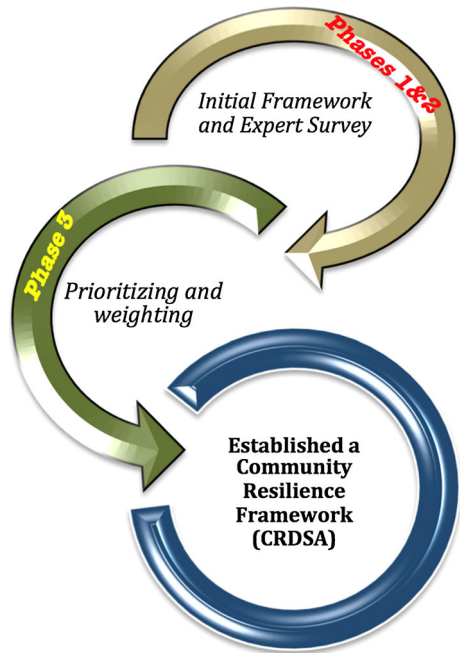
RQ1 What is the most adapted resilience assessment weighting system that best conveys community resilience measurement in the context of Saudi Arabia?

RQ2 To what extent do dimensions and criteria of the proposed community resilience framework to disasters (CRDSA) determine measurable outcomes of community resilience?

To establish a community resilience framework (CRDSA), the authors have adopted a mixed-method strategy (including quantitative and qualitative research) involving: a literature review, Delphi survey and AHP. The design is structured into three phases as illustrated in Fig. 1. In the first phase, the authors use a quantitative strategy through an opinion survey to establish public perception of the risk of disasters in Saudi Arabia (Alshehri et al. 2013). Several criteria under the proposed six dimensions were selected based on the outcome of this national survey combined with the literature review of related studies in the field (Twigg 2007; Cutter et al. 2008; Norris et al. 2008; Ainuddin and Routray 2012; Mayunga 2007; Burton 2012).

In the second phase, the Delphi, consensus-based consultation, is employed (Alshehri et al. 2014). All dimensions and their corresponding criteria were presented to an experts' panel to determine the level of importance and consensus for each dimension and criterion in relation to community resilience to disaster management in Saudi Arabia (Alshehri et al. 2014). In the final phase, the authors used AHP and a calculation method to establish the weights for each dimension and criterion. AHP has the ability to mix quantitative and qualitative attributes (Wedley 1990). Qualitative assessments are converted into quantitative measures by using Saaty's nine-point scales which link the framework together

Fig. 1 Research phases to establish a community resilience framework (CRDSA)



(Shapira and Simcha 2009). The qualitative dimension is factored in through the initial Delphi consultation (Alshehri et al. 2014).

3 Initial framework and expert survey

Based on a comprehensive literature and a national survey on public perception of disasters in Saudi Arabia (Alshehri et al. 2013), CRDSA was developed using the Delphi technique (Alshehri et al. 2014).

Moreover, a three-round Delphi study was conducted using a local and an international panel of experts with in-depth knowledge in the wide field of disaster management. The panel is used to achieve consensus on the dimensions and criteria of the proposed framework, focusing on six resilience dimensions identified earlier in the process: social; economic; physical and environmental; governance; health and well-being; and information and communication. A total of 62 criteria were identified. The resulting community resilience framework involves seven to fourteen criteria in each of the six identified dimensions (Alshehri et al. 2014).

After the Delphi expert survey, the CRDSA was finalised. The dimensions and their criteria were then used to strengthen the framework. The next objective, forming the focus of the paper, is to evaluate the weight of each dimension using AHP methodology. Therefore, between May and June 2013, a questionnaire was prepared and submitted to the experts for effective assessment of the proposed dimensions. Expert Choice software (2013) is used to codify, evaluate and assess the judgments of the consulted experts.

4 Prioritizing and weighting the community resilience framework dimensions and criteria

A multi-criteria decision-making (MCDM) process is essential for the performance evaluation of disaster management and is an effective technique for increasing the overall group decision-making consensus (Jiang and Yu 2013). However, the difficulty lies in the selection of a suitable underpinning mathematical model (Melón et al. 2008). Out of the existing methods of MCDM, the AHP enjoys a wider adoption and outcome satisfaction (Triantaphyllou and Mann 1995; Srdjevic 2007; Eakin and Bojórquez-Tapia 2008; Sanneh et al. 2013). Consequently, AHP is chosen for this study given its attributes, as elaborated below.

Zhang and Fu (2012) state that AHP can be used with, or in support of, other methodologies, while Öñüt and Soner (2008) point out that it can be used to blend different processes into a single overall score for ranking decision (Öñüt and Soner 2008). Lin et al. (2010) carried out a study using AHP with Delphi to generate an efficient management model. Ercoskun and Global (2012) suggested a technique integrating four methods: SWOT–CATWOE analysis, Delphi, AHP and a Geographic Information System, to evaluate the land-use suitability for cities. In that study, AHP was used to measure the importance or weight of each criterion (Ercoskun and Global 2012).

In addition, AHP has been combined with other approaches to achieve the desired ranking (Vaidya and Kumar 2006). For example, the ranking of enterprises according to the achieved level of business efficiency has been achieved by using the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method and AHP (Babic and Plazibat 1998). The PROMETHEE method is used for final ranking, whereas AHP is used to determine the importance of criteria (Babic and Plazibat 1998). Zhang and Fu (2012) integrated AHP with the data envelopment analysis (DEA) to establish a logistics system performance in which AHP was used to calculate the weights of the indicators of the performance (Zhang and Fu 2012). AHP in a further study is used to prioritize dimensions of the framework and to support decision-making (Vaidya and Kumar 2006).

Viswanadhan (2005) confirms that the computational issues such as defining and synthesising the weights can be completed using either software such as Expert Choice or manually (Viswanadhan 2005). Melón et al. (2008) indicate that the software Expert Choice easily and quickly supports the calculations and presentation of the results. It also can be used to reach consensus (Vaidya and Kumar 2006). Hence, in this study, the use of AHP is suggested for use with multiple experts supported by the Expert Choice software (2013).

The AHP process comprises the following steps (Lin et al. 2010; Tahriri et al. 2008):

- Constructing the hierarchy.
- Creating pair-wise comparisons to collect the data and establish priorities among the elements in each level in the hierarchy.
- Synthesising judgments (to obtain the set of overall or weights for achieving the goal).
- Evaluating and checking the consistency of judgements.

In the current study, the AHP was developed according to the process shown in Fig. 2. For this research, 23 experts were invited from those who participated in the Delphi surveys in order to avoid inconsistency and overlapping information (Lin et al. 2010); only 16 experts agreed to participate, which is an acceptable number (Omar and Jaafar 2011).

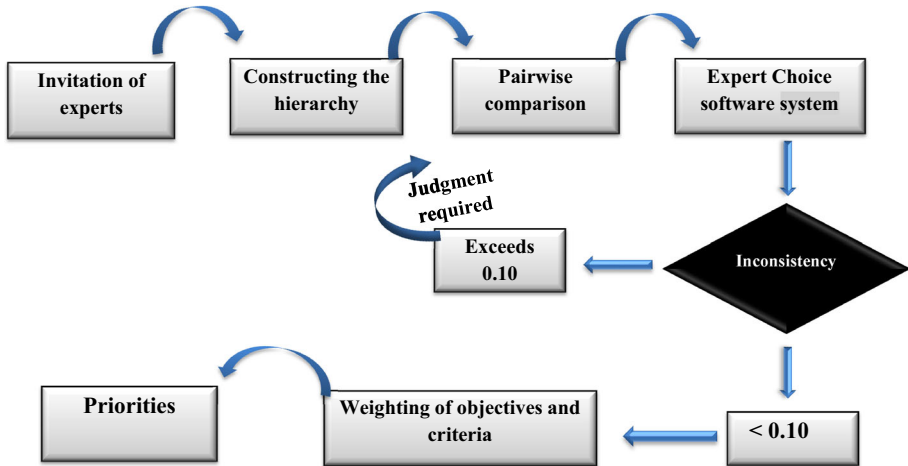


Fig. 2 Flow chart of the process of constructing assessment of CRDSA

Table 1 Expert's panel

Expert	Organisation
International	NHS Commissioning Board (UK)
	Crowd Modelling Ltd (UK)
	Asian Disaster Preparedness Centre (Bangladesh)
	Caribbean Emergency Responder's Training Academy (USA)
	Experts (Independent Consultant) from other countries (Greece, Nepal)
Government official	Civil Defence
	Royal Saudi Air Force
	Ministry of Health (MOH)
	Centre of Excellence for Climate Change Research (CECCR), King Abdulaziz University
Academia	Abdelaziz City for Science and Technology (Saudi Arabia)
	King Khalid University (Saudi Arabia)
	University Putra Malaysia (Malaysia)
Medical	Prince Sultan Military Medical City (PSMMC) (Saudi Arabia)
	NHS South (UK)
	Armed Forces Medical Services (MSD)

Although the sample size was small, several studies point out that panel size is not a limitation as AHP can be conducted with small number of participants (Lee and Walsh 2011).

The selected experts' experiences related to disaster management averaged 5 years, and as stated earlier, they were all involved in the Delphi surveys of this project (Alshehri et al. 2014). The experts in this study were recruited from a variety of disciplines in disaster management, locally and internationally, including in the USA (as illustrated in Table 1),

with an in-depth understanding of local and wider issues. Moreover, all international experts (a) understand or share the same local cultural and religious values and have for many of them worked previously in Saudi Arabia and (b) contribute their wider international experience acquired through extensive work in developed countries and relevant international organizations.

The pair-wise comparison matrices at the first level (dimensions) of the hierarchy were completed and sent via email in the form of a PDF to the selected experts. Initially, as noted earlier, 16 experts answered the pair-wise questionnaires. The experts were asked to fill in the pair-wise comparison matrices then to submit it online. Two experts were rejected because of their inconsistency ratio; the results of the remaining 14 experts were used to decide the rating. Finally, the consensus of the groups was calculated using Expert Choice (2013) software to generate the weights.

4.1 Constructing the hierarchy

Constructing the hierarchy involves breaking down the decision-making problem into a hierarchy, which can be divided into three parts: goal, criteria and its sub-criteria and alternatives (Ishizaka and Labib 2009). In this study, the critical success criteria related to community resilience to disasters, which were derived from the Delphi method (Alshehri et al. 2014), comprise six dimensions: social, economic, physical and environmental, governance, health and well-being, and information and communication. The components that best describe community resilience to disaster are presented on a three-tier hierarchy in an AHP model (Fig. 3), with the top level as a goal related to the problem. The second tier comprises six categories determined based on resilience dimensions (Alshehri et al. 2014). Finally, these dimensions have 62 criteria (7–14 per dimension) represented in the third tier that have been coded (see description of each code in Tables 4, 5, 6, 7, 8, 9). All these criteria were developed by a firm consensus within the expert panel in the Delphi method (Alshehri et al. 2014)

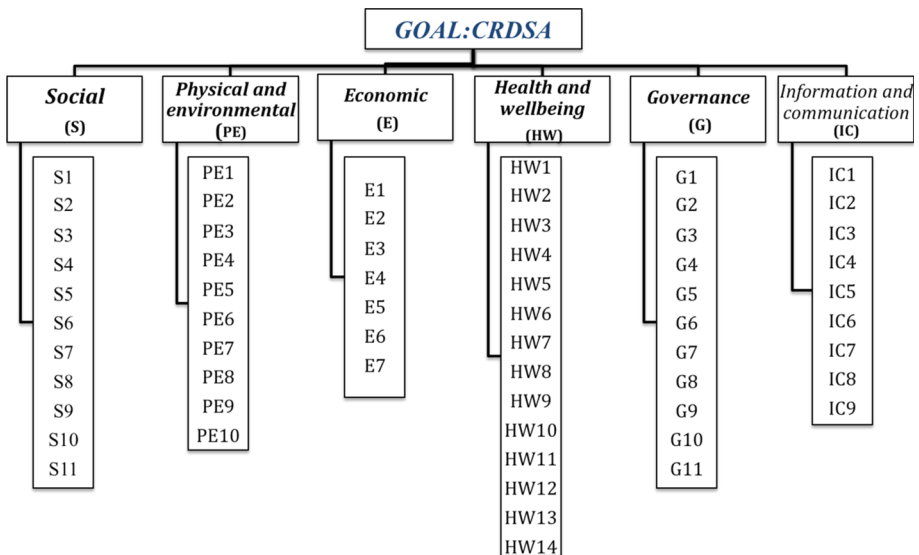


Fig. 3 Overall hierarchical structure of the AHP

4.2 Pair-wise comparison

Pair-wise comparison is the core of AHP (Saaty 1994). The first step after constructing the hierarchy in the AHP procedure is to make pair-wise comparisons between each dimension or criterion to create a scale for comparison (Saaty and Vargas 2001; Saaty 2008). Pair-wise comparisons indicate the relative importance between items in order to reach the overall goal (Tahriri et al. 2008).

For determining the importance of the dimensions, the experts made pair-wise comparisons of each dimension against the other five dimensions. The basis of judgment of the comparison was Saaty's nine-point scales (Table 2) in which the higher number means the chosen dimension is considered more important to a greater degree than the other dimension to which it is being compared. The pair-wise comparison values for the top-level dimensions were determined by the authors based on the Delphi surveys (Alshehri et al. 2014). The results of these pair-wise comparisons are discussed in the result section.

A pair-wise matrix was built comparing each dimension against the other five dimensions, creating a total of 15 matrices (see the example in Table 3) in order to define the weighted hierarchy for the CRDSA.

In contrast, the difficulty of doing comparison with more than seven objectives is highlighted by authors such as (Bahurmoz 2006; Saaty and Vargas 2012). Hence, pair-wise comparisons of the third level were more difficult and time-consuming as they involve 62 criteria, which could require 303 comparisons.

Expert Choice software (2013) was used to transform the comparisons of the dimensions into weights. The AHP method, through the use of the Expert Choice software, offers relative weights for each dimension. The assignment of the pair-wise comparison value was applied while maintaining the consistency level under 0.1 for each dimension comparison.

4.3 Expert Choice software

The consistency of judgments that the experts revealed during the series of pair-wise comparisons is an important consideration in terms of the quality of the crucial decision (Saaty 1999). AHP has the ability to measure the consensus of expert's judgments by calculating a 'consistency ratio' (CR) (Liedtka 2005). A $CR < 0.10$ is considered acceptable (Saaty 1994). Saaty (1999) points out that the inconsistency may occur in judgments of experts, which is inherent in the process of judgment; therefore, inconsistency of

Table 2 Saaty's nine-point scales adapted from (Saaty 1994, 2008)

Intensity of importance	Definition and explanation
1	Equally important
2	Equally to moderately more important
3	Moderately more important
4	Moderately to strongly more important
5	Strongly more important
6	Strongly to very strongly more important
7	Very strongly more important
8	Very strongly to extremely strongly more important
9	Extremely more important

Table 3 Pair-wise comparison matrix of the dimensions with respect to the goal

9 = Extreme 7 = Very strong 5 = Strong 3 = Moderate 1 = Equal 3 = Moderate 5 = Strong 7 = Very strong 9 = Extreme																		
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Health and wellbeing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Governance
Health and wellbeing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Information and Communication
Health and wellbeing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Physical and Environmental
Health and wellbeing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Social
Health and wellbeing	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Economical

<0.10 is acceptable (Saaty 1999). If the inconsistency exceeds 0.10, some reviews of judgment may be required (Andijani 1998; Saaty 1999).

Software such as Expert Choice has widely contributed to the success of the method (Ishizaka and Labib 2009). The Expert Choice software system combines many useful aspects such as automatic calculation of priorities and provides information about the inconsistencies of respondents’ judgments and methods to achieve a sensitivity analysis (Ishizaka and Labib 2009; Yang et al. 2007). Expert Choice can be used to calculate CR automatically for the full set of pair-wise comparisons (Liedtka 2005; Saaty and Vargas 2001; Yang et al. 2007; Ishizaka and Labib 2009). Hence, in this study, after all the pair-wise comparisons were assigned between the dimensions at the first level, the weighted hierarchy model was developed to form the complete weighted AHP in Expert Choice format.

The analysis is done in phases. First, pair-wise comparison is completed; next, the judgments are made; and finally, the synthesis is performed to generate the resulting weights. As a result of the difficulty of achieving the third level, as noted above, the priorities were achieved by another method as discussed below.

4.4 Weighting of the criteria: third level

As mentioned in Sect. 2.2, difficulty was experienced in weighting the 62 criteria. Therefore, the authors used a calculation method to establish the weights for each criterion. The authors combined the results of means, which were obtained under the Delphi method (Alshehri et al. 2014), with AHP results as follows:

- Collect the overall mean for each dimension.
- Divide the mean of each criterion by the overall mean of its dimension.
- Multiply the result of each criterion with the weight of its dimension obtained from the AHP.

The following equations illustrate this method:

$$t = \text{Mean of criterion}_1 + \text{Mean of criterion}_2 + \dots + \text{Mean of criterion}(n)$$

$$t = \sum_{i=1}^n mi = m_1 + m_2 + \dots + mn \tag{1}$$

$$p = \frac{\text{Mean of criterion}}{\text{The total means of dimensions criteria}} \quad (2)$$

$$p = \frac{m}{t}$$

$$\text{wc} = p \times \text{Weighting of dimension(AHP)} \quad (3)$$

$$\text{wc} = p \times \text{wd}$$

where: m = mean of criterion (Delphi method); p = proportion of criterion to the rest of the criteria in its dimension; t = the total means of dimension's criteria; wc = weighting of criterion; wd = weighting of dimension (AHP).

4.5 Proposed community resilience framework (CRDSA)

The proposed framework for assessment and implementation of CRDSA in this study includes examining the status of the six dimensions of this framework (i.e. social, economic, physical and environmental, governance, health and well-being, and information and communication). The authors used Eqs. 1, 2 and 3 discussed in Sect. 2.3 to determine the weights for each criterion in the six dimensions. Next, Microsoft Excel 2010 was employed to identify units as a percentage of each criterion, which can be used to facilitate the assessment process of the community resilience.

The following equations were used to explain the final result of the assessment of the CRDSA.

$$\text{tp} = \sum_{i=1}^n pi = p_1 + p_2 + \dots + pn \quad (4)$$

tp = total of proportion of criteria for each dimension

$$\text{WD} = \text{wd} \times \text{tp} \quad (5)$$

WD = the new weight of the dimension.

When the new weight of each dimension is obtained, then total assessment of community resilience to disasters is reached by calculating the sum of all the new weights (see Eq. 6):

$$\text{CRDSA} = \sum_{i=1}^6 \text{WD}_i = \text{WD}_1 + \text{WD}_2 + \dots + \text{WD}_6 \quad (6)$$

5 Results and discussion

According to Chan et al. (2014), consensus around experts' judgement can facilitate the implementation of strategic models such as CRDSA, as corroborated by De Lange et al. (2010). Hence, in this study, the contribution of the participant experts to Delphi and AHP has been the driving force behind the development of the proposed framework for assessing the community resilience to disasters in Saudi Arabia.

5.1 Weights allocation

The weights and ranking of the dimensions are derived from using Expert Choice software from the pair-wise comparison matrices (Fig. 4). The local weights are scaled to 1 across the second-level dimension giving $0.099 + 0.143 + 0.159 + 0.174 + 0.180 + 0.245 = 1.000$.

Addressing the consistency of judgments in defining the importance of the criteria forms one of the most important advantages of AHP as there is potential for inconsistency in experts’ judgments (Ishizaka and Labib 2009; Yang et al. 2007). The closer the score is to zero, the greater is the consistency (Salmeron and Herrero 2005).

Figure 5 reveals the final weights allocated to each dimension from the pair-wise comparison scores and the index for inconsistency that is 0.00331, which is <0.1 and therefore acceptable.

In this figure, in terms of the dimensions, the results reveal that the health and well-being dimension takes the highest overall weight and accounts for 24.5 % of the hierarchy total weight. The other dimensions are weighted as follows: governance dimension (18.0 %), physical and environmental dimension (17.4 %), economic dimension (15.9 %) and information and communication dimension (14.3 %). The lowest weighted is the social dimension (9.9 %).

To determine the weight of the criteria under each dimension, the authors used the equations highlighted in Sects. 2.3 and 2.4. Thus, Tables 4, 5, 6, 7, 8 and 9 display the credit and the proportion of each criterion against its dimension in the third hierarchy level (p). Weight allocations of criteria (wc) under each dimension appear as elaborated below.

5.1.1 Health and well-being (HW)

Throughout the process, this study found that the health and well-being dimension has the highest weighting. This result is consistent with previous studies that emphasise the importance of working to strengthen community health and well-being in order to cope with disasters (Morrissey and Reser 2007; Tianzhuo and Linyan 2014). As shown in Table 4, all criteria in this dimension are weighted around the same level of importance to the dimension (between 0.07 and 0.08). The most important criteria are ‘access to clean water and adequate sanitation’ and ‘food security’ with credits of 0.0191 and 0.0189, respectively.

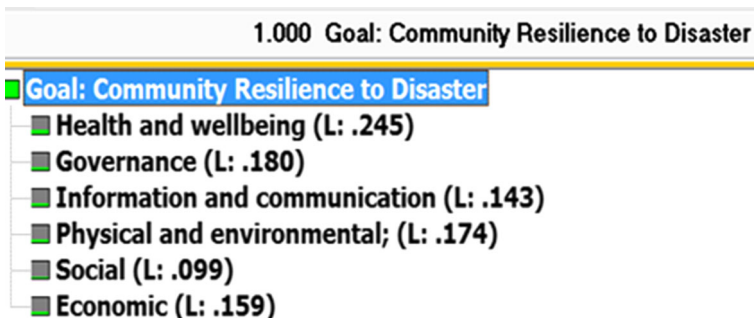


Fig. 4 Tree view of dimensions’ weighting



Fig. 5 Priority of the six dimensions

Table 4 Credit and the percentage of each criterion in order to health and well-being dimension

Dimension	CODE	Criteria	<i>p</i>	<i>wc</i>	<i>wc %</i>
Health and well-being	HW1	Access to clean water and adequate sanitation	0.08	0.0191	1.91
	HW2	Food security	0.08	0.0189	1.89
	HW3	Availability of trained health workers	0.07	0.0180	1.80
	HW4	Medical resources such as the availability of hospital beds	0.07	0.0179	1.79
	HW5	Infection control	0.07	0.0179	1.79
	HW6	Access to health assistance	0.07	0.0176	1.76
	HW7	Hygiene	0.07	0.0176	1.76
	HW8	Immunisation programmes	0.07	0.0175	1.75
	HW9	Effective biosecurity and biosafety systems	0.07	0.0174	1.74
	HW10	Disease surveillance	0.07	0.0174	1.74
	HW11	Family health education and training programmes	0.07	0.0166	1.66
	HW12	Identification/definition of special needs	0.07	0.0165	1.65
	HW13	Access to mental healthcare and psychological support programmes	0.07	0.0164	1.64
	HW14	Medical intelligence gathering	0.07	0.0163	1.63
			1	0.245	24.5

5.1.2 Governance (G)

There are several studies that highlight the importance of governance to reduce the impacts of disasters and return the community to its pre-disaster level (Lebel et al. 2006; Ahrens and Rudolph 2006). Table 3 illustrates all criteria under the governance dimension, which takes the second highest weight of 0.180. The relative importance of each criterion was established between 0.08 and 0.10 (Table 5). The most important criterion in this dimension is ‘disaster plans and policies, including mitigation and evacuation emergency management plans’ with a credit of 0.0182. These results are consistent with other studies that confirm the importance of this criterion of good governance (Lebel et al. 2006; Ahrens and Rudolph 2006).

Table 5 Credit and the percentage of each creation in order to governance dimension

Dimension	CODE	Criteria	<i>p</i>	wc	wc %
Governance	G1	Disaster plans and policies including mitigation and evacuation emergency management plans	0.1	0.0182	1.82
	G2	Unity of the leadership after the disaster	0.1	0.0174	1.74
	G3	The application of standards and regulations for buildings and infrastructure	0.09	0.017	1.70
	G4	Shared information (Transparency)	0.09	0.0168	1.68
	G5	Considering scientific analysis of risk assessment	0.09	0.0164	1.64
	G6	Integration with development policies and planning	0.09	0.0163	1.63
	G7	Institutional collaboration and coordination	0.09	0.0162	1.62
	G8	Clear partnership modalities defined and cooperation between concerned entities including private sector	0.09	0.0161	1.61
	G9	Participation of community members (volunteerism) including women and children	0.09	0.0156	1.56
	G10	Integrating populations with special needs into emergency planning and exercises	0.09	0.0154	1.54
	G11	International collaboration and coordination framework	0.08	0.0146	1.46
			1	0.18	18.0

Table 6 Credit and the percentage of each creation in order to physical and environmental dimension

Dimension	CODE	Criteria	<i>p</i>	wc	wc %
Physical and environmental	PE1	Lessons learnt from previous disasters	0.11	0.019	1.90
	PE2	Capacity of infrastructures to withstand extra pressure such as floodwater	0.11	0.0184	1.84
	PE3	Integration of services such as transportation systems, electric power and telephone	0.1	0.0182	1.82
	PE4	Shelters availability during emergencies such as schools and stadiums	0.1	0.0179	1.79
	PE5	Accessibility to critical infrastructure	0.1	0.0178	1.78
	PE6	Management of waste created by natural hazards	0.1	0.0174	1.74
	PE7	Mobile resources for reconstruction including trained worker	0.1	0.0173	1.73
	PE8	Location of built environment (probability of exposure to hazards)	0.1	0.0172	1.72
	PE9	Monitoring of current built environment and existing services	0.1	0.0168	1.68
	PE10	Brown field treatment (contaminated land with low levels of hazardous waste and pollutants)	0.08	0.014	1.40
			1	0.174	17.4

5.1.3 Physical and environmental (PE)

All criteria under the physical and environmental dimension are presented in Table 6. It also shows the range of proportion of the criteria (0.08–0.11) against the total dimension’s weight (0.174). The most important criterion in this dimension is ‘lessons learnt from

Table 7 Credit and the percentage of each creation in order to economic dimension

Dimension	CODE	Criteria	<i>p</i>	wc	wc %
Economic	E1	Funds available for reconstruction after disaster	0.17	0.0267	2.67
	E2	Access to financial services	0.15	0.0235	2.35
	E3	Level and diversity of economic resources	0.15	0.0232	2.32
	E4	Insurance coverage	0.14	0.0227	2.27
	E5	Home ownership status (home owner/renter)	0.14	0.0217	2.17
	E6	Income and employment situation	0.14	0.0217	2.17
	E7	Size of Gross Domestic Product (GDP) per capita	0.12	0.0194	1.94
			1	0.159	15.9

Table 8 Credit and the percentage of each creation in order to information and communication dimension

Dimension	CODE	Criteria	<i>p</i>	wc	wc %
Information and communication	IC1	Early warning system	0.13	0.0181	1.81
	IC2	Reliability of communication systems	0.12	0.0169	1.69
	IC3	Trusted sources of information	0.12	0.0167	1.67
	IC4	Backup of critical data	0.11	0.0162	1.62
	IC5	Responsibility of media	0.11	0.0158	1.58
	IC6	Use of community platforms, e.g. mosques	0.11	0.0154	1.54
	IC7	Visual alerting systems	0.11	0.015	1.50
	IC8	Ability to exploit social media	0.1	0.0147	1.47
	IC9	Ability to cascade information from international through regional to local communities	0.1	0.0142	1.42
			1	0.143	14.3

previous disasters' with a credit of 0.019. Other studies consider this criterion as essential to increase the adaptive capacity and to reduce the impacts of future disasters (McDaniels et al. 2008; Litman 2006). This criterion measures the willingness of the community and the government to increase resilience by avoiding mistakes made in previous disasters. Furthermore, it is important to have a good infrastructure which can withstand disasters and quickly mitigate their effects (Perera et al. 2010).

5.1.4 Economic (E)

Table 7 displays all the criteria, which are smaller in number than that in other dimensions. The proportion column illustrates the range of proportion of the criteria (ranging from 0.12 to 0.17). The relative importance of each criterion was determined and the most important is 'funds available for reconstruction after disaster' with a score of 0.0267, while 'size of Gross Domestic Product (GDP) per capita' is the lowest at 0.0194. This result underlines the importance of the first criterion for assessment of the resilience to cope with disaster (Hallegatte et al. 2007).

5.1.5 Information and communication (IC)

Table 8 clarifies all criteria under the information and communication dimension which has a weight 0.143. The proportion column represents the range of proportion of the

Table 9 Credit and the percentage of each creation in order to social dimension

Dimension	CODE	Criteria	<i>p</i>	wc	wc %
Social	S1	Risk awareness and training	0.1	0.0102	1.02
	S2	Risk perceptions	0.1	0.0098	0.98
	S3	Sense of community	0.1	0.0097	0.97
	S4	Personal faith and attitudes	0.1	0.0096	0.96
	S5	Trust in authorities	0.1	0.0095	0.95
	S6	Previous experience	0.09	0.0094	0.94
	S7	Social networks	0.09	0.0091	0.91
	S8	Faith organisations	0.09	0.0088	0.88
	S9	Education level	0.08	0.0078	0.78
	S10	Demography (age and gender)	0.08	0.0077	0.77
	S11	National language non-speaking (percentage)	0.08	0.0074	0.74
			1	0.099	9.9

criteria (0.10–0.13) against the total dimension’s weight. The relative importance of each criterion was determined with the critical criterion being ‘early warning system’ with a credit of 0.0181. The importance of this criterion is highlighted in several studies as an essential factor in saving lives and facilitating disaster recovery (Haynes et al. 2008; Mayhorn and McLaughlin 2014). Moreover, this figure reveals the importance of ‘the reliability of communication system’ criterion as the second most important value in this dimension. It is consistent with (Channa and Ahmed 2010) which confirms that the reliability of communication systems forms a vital factor for effective disaster management operations.

5.1.6 Social (S)

The social dimension has been used in several studies to measure the level of community resilience (Sherrieb et al. 2010). In our study, this dimension has the lowest weight from the AHP approach (0.099). Table 8 displays the value of each criterion against the total dimension. These range between 0.08 and 0.10. As shown in Table 9, ‘risk awareness and training’ is the critical criterion in this dimension.

These findings are consistent with previous studies which confirm that these factors are important in the measurement of the resilience to deal with disasters. For example, Ainuddin and Routray (2012) proposes a community resilience framework in order to increase community preparedness, awareness and risk perception to disasters in the future. Furthermore, The Coastal Community Resilience Index tool has been developed to increase risk awareness among local communities and to examine their resiliency in terms of some issues such as social system (Thompson et al. 2012).

On the other hand, Ainuddin and Routray (2012) and Cutter et al. (2010) have used awareness and risk perception as parameters to assess the level of community resilience; however, they identify health as a criterion under social dimension. Moreover, in CRDSA, ‘health and well-being’ has been given the consensus of the expert panel to be considered as a dimension, with its criteria (Alshehri et al. 2014). Furthermore, the current study has a number of criteria that were not used in previous studies, such as ‘effective biosafety and biosecurity system’, ‘previous experience’, ‘use of community platforms’ and ‘brown field treatment’ (Alshehri et al. 2014).

5.2 Measuring resilience

Assessing the community resilience to disasters allows a better understanding of the impact of disasters (Cutter et al. 2008; Ewing and Synolakis 2011) and helps decision-makers to formulate effective strategies in all phases of the disaster (Tianzhuo and Linyan 2014). However, it is important to measure community resilience over time (Kirmayer et al. 2009). A number of frameworks have been used to assess various forms of resilience (Leykin et al. 2013; Cutter et al. 2008). For instance, the Coastal Community Resilience (CCR) assessment tool can act as a powerful tool to begin the process of increasing resilience (US Indian Ocean Tsunami Warning System Program 2007). Similarly, Ewing and Synolakis (2011) point out that the Community Resilience Index (CRI) is an assessment tool for examining community resilience to coastal disasters. A toolkit for health and resilience in vulnerable environments (THRIVE) has been also developed, which comprises twenty resilience elements across four parts—built environment; social capital; services and institutions; and structural factors—as a community assessment tool that can support communities enhancement factors (Davis et al. 2005).

In this study, CRDSA provides an assessment system, with each criterion weighted to evaluate the level of the community resilience to cope with future disasters. This tool creates resilience scores for each of the six dimensions, as well as an overall score. Hence, it can be used to improve the resilience of community by implementing some of the proposed criteria. Figure 6 shows the overview of the final outcome of creating the Measurement Resilience tool for the CRDSA. To facilitate the computational process and to give results, it is assumed that the weight of each dimension is equal to one. The result obtained from the Measurement Resilience tool of CRDSA can be displayed on a spider diagram that illustrates the relative importance of criteria of resilience under all six dimensions.

As to the limitations of this study, including the generalisation of the findings, it is worth noting that each community may exhibit unique characteristics, i.e. sociocultural, geographic, economical, and political (Tam et al. 2013), which can enhance either resilience or vulnerabilities (Smith and Boruff 2011). The proposed community resilience

Dimension	AHP weight	New weight (WD)	Health and Wellbeing (HW)	Governance (G)	Physical and Environmental (PE)	Economic (E)	Information and Communication (IC)	Social (S)
Health and wellbeing	25%	0%	HW1 0.0191%	G1 1.82%	PE1 1.90%	E1 2.67%	IC1 1.81%	S1 1.02%
Governance	18%	0%	HW2 0.0189%	G2 1.74%	PE2 1.84%	E2 2.35%	IC2 1.69%	S2 0.98%
Physical and Environmental	17%	0%	HW3 0.018%	G3 1.70%	PE3 1.82%	E3 2.32%	IC3 1.67%	S3 0.97%
Economic	16%	0%	HW4 0.0179%	G4 1.68%	PE4 1.79%	E4 2.27%	IC4 1.62%	S4 0.96%
Information and communication	14%	0%	HW5 0.0179%	G5 1.64%	PE5 1.78%	E5 2.17%	IC5 1.58%	S5 0.95%
Social	10%	0%	HW6 0.0176%	G6 1.63%	PE6 1.74%	E6 2.17%	IC6 1.54%	S6 0.94%
Total	100%	0%	HW7 0.0176%	G7 1.62%	PE7 1.73%	E7 1.94%	IC7 1.50%	S7 0.91%
				HW8 0.0175%	G8 1.61%	PE8 1.72%	IC8 1.47%	S8 0.88%
		HW9 0.0174%	G9 1.56%	PE9 1.68%	IC9 1.42%	S9 0.78%		
		HW10 0.0174%	G10 1.54%	PE10 1.40%		S10 0.77%		
		HW11 0.0166%	G11 1.46%			S11 0.74%		
		HW12 0.0165%						
		HW13 0.0164%						
		HW14 0.0163%						
<i>tp</i>				25%	18%	17%	16%	14%

Fig. 6 Measurement Resilience tool of CRDSA

framework (CRDSA) is the first milestone towards the process of building community resilience to disaster in Saudi Arabia (Alshehri et al. 2014). This framework is the result of contributions from international experts that complement solicited local experts (Alshehri et al. 2014).

Therefore, in this study, the results of means criteria of the proposed resilience framework, which were obtained under the Delphi method, have been combined with AHP results that were used as the assessment tool; this may pose some limitations as a result of the importance of each criterion for such community because of the dynamic and complex nature of people’s interaction with their communities. The authors believe that this limitation can be solved by the identification of the specific criteria related to their community.

It is important to use benchmarks for community resilience to disaster measurement (Doyle 1996; US-IOTWS 2007). The paper reviews several studies to determine ranges of resilience scores according to the outcome of the measurement tool of CRDSA. For example, AWM Strategy Team (2010) benchmarked Community Economic Resilience Index in the region of the West Midlands, UK, by allocating a score between 0 and 1 to determine their resilience to disasters (AWM Strategy Team 2010). Moreover, Stephenson et al. (2010) suggest a Benchmark Resilience Score between 0 and 100 % to measure an organisation’s resilience to disasters according to five levels. Scores between 81 and 100 % form the top level and convey an excellent resilience, while scores below 49 % reflect very poor resilience, forming the lowest level (Stephenson et al. 2010). Furthermore, US-IOTWS 2007 recognises a scale scores between 0 and 5 which can be used to give an overall indication of resilience community in five levels. These levels are: 5 Excellent (81–100 %), 4 Very Good (61–80 %), 3 Good (41–60 %), 2 Fair (21–40 %), 1 Poor (1–20 %), and 0 reveals the absence of resilience (US-IOTWS 2007).

Therefore, Benchmark Resilience Scores for the CRDSA framework were identified to evaluate the resilience of a community in the context of Saudi Arabia (Fig. 7). This scale indicates the relative resilience scores of a community, using the six dimensions of CRDSA with all 62 criteria, and can be used for evaluating the resilience weaknesses and strengths for each dimension.

Table 10 describes the Benchmark Resilience Scores as: the score 0 is considered as ‘Absence’ which means there is no resilience and the community is vulnerable to disasters. A community that scores <21 will be considered ‘Very low’, while the community that scores between 21 and 40 will be considered as ‘Low’; a community evaluated between 41 and 60 will be considered as ‘Fair’; a community assessed between 61 and 80 will be

1	Very High	Resilience ↑	$81\% \leq R \leq 100\%$
0.8	High		$61\% \leq R \leq 80\%$
0.6	Fair		$41\% \leq R \leq 60\%$
0.4	Low		$21\% \leq R \leq 40\%$
0.2	Very Low		$1\% \leq R \leq 20\%$
0	Absence		$R \leq 0$

Fig. 7 Benchmark Resilience Scores

Table 10 Description of the Benchmark Resilience Scores of CRDSA

Score %	Description
81–100 Very high	The community has a very high level of resilience to cope with disaster. The majority of criteria have been reached
61–80 High	The community has a high level of resilience to cope with disaster. The community scores well in most criteria, taking into account that this community needs to focus on criteria which have not met the required score and should work to develop them
41–60 Fair	The community has a moderate level of resilience to cope with disaster. The community meets around half the criteria. The community needs to find criteria which have not met the required score and should work to develop them
21–40 Low	The community has a low level of resilience to cope with disaster. Most of criteria have <i>Not</i> been reached which makes the community vulnerable to disasters. However, it has a platform of resilience that can be used to increase its resilience
1–20 Very low	The community has a very low level of resilience to cope with disaster. The majority of criteria have <i>Not</i> been reached which makes the community vulnerable to disasters. It is clear that there is some very simple resilience but not enough to cope with disaster. This level points to the urgent need to build community against disasters
0 Absence	The community has no level of resilience to cope with disaster. It means that the community is vulnerable to disasters. At this level, it is important to find the resilience components of community which can be used to build community resilience to disasters

considered as ‘High’; and finally a community scored between 81 and 100 will be considered as ‘Very High’.

6 Conclusion

In summary, community resilience to disasters is necessary to rebuild an affected community to pre-disaster levels. In that respect, measuring community resilience is essential to identify the criteria that can be used to increase the resilience of a community. This study presents the dimensions and criteria of CRDSA collected through the Delphi method. The authors then used AHP as a systematic methodology of acquiring knowledge from human experts through group decision-making for building the analytical framework.

The paper answers the posited research questions by (a) proposing a new weighting system for each dimension and criterion of CRDSA using AHP and related equations and (b) providing the first assessment tool to measure and grade the level of resilience to disaster of a given community in Saudi Arabia. Dimensions and criteria of the CRDSA can determine measurable outcomes of community resilience based on this tool and the Benchmark Resilience Scores.

Further research is essential to validate the proposed weighting system of CRDSA. The validation and stress testing of the proposed community resilience framework is essential to ensure that it works. Ho et al. (2009) confirm that strong evidence can be gained when a method is validated during a real study (Ho et al. 2009). The authors have a good opportunity to validate this framework in a real mass-gathering event. Saudi Arabia receives about 3 million people yearly from over the world in Makkah for the Hajj (pilgrimage) event.

The authors believe that the current framework can be applied for both permanent local Saudi communities as well as temporary ones such as experienced during the Hajj or

Umrah events. This can be explained by the fact that (a) for each Hajj, authorities implement a number of requirements 1 year in advance such as the coordination of all government sectors, implementation of extensive planning and the use of vast resources (Memish 2002, 2010) and (b) according to CDSI (2014), the population of Saudi Arabia is estimated to be around 30.8 million, of which 10 million (33 %) are non-Saudi migrant workers from various geographic and cultural backgrounds.

Hence, the authors have identified and are in the process of delivering this validation component using the Hajj event. The research is commissioned and supported by Saudi authorities who will assist and endeavour to deliver the resulting community resilience framework across the country.

Acknowledgments The authors sincerely thank all experts involving in the AHP panel for their survey responses and insightful comments.

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