Selection of surrogates to assess social resilience in disaster management using Multi-Criteria Decision Making

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Abstract

Purpose: The complexity and dynamic nature of social systems often challenge the assessment of their resilience in a disaster context. Innovative resilience assessment approaches are required to capture key facets of resilience indicators to deepen the understanding of social resilience. Surrogates can adequately represent the target indicator that is difficult to measure, since surrogates are defined as key facets of a target indicator.

Design/methodology/approach: To optimize the selection of surrogates, five key evaluation criteria were used. Disaster management experts completed an online survey questionnaire and evaluated three potential surrogate options. Surrogates were then ranked using PROMETHEE, a multi-expert multi-criteria group decision analysis technique.

Findings: A framework is proposed to evaluate and rank potential surrogates to assess social resilience in a disaster context. Three potential surrogates identified in a case study for each of the five social resilience indicator were ranked. In most instances, highly experienced cohort of practitioners and policy makers aligned their preferences of surrogates with the overall ranking of surrogates obtained in this study.

Research limitations/implications:

The resilience indicators used in this study to explore surrogates are largely applicable in all contexts. However, the preference of surrogates may vary for a different disaster, socio-cultural, and geographical contexts.

Practical implications:

Once the surrogate is selected for a particular context through the selection process proposed in this paper, the selected surrogate can be used to update the resilience status regularly. The first ranked surrogate for each of the social resilience indicator can be applied, since the findings revealed that the first ranked surrogate can be the most critical facet in the context of the social resilience indicator being measured.

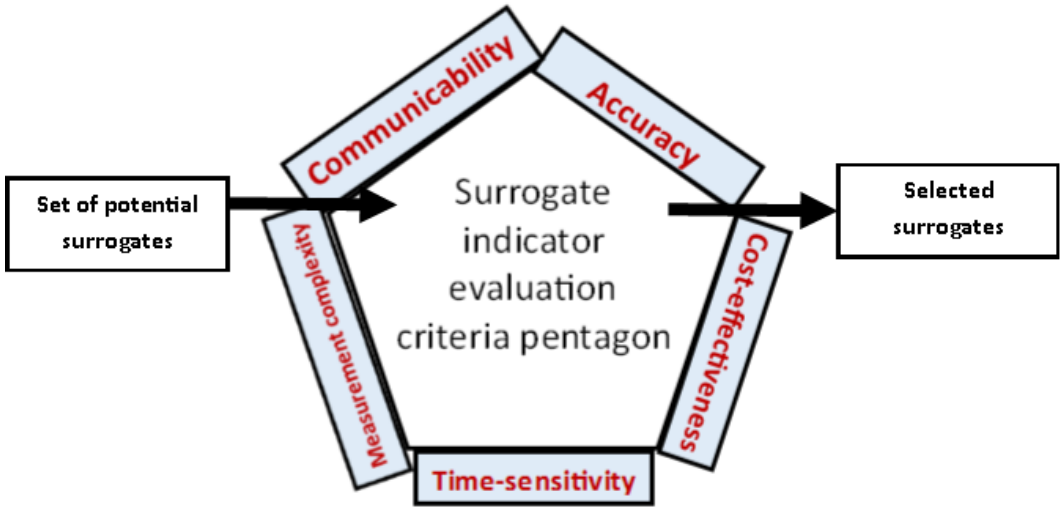
Social implications:

The framework and the selection of optimal surrogates will assist to overcome the conceptual and methodical challenges of social resilience assessment. The applicability of selected surrogates by practitioners and policy makers in disaster management will play a vital role in resilience investment decision making at the community level.

Originality/value: The use of surrogates is an innovative approach to measure social resilience in disaster management, which was applied to other fields such as ecology and clinical medicine to overcome the challenges in measuring indicators.

Keywords: Community resilience; Disaster resilience; Resilience assessment; Resilience indicator; Resilience measurement

Graphical abstract



1. Introduction

The concept of resilience has gained prominence in the field of disaster management, and has been increasingly used in research and public policy arenas (Demiroz and Haase 2018). Many different methods exist to define, understand, and measure resilience (Tiernan et al. 2018), since resilience is mostly comprehended as a perspective than a well-defined concept (Roostaie et al. 2019). Hence, the literature on measuring resilience is still evolving in terms of methodological processes and rigor, in addition to addressing the conceptual and practical challenges in operationalizing resilience measurement frameworks (Gregorowski et al. 2017).

Saja et al. (2018), 863) defined social resilience as the ability of social systems and mechanisms to prepare and adapt to disaster risks and also the ability to recover better, quickly, in a way that mitigates future disruptions and their impact. Due to the dynamic nature of social resilience characteristics, particularly in a disaster context, measuring resilience is challenging and difficult (Saja et al. 2019). Conceptual variations in defining and framing social resilience add further complexity to its measurement. Moreover, there is limited research that systematically investigates the validity and transferability of resilience theory and related taxonomy to other settings (Mendonça et al. 2018).

Many social resilience assessment frameworks have utilized indicator based measurement approaches without a rigorous conceptual framework. There is no consistent or systematic approach/process to identify key facets of an indicator that can guide the comprehensive assessment of resilience in a disaster context. Most often publicly available data such as census data have been used to measure resilience indicators, but are outdated in some contexts and not adequate to provide a robust or useful measure of resilience (King and MacGregor 2000). The existing resilience assessment methods are mostly linear and static assessments, therefore, are limited in measuring dynamic and complex social resilience characteristics (Saja et al. 2019; Buckle 2006). Many key resilience indicators, mostly process oriented resilience indicators such as community competence, social equity, and community cultures, are commonly neglected in the current resilience measurement methodologies. However, these process oriented indicators are important in order to obtain a robust measure of resilience and to facilitate effective disaster resilience investment decisions.

In order to overcome the challenges and complexities in indicator measurement, a surrogate approach, which has been successfully adopted in other disciplines such as clinical medicine and ecology, is proposed (Barton et al. 2015). A surrogate is defined as an alternative measure to determine the target indicator (Miguntanna et al. 2010; Rodrigues and Brooks 2007). The adoption of the surrogate approach can help to capture key facets of an indicator to be measured, so that the challenges in measuring dynamic and complex resilience indicators can be overcome. Accordingly, surrogates can be considered as an alternative and innovative way to measure social resilience to disasters (Cutter 2016; Ziyath et al. 2013; Sharifi 2016; Kulig et al. 2013). In the surrogate approach, many potential surrogates can be identified from the key facets of a target resilience indicator. Some surrogates can be easily operationalized in practice, because they are relatively less complex to measure, easy to communicate and cost-effective compared to other surrogates. The need for effective surrogates is critical to overcome the conceptual and methodical challenges in measuring social resilience. In this study, a framework for selecting optimum surrogates was developed and tested using multi-expert elicitation with five key social resilience indicators selected from Saja et al. (2018)'s '5S' social resilience framework. The objective of this manuscript is to present the processes and outcomes of evaluation and ranking of potential surrogates to select the optimum surrogates for five selected social resilience indicators in a disaster context.

2. Surrogate analogous model in different disciplines

The selection of a good surrogate or a set of surrogates can help to overcome the practical challenges in measuring complex and abstract social resilience characteristics. Surrogate measurement in the context of this study is the effective method to represent the target indicator either through direct or indirect measures or a combination. The quality and effectiveness of a surrogate depends on a well-established relationship between the primary indicator of measure and the surrogate indicator being employed (Grayson et al. 1996).

Figure 1 highlights an example of conceptual analogous surrogate models in clinical medicine, ecology, and in social resilience to disasters adapted from Barton et al. (2015). For example, in clinical medicine, the prediction of stroke risk can be done by measuring elevated blood pressure as a surrogate measure. In ecology, the desired environmental state can be measured using Lichen instead of measuring environmental pollutants. Similarly, in the social resilience literature, social cohesion can be measured using legal cases/complaints against neighbors or community members as a potential surrogate instead of measuring social trust, which is an abstract and multi-faceted social resilience indicator.

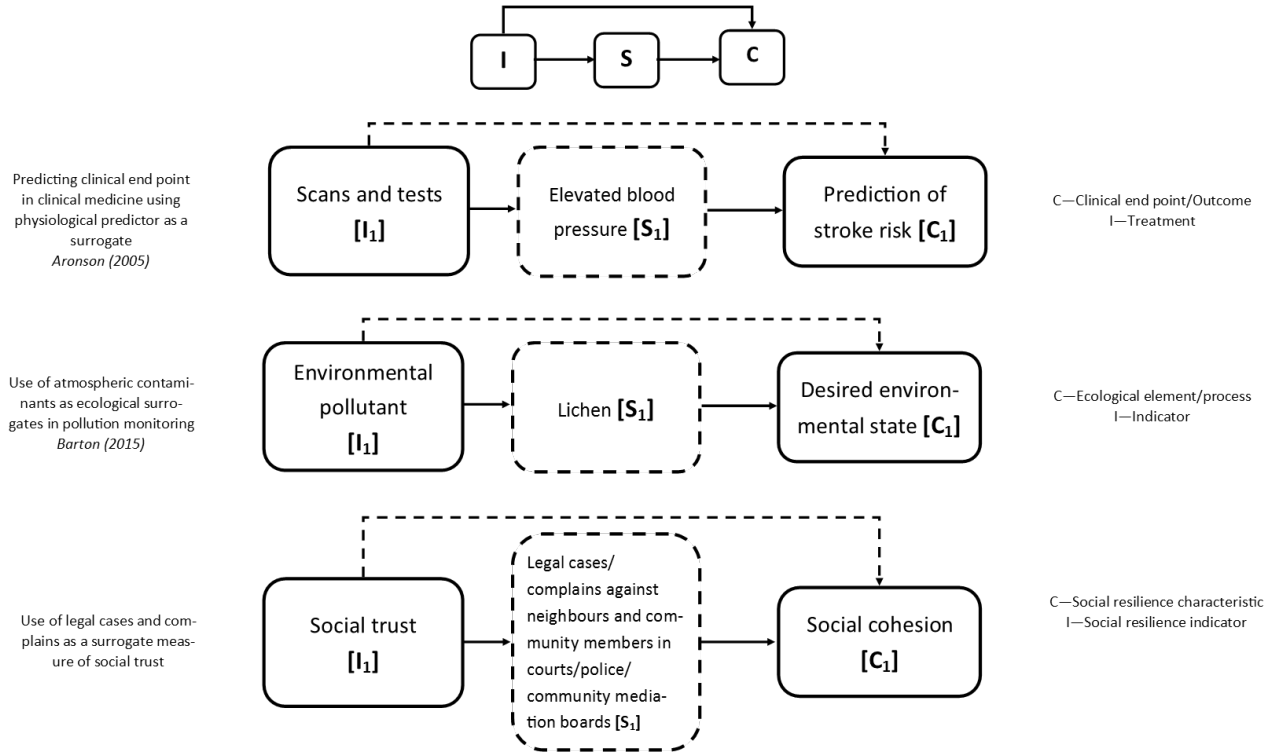


Figure 1. Conceptual analogous surrogate model examples in clinical medicine, ecology, and social resilience to disasters adapted from Barton et al. (2015)

3. Social resilience indicators and potential surrogates in a disaster context

An adaptive and inclusive '5S' model social resilience framework developed by Saja et al. (2018) consists of 46 key social resilience indicators structured under 16 resilience characteristics in the following five key social dimensions: social structure, social capital, social mechanisms, social equity, and social beliefs (Saja et al. 2018).

This framework is provided in Appendix A.1 of the supplementary information. From this framework, the following five key process-oriented social resilience indicators from each of the five dimensions were selected for developing surrogates as they are often abstract and often difficult to measure directly:

1. Access to transport facility for evacuation during disasters, to measure the mobility of people;
2. Social trust during disasters and recovery, to measure social cohesion;
3. Learning from past disaster experience, to measure community competency;
4. Involvement and equity for persons with special needs in different phases of disasters, to measure community inclusiveness and equity; and
5. Existing cultural and behavioral norms in relation to disaster risks and managing disasters, to measure local cultural beliefs and norms.

A case study research was carried out in four case study areas in Sri Lanka to explore potential surrogates for the five selected key social resilience indicators (Brief summary of the case study research and findings are provided in Appendix A.2). This study identified key facets for each of the resilience indicators that can be used as potential surrogates. Finally, three potential surrogates for each of the five key social resilience indicators as listed in Table 1 that were then identified across all four case study areas, were selected for evaluation and ranking.

Table 1. Potential surrogates to measure five resilience indicators

Resilience indicator	**Potential surrogate measures**
I1: Measuring 'social mobility and access to transport facilities' using surrogates	S11: Transport facilities available (emphasis to access transport for persons with special needs)
	S12: Availability of evacuation places and centers
	S13: Awareness raising programs/plans and early warning systems
I2: Measuring 'social trust' using surrogates	S21: Effectiveness of CBO's activities/social service
	S22: Level of services and resources of local authorities/Support for people from state institutions
	S23: Functioning and effectiveness of disaster relief/management system and complain mechanisms
I3: Measuring the 'learnings from the past' using surrogates	S31: reaction to disaster early warning
	S32: awareness and disaster knowledge level
	S33: new DRR programs including new construction methods (e.g. Houses)
I4:Measuring 'involvement/equity for persons with special needs (PwSN)' using surrogates	S41: Social safety programs for PwSN
	S42: PwSN Committees/registered groups or representation of PwSN in committees
	S43: Organizations/projects for PwSN
I5: Measuring 'cultural/religious norms and practices' using surrogates	S51: faith-based organizations/practices/activities
	S52: culture of women in the society
	S53: involvement of religious institutions in disaster preparedness, relief and response activities.

4. Research method

4.1. Research framework for selecting surrogates to assess social resilience indicators

The framework shown in Figure 2 was used to select the most robust surrogates by evaluating and ranking potential surrogates listed in Table 1 for the five key social resilience indicators. Two key strategies used in selecting optimum surrogates for final application were:

a. Evaluation of potential surrogates: A set of potential surrogates was evaluated independently by the disaster management experts which was undertaken through an online survey. Each potential surrogate was assessed against the five evaluation criteria. The outcome of this step answered the question, 'to what extent can each potential surrogate represent the facets of intended social resilience indicator?'
b. Ranking of potential surrogates: Multi-criteria decision analysis was employed using the survey data to select the surrogates that best represent the facets of the target indicator. The outcome of this step answered the question, 'what are the effective surrogates to represent the facets of the target resilience indicator and how robust and reliable are the potential surrogates?'

Each of the key components in the Framework shown in Figure 2 are discussed in detail below:

- Step 1: Evaluation of potential surrogates (Section 4.2)
- Step 2: Ranking of potential surrogates (Section 4.3)

The final outcome of this study is the selection of optimum surrogates for application, which is the first ranked surrogate for each of the five social resilience indicators. The first outcome from step 1 is an independent evaluation of surrogates by experts, which were then aggregated in the multi-criteria group decision system to rank surrogates (the second outcome from step 2). The outcomes from this study (step 1 and 2) are sequential, in which the first outcome leads to the second and the second outcome leads to the final outcome.

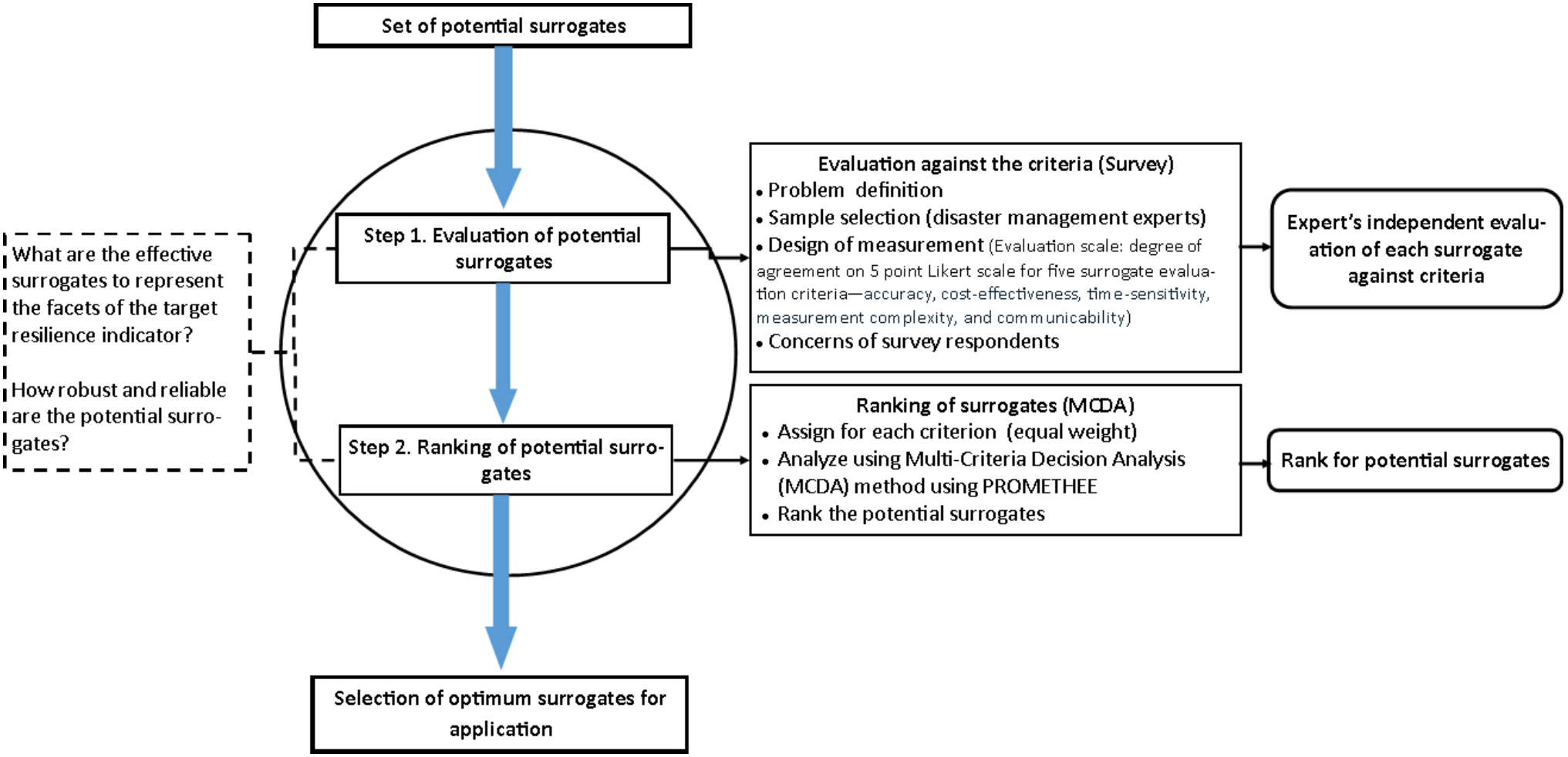


Figure 2. Research framework to select optimum surrogates to assess social resilience indicators

4.2. Step 1: Online survey to evaluate potential surrogates

When the identification of potential surrogates is completed, each surrogate needs to be independently evaluated against a set of key criteria to guide the selection of the best surrogates. Survey research method was employed using an online questionnaire. In the context of social resilience, the following five criteria were used for evaluating the identified surrogate indicators: accuracy, cost-effectiveness, time-sensitivity, measurement complexity, and communicability (see section 4.2.2).

The survey targeted experts with direct experience in disaster management to provide insights as to how the proposed potential surrogates can be applied to measure the target indicator. In order to reach a diverse set of expertise, an online survey questionnaire was chosen as the most appropriate data collection method. The surrogates were evaluated by the experts based on their perceptions and experience in measuring resilience indicators in a disaster context which was undertaken as part of this study (Donnelly et al. 2007). The experts were identified through purposive sampling. The experts evaluated the potential surrogates against five surrogate evaluation criteria using Likert scale ranging from very strong agreement to very weak agreement.

Sapsford (2006) suggested four key elements for implementing survey based research: problem definition, sample selection, design of measurements, and concern for respondents. Brief description of how each element was approached is summarized below:

I. Problem definition: Evaluation and ranking of three potential surrogates listed in Table 1 in Section 3 of this manuscript. This study also aimed to analyze the opinions of disaster management experts from different cohorts such as practitioners, researchers, and policy makers on the performance of potential surrogates against the surrogate evaluation criteria.
II. Sample selection (deciding who/what is to be counted): The selection of respondents was based on a purposive sampling strategy. Multi expert opinions were obtained for decision making for analysis using a multi-criteria decision-making method. Respondents represented the community of practitioners, policy makers and researchers. Majority of the respondents had higher level educational qualifications and experience in disaster risk management and development work. The detailed profile of survey respondents is provided in Table 2.
III. Design of measurements (deciding what is to be measured and how): The potential surrogates were evaluated against five most important criteria (accuracy, time sensitivity, measurement complexity, communicability, and cost-effectiveness) on a Likert scale of 1 to 5 (very good, good, neutral, not good, and not very good). Each criteria is explained in Section 4.2.2.
IV. Concern for respondents (ethical responsibility for prevention of harm or discomfort): Anonymity and confidentiality of respondents and responses were assured through the online survey. The basic profile information of the participants were requested for better analysis of the result, but anonymity was ensured without personal identification of the respondents.

4.2.1. Survey respondent/experts' profile

A total of 208 experts were approached as part of the purposive sampling approach. The email addresses of 208 experts were obtained from national and regional disaster management networks in Sri Lanka and South Asia, who have worked with a number of international organizations, research organizations, and government agencies. A total of 66 experts responded to the survey. The response rate for this survey was 32%.

Among the experts who responded to the survey, 84% (n=55) hold at the minimum, a Masters Degree qualification and 69% (n=45) had more than 5 years of experience in disaster management. Further, 56% of the experts were from International/local NGOs/UN agencies and 25% were from the University/Research organizations. The cluster of experts included 52% Practitioners (n=34), 23% Policy makers (n=15), and 26% Researchers (n=17), making the responses inclusive and representative of all key segments in the disaster management domain. In terms of the geographical location of the experts, 33% were from Sri Lanka and 29% were from South Asia region excluding Sri Lanka (see Table 2 for more detail categories of experts' profile). Hence, the responses are largely influenced by South Asian context, which share similar socio-economic characteristics.

Table 2. Key characteristics and statistical data on the experts

Categories	**Key characteristics**	**# of experts**	**% of experts**
Educational qualifications	PhD	15	24
	Master degree	40	60
	Bachelor degree	7	10
	Other	4	6
Experience	Less than 3 years	8	11
	3-5 years	13	20
	5-10 years	19	29
	More than 10 years	26	40
Employment	Researchers	17	26
	Practitioners	34	52
	Policy makers	15	23
Affiliation	Government Department	7	11
	Local NGO/ Community Based Organization	6	10
	International NGO	23	35
	UN agency	7	11
	Private sector/donor agency	4	6
	Research organization/institute	5	7
	University	12	18
	Other	2	3
Location (country/region)	Sri Lanka	22	33
	South Asia (Except Sri Lanka)	19	29
	Australia/Pacific	4	7
	American continent	5	7
	Europe	2	4
	Africa	6	8

	Middle East	2	4
	South East Asia	6	8

4.2.2. Key criteria to evaluate surrogate indicators to measure social resilience

The experts evaluated whether the proposed surrogate can measure the target indicator based on the evaluation criteria on a 1-5 Likert scale. The following five surrogate evaluation criteria, adapted from Lindenmayer et al. (2015) and Birkmann (2006) were used to evaluate the social resilience indicators:

a) Accuracy: The level of precision of a surrogate in predicting the target indicator. The experts evaluated the accuracy based on their understanding of how closely the surrogate is linked to the target indicator.

b) Cost-effectiveness: This is a compromise between the cost and benefits associated with the measurement of a surrogate and was evaluated by determining the cost of acquiring a surrogate that is typically related to time, resources costs associated with data collection, processing, and analysis (FAO 2008) and the level of benefit from such cost.

c) Time sensitivity: The ability of a surrogate to measure the target indicator in the different phases of a disaster (preparedness, recovery, and post-disaster). Experts judged if the proposed surrogate has the ability to measure the progress or trend at different time periods (Mitchell 2013) and capable of being updated regularly (Donnelly et al. 2007). As resilience is a time dependent phenomenon, an indicator should be adaptable to measure all phases of a disaster.

d) Measurement complexity: When a surrogate is selected, it is important to understand what data is needed and available to measure the surrogate or the level of complexity inherent in accessing the data from disaster management authorities (Birkmann 2006).

e) Communicability: The measure of how easily a surrogate indicator can be understood by a wide range of stakeholders involved in disaster management (practitioners, policy makers, and researchers). Experts judged if the proposed surrogate is easy to communicate without compromising its quality and validity.

4.3. Step 2: Ranking of potential surrogates

The final ranking of surrogates was done using the following three steps:

I. Assign a weight for each criterion: Based on the importance of the criteria, a weight can be applied to each of the five surrogate evaluation criteria. In this study, all five criteria were considered equally important; hence, an equal weight was applied.
II. Analyze using a multi-criteria decision-making method: A multi-criteria decision making method was employed to select the best surrogates to measure the required social resilience indicator.
III. Rank the potential surrogates: The decision about which surrogate(s) to select is often based on both, scientific validity and practical considerations such as budget limitations and legislative requirements (Lindenmayer et al. 2015). Although a surrogate may be cost-efficient, it could be unreliable due to high uncertainty (Lindenmayer et al. 2015). Therefore, selecting the best surrogate requires optimization of performance against a set of key evaluation criteria.

4.3.1. Data analysis: Multi-criteria decision analysis to rank potential surrogates

Multi-Criteria Decision Analysis (MCDA) techniques can be used as a consistent method to evaluate, rank, and select resilience indicators (Carone et al. 2018). Cinelli et al. (2014), 146) defined MCDA "as a tool to support the process of decision making by taking into

consideration multiple criteria in a flexible manner, by means of a structured and intelligible framework" (p.146). Hence, Survey data was analyzed using MCDA by aggregating all completed responses in the online questionnaire. Firstly, an analysis was carried out on respondent characteristics including current or past role of respondents in disaster and resilience related activities, number of years of experience in disaster risk reduction and resilience building projects, and affiliation of past/current employment such as a researcher/academic, practitioner, and/or policy maker. Secondly, Multi Experts - Multi Criteria Decision Analysis (ME-MCDA) was carried out, in which the response scale from each respondent for each surrogate against five surrogate evaluation criteria was aggregated for all the survey respondents to obtain a ranking.

In this study, PROMETHEE method was used for MCDA, because it can provide software supported data management and supports comparison of scenarios for different weights for criteria and their visualization. By analyzing several MCDA methods to select the indicators, mostly process-oriented indicators, Verheyden and De Moor (2016) recommended PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) as a highly robust approach compared to other MCDA methods such as Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), and Technique of Order Preference Similarity to the Ideal Solution (TOPSIS). PROMETHEE is a preference function-based outranking method that can provide a ranking order of the decision options/alternatives. In this study, PROMETHEE analysis was conducted using Visual PROMETHEE software. Visual PROMETHEE is a multi-criteria decision aid (MCDA) software that is designed to evaluate several possible decisions according to multiple criteria, identify the best possible decision, rank possible decisions from the highest to the lowest rank, visualize decision or evaluation problems to better understand the difficulties in making good decisions, and achieve consensus decisions when several decision-makers have conflicting points of view (VP 2013). A nine step method that was used to select and apply PROMETHEE as a MCDA technique to analyze the survey data is shown in Appendix A.3.

Final decision was made to rank the potential surrogates to select the best performing surrogates. Multi-expert group decision flow chart shown in Figure 3 depicts the flow of inputs from experts to the final decision-making matrix using PROMETHEE Group Decision Support System (GDSS) algorithm. Initially, the Likert scale evaluation value of each expert for each surrogate against five criteria was entered into the PROMETHEE software independently (the expert evaluation value was based on 1-5 Likert scale). By running the PROMETHEE analysis, potential surrogates were ranked by each expert and net flow values for each surrogate was obtained. In the next step, GDSS algorithm was implemented in PROMETHEE to obtain final ranking by taking each expert as a criteria and each surrogate as an alternative. The net flow value was then entered into PROMETHEE again for each of the surrogates against all 66 experts as criteria. The final ranking was obtained by performing the multi-criteria decision analysis again using the experts as criteria.

Further to the PROMETHEE ranking, the GAIA (Geometrical Analysis for Interactive Aid) in Visual PROMEHTEE software provides a complementary visual analysis of the results produced in PROMETHEE. Each surrogate is represented by a point in the GAIA plane and its position is related to its evaluations on the set of multi-criteria in such a way that actions with similar profiles will be closer to each other. GAIA representation visuals were used to undertake two more distinctive analyses based on the evaluation of potential surrogates to see how different years of experience and experts from different cohorts (employment) aligned with the overall PROMETHEE ranking results as well as how their preferences varied with the overall PROMETHEE ranking. The analysis of employment category broadly covered two other categories: educational qualifications and affiliation. Majority of the researchers who

have PhD qualifications were from a university and/or research institution. Similarly, most of the practitioners were from international and national NGOs, and the policy makers were from government and UN agencies. Therefore, the analysis of qualifications and affiliations mostly aligned with the employment category analysis, which is presented in Sections 5.2 – 5.6.

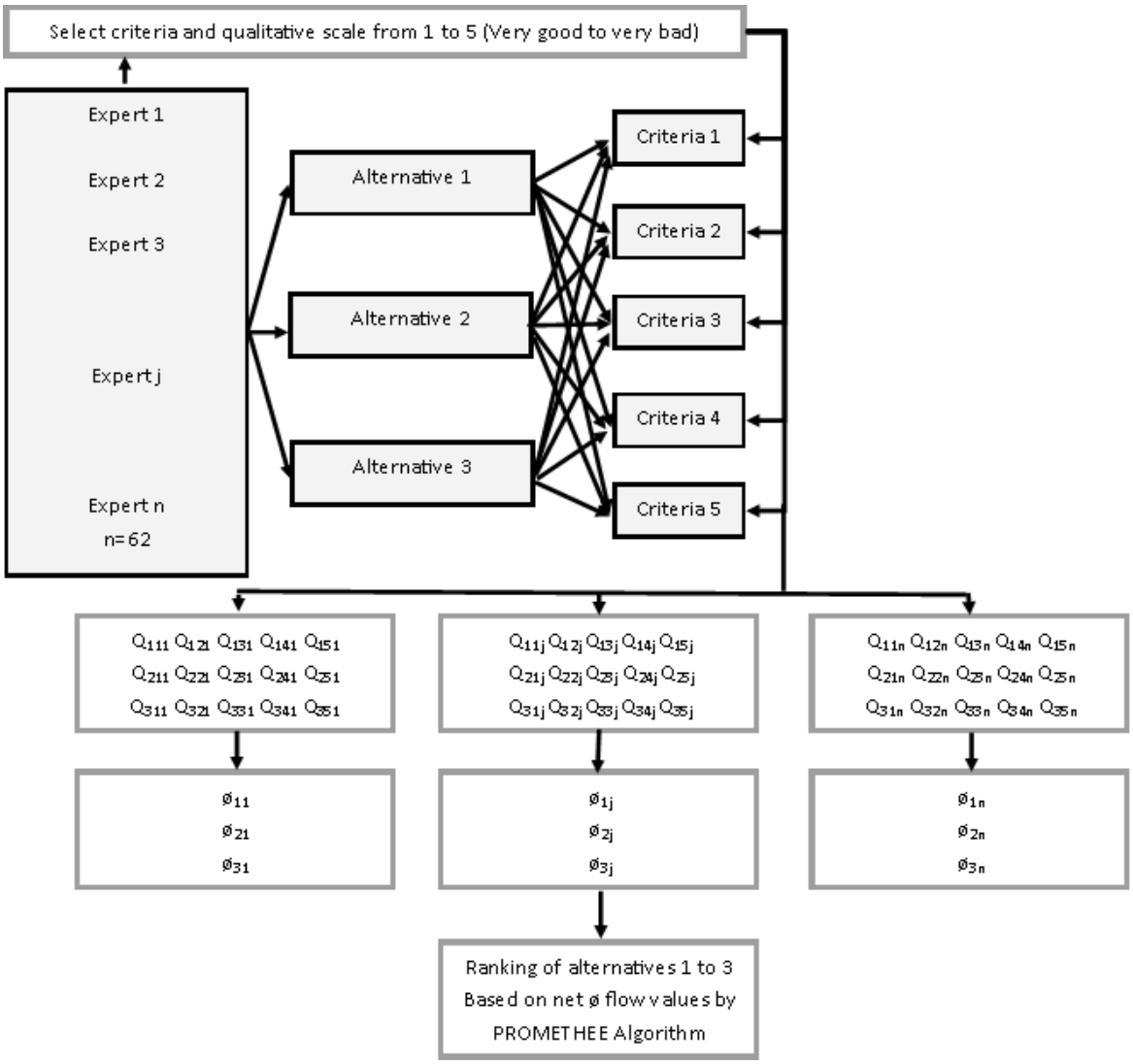


Figure 3. Multi-expert multi-criteria group decision support system flowchart

5. Results and discussion

5.1. Ranking of potential surrogates using PROMETHEE analysis

The results of PROMETHEE Multi-Expert Multi Criteria Decision Analysis (ME-MCDA) are presented below (sections 5.2 to 5.6) in two sub-sections for each of the social resilience indicators:

1. Ranking of potential surrogates: Overall PROMETHEE ranking for each social resilience indicator and corresponding net Phi values (Table 3), was based on the analysis of alternatives against all five criteria as an overall group decision making using the inputs from multi-experts. The Phi value is the multi-criteria net flow value which is the result of all the pairwise comparisons of the alternatives (i.e. surrogates).

2. Analysis of opinions about potential surrogates by different cohorts of experts: It is possible that different types of disaster management experts can have different preferences for surrogates. Since the experts who participated in the evaluation of surrogates have different levels of experience and also belong to different categories such as practitioners, researchers, and policy makers, it is important to analyze similarities and differences between their preferences. GAIA representations are shown in Figures 4a-8a for different years of experience ranging from >10 years, 5-10 years, 3-5 years, to <3 years, while GAIA representations are shown in Figures 4b-8b for different types of experts ranging from practitioners, researchers, and policy makers.

A walking weight sensitivity analysis was done for all five indicators. The results of equal weights for different types of experts (employment type) showed that there is no difference in the ranking for all five indicators. Further, the equal weight analysis for cohorts with different years of experience showed that there is no change in the overall ranking of surrogates except for the fifth indicator. For the fifth indicator, the second and third ranks are inter-changed.

Table 3 - Overall PROMETHEE rankings for five social resilience indicators

Resilience indicator	Rank	Alternatives (Potential surrogate measures)	Net Phi
I1: Measuring 'social mobility and access to transport facility' using surrogates	**1**	S12: Availability of evacuation places and centers	0.0318
	2	S13: Awareness raising programs/plans and early warning systems	-0.0080
	3	S11: Transport facilities available (emphasis to access transport for persons with special needs)	-0.0239
I2: Measuring 'social trust' using surrogates	**1**	S21: Effectiveness of CBO's activities/social service	0.0500
	2	S22: Level of services and resources of local authorities/Support for people from state institutions	-0.0125
	3	S23:Functioning and effectiveness of disaster relief/management system and complain mechanisms	-0.0375
I3: Measuring the 'learnings from the past' using surrogates	**1**	S31: Reaction to disaster early warning	0.0750
	2	S32: Awareness and disaster knowledge level	0.0136
	3	S33: New DRR programs including new construction methods (e.g. Houses)	-0.0886
I4:Measuring 'involvement/equity for persons with special needs (PwSN)' using surrogates	**1**	S41: Social safety programs for PwSN	0,0466
	2	S43: Organizations/projects for PwSN	0,0080
	3	S42: PwSN Committees/registered groups or representation of PwSN in committees	-0,0545
I5: Measuring 'cultural/religious norms and practices' using surrogates	**1**	S52: Culture of women in the society	0,0318
	2	S51: Faith-based organizations/practices/activities	0,0045
	3	S53: Involvement of religious institutions in disaster preparedness, relief and response activities.	-0,0364

5.2. Indicator 1: Measuring ‘social mobility’

In this study, the surrogate ‘S12 - measure of evacuation places and centers’ was preferred over the other two surrogates (S13 and S11) by the experts. Social mobility is influenced by the evacuation potential of the population at-risk from emerging disasters. Access to demarcated evacuation places and designated evacuation centers is an important factor for evacuation decision making in the event of disasters (Bañgate et al. 2017) because the degree of availability of evacuation centers and the level of awareness largely influence the decision for evacuation and mobility in times of disasters.

The identification and demarcation of evacuation places and centers may have been done by authorities. However, the level of awareness of evacuation places and centers among the population who are vulnerable to disasters may be lacking to enable effective social mobility. On the other hand, evacuation in times of disasters using vehicles is most often a challenge in the urban context, where streets can be narrow, resulting in traffic congestion. Hence, the availability of transport facilities sometimes may not provide a good measure of social mobility during disasters.

Opinions of cohorts of experts on surrogates to measure indicator 1

Experts with over five years of experience largely preferred the surrogate S12 over S13 and S11. However, the experts with average experience between 3 – 5 years opted for S13 as the surrogate measure of choice. Similarly, the experts with less than three years of experience out-ranked S13 over S11 and S12. Overall, the results are skewed towards S12, because the experts who have more than five years of experience formed the majority surveyed (68%). As shown in Figure 4a, the orientation of the decision axis (red thick axis) indicate which cohorts of experts are in agreement with the PROMETHEE rankings and who are not. Although it is obvious that the availability of transport facilities and effective early warning messages are key to timely mobility of people at-risk, the availability of evacuation centers and people’s awareness of these can be the most important factor in determining the effectiveness of social mobility. This could be the reason for the most experienced cohort of experts, aligned with the overall PROMETHEE ranking of the surrogate (Figure 4a).

Based on occupation, all three groups of experts - practitioners, policy makers, and researchers - ranked S12 as the most preferred surrogate. The surrogate S13 was ranked second by policy makers and researchers. However, it was the less preferred option for practitioners. Similarly, Surrogate S11 performed better for practitioners, compared to researchers and policy makers (Figure 4b). Practitioners had a strong preference for surrogate S12 and S11. However, policy makers had greater preference for surrogate S13 compared to S11. The surrogate S11 did not perform well among researchers and policy makers compared to surrogates S12 and S13. Disaster Management practitioners preferred the measure of evacuation places and centers (S12) and available transport facilities (S11) to predict the mobility and transport accessibility compared to the measure of awareness programs/early warning (S13). People need to be well aware of disaster risk mitigation and response strategies, because early warning is not enough for timely evacuation (Dash and Gladwin 2007). Hence, the awareness of the availability of evacuation places/centers and knowing about the availability of transport facilities and how to access them becomes important measures as prioritized by the practitioner community.

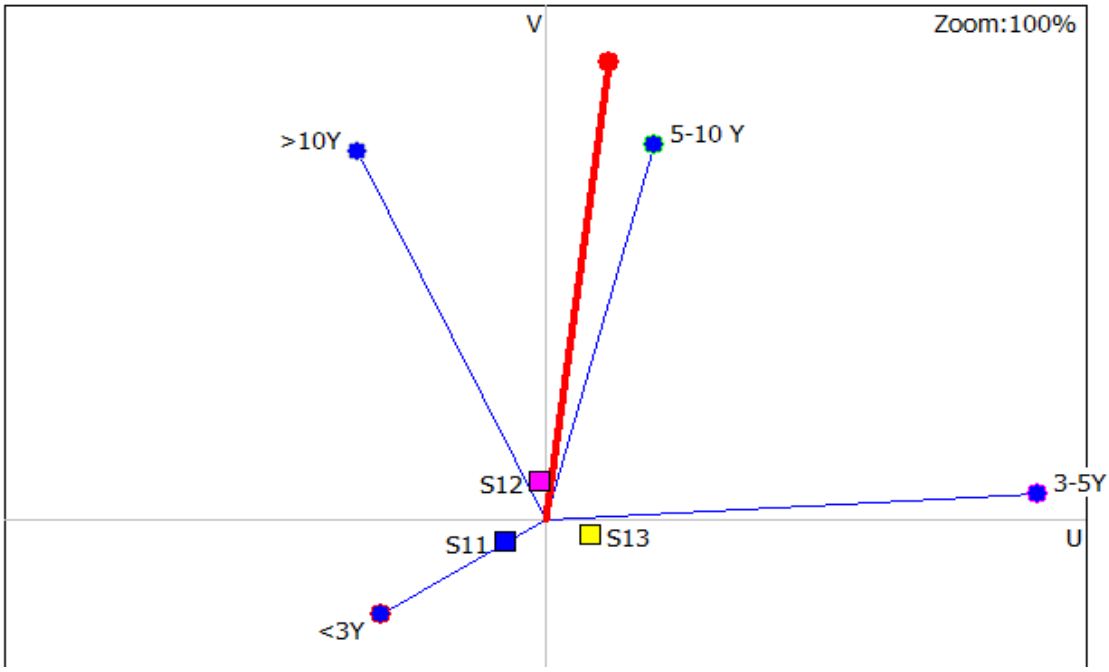


Figure 4 (a). GAIA representation of surrogates to measure social mobility for experts with varied years of experience

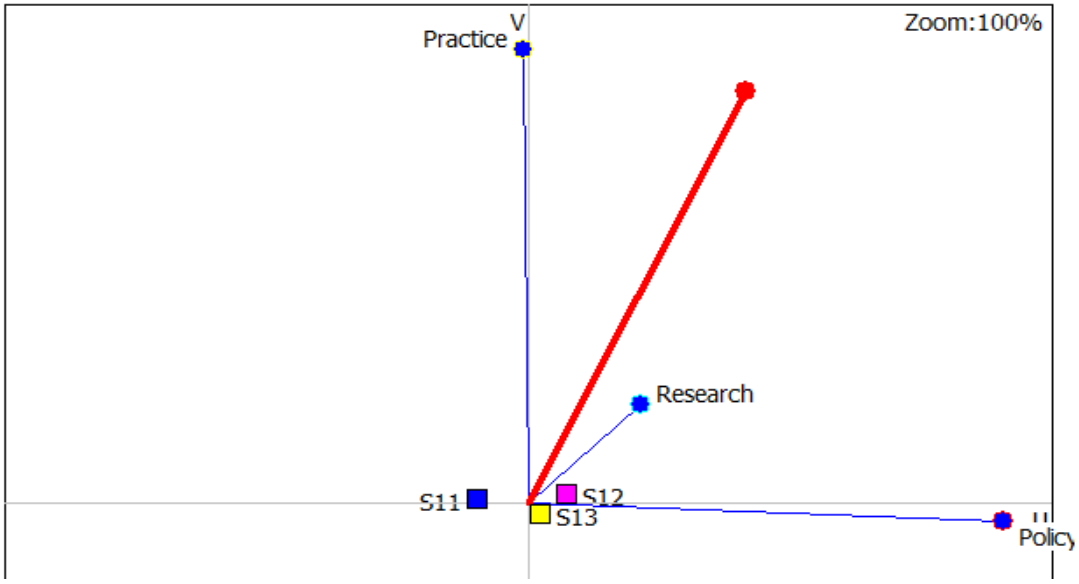


Figure 4 (b). GAIA representation of surrogates to measure social mobility for different types of experts

Legend for Figures 4(a) and 4(b)

S11	Transport facilities available (emphasis to access transport for persons with special needs)
S12	Availability of evacuation places and centres
S13	Awareness raising programs/plans and early warning systems

Experts with less than 3 years of experience	Practitioners
Experts with 3—5 years of experience	Policy makers
Experts with 5—10 years of experience	Researchers
Experts with more than 10 years of experience	

5.3. Indicator 2: Measuring 'social trust'

In this study, the surrogate S21 - effectiveness of Community Based Organizations' (CBO) activities/social service was ranked first in PROMETHEE ranking. The important role of CBOs in disaster management has been well established in disaster resilience literature (Drennan and Morrissey 2018). Hence, the effective functioning of CBOs becomes a key measure for social trust. In the current literature, the number of registered CBOs in the area obtained from publicly available census data is generally used as a measure of resilience assessment. However, the assessment of social trust is more than just numbers of CBOs as it should capture how those CBOs function in a community to build trust and the extent to which they engage with the community (Cutter 2016). The effectiveness of CBO activities can therefore be measured by analyzing the annual reports submitted to local authorities, which can help to determine the level of trust they have built with the community in disaster related activities. Comparison of CBO functions regularly can assist to measure their effectiveness and to understand the changes in social trust.

It was also evident from this study that the surrogate S22 – the existing level of services and resources from the local authorities/state institutions is a good measure of social trust compared to the surrogate S23 – the functioning and effectiveness of disaster management mechanisms to measure social trust. In a resource limited local governance, the functioning and effectiveness of disaster management mechanisms are mostly weak, where the trust is built through routine work and development activities. Therefore, the effectiveness and satisfactory level of routine services and resource allocation to the community by local authorities can be a better measure of social trust than the measure of functioning of disaster management mechanisms.

Opinions of cohorts of experts on surrogates to measure indicator 2

Figure 5(a) shows that the results are skewed towards S21, where the decision of experts with over 10 years of experience is closer. However, experts with 3-5 years of experience preferred S22 over S21 and S23. The experts with 5-10 years of experience were not conclusive about their preference between S21 and S23, while experts with less than 3 years of experience were not conclusive in preferences between S21 and S22. The less experienced cohort (less than 5 years of experience) preferred the measure of service and resources by the local authorities and government departments as a good surrogate than the effectiveness of CBOs to assess social trust. The policy and practice groups aligned with the overall PROMETHEE rankings. However, the highest preference of the research group inclined towards surrogate S22 as shown in Figure 5(b), which is similar to the preferences of less experienced cohort of experts.

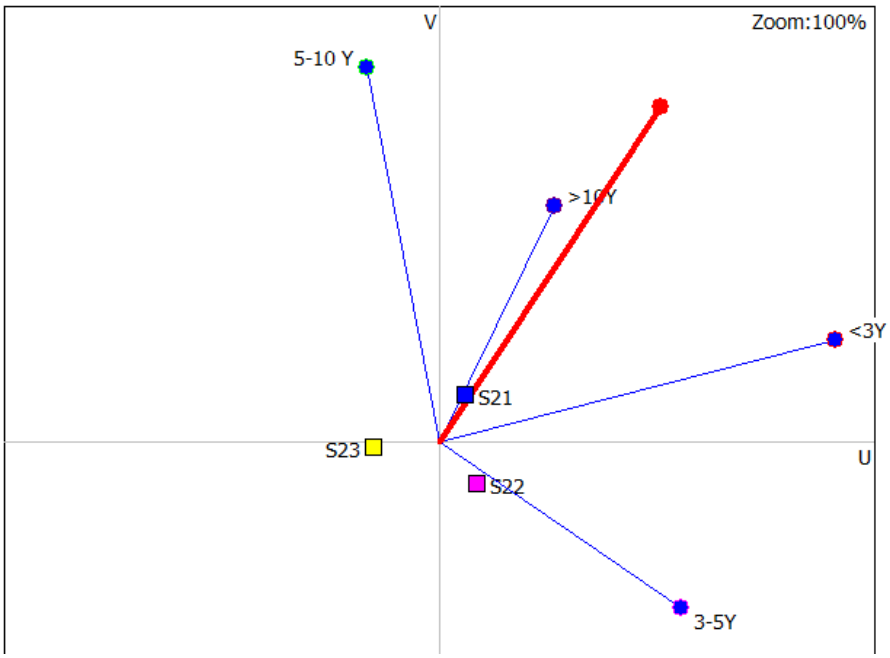


Figure 5 (a). GAIA representation of surrogates to measure social trust for experts with varied years of experience

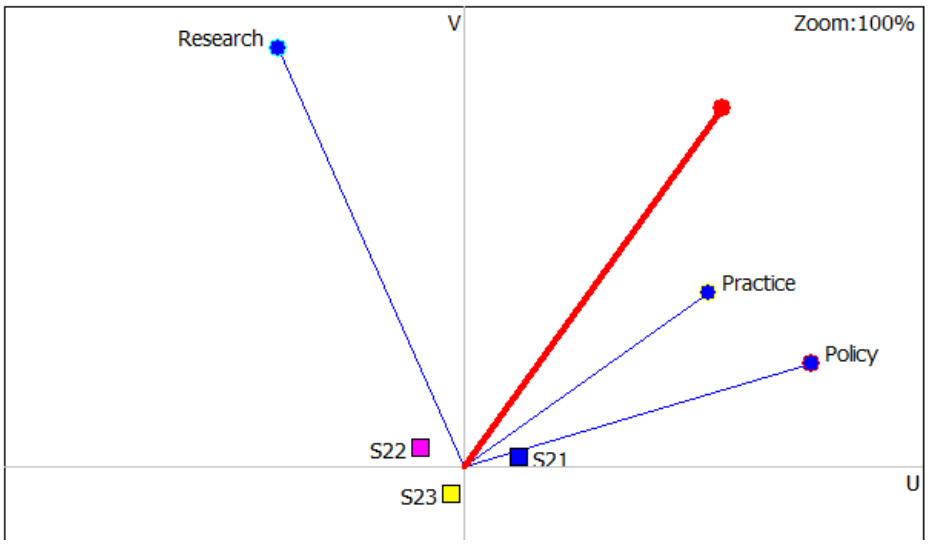


Figure 5 (b). GAIA representation of surrogates to measure social trust for different types of experts

Legend for Figures 5(a) and 5(b)

S21	Effectiveness of CBO's activities/social service
S22	Level of services and resources of local authorities/Support for people from state institutions
S23	Functioning and effectiveness of disaster relief/management system and complain mechanisms

Experts with less than 3 years of experience	
Experts with 3—5 years of experience	
Experts with 5—10 years of experience	
Experts with more than 10 years of experience	

Practitioners
Policy makers
Researchers

5.4. Indicator 3: Measuring ‘learnings from the past’

Surrogate S31 – the reaction by the community to disaster early warning messages was preferred compared to other two surrogates (S32 and S33) to measure learnings from the past disasters in the PROMETHEE ranking. Although, S32 – the level of awareness and disaster management knowledge and S33 – new DRR programs implemented such as new methods of housing construction - can provide an easy measure of learnings from past disasters as a key community competency to disaster resilience, experts prioritized the reaction to disaster early warning messages as a good surrogate measure to assess learnings from past disasters. Many success and failure stories across the world have confirmed that early warning systems are key to saving lives, mitigate damage and losses, which in turn enhances social resilience. This could be because effective early warning have saved many fatalities in the past and every time when there is a disaster, people learn new ways to react to early warning (Keating et al. 2016). Therefore, lessons from reacting to disaster early warning can provide a good measure of learnings from past disasters.

The improvements or lapses as to how the community reacts to the disaster early warning messages can be measured to understand whether the community has learned lessons from the past disaster experiences. Sharma and Patt (2012) identified three different key elements for learnings from the past disaster experience related to early warning response: the severity of the impact of past disaster experience; past experience with false early warning alarms; and past evacuation experience including the quality of evacuation centers. The data and reports in relation to the above three elements on reaction to early warning available at the divisional/district level disaster management center or committee, can be analyzed to assess learnings from past disasters.

Opinions of cohorts of experts on surrogates to measure indicator 3

Experts with experience of over 10 years had similar overall preferences towards indicator 3 surrogate measures. As shown in Figure 6(a), the top preference of experts with over 10 years of experience and experts with less than 5 years of experience was S31. Figure 6 (b) also indicates that the top ranked surrogate among research and practice-based experts is S31. Surrogate S32 – the level of awareness and knowledge about disasters can also be a good measure for learnings from the past disasters, similar to surrogate S31 – reaction to disaster early warning messages, which is preferred by policy experts and experts with 5-10 years of experience. More awareness and better knowledge about disaster risks will lead to better reaction to disaster early warning messages. However, the performance of surrogates S31 and S32 may be different for different criteria. For example, the measurement complexity of surrogate S31 – reaction to disaster early warnings can be higher compared to surrogate S32 – measure of awareness and disaster knowledge level.

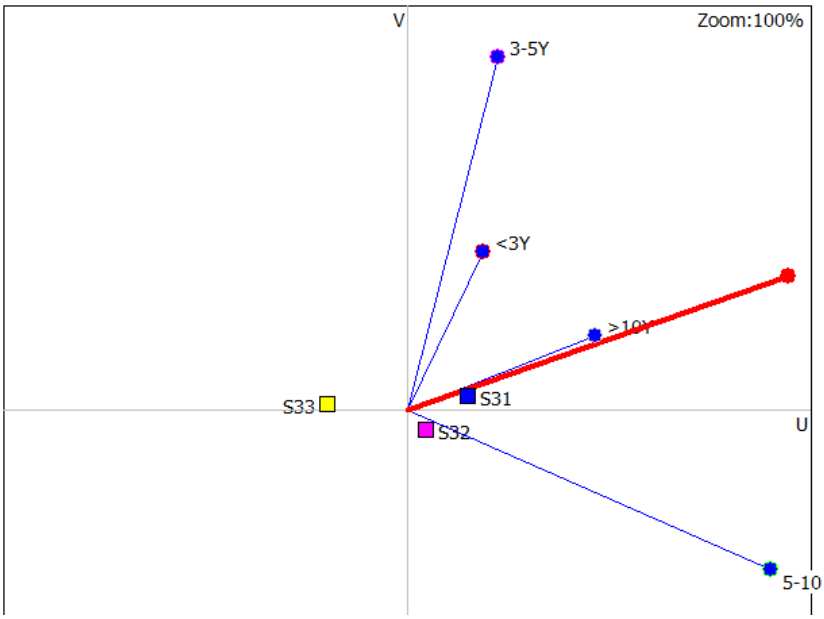


Figure 6 (a). GAIA representation of surrogates to measure learnings from the past disasters of experts with varied years of experience

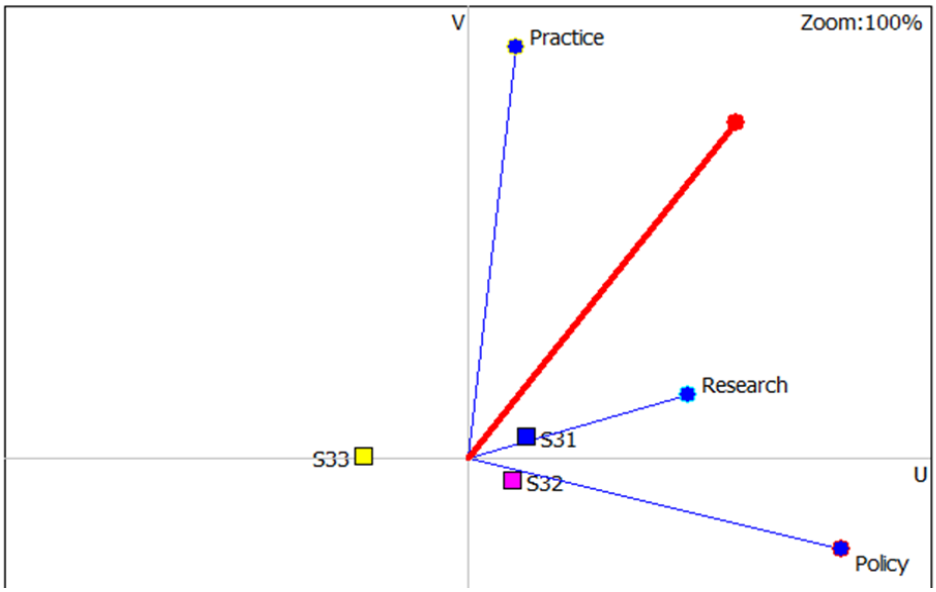


Figure 6 (b). GAIA representation of surrogates to measure learnings from the past disasters of different types of experts

Legend for Figures 6(a) and 6(b)

S31	Reaction to disaster early warning
S32	Awareness and disaster knowledge level
S33	New DRR programs including new construction methods (e.g. Houses)

Experts with less than 3 years of experience	Practitioners
Experts with 3—5 years of experience	Policy makers
Experts with 5—10 years of experience	Researchers
Experts with more than 10 years of experience	

5.5. Indicator 4: Measuring 'involvement/equity for Persons with Special Needs (PwSN)'

In this study, surrogate S41 - Social safety programs for Persons with Special Needs (PwSN) was preferred compared to the other two surrogates (S42 and S43) to assess the involvement and equity measures. The other two surrogates are S43: Organizations/projects for PwSN and S42: PwSN Committees/registered groups or representation of PwSN in committees. The social safety programs focus on vulnerable groups in a community in a disaster situation. The inclusion of PwSN such as disabled, elderly, and women headed households in the existing social safety programs help to improve their resilience to disasters. The effectiveness of social safety programs targeting PwSN can be assessed by analyzing the data from such programs, for example, appropriate targeting of the population in-need who are most vulnerable to disasters and how they have contributed to address the gaps in equity and involvement of PwSN to increase their resilience.

Surrogate S43 - availability of projects or specific organizations to work on PwSN can be another potential surrogate which was ranked second by the experts. This can be measured by analyzing the achievement of projects targeting PwSN and the functional effectiveness of organizations formed for PwSN to address their specific problems in resilience building. This study found that the surrogate S42 - the representation of PwSN in committees/the existence of such committees/registered groups as the least preferred surrogate to indicate the involvement and equity for PwSN. The participation in committees most often do not completely reflect the active implementation of projects which can bring real impact, could be the reason for selecting it as the least preference compared to social safety programs that can indicate the tangible involvement of people in building resilience.

Opinions of cohorts of experts on surrogates to measure indicator 4

The preference of all cohorts of experts retained S41 as the first ranked surrogate, except the cohort with 5-10 years of experience, who ranked S43 as their first preference. However, all cohorts ranked S42 as the least preferred surrogate as shown in Figures 7(a) and 7(b). Similarly, preferences of practitioners and policy makers were aligned with the overall ranking of surrogates, whereas the first preference of researchers was the surrogate S43 – 'the availability of organizations and projects' targeting PwSN. This preference was similar to the cohort of experts with 5-10 years of experience. In conclusion, preference of more experienced practitioners and policy makers were same as the overall preference of surrogates to measure indicator 4. Further, all cohorts of experts ranked surrogate S42- 'representation of PwSN in committees or in registered groups as a weak surrogate to measure the involvement and equity for PwSN.

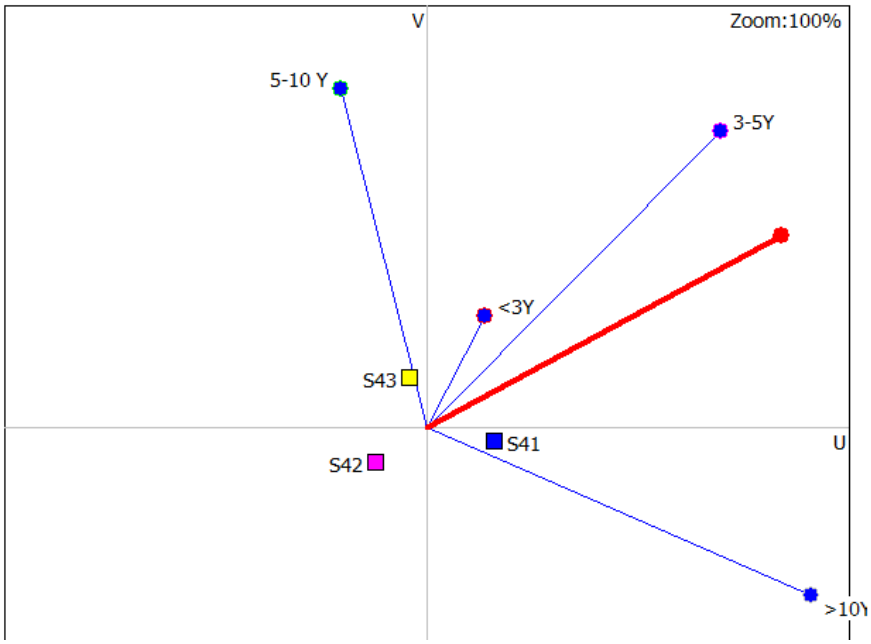


Figure 7 (a). GAIA representation of surrogates to measure 'involvement/equity for PwSN' of experts with varied years of experience

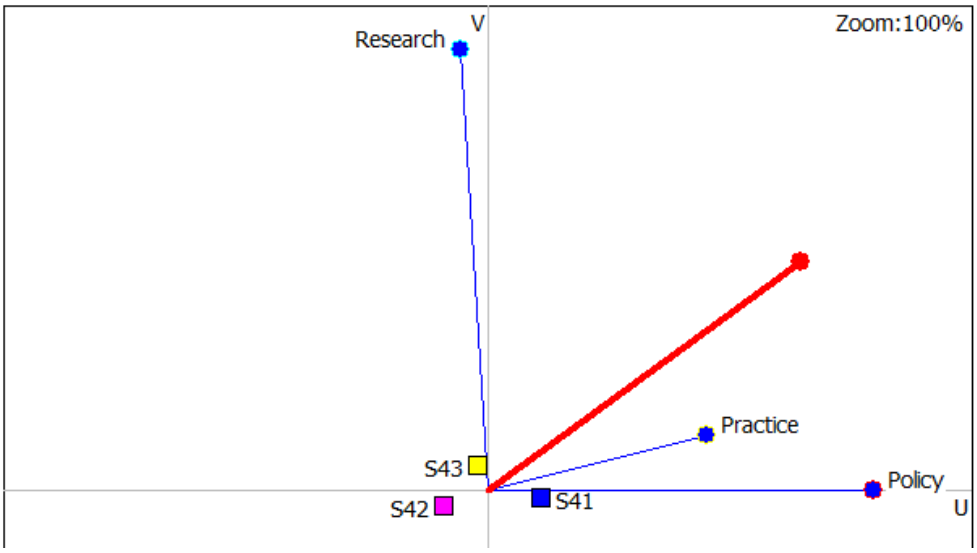


Figure 7 (b). GAIA representation of surrogates to measure 'involvement/equity for persons with special needs (PWSN)' of different type of experts

Legend for Figures 7(a) and 7(b)

S41	Social safety programs for PwSN
S42	PwSN Committees/registered groups or representation of PwSN in committees
S43	Organisations/projects for PwSN

Experts with less than 3 years of experience	Practitioners
Experts with 3—5 years of experience	Policy makers
Experts with 5—10 years of experience	Researchers
Experts with more than 10 years of experience	

5.6. Indicator 5: Measuring ‘cultural/religious norms and practices’

In this study, the first ranked surrogate for measuring cultural/religious norms and practices was S52: culture of women in the society. Among the three surrogates evaluated by experts, surrogate S51: faith-based organizations/practices/activities was ranked second and surrogate S53: involvement of religious institutions in disaster preparedness, relief and response activities was the least preferred surrogate to measure cultural/religious norms and practices. According to experts’ evaluation of surrogates, it is evident that most of the experts preferred the most critical factor of the respective resilience indicator as the most preferred surrogate. For example, the interaction between culture, social networks, and personal attributes of women play a key role in determining social resilience in communities that prioritize the cultural and religious norms and practices (Cottrell 2006). Since the cultural practices among women, such as their engagement in public forums and participation in awareness programs, are critical in determining the resilience of the community to disasters, the measure of gender based practices was preferred as an important surrogate in this study compared to faith-based practices and involvements.

Women, who mostly play a complementary role rather than an independent role, are one of the social segments that are highly exposed to disasters due to many gender specific vulnerabilities such as cultural restrictions on mobility and decision making powers (Alam and Rahman 2014). Hence, cultural behaviors of women play an important role in assessing the resilience of social/cultural beliefs to disasters. This can be measured by the level of participation of women in disaster preparedness activities, early warning drills, and active contribution to disaster management committees.

Opinions of cohorts of experts on surrogates to measure indicator 5

As shown in Figures 8 (a), highly experienced cohort of experts with more than 5 years differed from the overall ranking and opted for surrogate S51 as their first preference to measure cultural/religious norms and practices. However, experts with less than 5 years of experience have shown a similar preference to overall ranking. Similarly, the practitioners and policy makers followed the same preference of overall ranking, the cohort of researchers differed from overall ranking, selecting S51 as their first preferred surrogate (Figure 8(b)). Hence, the different cohort of experts have contrasting opinions between S52 and S51 as the priority surrogate to assess cultural/religious practices and norms. From the analysis, researchers viewed the role of faith based practices as an important element in measuring social beliefs compared to cultural practices specific to women, since some specific cultural practices are at times influenced by faith orientations. Hence, measuring faith based practices (surrogate S51) in a community can provide a broader measure including the gender specific cultural practices that can enhance or deteriorate resilience.

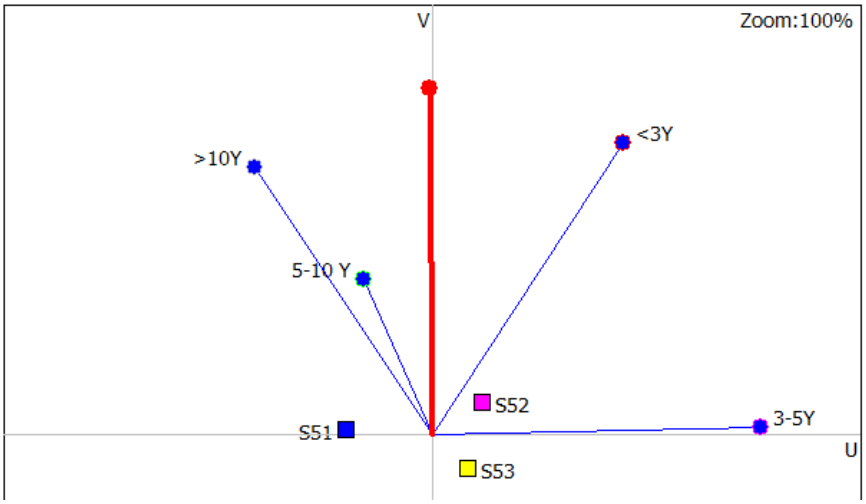


Figure 8 (a). GAIA representation of surrogates to measure 'cultural/religious norms and practices' of experts with varied years of experience

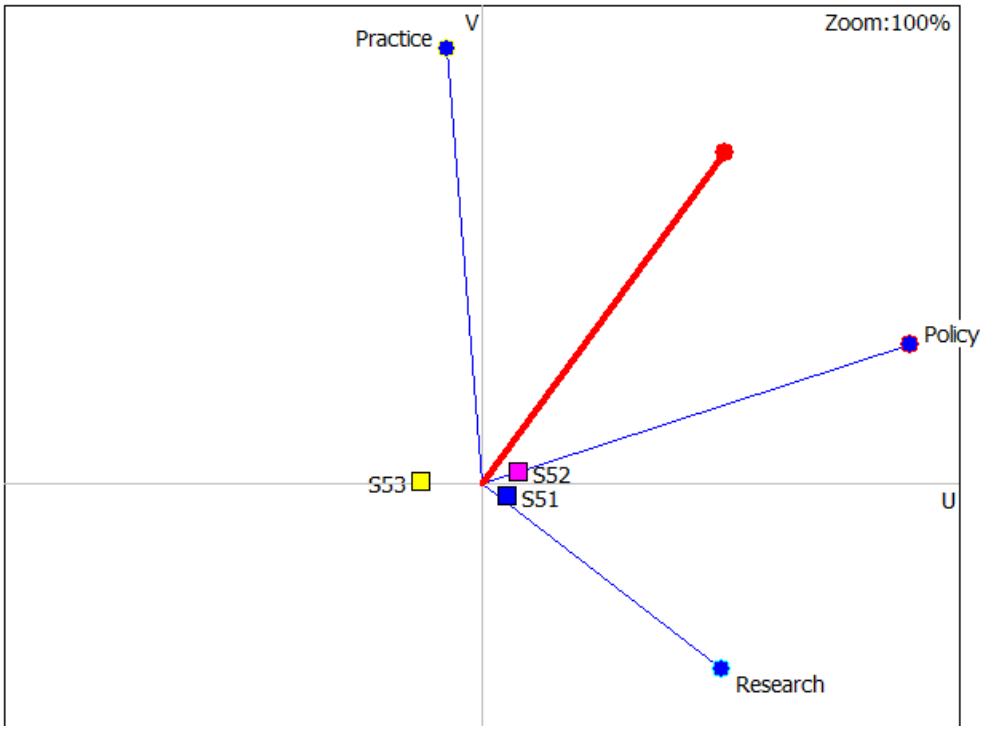


Figure 8 (b). GAIA representation of surrogates to measure 'cultural/religious norms and practices' of different type of experts

Legend for Figures 8(a) and 8(b)

S51	faith-based organisations/practices/activities
S52	culture of women in the society
S53	involvement of religious institutions in disaster preparedness, relief and response activities

Experts with less than 3 years of experience	Practitioners
Experts with 3—5 years of experience	Policy makers
Experts with 5—10 years of experience	Researchers
Experts with more than 10 years of experience	

6. Conclusions and recommendations

A framework was proposed in this study to optimize the selection of potential surrogates to assess social resilience indicators which included two key steps: (1) evaluation of surrogates against five surrogate evaluation criteria; and (2) ranking of potential surrogates based on the evaluation results. Three potential surrogates for each of the five selected social resilience indicators were identified in an exploratory case study in a disaster context and were evaluated independently against five criteria by multiple experts consisting of practitioners, researchers, and policy makers through an online survey. Potential surrogates were then ranked using multi-criteria group decision support system in PROMETHEE.

The most-preferred surrogate (first ranked) can be the utmost critical facet of the respective resilience indicator in a disaster context. Hence, the first ranked surrogate can provide a fairly good representation of overall resilience of the respective indicator as it is also very relevant in practice. However, divergent opinion exists among the different cohort of experts on the overall ranking of surrogates. For example, the comparison between overall ranking of surrogates and the ranking of different cohort of experts showed that the preferences of experts with more than five years of experience from practitioners and policy makers have mostly aligned with overall ranking of surrogates. Results further revealed that experienced practitioners tend to opt for surrogates that can be easily measured using existing data and communicated without much complexities for effective policy decisions.

The results from this study will also have greater practical applicability in the field and policy decisions, since more than two-third of the experts are highly experienced practitioners and policy makers in disaster management. Future research should focus on the lessons from the applicability of selected surrogates in different geographic and disaster contexts that can help to overcome the limitations in resilience measurement and improve the existing social resilience measurement methods. Further, future research can also expand the samples to include more researchers and policy makers to increase the robustness of surrogate preferences.

7. Supplementary information

In Appendix A.1 - A ‘5S’ model social resilience framework that was used for selection of social resilience indicators to develop surrogates, in Appendix A.2 - A brief summary of the case study research findings, and in Appendix A.3 nine-step MCDA selection and application method, are provided.

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Supplementary information

Selection of surrogates to assess social resilience in disaster management using Multi-Criteria Decision Making

Appendix A.1 - Supplementary Information (5S social resilience framework)

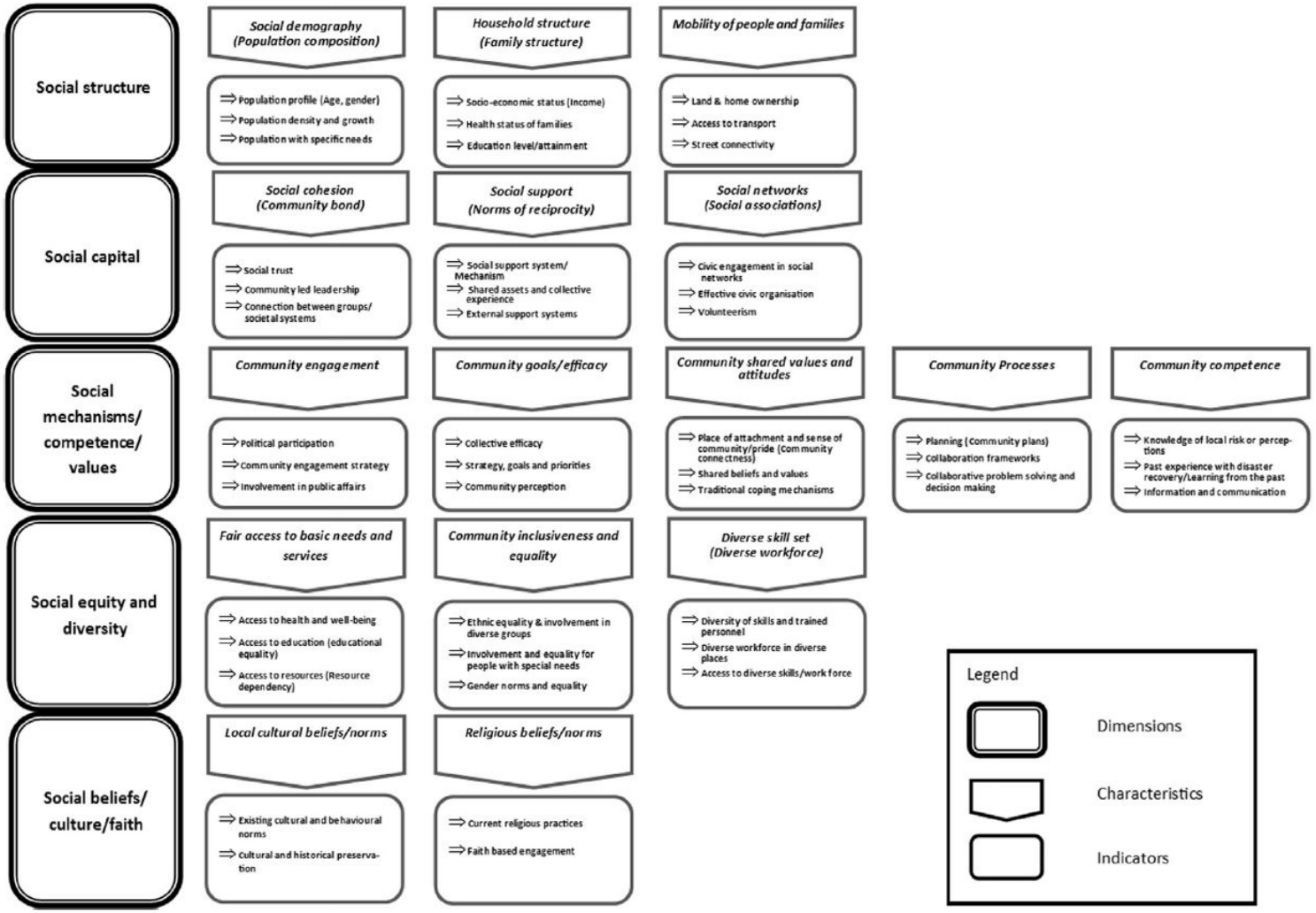

Figure A.1. A 5S model adaptive and inclusive social resilience framework of Saja et al. (2018)

Appendix A.2 - Supplementary Information (surrogate identification using a case study research)

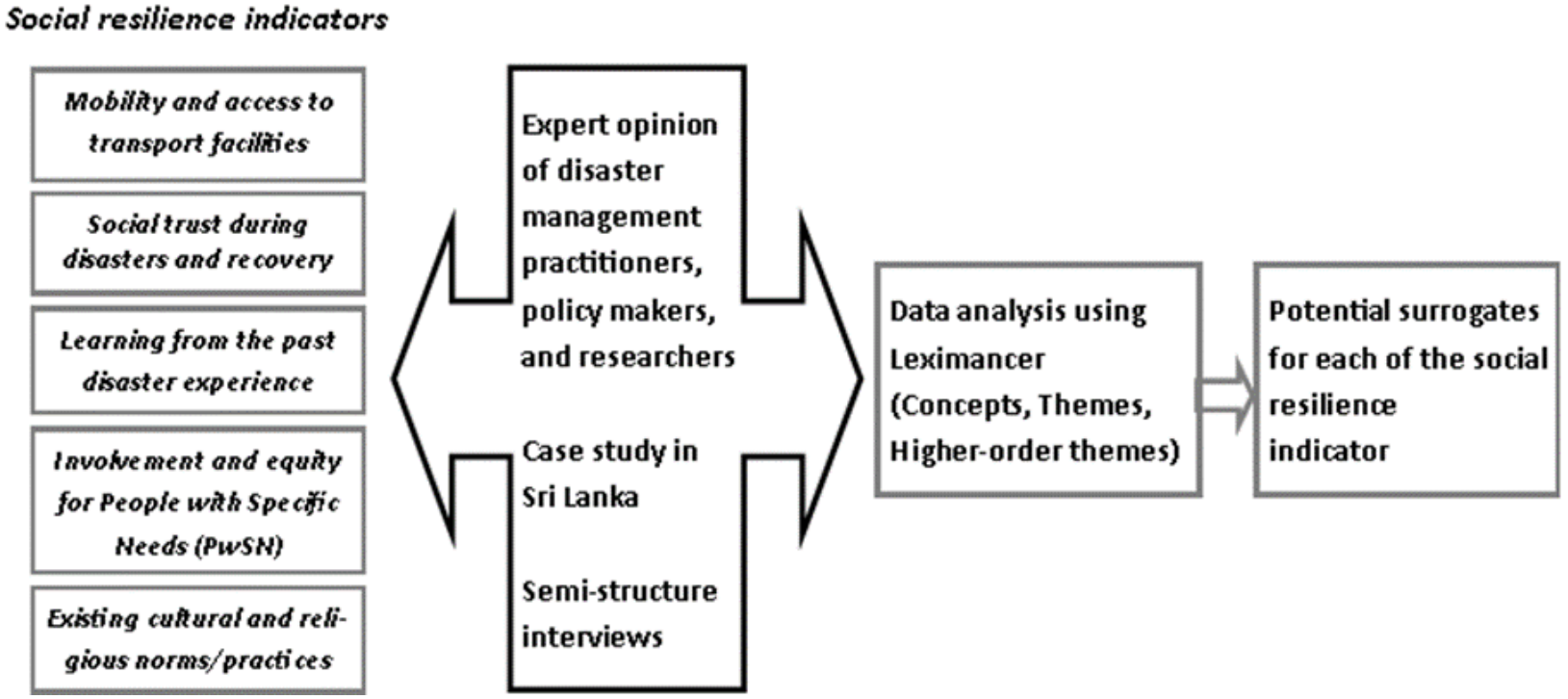

Figure A.2. Exploring surrogates to measure five selected social resilience indicators

A case study research was conducted to identify potential surrogates to measure the five selected key social resilience indicators. A number of 50 semi-structured interviews were carried out with disaster management practitioners and policy makers in four selected case study locations in Sri Lanka. The data obtained from interviews were analysed using Leximancer to generate concepts, themes and higher-order themes. A set of higher-order themes were then analysed across four case studies using pattern matching as a cross-case synthesis exercise to select a set of potential surrogates to measure each of the social resilience indicator. Three potential surrogates for each of the indicator found across all four case studies were used in this study for evaluation.

Appendix A.3 - Supplementary Information (Nine step MCDA selection and application method)

A.3.1. Multi-Expert Multi-Criteria Decision Analysis (ME-MCDA): Evaluation and ranking of potential surrogate indicators

In this research, a multi-criteria decision analysis (MCDA) method is required to analyse the multi-expert judgements of potential surrogates against set of key criteria and can rank the potential surrogates from the best to the poorest. The nine stage MCDA process shown in Figure A.3.1 below is as follows:

1. Experts were selected as per the sampling criteria

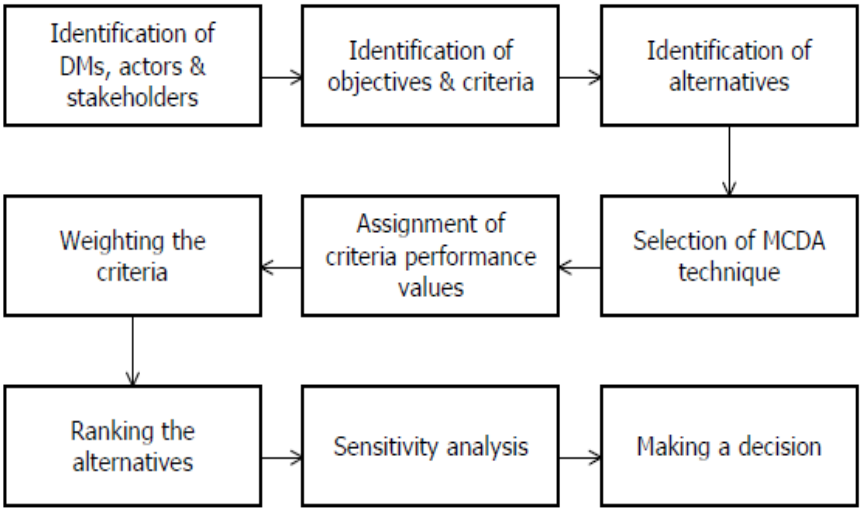

Figure A.3.1. Nine 1stages of MCDA process (Hyde 2006)

2. Identification of criteria: Five key criteria were identified from the literature review on surrogate evaluation
3. Identification of alternatives: Alternatives are the three potential surrogates that were identified in a case study research in the previous phase of this study listed in Table 1.
4. Selection of MCDA technique: There are many multi-criteria decision analysis techniques. For example, Analytical Hierarchy Process (AHP), MACBETH, Preference Ranking Organization METHods for Enrichment Evaluations (PROMETHEE), and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). Among many MCDM methods, PROMETHEE-GAIA has been used by many researchers to select the best actions based on multiple criteria. Verheyden and De Moor (2016) from their research on 'process-oriented social responsibility indicator for mutual funds', found that PROMETHEE to be the most appropriate methodology from the set of robust options in terms of academic and professional applications. The Table A.1 below produced by Verheyden and De Moor (2016) compares four MCDM methods against their overall robustness, ease of implementation, transparency and ease of understanding, and extensiveness of sensitivity analysis in the context of qualitative indicator applications. PROMETHEE has positive aspects in all application criteria of MCDM methods. Similarly, Carone et al. (2018) also used PROMETHEE to rank communities based on the assessment of selected social resilience indicators. Hence, PROMETHEE was selected as the MCDA technique for the evaluation and ranking of potential surrogates to measure social resilience indicators. PROMETHEE-GAIA software support the comparison of alternatives between assessments at different stages of information (dynamic re-evaluation), which is a disadvantage in all other MCDA software (Cinelli et al. 2014) PROMETHEE method is also useful because it can provide software supported data management and supports comparison of scenarios for different weights for criteria and their visualization. Visual PROMETHEE software was used for this analysis.

Table A.3.1 – Comparison of Multi-Criteria Decision Analysis (MCDA) methods (Verheyden and De Moor 2016) (p.80)

	AHP	*MACBETH*	*PROMETHEE*	*TOPSIS*
Application comparisons				
Overall robustness		x	x	x
Academic application				
Ease of implementation	x		x	x
Transparency and ease of understanding	x		x	x
Professional application				
Extensiveness of sensitivity analysis			x	

Note: Comparison of the applied methods with respect to the criteria relevant to both the academic and professional application of the indicator.

5. Assignment of criteria performance values: The values were five point Likert scale (1-5) from very good to not very good.
6. Weighting the criteria: Equal weight was assigned for all five surrogate evaluation criteria, since all criteria were deemed equally important.
7. Ranking the alternatives: Visual PROMETHEE was used to rank the alternatives. Each expert ranking was compiled to Group Decision Support System (GDSS) feature to obtain the final ranking.
8. Sensitivity analysis: Criteria weights can be changed using walking weights feature to do the sensitivity analysis. Sensitivity analysis was not reported in this manuscript.
9. Making a decision: Final ranking of potential surrogates was made to select the best performing surrogates.

A.3.2. How PROMETHEE ranking is calculated

PROMETHEE I method can provide the partial ordering of the decision alternatives, whereas, PROMETHEE II method can derive the full ranking of the alternatives by using a net flow, though it loses much information of preference relations. The procedural steps of PROMETHEE II method are elicited as follows.

Step 1: After normalizing the decision matrix, calculate the evaluative differences of i^{th} alternative with respect to other alternatives. This step involves calculation of differences in criteria values between different alternatives pairwise.

Step 2: Calculate the preference function $Pj\ (i, i')$: There are mainly six types of generalized preference functions which require the definition of some preferential parameters, such as preference and indifference thresholds. However, in real time applications, it may be difficult for the decision maker to specify which specific form of preference function is suitable for each criterion and also to determine the parameters involved. To avoid this problem, the following simplified preference function is used here.

$$Pj\ (i, i') = 0\ if\ Rij\ \leq Ri'j$$
$$Pj\ (i, i') = (Rij - Ri'j)\ if\ Rij\ > Ri'j$$

Where R_{ij} is the performance of i^{th} alternative on j^{th} criterion in the normalized decision matrix.

Step 3: Calculate the aggregated preference function, considering the criteria weights.

Where, *q* and *p* are respectively the indifference and preference thresholds. The meaning of these parameters is the following: when the difference of results is less than *q*, that is considered as negligible by the decision-maker and the preference degree is equal to zero. If the difference is greater than *p that* is considered to be significant (*p* cannot be smaller than *q*). Therefore, the maximum value of the preference degree is equal to one. In some cases, when the difference is between the two thresholds, the preference degree is calculated using a linear interpolation. For this research, the 'level' function is used for the net outranking flows for each of the expert. For the GDSS, Linear function is used, since the net flow is a quantitative value. The Usual (type I) and Level (type IV) preference functions are best suited for qualitative criteria. According to PROMETHEE guideline, the 'Level' preference function is a good choice for qualitative criteria such as 5-point scale if we need to differentiate smaller deviations from larger ones. In the 'Level' preference function, indifference q = 0, and there is a strong preference for an action as soon as there is a difference. If the preference is between 0 and 1, then the preference value is 0.5.

Step 4: Determine the leaving and the entering outranking flows as follows
Leaving (positive) flow for i^{th} alternative

$$\emptyset + (i) = \frac{1}{m-1} \sum_{i'=1}^{m} \pi(i, i') \quad (i \neq i')$$

Entering (negative) flow for i^{th} alternative

$$\emptyset - (i) = \frac{1}{m-1} \sum_{i'=1}^{m} \pi(i', i) \quad (i \neq i')$$

The leaving flow expresses how much an alternative dominates the other alternatives, while the entering flow denotes how much an alternative is dominated by the other alternatives.

Step 5: Calculate the net outranking flow for each alternative to rank the alternatives using PROMETHEE II ranking.

$$\emptyset(i) = \emptyset + (i) - \emptyset - (i)$$

Step 6: Determine the rankings of all the considered alternatives depending on ø (*i*) values, which is the net phi values. The best alternative would have the highest ø (*i*) value according to PROMETHEE II ranking. In this study, PROMEHTEE II ranking is used.

Step 7: Group Decision Support System (GDSS)
The preference function will determine the role played by the difference between the net flows of the actions. In the net flow for each expert (criteria in GDSS), which is used in the GDSS as a value for the alternatives, a small difference can be significant. Hence the use of a V-shape preference function with the preference threshold equal to 2 is justified. Multi-expert group decision flow chart shown in Figure 3 in the manuscript depicts the flow of inputs from experts to the final decision making matrix using PROMETHEE algorithm.

A.3.3. References

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