Towards a Local-Level Resilience Composite Index: Introducing Different Degrees of Indicator Quantification

Sebastian Jülich¹

Published online: 24 March 2017

© The Author(s) 2017. This article is an open access publication

Abstract Within disaster resilience research there is a trend of developing quantitative metrics for resilience analysis. Quantitative indicators can be useful for decision makers in the field of resilience building to prioritize preventive actions to target the least resilient. This study explores possibilities and constraints in quantifying disaster resilience at the local level. While national or regional-level indicators mostly employ existing secondary source data, at the local level it is necessary to collect new data in most cases. The main aim of this study is to investigate how resilience indicators with different stages of operationalization can be developed at the local level. Using the example of the Swiss canton of Grisons, three local-level partial indicators for community resilience against natural hazard are developed. In this process qualitative research is the necessary basis to construct quantitative indicators. For each partial indicator different stages of quantification are offered to illustrate how quantitatively operationalized indicators can be developed and to examine their strengths and weaknesses. For this purpose a classification of different indicator operationalization stages is proposed, ranging from vague qualitative criteria to fully quantified criteria.

Keywords Disaster resilience · Indicator development · Resilience index · Risk and loss perception · Switzerland

1 Introduction

In social science natural hazard research, the terms “risk” and “vulnerability” were the dominating terms a decade ago. Increasingly, however, the term “resilience” is gaining in importance (Alexander 2013). As a result, two out of three social science related natural hazard projects under the European Union’s Seventh Framework Programme for Research (FP7) between 2007 and 2013 employ “resilience” as the central term (for example, CAPHAZ-NET—Social capacity building for natural hazards toward more resilient societies; emBRACE—Building Resilience Amongst Communities in Europe). Resilience is the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic functions (Welsh 2014). The Intergovernmental Panel on Climate Change (IPCC) defined resilience as the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC 2014).

The FP7 emBRACE project framed resilience as a concept that comprises the domains “Actions,” “Learning,” and “Resources and Capacities.” These domains are embedded in the disaster risk governance context of laws, policies, and responsibilities. The resilience of a community is furthermore influenced by its wider context, changes, and disturbances. Figure 1 presents the community disaster resilience framework developed by the emBRACE project.

In disaster risk and vulnerability research one research area is the issue of quantification (Birkmann 2006).

✉ Sebastian Jülich
sebastian.juelich@gmx.de

¹ Regional Economics and Development, Economics and Social Sciences, Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland

Fig. 1 The European Union's emBRACE (Building Resilience Amongst Communities in Europe) community disaster resilience framework. Source emBRACE Consortium (2015, p. 7)

Accordingly in disaster resilience research one research strand is the quantification of resilience by means of indicators. An indicator is a quantitative or qualitative measure derived from a series of observed facts that reveal the relative position of a unit of analysis in a given area. Indicators are useful in identifying trends and drawing attention to particular issues. They can also be helpful in setting policy priorities and in benchmarking or monitoring performance. A composite index is formed when individual single or partial indicators are compiled into one index based on an underlying theoretical model or framework. The composite index should ideally measure multidimensional concepts that cannot be captured by a single indicator. In this way, composite indices can summarize complex, multidimensional realities with a view to supporting decision makers (OECD 2008; Tate 2012).

The measurement of resilience is essential for monitoring progress towards resilience building and to compare benefits of increasing resilience with the associated costs. Resilience indicators facilitate identifying priority needs for resilience improvement. Beyond that, resilience metrics are the basis for establishing a baseline or reference point from which changes in resilience can be measured. Due to the complex nature of resilience, there never will be the one indicator to measure resilience. Hence, a set of partial indicators is needed. The first step in the process of partial

indicator development is to clarify by means of qualitative research what measures to implement, and to investigate causal connections between observable characteristics and the resulting resilience. These connections and characteristics differ by place, context, and hazard. This qualitative research is the basis for the development of quantitative metrics. Quantitative indicators are useful for decision makers to prioritize preventive actions to increase resilience. But the spectrum of what is called an indicator is broad and is very often not addressed. Therefore, in the following section, a schematic of different stages of indicator operationalization is proposed using an example of drought resilience in the state of Odisha (formerly Orissa) in eastern India. This empirically researched example is particularly useful for illuminating differences of quantification. In the subsequent section, this schematic of operationalization is employed to illuminate possibilities and constraints in the development of quantitative resilience indicators. This draws on empirical research conducted in a case study in the canton of Grisons in eastern Switzerland. This multiple hazards case study was part of the FP7 project “Building Resilience Amongst Communities in Europe” (emBRACE).

Resilience indicators applicable at the national or regional level mostly employ existing statistical data (Cutter et al. 2008; Burton 2015). Indicators at the national level allow the comparison between countries, and indicators at the provincial, state, or county level allow comparison of subnational areas according to data availability. At even higher spatial resolutions, resilience assessments at local levels face the challenge that existing secondary source data often are not available at the resolution needed to generate comparative statements for various households or areas within a municipality. And when data are available, they are often very limited due to privacy constraints. At the local level it is mostly necessary to collect new data when conducting a resilience assessment. If individual disaster prevention is the focus of an indicator, the household is probably the most suitable unit of analysis. A household can be defined as the basic residential unit in which economic production, consumption, inheritance, child rearing, and shelter are organized and carried out, and it may or may not be synonymous with family (Haviland 2003). If the goal is to capture organizational issues at the local level, such as disaster response capabilities, the municipality is probably the most suitable unit of analysis. If resilience measuring is approached through place-based analysis, raster points on maps can be appropriate as units of analysis.

The main aim of this study is to investigate how resilience indicators at the local level can be developed. The focus is on partial indicators that measure the risk/loss perception subcomponent of resilience. In this context, the

emphasis is on methodological issues and on different stages of indicator operationalization.

2 Stages of Indicator Operationalization

When it comes to the operationalization of indicators, there is a wide range between indistinctly defined indicators and fully quantified indicators, a fact that is frequently left unaddressed in the research literature. To address this gap, a classification of different indicator operationalization stages is proposed. To illuminate those different stages or degrees of indicator operationalization, access to credit is introduced as one dimension of drought resilience in rural areas of east India (Jülich 2013, 2015). This setting serves as an example to illustrate seven stages of indicator quantification.

Household access to credit is an important resilience factor in eastern India. For many households borrowing money is a major coping strategy during and after times of drought. In addition to what kind of security can be presented by a household, the determining factor of what kind of credit conditions a household has access to is its social networks and reputation within the village community. In the sphere of formal institutions, there is credit raising from the State Bank of India. For subsistence farmers who own land and have proof of this in the form of a land title, the interest rate per annum (pa) is 12%, if the land functions as security for the credit. Households have potential access to this form of credit, if they own enough land for security. The land quality and fertility has to be sufficient to be hypothecated and a formal land property title is necessary. If formal credit raising fails, households are dependent on borrowing money based on informal institutions. Some households are in the position to borrow money from a relative outside the village, usually without interest to be paid. The rest of the informal sphere is dominated by local traders, whose interest rates are much higher than those of formal moneylenders. If the household can present a certain amount of gold as security, mostly in the form of jewelry worn by women, the interest rate is 3% per month (pm); resulting in 36% pa, if the interest is paid regularly each month. The situation for the household is worse if only agricultural tools or animals can be presented as security. In this case, an interest rate of 5% pm/60% pa has to be paid. However, particularly during droughts some households cannot present any security like gold, tools, or animals because they have already been sold to buy food. If no security is presented, the credit relation is based on trust and the borrower has to be known to the trader. The interest rate in that case is 10% pm/120% pa. To be dependent on such credits has to be seen as a sign of low social resilience. In the short term, these credits might help to cope

with drought, but research indicates that, in the long term, they very often lead into overindebtedness (Jülich 2015). Such excessive indebtedness depletes future options for development and, as a consequence, the access to credit determines the risk of overindebtedness that comes with certain credit conditions and affects resilience. Credits by the State Bank of India, by traders with 3% pm interest, and credit from relatives bear a relatively low risk of overindebting, at least compared to the other alternatives present in the region.

A qualitative investigation of the causal connections between drought resilience and access to credit is the basis for the development of an indicator that captures credit as one dimension of drought resilience. Drawing on this example, Table 1 shows seven stages of indicator operationalization, with an increasing degree of quantification from stage 1 through stage 7.

3 Quantitative Indicator Development

The quantitative indicator development in the emBRACE case study was guided by the general hypothesis: Resilience against natural hazards varies at the local level and can be characterized by measurable characteristics that indicate the degree of disaster resilience. From this hypothesis the central research question was derived: Are there measurable differences in resilience at the local level? In order to answer this main research question, the following secondary questions arose: Which socio-economic or demographic characteristics can be employed to measure the disaster resilience of populations at the local level? How can these characteristics be utilized to give an indication of disaster resilience? Since disaster resilience is a complex phenomenon with various dimensions, it cannot be captured by a single partial indicator. Several indicators are needed to reflect the multidimensional nature of disaster resilience.

To investigate these dimensions of resilience, expert interviews with various stakeholders from the field of natural hazard prevention, disaster response, and information platforms were conducted in the canton of Grisons, Switzerland. For this, a matrix was developed that shows on one axis all the natural hazard-induced disasters that can occur in the study region (intense rainfall and snowfall, snow avalanches, storms, wind, hail, floods, debris flows, rockslides, rockfalls, landslides, earthquakes, droughts), and shows on the other axis the following guiding questions: Who in particular was affected during past disasters and who was not affected? What measures helped against the disaster? Who is very well informed, aware, and prepared for the disaster and who is not? Who would recover best from a disaster and who would severely struggle to

Table 1 Stages of indicator operationalization based on an example of drought resilience in eastern India

No.	Stage of indicator operationalization	Indicator example of drought resilience in eastern India
1	Indicator criteria only	<i>Credit</i> plays a certain role
2	Link of the indicator criteria to unit of analysis specified	<i>Access</i> to credit plays an important role
3	Direction of the link to resilience defined (positive or negative correlation)	Access to credit <i>increases</i> resilience
4	Indicator criteria specified	Access to credit <i>with reasonable interest rates</i> increases resilience
5	Unit of analysis defined	Access to credit with reasonable interest rates increases the resilience of a <i>household</i>
6	All indicator criteria operationalized	Access to credit with <i>interest rates below 12% pa</i> increases the resilience of a household
7	Completely quantified indicator	The <i>number of credit sources</i> with interest rates below 12% pa the household has access to in times of drought, <i>divided by 3</i> is a measure of resilience <i>on a scale from 0 to 1</i> (to allow combination with other partial indicators that reflect other drought resilience dimensions)

recover? Who would even have positive externalities from a disaster? Who has more human, social, or financial capital than others? Who is resilient and who is not? The aim of these guiding questions was to identify measurable characteristics that can be employed as a measure for disaster resilience differences.

With this matrix, the stakeholders were questioned on each combination of possible disaster-generating hazards in the region and asked the guiding questions listed above. The guiding questions were used as interview openers to identify thematic indicator complexes (for example, local disaster prevention knowledge). Once such a thematic complex was identified, it was investigated in depth for all relevant aspects connected to it (for example, households' residence time). This was the qualitative basis for the quantitative indicator development. Three thematic indicator complexes—residence time, past disasters, and warning systems—resulted from the matrix interviews and were taken as exemplary outputs for the development of quantitative indicators. These complexes are discussed in the next three sections. All three presented indicators are completely quantified, but partially lower quantification stages are offered to discuss possibilities and constraints of different stages of quantification.

If several completely quantified partial indicators are developed, it is crucial to transform the input parameters to the same numerical dimension reflecting the level of resilience. Otherwise the partial indicators cannot be combined in the form of a composite index. In this study, values between 0.0 and 1.0 were chosen as the indicator value range, with consistently 0 indicating lowest/no resilience and 1 representing highest resilience. Most composite indices, like the Human Development Index (HDI) developed by the United Nations Development Programme, operate between 0 and 1 (UNDP 2007). The main advantage of this numerical range is that all mathematical operations have the same effect within the whole range,

contrary to numerical ranges like 0–10, or 0–100. This is because mathematically numbers between 0 and 1 act differently than numbers above 1 in response to operations like squaring: for instance, figures between 0 and 1 decrease if squared, and figures greater than 1 increase. It would distort results in some cases, if input indicator values above and below 1 were used with the same equations. That is why for all developed partial indicators a transformation of input variables into numbers between 0.0 and 1.0 was chosen.

The three developed indicators aim to quantify the subcomponent “Risk/loss perception” within the domain “Learning” in the emBRACE community disaster resilience framework (Fig. 1). Without further indicators quantifying the other domains of resilience, the developed indicators are not able to capture the complex phenomena of resilience in their entirety.

4 Residence Time as a Partial Resilience Indicator

This partial resilience indicator aims at capturing the risk/loss perception subcomponent of resilience. All questioned disaster experts confirmed a positive relation between the residence time of households and natural hazard awareness. In this form the indicator is already operationalized at stage 4 or 5 (Table 1), depending on the determination of the unit of analysis.

For further quantification, unpublished empirical data collected for a study by Buchecker et al. (2016) were employed. The study explored factors that can positively influence local populations' attitudes towards integrated risk management. They conducted a household survey in two Swiss Alpine valleys, in which a disastrous flood event had taken place 2 years before (Demeritt et al. 2013). A total of 2100 standardized questionnaires were sent to all households in the Lötschen valley and to a random sample

of the households in the larger Kander valley. The response rate was 30%. Table 2 shows the results for two questions on the residents' disaster prevention knowledge, itemized according to how long the respondents' already live in the valley.

In general the residence time of all respondents in both valleys is relatively long. In the Kander valley there is a clear association between increasing residence time in the valley and how well the respondent assessed her/his information level on disaster prevention. In the Lötschen valley there is a clear association between residence time in the valley and knowledge about places at risk in the village. The data suggest that prevention knowledge increases for up to 40 years for someone living in the same valley. The interviewed disaster experts confirmed a steep learning curve within the first 10 years of residence time at one place. In terms of quantification this led to a minimum goalpost of 0 years, a maximum goalpost of 40 years and a logarithmic run of the curve. Formula 1 captures all three characteristics. Unit of analysis is a household and the only input parameter is the time of residence of the household within the village.

Partial Resilience Indicator 1

$$= \min.\{\log_{40} \text{Residence years} + 1; 1\} \quad (1)$$

Formula 1 creates just values between (and including) 0 for lowest resilience and (including) 1 for highest resilience. Values above 1.0 are not allowed by this minimizing function. Hence, the concept of goalposts (UNDP 2007, p. 356) or minimum/maximum (OECD 2008, p. 85) is employed. Higher values than a residence time of 40 years have no further effect and would also result in an indicator value of 1.0. According to the classification of indicator operationalization stages

Table 2 Residents' assessment of their disaster prevention knowledge itemized to residence time in the Lötschen and Kander valleys, Switzerland

	Years already living in the Lötschen Valley	Years already living in the Kander Valley
I am well informed about disaster prevention measures		
Disagree	43	27
Rather disagree	40	38
Rather agree	43	35
Agree	45	42
I know which places are at risk in the village		
Disagree	30	35
Rather disagree	36	33
Rather agree	42	35
Agree	45	39

proposed in Table 1, the indicator formula 1 is fully quantified at stage 7. Figure 2 visualizes the run of the resulting curve of formula 1. On the horizontal axis the input parameter is shown, and on the ordinate axis the resulting level of resilience according to the resilience indicator formula 1 is shown.

Residence time is only suitable for capturing the risk/loss perception of disasters that occur relatively frequent. When it comes to more infrequent disasters, like high magnitude earthquakes or tsunamis with a probability of occurrence exceeding one or two generations, residence time is not an appropriate measure for risk/loss perception.

5 Awareness through Past Natural Hazard-Induced Disasters as a Partial Resilience Indicator

The interviewed disaster experts pointed out that disaster impacts are predominantly negative at the time of occurrence. But once direct impacts of a disaster are endured, the disaster starts to act positively in terms of awareness building. Hence, past disasters have positive effects on the awareness of people and increase their resilience. The manifestation of hazard in the form of a disaster increases in the aftermath with the willingness to invest in mitigation measures. Research even indicates that disasters have acted as catalysts for the construction of preventive measures, which had been previously planned, but for which no political support was available through which to mobilize funding.

This leads to a stage 3 operationalized indicator: The occurrence of disasters in the region in the past increases resilience. By making this disaster specific the indicator becomes stage 4 operationalized: The occurrence of a specific type of disaster (flood, debris flow, avalanche, and so on) in the region increases the resilience against that type of disaster.

To further refine this stage 4 indicator to stage 5 the unit of analysis can be defined, as canton or municipality for instance. Data collection for this indicator through empirical research is relatively easy if operationalized between stage 3 and stage 5. However, the dimension of time, the intensity of past disasters, and their spatial dimensions remain indefinite. For a stage 6 or 7 indicator quantification, these three subfactors have to be defined.

5.1 Single Factor Time

First the issue of time is investigated. People's active memory of natural hazard-induced disasters is astonishingly short, a phenomenon confirmed by all interviewed experts. But to determine how fast people forget is difficult. The interviewed experts were not able to operationalize the curve of forgetting. Some experts indicated that after

Fig. 2 Transformation of formula 1 (partial resilience indicator 1) input values to resulting partial resilience indicator values

5 years quite an amount of memory is gone, and after 10 or 15 years only very few people actively remember in a way that it shapes their preventive behavior. Wagner (2004, p. 84, 88) conducted research on the curve of forgetting using the example of river floods in Alpine areas. He found that the half-value time is around 14 years, that is after 14 years only half of the people are still aware of a certain flood in the area. Using flood risk perception in the United States as an example, Lave and Lave (1991, p. 265) employed flood insurance as an indicator for the fading memories of the flood. They found that after flood events the demand for flood insurance rises sharply, but about 15% of policy holders drop their flood insurance each year if there is no further major flood event. This results in a half-value period of only about 4 years. There is a distinction between just remembering a disaster when asked by a researcher, as in the case of Wagner (2004), and actively recalling a disaster so that it still shapes the awareness and willingness to actually take or maintain mitigation measures, as in the case of Lave and Lave (1991). For indicator operationalization it is desirable to capture the latter. This is why a rather steep and exponentially falling run of the curve of forgetting is suggested in terms of quantifying the factor of time for this awareness indicator.

$$\text{Single factor Time} = \max.\{2 - \sqrt[4]{\text{Years} + 1}; 0\} \quad (2)$$

The maximum value for the single factor time is 1.0, when the disaster occurred less than 1 year ago, and the minimum value is 0.0, when the disaster occurred 15 years ago. When a disaster was experienced more than 15 years ago, the value would become negative. That is why a maximizing function was chosen to eliminate negative

values. Figure 3 demonstrates the transformation of the number of years since a disaster into the resulting single factor time as determined by formula 2.

5.2 Single Factor Intensity

Paul Slovic (1987) points out in his research on the perception of risks that the majority of people rely on intuitive risk judgments, typically called risk perceptions. This risk perception is strongly shaped by the news media and other information sources. For this partial resilience indicator it is attempted to transfer the qualitative and rather subjective perception of risks into a more objective and quantitative measure of risk/loss perception. While actual disastrous events strongly increase awareness, it can be observed that once news coverage stops awareness starts to decrease as time passes without further disaster events.

The research of Wagner (2004) reveals that the magnitude of a hazard event highly influences the curve of forgetting. For stage 7 quantification, this aspect is captured by a second single factor. Discussion on measures with the interviewed experts points towards casualties as the most suitable operationalization of the severeness of a past disaster. The number of deaths is recorded in most disaster databases and can be employed for all types of natural hazard-induced disasters. Compared with other countries, the number of casualties as a result of natural hazard-induced disasters is relatively low in Switzerland. That is why a maximum goalpost of 10 deaths is suggested. This single factor has to be revised carefully when this indicator is employed in other countries because casualties might not always be the best measure to differentiate the severeness of hazard events. In

Fig. 3 Transformation of formula 2 (single factor time) input values to resulting single factor values

some cases the number of affected people or properties might be a more appropriate measure. Evidence for a nonlinear run of the curve were too weak, this is why formula 3 is constructed straightforwardly in a linear way.

$$\text{Single factor Casualties} = \min.\left\{\frac{\text{Deaths}}{10}; 1\right\} \quad (3)$$

Figure 4 displays the formula 3 transformation of casualties caused by a disaster into the resulting single factor casualties.

5.3 Single Factor Distance

The final single factor is the spatial dimension of past disasters. Research indicates that the distance between the place of residence and the point of hazard occurrence plays a crucial role. As with the other two single factors, a goalpost line has to be drawn somewhere for the distance factor. Since topography, the range of media, and individuals' ranges of activity influence the perception of disasters, it is particularly difficult to decide on the maximum goalpost and the run of the curve. After consultation with the natural hazard prevention stakeholders, a straightforward linear run with a threshold beeline distance of 50 km is suggested. This enables an easy implementation within Geographical Information Systems (GIS).

$$\text{Single factor Distance} = \max.\left\{1 - \frac{\text{Kilometres}}{50}; 0\right\} \quad (4)$$

Figure 5 shows the proposed transformation of the disaster distance into the resulting single factor distance as expressed by formula 4. Due to the way this single factor is constructed, it works only for disasters that affect a locally limited area. For large-scale disasters like hurricanes, tsunamis, or droughts this way of computing distance is not suitable.

5.4 Combining the Three Single Factors

All three single factors can produce values between 0 and 1. The three single factors are combined in formula 5 in a linear way so that only indicator values between 0 (indicating low resilience) and 1 (indicating high resilience) are produced. More complex or nonlinear combinations of the single factors would be possible, but the analyzed data do not justify an exponential, logarithmic, or nonequal weighted combination.

$$\begin{aligned} \text{Partial Resilience Indicator 2} \\ = \text{Casualties} \left(\frac{\text{Time} + \text{Distance}}{2} \right) \end{aligned} \quad (5)$$

The three single factor formulas (2, 3, and 4) inserted into formula 5 results in formula 6.

Fig. 4 Transformation of formula 3 (single factor casualties) input values to resulting single factor values

$$\begin{aligned} \text{Partial Resilience Indicator 2} = \min.\left\{\frac{\text{Deaths}}{10}; 1\right\} \\ \times \left(\frac{\max.\{2 - \sqrt[4]{\text{Years} + 1}; 0\} + \max.\{1 - \frac{\text{Kilometres}}{50}; 0\}}{2} \right) \end{aligned} \quad (6)$$

The unit of analysis is a raster cell on a map. The input parameters are disasters of the latest 15 year period available. The location of the disaster has to be geocoded. By inserting these input parameters by means

Fig. 5 Transformation of formula 4 (single factor distance) input values to resulting single factor values

of formula 6 into a GIS, a value for each raster cell can be computed. If a cell is influenced by more than one disaster, the respective values are added together.

6 Warning Services as a Partial Resilience Indicator

The indicators “residence time” and “past disaster awareness” produce continuous resilience values between 0 and 1. The thematic complex of warning systems has been picked to demonstrate how in terms of stage 7 quantification binary indicators can be transferred into this numerical dimension.

Research indicates that persons and households who are subscribed to one of the natural hazard warning services present in the study region (for example, MetoSwiss and respective public cantonal building insurance systems) are more resilient than others. A warning message received in time and interpreted properly can effect individuals’ efficacy in getting themselves or their belongings to safety—for example by proceeding to safe zones, bringing valuables upstairs in the case of flooding, parking the car in the garage in the case of hail or on higher ground in the case of a river flood, being on the right side if the only road of a closed off valley is likely to be blocked by avalanche or debris flows, and so on.

This indicator is constructed as an all or nothing indicator. As a result, the indicator allows only two values: 0.0 if the analyzed household or person is not subscribed to a warning service, or 1.0 if the household or person is subscribed to at least one natural hazard warning service. Therefore, the value of formula 7 is defined by an indicator function.

Partial Resilience Indicator 3

$= 0$ if not subscribed to warning service(s)

Partial Resilience Indicator 3

$= 1$ if subscribed to at least one natural hazard warning service

(7)

The most appropriate unit of analysis for this partial resilience indicator is single individuals or households. If subparts of municipalities are supposed to be compared in terms of disaster resilience, all households in an area can be surveyed or a random sample can be taken and mean values can be calculated.

7 Conclusion

This article outlines different stages of indicator operationalization. Because several fully quantified single indicators were developed, the input parameters were always transformed into the same numerical dimension reflecting the level

of resilience. In this study 0.0–1.0 was chosen as an indicator value range, with 0 consistently indicating the lowest/no resilience and 1 representing the highest resilience.

It is not always possible to operationalize an indicator to quantification stage 7, nor is it reasonable to expect to be able to do so. A higher level of quantification does not automatically equate with higher relevance to resilience assessment. However, there is currently an increasing demand by policy-makers and practitioners for concrete quantitative measures of resilience. This kind of demand always needs to be addressed by science with the aim that any resilience assessment determines the appropriate stage of indicator operationalization.

However, quantification, especially to stage 7 according to the schematic proposed in this article (Table 1), inevitably means determination. The reason for this is that, questions such as whether to employ parameters and, if so, where to set their thresholds cannot be ignored. These issues have to be determined by means of formulas. The same is true with each transformation of measurable characteristics into the chosen indicator value range. Such parameters do, however, inevitably have to be determined if fully quantified indicators are to be developed. This very determination comes along with contestability because in most cases other parameters or curve runs are imaginable. This is the reason why all steps of decisions made during the quantification of indicators should be laid open. Quantitative indicators are to be seen as the best possible quantitative operationalization according to present qualitative knowledge about resilience in a study region.

The three developed partial indicators represent a measure for the risk/loss perception subcomponent of resilience. Only in combination with additional partial indicators that capture other subcomponents of resilience is it possible to reflect the complete view of household or community resilience against natural hazard-induced disasters. Quantified indicators are never all-encompassing for all times and all regions. When indicators are transferred from one region or country to another, or from one hazard context to another, the indicators have to be revalidated carefully to ensure that they actually measure the intended concept.

Acknowledgements This work was supported by the European Union 7th Framework Program within the project emBRACE (Building Resilience Amongst Communities in Europe) under Grant Agreement Number 283201. Many thanks to Matthias Buchecker for access to his raw data of the KULTURisk case study, to Jonas Lichtenhahn for supporting the indicator development, and to Marco Pütz, Hugh Deeming, Christopher Burton, Viola Haarmann, and the anonymous peer reviewer for their extensive feedback.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

- Alexander, D.E. 2013. Resilience and disaster risk reduction: An etymological journey. *Natural Hazards and Earth System Sciences* 13(11): 2707–2716.
- Birkmann, J. (ed.). 2006. *Measuring vulnerability to natural hazards: Towards disaster resilient societies*. Tokyo: United Nations University Press.
- Buchecker, M., D. Ogasa, and E. Maidl. 2016. How well do the wider public accept integrated flood risk management? An empirical study in two Swiss Alpine valleys. *Environmental Science and Policy* 55: 309–317.
- Burton, C.G. 2015. A validation of metrics for community resilience to natural hazards and disasters using the recovery from Hurricane Katrina as a case study. *Annals of the Association of American Geographers* 150(1): 67–86.
- Cutter, S.L., L. Barnes, M. Berry, C.G. Burton, E. Evans, E.C. Tate, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18(4): 598–606.
- Demeritt, D., S. Nobert, M. Buchecker, C. Kuhlicke, M. Ferri, and B. Parkes. 2013. Assessing the roles and effectiveness of flood mapping and communication as a disaster risk reduction strategies. Public report of the EU FP7 project KULTURisk Knowledge-based approach to develop a culture of risk prevention. http://www.kulturisk.eu/results/wp5/2013-Kulturisk_D-5-5_public.doc.pdf?attredirects=0&d=1. Accessed 15 Mar 2017.
- emBRACE Consortium (Building Resilience Amongst Communities in Europe Consortium). 2015. EU Project emBRACE. Policy Brief Series. The emBRACE Framework of Community Disaster Resilience. Full Context Brief. <https://drive.google.com/file/d/0BySVyEajWokmNTIxbjNuWDI5dlU/view>. Accessed 15 Mar 2017.
- Haviland, W.A. 2003. *Anthropology*. Belmont, CA: Wadsworth Publishing.
- IPCC (Intergovernmental Panel on Climate Change). 2014. Summary for policymakers. In *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, 1–32. Cambridge and New York: Cambridge University Press.
- Jülich, S. 2013. Drought. In *Encyclopedia of crisis management*, ed. K.B. Penueel, M. Statler, and R. Hagen, 300–301. Thousand Oaks, CA: SAGE Publications.
- Jülich, S. 2015. Development of a composite index with quantitative indicators for drought disaster risk analysis at the micro level. *Human and Ecological Risk Assessment* 21(1): 37–66.
- Lave, T., and L. Lave. 1991. Public perception of the risks of floods: Implications for communication. *Risk Analysis* 11(2): 255–267.
- OECD (Organisation for Economic Co-operation and Development). 2008. *Handbook on constructing composite indicators: Methodology and user guide*. Paris: OECD.
- Slovic, P. 1987. Perception of risk. *Science* 236(4799): 280–285.
- Tate, E. 2012. Social vulnerability indices: A comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards* 63(2): 325–347.
- UNDP (United Nations Development Programme). 2007. Human Development Report 2007/2008. Fighting climate change: Human solidarity in a divided world. New York, USA: UNDP.
- Wagner, K. 2004. Natural hazard awareness and communication with the example of flashfloods and landslides in four municipalities of the Bavarian Alpine region (*Naturgefahrenbewusstsein und -kommunikation am Beispiel von Sturzfluten und Rutschungen in vier Gemeinden des bayerischen Alpenraums*). Doctoral dissertation. Technical University of Munich, Munich, Germany (in German).
- Welsh, M. 2014. Resilience and responsibility: Governing uncertainty in a complex world. *The Geographical Journal* 180(1): 15–26.