Chapter 3
Resilience Indicators

Abstract This chapter analyzes and classifies the different resilience indicators available in literature, since there is no a widely accepted type of indicator that should be used to measure resilience. A list of existing resilience indicators is provided together with different classification methods, which are based on the hazard type, the temporal scale, the measurement method etc.

3.1 Why Resilience Indicators?

The vagueness of the concept of resilience makes it difficult to define, but it becomes even more problematic when trying to measure it. The motivations and goals of resilience measurement are as different as the proponents advocating for them. Most researchers in the field emphasize that research on measuring community resilience is still in the early stages of development. There is no single or widely accepted method to the measurement issue as the landscape of resilience indicators is confusing and increasingly hard to navigate (Cutter et al. 2014). This is particularly the case for community resilience to disasters, since this concept raises not only questions related to the measurement of resilience, but also related to the definition and conceptualizations of communities. Since communities are interconnected systems whose indicators may apply to different scales and policy realms and also address different types of shocks. Resilience indicators can help to characterize the basic elements of the targeted system or unit of analysis and thus help to raise community awareness, because whenever there is a benchmarking, weak and strong points are identified and so it is easier to know where to address the funds to enhance the system. Being explicit about the objectives and motivations of measuring resilience is of critical importance for choosing the right approaches that integrate current conceptualizations and operationalizations of resilience.

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3.2 Type of Assessments

Three main categories are defined for the different resilience assessment approaches:

- *indices*
- *scorecards*
- *tools and models*

Indices are those quantifiable that represent a selected characteristic of resilience and these individual indicators are combined to create an index. The relationship between the indicators and the phenomenon they are measuring may be more or less direct. Indices are a statistical approach that summarizes observations or measurements by aggregating multiple indicators into a single value.

Scorecards provide an evaluation of performance or progress toward a goal. A vastly used method of this kind are the checklist, a series of questions related to presence or absence of resilience-related items and actions. A score is then produced based on how often the items are present, used, and so forth. Scorecards can have numerical values (1–10), letter "grades" such as (A–F), or descriptors such as "excellent to poor". Scorecards are normally based on qualitative assessments and then converted to scores, while indices mostly use quantitative data to derive the index value.

Tools and models. *Models* create simplified representations of processes using mathematical formulas to approximate and understand the relationships and the interactions in the real world. Models can characterize economic resilience or resilience of a specific place. Models can be used to characterize economic resilience (Rose and Liao 2005) in a computational way or to characterize the resilience of specific places (Renschler et al. 2010). *Tools* have been developed to provide a guidance for assessing resilience with sample procedures and survey instruments, or data for use in compilation of indices or scorecards.

3.3 Methodological Approaches

There are two main different types of approaches. The first one is an *idiographic measurements or bottom-up*, which are locally generated and customized to particular places (Pfefferbaum et al. 2014). Typically use qualitative methodology and stress the resilience using highly localized data that may not be widely available. Due to the local knowledge and information these kind of case studies are rich and detailed, but the ability to compare across places is difficult because of the variability of the data and the different contexts and meanings of resilience.

On the other hand there are the *nomothetic or top-down* type assessments, which strive toward comparisons across varying units of analysis. They tend to use larger spatial units such as states or nations. This allows comparing units of analysis using standardized data, which make these types of resilience indices more amenable for examining spatial variability, allocating resources, and/or monitoring progress-all done at state, national, or international scales.

3.4 List of Existing Indicators

Many frameworks are available in literature as shown in Chap. 1. Different frameworks propose similar indicators and most of them overlap each other. After an extensive comparison between different frameworks, below is reported a comprehensive list of resilience metrics which is mainly based on the work of Mileti (1999), Renschler et al. (2010), Cutter et al. (2014) and Burton (2015). The metrics are grouped according to five domains and are shown from Tables 3.1, 3.2, 3.3, 3.4, and 3.5.

Table 3.1 List of social resilience indicators

Social resilience indicators		
Category	Resilience metric	Data source
Educational attainment equality	Absolute difference between % population with college education and % population with less than high school education	Norris et al. (2008) and Morrow (2008)
Pre-retirement age	% population below 65 years of age	Morrow (2008)
Transportation	% households with at least one vehicle	Tierney (2009)
Communication capacity	% households with telephone service available	Colten et al. (2008)
English language competency	% population not speaking English as a second language	Morrow (2008)
Non-special needs	% population without sensory, physical, or mental disability	Center (2002)
Health insurance	% population with health insurance	Center (2002)
Mental health support	Psychological support facilities per 10,000 persons	Cutter et al. (2014)
Food provisioning capacity	Food security rate	Cutter et al. (2014)
Physician access	Physicians per 10,000 persons	Norris et al. (2008)
Social capacity	% population that is not institutionalized or infirmed; % population that is not a minority; % population with at least a high school diploma; % population living in high-intensity urban areas	Burton (2015)
Community health	Social assistance programs per 1,000 population	Burton (2015)
Well-being	Adult education and training programs per 1,000 population; child care programs per 1,000 population; community services (recreational facilities, parks, historic sites, libraries, museums) per 1,000 population; internet, television, radio, and telecommunications broadcasters per 1,000 population; health services per 1,000 population	Burton (2015)

(continued)

Table 3.1 (continued)

Social resilience indicators		
Category	Resilience metric	Data source
Equity	Ratio between the % of minority population to % non minority population	Burton (2015)
Population wellness	% black infant mortality rate	Norris et al. (2008)
Social vulnerability	SoVI index	Morrow (2008), Cutter et al. (2008), and Tierney (2009)
Racial/ethnic inequality	Value of difference in % of black & % of white	Norris et al. (2008) and Cutter et al. (2008)
Crime rate	Crime rate per 10,000	Colten et al. (2008)

Table 3.2 List of economic resilience indicators

Economic resilience indicators		
Category	Resilience metric	Data source
Home ownership	% owner-occupied housing units	Norris et al. (2008) and Cutter et al. (2008)
Employment rate	% labor force employed	Mileti 1999
Income distribution and equality	Gini coefficient	Norris et al. (2008)
Non-dependence on primary sector + tourism	% employees not in primary sectors (e.g. farming, fishing, forestry, extractive industry) and tourism	Berke and Campanella (2006)
Gender income equality	Female labor force participation	Bank (2015)
Business size	Ratio of large to small businesses	Norris et al. (2008)
Large retail-regional/national geographic distribution	Large retail stores per 10,000 persons	Cutter et al. (2014)
Federal employment	% labor force employed by federal government	Burton (2015)
Economic/ livelihood	% female labor force participation rate (FLFP)	Burton (2015)
Stability	Per capita household income	Burton (2015)
	Median household income	Norris et al. (2008) and Cutter et al. (2008)
	Mean sales volume of businesses	Burton (2015)
Resource equity	Lending institutions per 1,000 population	Burton (2015)
	Ratio % white to % nonwhite homeowners	Norris et al. (2008)

Table 3.2 (continued)

Economic resilience indicators		
Category	Resilience metric	Data source
Economic	% commercial establishments outside of high hazard zones (flood, surge)	Burton (2015)
Infrastructure exposure	Density of commercial infrastructure	Burton (2015)
Poverty	Poverty percentage	Norris et al. (2008), Morrow (2008), and Enarson (2007)

Table 3.3 List of community capital indicators

Community capital indicators		
Category	Resilience metric	Data source
Place attachment	Net international migration	Morrow (2008)
	% population born in a state that still reside in that state	Vale and Campanella (2005)
Political engagement	% voting participating in presidential election	Morrow (2008)
Social capital-religious organizations	Population affiliated with a religious organization per 10,000 persons	Morrow (2008)
	Religious organizations per 1,000 population	Murphy (2007)
Social capital-civic organizations	Civic organizations per 10,000 persons	Morrow (2008)
		Murphy (2007)
Social capital-disaster volunteerism	Red cross volunteers per 10,000 persons	Cutter et al. (2014)
Citizen disaster preparedness and response skills	Red cross training workshop participants per 10,000 persons	Cutter et al. (2014)
Social capital	Social advocacy organizations per 10,000 population	Murphy (2007)
	Arts, entertainment, and recreation centers per 10,000 population	Burton (2015)
	Civic organizations per 10,000 population	Morrow (2008)
		Murphy (2007)
Creative class	% workforce employed in professional occupations	Burton (2015)
	Professional, scientific, and technical services per 1,000 population	Burton (2015)
	Research and development firms per 1,000 population	Burton (2015)
	Business and professional organizations per 1,000 population	Norris et al. (2008)
Cultural resources	National Historic Registry sites per square mile	Burton (2015)

Table 3.4 List of institutional resilience indicators

Institutional resilience indicators		
Category	Resilience metric	Data source
Mitigation plan capita	Ten year average per capita spending for mitigation projects	Cutter et al. (2008)
Jurisdictional coordination	Governments and special districts per 10,000 persons	Cutter et al. (2014)
Disaster aid experience	Presidential disaster declarations divided by number of loss-causing hazard events from 2000 to 2009	Cutter et al. (2014)
Local disaster training	% population in communities with Citizen Corps program	Cutter et al. (2014)
Performance regimes-state capital	Proximity of county seat to state capital	Cutter et al. (2014)
Performance regimes-nearest metro area	Proximity of county seat to nearest county seat within a Metropolitan Statistical Area	Cutter et al. (2014)
Population stability	Population change over previous five years	Cutter et al. (2014)
Nuclear plant accident planning	% population within 10 miles of nuclear power plant	Cutter et al. (2014)
Crop insurance coverage	Crop insurance policies per square mile	Cutter et al. (2014)
Hazard mitigation/	% population covered by a recent hazard mitigation plan	Burby et al. (2000) and Godschalk (2007)
planning	% population participating in Community Rating System (CRS) for flood	Burby et al. (2000)
	% households covered by National Flood insurance Program policies	Godschalk (2003, 2007)
Mitigation and social connectivity	% population covered with Citizen Corps program	Godschalk (2003)
Municipal services	% workforce employed in emergency services (firefighting, law enforcement, protection)	Sylves (2007)
Development	% land cover change to urban areas from 1990 to 2000	Burton (2015)
Political fragmentation	Number of governments and special districts	Norris et al. (2008)
Housing types	% housing units which are not manufactured homes	Cutter et al. (2003)
	% housing that is not a mobile home	Cutter et al. (2003)
Evacuation potential	Major road egress points per 10,000 persons	Cutter et al. (2014)

(continued)

Table 3.4 (continued)

Institutional resilience indicators		
Category	Resilience metric	Data source
Housing stock construction quality	% housing units built prior to 1970 or after 1997	Mileti (1999)
Access and evacuation	Principal arterial in miles	NRC 2006
	Number of rail in miles	Burton (2015)
High speed internet infrastructure	% population with access to broadband internet service	Cutter et al. (2014)
Shelter capacity	% housing that is vacant rental units	Tierney (2009)
	Hotels and motels per square mile	Tierney (2009)
	Fire, police, emergency relief services, and temporary shelters per 1,000 population	Burton (2015)
	% fire, police, emergency relief services, and temporary shelters outside of hazard zones	Burton (2015)
	Schools (primary and secondary education) per square mile	Ronan and Johnston (2005)
Infrastructure exposure	Density of single-family detached homes	Burton (2015)
	% building infrastructure not in flood and storm surge inundation zones	Burton (2015)
	% building infrastructure not in high hazard erosion zones	Burton (2015)

Table 3.5 List of environmental resilience indicators

Environmental resilience indicators		
Category	Resilience metric	Data source
Local food suppliers	Farms marketing products through Community Supported Agriculture per 10,000 persons	Cutter et al. (2014)
Natural flood buffers	Wetlands loss	Gunderson (2009)
Efficient energy use	Megawatt hours per energy consumer	Cutter et al. (2014)
Pervious surfaces	Average percent perviousness	Cutter et al. (2014)
Efficient water use	Inverted water supply stress index	Cutter et al. (2014)
Risk and exposure	% land area that does not contain erodible soils	Cutter et al. (2008)
	% land area not in an inundation zone (100/500-year flood and storm surge combined)	Burton (2015)
	% land area not in high landslide incidence zones	Burton (2015)
	Number of river in miles	Burton (2015)

(continued)

Table 3.5 (continued)

Environmental resilience indicators		
Category	Resilience metric	Data source
Sustainability	% green space/undisturbed land	Cutter et al. (2008)
	% land area with no land-cover/land-use change, 1992–2001	Burton (2015)
	% land area under protected status	Burton (2015)
	% land area that is arable cultivated land	Burton (2015)
Protective resources	% land area that consists of windbreaks and environmental plantings	Burton (2015)
	% land area that is a wetland, swamp, marsh, mangrove, sand dune, or natural barrier	Burton (2015)
	% land area that is developed open space	Burton (2015)
Hazard event frequency	Frequency of loss-causing weather events (hail, wind, tornado, hurricane)	Burton (2015)

3.5 Classification of Indicators

An indicator, as can be inferred, simply "indicates" something or communicates information about a phenomenon of interest, which is called the *indicandum*. This phenomenon is sometimes difficult to analyze, difficult to measure or even it may not be measurable at all (Meyer 2011). Since resilience is difficult to define and analyze, there are several different ways to classify the indicators of resilience. During a classification process different methods, such as spatial scale, temporal scales, hazard type etc. can be considered. The majority of the indicators are time and spatial dependent and are difficult to be transferred from one scale to another. So it is important to distinguish between indicators which are specific to the case study considered and the ones that can be generalized and extended to different hazards, communities etc. (Weichselgartner and Kelman 2014). Another important characteristic of the indicators is their *relation to the phenomenon and resilience*, because it is a prerequisite for measuring resilience in quantitative terms. So it is possible to distinguish between indicators which can not be *ordered* or *ranked* (e.g. gender or hazard type), the ones that can only be ranked (e.g. education level) and the ones that can be ranked and ordered by quantifying the interval between classes (e.g. net income in Euro/year).

3.6 State of Art on Classification Methods

The first comprehensive work on classification about resilience metrics have been performed in the European project EMBRACE (Rodriguez-Llanes 2013) which proposed the following categories:

1. *Inherent or adaptive*
2. *Outcome or process*
3. *Domain*
4. *Relation with the phenomenon*
5. *Composite indicators*
6. *Scale of applications*
7. *Level of measurements*
8. *Resources & Capacities, Actions and Learnings*
9. *Generalization*
10. *Relation to resilience*
11. *General importance*
12. *Pre/Post-hazard event phase*
13. *Qualitative or quantitative*

However, the classification proposed in Embrace presents some limitations, because some of these categories overlap each other and they are not integrated in a useful manner, but they have the advantage of listing a series of characteristics of the indicators.

3.7 Proposed Classification Method

After reviewing the state of the art on classification methods, a new classification method is presented. Through this classification, it is possible to help decision makers in selecting the proper indicators for their problem at hand. This classification will allow them to assess resilience quantification properly and select the optimal resilience strategy. Based on these considerations, the resilience metrics listed from Tables 3.1, 3.2, 3.3, 3.4, and 3.5 have been classified according to 7 categories (or classification methods) below

1. *Hazard Type*
2. *Temporal scale*
3. *Spatial scale*
4. *Building type*
5. *Level of Development*
6. *Domain*
7. *Measurement method*

In the columns of Table 3.6 are shown the seven proposed classification methods, while in the rows are reported the different corresponding classes.

In the following paragraphs are described in detail the different classification methods.

Table 3.6 Classification method in PEOPLES framework

Classification method in PEOPLES framework						
Hazard type	Temporal scale	Spatial scale	Building type	Level of development	Domain	Measurement method
Natural (e.g. flood, earthquake, tsunami fire, tornado, hurricane etc.)	Pre-phase (Prepared-ness)	Building	Critical facility (e.g. hospital, cit-hall etc.)	Developed countries	Social/ Cultural	Quantitative
Man-made (e.g. terrorism, wars, criminality, power outage, etc.)	Short-term (Emer-gency response)	Building block (Neigh-bor-hood)	Residential building	Under-developed countries	Economic	Qualitative
	Long term (Recon-struction phase)	City/ State	No building type	Not in country scale	Ecological /Environmen-tal	
		Region			Governmental/ Welfare/ Institutional	
		Country			Physical/ infrastructural	

3.7.1 Hazard Type

In literature can be found resilience indicators that are just defined for a specific hazard corresponding to the specific case study presented. For example, Kafle (2012) developed a method (CRI) for measuring community resilience using process and outcome indicators in 43 coastal communities in Indonesia. He emphasized that community resilience can be measured, but in each measurement both location and hazard should be specified. It is also obvious that every community according to its geographic location, face with specific natural hazards, so it is essential to cope with them and not with all of the types. This is why considering this category is necessary for the indicators' classification.

3.7.2 Temporal Scale

Resilience, means "the ability to recover from (or to resist being affected by) some shock, insult or disturbance". Recovery is a concept which is intertwined with time.

In this case, resilience can be considered as a dynamic quantity that changes over time. Three temporal levels can be defined:

- Pre-hazard event phase (Preparedness);
- Short-term post-hazard event (Emergency response phase);
- Long-term post-hazard event (Reconstruction phase);

The indicators within the *Pre-hazard event phase* evaluate how much the system, is ready to face unpredictable events. Indicators related to this phase mainly address the reduction of risks and vulnerabilities. For example, the existence of a mitigation plan is an indicator of this category. The indicators within the *emergency response phase* describe the ability and the speed of a system in responding the initial needs after an extreme event. Examples of these systems can be the fire, police, emergency relief services which are vital in the first moments of the turbulence situation. Finally the indicators within the category of the *reconstruction phase*, mainly address capacities to cope after a hazard event, measure the ability and the speed of a system to recover itself and reach its initial condition pre-event. As an example, home ownership, population income and poverty are indicators which affect the reconstruction phase level. It is also possible that some indicators can vary between all the temporal scales, such as population age etc.

3.7.3 Spatial Scale

This classification emphasizes the importance of quantifying place-specific indicators. In fact, the resilience indicators may refer to a small unit of analysis (e.g. single building unit), or can be related to a whole city or nation. This classification divide indicators according to five categories which are:

- Building unit;
- Building block;
- City/state;
- Region;
- Country;

At the *building unit scale* the resilience-based design considerations will be taken into account. For example, access/evacuation potential in buildings depends on the existence of emergency exit. The *neighborhood* is a part of a town or city, such as city center, immigrants quarter etc. The *region* is a part of a country that is different from other parts in some way, such as northern region, which can include some cities. The indicators in each category (neighborhood/city/region/country) are subsets of a larger group. The classification has been made just to facilitate resilience quantification in a proper scale. The first and the last groups will be also divided into smaller scales considering building type and the country level of development.

3.7.4 Building Type

This classification can be split in three groups:

- Critical facilities (e.g. hospitals, city-hall, etc.);
- Residential buildings;
- No building type;

Critical/essential facilities are those facilities that provide services to the community and should be operative after a hazard. They include hospitals, police stations, fire stations, schools etc. Examples of indicators which belong to the first group are for example the accessibility and the special needs for disabled, which is more necessary to take into account for essential facilities than residential buildings.

3.7.5 Level of Development

Two categories can be determined within this classification:

- Developed countries;
- Underdeveloped countries;

This classification is important because some indicators for lifelines (e.g. communication, transportation etc.) all depend on the country‘s infrastructures condition, which is different in *developed* and *under-developed* countries. So this classification affects the resilience assessment, because some indicators might not be applied in underdeveloped countries.

3.7.6 Domains

Indicators can also be classified according to their domains or perspectives. For example there are indicators referring to ecological and social-ecological resilience, psychological resilience, critical infrastructural resilience or organizational and institutional resilience (Birkmann et al. 2012). The categories which belong to this type of classification are:

- Social;
- Economic;
- Ecological/environmental;
- Governmental/welfare/institutional;
- Physical/infrastructural;

Below is given a brief description of each one of this category.

Social resilience: the ability of groups or communities to cope with external stresses and disturbances, such as Child and Elderly Services, Community Participation etc. *Economic resilience*: the ability of the economy to cope, recover, and reconstruct and therefore to minimize aggregate consumption losses. For example the economic development indicators that consist of financial services, industry- employment services and industry production. *Ecological/Environmental resilience*: is the capacity of an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly, such as biodiversity, water and air quality etc.

Governmental/welfare/institutional resilience: In contrast to the more or less spontaneous individual and neighborhood responses to extreme Events, governmental services are designed to allow an orderly response, for example legal and security services such as police, Emergency, and fire departments.

Physical/infrastructural resilience: this dimension focuses on a community's infrastructures, such as transportation, facilities, health care, etc.

3.7.7 Measurement Method

They belong to this classification two categories:

- qualitative indicators;
- quantitative indicators.

Whenever a description is made, qualitative or quantitative assessments are necessary because some aspects in life cannot be measured and shall be described without a scale. These indicators can be used to identify the important constituent characteristics that shape community resilience. However, the use of *qualitative indicator-based approaches* have the limitation that some indicators cannot be extent into further comparisons and it is not possible to generalize because sometimes these indicators propose their own frameworks and rely on specific perspectives. Aspects such as learning, reorganization, risk awareness or willingness are good examples of qualitative indicators. The use of these indicators is due to the fact that community resilience may be understood as a multi-faceted concept that goes beyond isolated capacities and views communities not only in spatial terms, but also recognize common interests, values and social structures (Twigg 2009). So, the disaster resilience community is defined as an ideal state, which in reality is never achievable.

An example of classification for qualitative indicators is to group them based on: *governance*, *risk assessment*, *knowledge and education*, *risk management and vulnerability reduction* and *disaster preparedness and response*. All these indicators include both outcome and process indicators and cover a broad range of topics. This classification has been provided by UNISDR and their "Making Cities Resilient" initiative (UNISDR 2012).

A different classification for qualitative indicators would be to organize the indicators on: organization and coordination, budget and incentives to invest in risk reduction, update data on *hazards and vulnerability, invest and maintain risk reducing infrastructure, assess the safety of critical infrastructure, enforce risk compliant building regulations, ensure education programs, protect ecosystems and natural buffers, install early warning systems* and last but not least, *ensure the needs of the affected population*. This kind of classification is done to address large communities, since most of the indicators focus on critical infrastructures, cover governmental aspects, education and training drills. The "Disaster Resilience Scorecard for Cities" (UNISDR 2012) is a good example of this type of approach. However a more common classification for qualitative indicators would be to gather the indicators in more general aspects such as: *external resources, assets, capacities and qualities*. Typical external resources are connections & information, services and natural resources. The assets can be split on human, social, political, environmental, economic and physical. The basic capacities to be considered resilient are *to be resourceful, to be flexible and to learn.* Finally, a resilient community has assets that are strong, well located, diverse, redundant and equitable. This classification was presented by the International Federation of Red Cross and Red Crescent Societies in 2012 about "Characteristics of a Safe and Resilient Community" (IFRC 2012).

It is important to highlight that is possible to make qualitative indicators "quantifiable". There are several examples published like to use a "structured subjective" method (Forrester et al. 2015), coding schemes, to derive proxies or to use rating scale. However, it has to be noted that despite transferring qualitative indicators into quantitative metrics, the underlying information remains still subjective.

Qualitative indicator-based approaches take into account that resilience is a dynamic and multi-faceted concept that relates to multiple levels. Most approaches also define communities not only in spatial terms, but equally consider social and societal factors such as common interests and values of communities. These go beyond basic resources, capacities or assets of a disaster resilient community by identifying important qualities and processes.

On the other hand, *quantitative indicators* provide concrete metrics that are provided with data sources, justifications and sometimes the relationship to resilience. Aspects such as equity, diversity, efficacy, participation, coordination and communication are central pillars of such approaches indicators. The typical use of these indicators are single values that are added to a composite indicator, what makes them an attractive tool for informing the decision making process. However since not always is possible to quantify actions or aspects, quantitative indicators usually rely on proxy indicators, since often represent the only way to cover specific aspects of community resilience. One condition for quantitative indicators, in contrast to qualitative indicators, is that they have to be fully operationalized. For example, the indicator "percentage of citizens with access to a 4G connection mobile phones" is a fully operationalized quantitative/objective indicator, whereas "trust in politicians" is an example of qualitative/subjective indicator covering individual judgment or perceptions. One case of quantitative indicators

is to align them into domains such as social resilience (income and educational equality, presence of civic organizations, disaster volunteering, community health, well-being, equity...), economic resilience (livelihood stabilities, resource diversity...), community capital (as place attachment, political engagement, relationships between individuals...), institutional resilience (insurance coverage, disaster aid experiences, local disaster trainings, hazard mitigation and planning, urban development...), housing/infrastructural resilience (housing types, health care facilities, communication and transportation networks) and environmental resilience (risk and exposure, presence of protective resources, sustainability...) (Cutter et al. 2014). Another good example of quantitative indicator is the proposed by Cimellaro et al. (2015) to obtain a new resilience index for urban water distribution networks. This study proposes an index based on the product of three indicators: one describes the demand and is based on the number of users temporary without water; the second describes the capacity and is based on the tank water height; the third is based on the water quality. The first index is based on different indicators as number of households without water service, water volume, intensity, control time. The second one, related with capacity, takes into account the tank water level, the reserve capacity of the tank and the number of tanks. Finally, the index that estimates the quality of water uses qualitative indicators before and after the disruptive event. These indicators will help planners and engineers to evaluate the functionality of a water distribution system which consists in delivering a certain demand of water with an acceptable level of pressure and quality. The quantitative indicator-based approach provide concrete metrics which are able to cover different perspectives of community resilience.

3.8 Aggregation of Indicators

Typically the result of an analysis with different indicators, no matter the classification, is a **composite indicator** rather than numerous discrete indicators, since is easier to comprehend to the general public and to the policymakers as well (OECD 2008). Therefore decision makers request the aggregated results in most cases. The aggregation of indicators can support the illustration of a complex and multidimensional problem. In addition, the step of aggregation is combined often with a *weighting factor* for each indicator. Different weights might influence the aggregation results to a smaller or larger extent, generating a loss of underlying information. Moreover, when dealing with complex phenomena, a combination of individual components means often to compare datasets that have been generated from data sources of various statistical and scale levels. Therefore, the decision whether to aggregate should be carefully considered. The purpose of the study should be taken always into account, since is the main criterion. An aggregation may be useful if the outcome is intended to identify hot spots or to support the allocation of resources based on the comparison of different regions or communities. However, when the study main objective is to identify those aspects that lead to low resilience or has the main aim to develop strategies or select future activities to

increase resilience, the step of aggregation may be disregarded in favor of a more holistic view of how the disaggregated indicators fit into the bigger picture.

Whenever an aggregation is carried out it is absolutely necessary to make transparent which methodology has been applied and with which weight each individual indicator has contributed to the overall result. It is also highly recommended to keep hold of the information of the underlying individual components to be able to explain the reasons behind aggregating results.

3.9 Selection of Key-Indicators for Specific Case Study

The classification methods given in Sect. 3.7 may be used to select the *key-indicators* for a specific case study (e.g. building, community, etc.) from the list given in Sect. 3.4. Then in detail, the *key-indicators* are defined as indicators that:

- *are rated with a high importance by the case studies;*
- *are universally applicable;*
- *show a clear relation to resilience;*
- *were mentioned by more than one case study.*

Once the characteristics are established, a list with all the important indicators is ready to be composed. Some important indicators might not be considered in this list due to the applied criteria (especially the criteria "mentioned by more than one case study" reduces the list significantly), but this way of filtering allows communities to create a list of indicators that is concise and substantive.

3.10 Potential Challenges of Community Resilience Assessment Using Indicators

There exist potentials and advantages of *indicator-based approaches* for assessing community resilience and presents indicators that enable transferring theoretical and conceptual considerations into specific applications. The theoretical basis for grounding the indicators resides in the theory of change held by case study practitioners. These indicators can be classified or systematized in different groups for an easy understanding.

Community resilience is sometimes considered as a dynamic and steadily reshaping process that can be neither assessed through a static snapshot in time nor, alternatively, by considering "the resilient community" as an achievable end goal. Going beyond the assessment of only that which is simply measurable, it is aimed at capturing community resilience in its constituent facets including transformative aspects of resilience as well as different perspectives of communities.

Indicator-based approaches for assessing resilience are promising tools, because they allow – when evaluated at regular intervals – monitoring changes over time in both magnitude,direction and space (Cutter et al. 2010). They allow identifying

the major weaknesses or drawbacks of resilience. Resilience indicators help setting policy priorities, allocating resources – financial, personnel, technical, etc. – before and after a hazard event and evaluating the effectiveness of risk reduction efforts or emergency activities. The use of *qualitative indicators* for constant comparison and evaluation of changes in the spatial and temporal domain is more difficult than with *quantitative indicators*, because the data are subjective.

3.11 Relationship Between Vulnerability Indicators and Resilience Indicators

Resilience and *vulnerability* are related terms, even though the relationship between both concepts is not clearly defined.

Vulnerability focuses more on static stressors such as the exposure and sensitivity, and, respectively the hazard, exposure and disaster risk of the system, while resilience is a dynamic concept which adds transformative aspects such as learning, critical reflection or re-organisation.

Whereas research efforts on *vulnerability indicators* have increasingly provided useful indicators that are being applied in different fields of application (e.g. climate change vulnerability, hazard mitigation planning, social vulnerability etc.), the research efforts in *resilience indicators* is relatively slow due to the challenges that occur when implementing operational frameworks of resilience, and to the transformative nature of resilience.

3.12 The Progress of Grounding Indicators Set

Indicators can be grouped taking into account several aspects such as: the indicator title, the type of measurement used, the relationship of the indicator to resilience, the methods of data collection, the scale of application, the context- and hazard-specificity, the effort of indicator development and an evaluation of the overall importance of the indicator for determining resilience.

One of the main challenges of the indicator analysis is to synthesize the indicators identified by the different case studies, since they may differ considerably in terms of the applied scales, methods of data collection, types of natural hazards, and perspectives of community resilience. Some of the indicators for example may be related to the individual scale and be measured through interviews or questionnaires (e.g. “Belief in”), while others apply at the community scale and have to be measured with quantitative survey or existing statistics (e.g. “% of”). Therefore, first, it is useful to distinguish the indicators according to some criteria distinguishing indicators that can be measured with the help of qualitative research methods from indicators that can be better measured with quantitative methods; and also separating the indicators that can be applied across contexts from indicators that have to be used with local-context or hazard specificity.

3.13 Examples of Measurement Methods

In Table 3.7 is given a list of the different measurements methods to assess resilience categorized according to its *type*, the *spatial scale* and the *method*. Communities employing a bottom-up approach can develop or adapt simple measurement schemes to gauge their own baselines, capacities, assets or some combination of these. State and federal entities can equally develop comparative assessments of

Table 3.7 Methodologies to evaluate resilience

Measure name	Type	Spatial	Focus	Method
APIRE	Tool	Country	Whole community	Top down
BRIC	Index	USA counties	Whole community	Top down
CART	Tool	Community	Whole community	Botton up
CC RAM	Tool	Community	Whole community	Botton up
CDRI	Index	USA coastal counties	Whole community	Top down
Coastal Resilience index	Score-card	Community	Whole community	Botton up
CoBRA	Tool	Community	Whole community	Botton up
Community Resilience system	Tool	Community	Whole community	Botton up
Community Resilience index	Index	Community	Asset	Top down
CREAT	Tool	Infra-structures	Whole community	Top down
DFID Resilience	Tool	Country	Whole community	Botton up
FAO Livelihoods	Index	Community	Asset	Botton up
Financial system Resilience	Index	Infra-structures	Asset	Top down
FM Global Resilience	Index	Infra-structures	Whole community	Top down
NIST	Tool	Infra-structures	Whole community	Top down
Oxfam GB	Index	Community	Whole community	Botton up
PEOPLES	Tool	Community	Whole community	Top down
RCI	Index	USA metro areas	Asset	Top down
ResilUS	Tool	City	Asset	Top down
RMI	Index/Tool	Infra-structures	Whole community	Top down
Rockfeller 100 Resilience cities	Tool	Community	Whole community	Botton up
RRI	Index	Community	Whole community	Botton up
SPUR	Score-card	Community	Asset	Botton up
Surging Seas	Tool	USA coastal countries	Whole community	Top down
TNC Coastal Resilience	Tool	Coastal areas	Whole community	Top down
UNISDR Resilient cities	Tool	Cities	Whole community	Botton up
USAID Resilience	Tool	Countries	Whole community	Botton up

baseline or capacity indicators, but these must be approached differently and use consistent types of data to standardize the inputs. The progresses in enhancing resilience will generate changes in policy at local, state, and federal levels and within the public and private sectors. Such changes will require the development of a new set of tools and indicators that are co-produced and address the social dynamics and decision making within communities, as well as assessing baseline conditions and capacities in short, medium, and long terms.

3.14 Remark and Conclusions

Measurement tools and indicators cannot create a resilient community, but they can assess resilience and provide a community the directions for becoming safer, stronger, and more vibrant in the face of unanticipated events. This chapter emphasizes that it is important to decide and establish a norm to classify the indicators, but this classification can vary throughout the different case studies and/or projects. Several classifications are presented showing that there are many options available, so the more suitable classification should be determined based on the parameters that are going to be analyzed.

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