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# Indicators in risk management: Are they a user-friendly interface between natural hazards and societal responses? Challenges and opportunities after UN Sendai conference in 2015

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ABSTRACT

Risk management indicators are used to mitigate the potentially dramatic effects of natural hazards. Local authorities and managers use them in elaborating rescue and urbanism plans, which do not always work, highlighting society's vulnerability in the particular context of global environmental and climate changes. Within this context, the United Nations (Sendai, 2015) advised to construct a series of indicators to better cope with human losses and economic disasters. Actually, the question is whether or not such indicators do constitute successful decision-making tools. In this article, we critically reviewed the recent literature (from 2013 to 2017) using the Web of Science database of *Clarivate Analytics* to assess how indicators are currently being constructed in risk management, with a focus on risks of inundations, coastal and seismic risks. This task allowed us to discuss the spatial and temporal scale at which indicators of risk management can be applicable, to what extent they should be physically oriented and if they can fit the needs of governance framework. Based on our findings, we suggest further work on a new series of less descriptive, more dynamic and more user-friendly indicators. Finally, we encourage the dire need for continuous work to overcome the misinterpretation of used indicators and how to reduce the communication gap between the scientific community, decision makers, managers and the population.

## 1. Introduction

Every year the world feels new burdens due to either climate-related or telluric natural hazards with strong societal, economic, and environmental issues. In 2017 alone there were 318 disasters recorded, with 9503 deaths, 96 million people affected, together with 314 billion dollars of economic damage, making it the second most costly year ever [1]. For decades, it has broadly been acknowledged that the disasters that cause human and economic losses are not only natural, but depend on the social conditions of the areas where natural hazards occur [2]. In order to make society respond more efficiently, and to tackle the increasing losses, the United Nations (UN) developed disaster risk management plans to set goals and objectives for reducing risks associated with natural hazards. After the International Decade for Natural Disaster Reduction (1990–1999), disaster risk and risk management expectedly attracted more attention worldwide. One of the frameworks developed was that from the "Program for Latin America and the Caribbean", which, in addition to relative indicators at the national level, included a limited number of aggregate indicators to serve policy makers. Four composite indicators were used to measure each country's progress in risk management and its proposed monitoring tool for risk management is still used in modified form on national levels [9,100,101]. On a larger, global scale, the first framework for disaster risk reduction, i.e., the *Hyogo Framework for Action 2005–2015*, was adopted. The five priorities for action were: ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation; identify, assess, and monitor disaster risks and enhance early warning; use knowledge, innovation, and education to build a culture of safety and resilience at all levels; reduce the underlying risk factors; strengthen disaster preparedness for effective responses at all levels [108]. Among its identified shortcomings was the need to encourage a mutual responsibility for disaster resilience at all levels [88], which was

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hopefully overcome in the most recent plan, i.e., the *Sendai Framework for Disaster Risk Reduction 2015–2030* [3].

The Sendai Framework aims at achieving a significant reduction of disaster risk and losses during a 15-year-period and consists of seven global targets, which are proposed to reach the goal by using appropriate indicators. There are four priority areas for action: better disaster risk knowledge, improved risk governance and management, new research into resilience practices, and improved post-disaster and recovery phase. The missing gap on mutual responsibility from the Hyogo Framework is now addressed, but with subsisting doubts on how to implement it [88]. The Sendai's flaws are the lack of the targets that specify a measure of improvement in disaster risk to be made, first five years are meant to serve as period to put together disaster risk reduction strategies, and sometimes the objectives are expected to be attained on a global level [71]. The proposed indicators mainly apply to the monitoring of national policies and carrying out the Sendai policy, rather than the implementation of local strategies [4,105]. The key objective of adapting the framework for local contexts has recently been addressed [88,92], coming from the positive example of increased resilience to floods and droughts in Peru, where the teams of locals worked together with external researchers to identify vulnerabilities and possible solutions [92]. Similarly, measuring societal resilience at country level (Germany) is underlined as problematic for local level assessment since demographic information cannot be profound [107]. These examples of governance and institutional arrangements put back on stage the bottom-up arrangements (participatory approach derived from a common work of a group of involved members of society, conversely to top-down arrangement decided from above) for management that better suits different local contexts [92]. Finally, seeking for Sendai's framework to succeed, the open-source knowledge transfer of reviewed information on disaster risk reduction from researchers to practitioners has to be established [104].

The UN also calls for a better dialogue between experts and civil society (the community flow) and, since the key terms like *disaster risk, hazards, vulnerability* and *resilience* used in the literature are sometimes differently defined, it recommends the use of a defined terminology related to disaster risk reduction as it follows. The UN defines *hazards* as processes that may negatively affect humans physically, socially and economically or through an environmental degradation, with either natural, anthropogenic or socio-natural origins. *Vulnerability* is the condition that increases the human susceptibility to the impacts of hazards. *Disaster risk* is determined probabilistically as a function of hazard, vulnerability, exposure and capacity. Complimentary to vulnerability, *resilience* is the ability to recover from and adapt to the impacts of a hazard in a timely and efficient manner. Surprisingly, among 38 defined terms in the UNISDR report on indicators and terminology relating to disaster risk reduction, the term *indicator*, widely understood and used by the risk managers, is not among them [3]. Therefore, we decided to pay attention to indicators themselves as a key tool in disaster risk management.

**Table 1**
Articles dealing with indicators and vulnerability or resilience, and additional alternating entries (see text).

| | | Natural hazard | Natural risk | Natural disaster |
|---|---|---|---|---|
| Number of papers | All years (1975–2018) | 224 | 326 | 220 |
| | 2013–2017 (% of papers from the chosen interval) | 172 (76.8%) | 237 (72.7%) | 176 (80%) |
| Number of papers with the term "indicator" in the title | All years (1975–2018) | 32 | 46 | 29 |
| | 2013–2017 (% of papers from the chosen interval) | 27 (84.4%) | 39 (84.8%) | 25 (86.2%) |

The term indicator is widely used by different branches of science, from mathematics and economics to natural sciences, but also in engineering or policy-making. For example, indicators are common in territorial and environmental planning, standing for a measure of environmental properties [5]. For instance, vulnerable species are an indicator allowing evaluating the quality of a marine environment [6]. To use indicators as a clear basis for decision-making, it is needed to precisely define what the term "*indicator*" means in our specific context of research [5]. As stated in the book edited by Jörn Birkmann [8], different authors would define indicators differently. Birkmann defines the vulnerability indicator for hazards of natural origin as "a variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural origin" [8]. Additionally, in risk management, every measure of environmental, social or economical phenomena used to evaluate or to set environmental, social or economical changes and goals could be considered as an indicator [5,9].

But an indicator is not only a variable; it is also often a combination of variables. An indicator is above all the quantitative or qualitative translation of the state of a concept or a phenomenon. The main characteristic of an indicator is to "simplify" the information, to make it more compact to allow a better understanding of the phenomenon, especially for a non-specialist audience. The indicator is also a replicable element that can be used to track a phenomenon in time and space. In the field of natural hazards, the composite characteristic is of special importance, since it makes it possible to combine physical, social and economic variables to evaluate a state, like for example the level of risk, and the recovery after the risk. It thus allows better preparing systems for much more effective surveillance and warning. Nowadays, managers need control instruments. Since indicators somewhat guarantee decisions' fairness and rationality, thus allowing negotiation, their control constitutes one of the main stakes of risk management [7,76].

To take into account human welfare, disaster risk management should, however, be parameterized using more sensitive and sensible indicators [10]. Within this context, since indicators are designed to comply with the application of the Sendai Framework [11], the question is whether or not they respond to the societal need of serving as decision tools, that is to say, to reduce impacts and to facilitate the resilience of societies. Do they remain useful to policy makers to inform and attend the well-being of general population, as they are meant to? Since risk is a cross-sectoral domain between natural and social sciences, there is indeed a dire need to integrate different parameters into a global approach that should be comprehensive for all the actors involved, and allowing identifying reliable indicators related to multiple risks [12], which are not just the sum of single hazards [96]. It is, thus, important to clearly define which risk components are used in the analysis [93], and it would be necessary to include all multiple dimensions of risk in the assessment. Different societies face different risks and, although they sometimes face the same hazard (i.e., floods), societies do not have the same level of vulnerability and resilience confronting it (e.g., Bangladesh versus the USA [97]). This contributes to plenitude of indicators used in description of hazards, and even more of indicators describing societal vulnerability. The rising questions are, therefore, whether the indicators are useful, how are they used and is it rational to seek holistic or universal indicators.

In this review we respond to these questions thanks to an analysis of the literature, evaluating how the authors construct and use indicators. We focus on frequently used indicators in natural hazard assessment concerning large catastrophic events and we answer questions arising from this assessment regarding the spatial and temporal scale and the social and environmental nature of indicators used.

## 2. Methods: data source and papers selection

For the selection of papers to be included in our bibliographic

**Table 2**
Studies specifically using indicators 2013–2017.

| Nb | Author(s), year | Case study/review | Type of indicators used/Terminology | Hazard/Topic |
|---|---|---|---|---|
| 1 | Asadzadeh et al., 2017 [13] | Review | Composite indicator building for community disaster resilience; indicators vs. factors (components) | / |
| 2 | Murgante et al., 2017 [14] | Case study (Iran) | Indicators evaluated according to five dimensions: economic, social, political, physical and operational index; indicator ~ index | earthquakes |
| 3 | Fatemi et al., 2017 [15] | Review (Iran) | Valid and useful indicators of the social vulnerability in disasters; indicators vs. variables | / |
| 4 | Minos-Minopoulos et al., 2017 [17] | Case study (Greece) | Archaeological Site Vulnerability Index; index > indicator > factor | earthquakes |
| 5 | De Ruiter et al., 2017 [20] | Review | Physical vulnerability indicators grouped in three categories; social ones in four | earthquakes and floods |
| 6 | Calo-Blanco et al., 2017 [21] | Case study (Chile) | Indicators to measure social cohesion; indicators ~ variables | earthquakes |
| 7 | Papathoma Köhle et al., 2017 [89] | Review | Indicators for debris flow physical vulnerability assessment of buildings | debris flow |
| 8 | Sena et al., 2017 [90] | Case study (Brazil) | Vulnerability and hazard indices based on two variables each, exposure based on one variable. | drought |
| 9 | Barrantes-Castillo et al., 2017 [31] | Case study (Costa Rica) | Affectation indicator for natural hazards, based on indicators of direct and indirect affectation; indicators vs. variables | multiple |
| 10 | Doorn, 2017 [34] | Review | Discuses resilience indicators, uses example of [102] to show social resilience being valued, with 7 social categories; indicators vs. variables | / |
| 11 | Jülich, 2017 [35] | Case study (Switzerland) | Three local-level partial indicators for community resilience with stages of indicator operalization; indicators vs. variables (parameters) | floods |
| 12 | Kuentz-Simonet et al., 2017 [38] | Case study (France) | Social vulnerability, quality of life indicators; indicators vs. variables | climate change |
| 13 | Pandey et al., 2017 [39] | Case study (India) | 44 indicators selected for each dimension of vulnerability and for each capital; indicators ~ variables | climate change |
| 14 | Xie and Zheng, 2017 [40] | Case study (China) | Comprehensive indicator of climate adaptability with five factors and for each factor 3–4 single indicators; comprehensive indicator > factor > indicator | climate change |
| 15 | De Almeida et al., 2016 [22] | Case study (Brazil) | DRIB Index (based on WorldRiskIndex): four indicators describing the exposure; vulnerability based on 32 societal indicators; index ~ indicator, indicators ~ variables | landslides, floods, droughts, sea level rise |
| 16 | HS Chang and Chen, 2016 [24] | Case study (Taiwan) | Seven indicators in vulnerability (positive and negative), six in resiliences | floods |
| 17 | Nguyen et al., 2016 [28] | Review | Coastal (social) vulnerability index based on both physical and social parameters, as in literature; indicators vs. variables (parameters) | coastal |
| 18 | Cutter, 2016 [32] | Review | 27 disaster resilience assessment approaches, each evaluated using four main attributes; indicators (concepts, attributes) vs. variables | / |
| 19 | Amjath-Babu et al., 2016 [91] | Case study (Sub-Saharan countries) | Agricultural transition, multi-dimensional transition index and constituent intermediate indices; domains of indicators with constituent sub-indicators | groundwater |
| 20 | Khalili et al., 2015 [23] | Case studies (Australia) | Extracted and assessed social resilience indicators classified for each phase of disaster: pre-disaster, response and recovery; indicators (qualitatively) | floods |
| 21 | SE Chang et al., 2015 [29] | Case study (Canada) | Hazard Vulnerability Similarity Index: the framework around major types of capital: 20 indicators (each with only 1 variable selected); indicators vs. variables | coastal |
| 22 | Siebeneck et al., 2015 [33] | Case study (Thailand) | 25 variables grouped in four factors; variables selected to serve as indicators of resilience; factors (indicators) ~ variables | floods |
| 23 | Asare-Kyei et al., 2015 [37] | Case study (Ghana-Benin-Burkina Faso) | Participatory indicator development: 50 indicators selected in all three countries at the local level, 42 indicators at the national level; indicators vs. variables | multiple |
| 24 | Eidsvig et al., 2014 [19] | Case studies (6, Europe) | Socioeconomic vulnerability estimation, with the criteria for indicators' ranking; indicators ~ variables | landslides |
| 25 | Holand, 2014 [26] | Case study (Norway) | 9 lifeline vulnerability indicators addressing level of exposure; lack of redundancy; travel time or distance. | lifelines |
| 26 | Lee, 2014 [27] | Case study (Taiwan) | 13 social vulnerability indicators; indicators ~ variables | floods |
| 27 | Loomis and Paterson, 2014 [30] | Case study (USA) | Five report card level ecosystem services with their corresponding indicators; indicators vs. variables | coastal |
| 28 | Tonmoy et al., 2014 [36] | Review | Methodological challenges facing indicator-based vulnerability assessment; indicators ~ variables | climate change |
| 29 | Imbrenda et al., 2014 [94] | Case study (South Italy) | Structural, biophysical and socio-economic indicators in an upgraded environmentally sensitive areas model. | soil and land degradation |
| 30 | Naumann et al., 2014 [95] | Case study (Africa) | Composite drought vulnerability index, consisted of 4 components and in total 17 variables | drought |
| 31 | Nguyen and Corotis, 2013 [16] | Review | Social, corruption perception index for society development indicators | earthquakes |
| 32 | Grozavu et al., 2013 [18] | Case study (Romania) | Physical quantitative indicators (distance from landslides and riverbanks, water level growth and service capacity of roads); indicators vs. factors | landslides and floods |
| 33 | Lung et al., 2013 [25] | Case study (Europe) | Indicator constructed of hazard and demographic variables, indicators vs. variables | heat stress, floods and forest fires |

analysis, the multidisciplinary science catalogue Web of Science database was used. In order to obtain as many papers as possible in line with this survey, the following keyword searches were performed based on the topic: "vulnerability" OR "resilience" AND "indicator", with the third alternating entry "natural" AND "risk", "natural" AND "hazard", "natural" AND "disaster". In addition, research with the keyword "indicator", this time based on the article's title, was carried out, in order to particularly analyse papers that critically valuate indicators. To limit the results to peer-reviewed, published works, the search was restricted to scientific articles and reviews. Finally, to evaluate any impact of the UN Sendai conference, we focused only on two years before and after the conference, collecting papers from 2013 to 2017. Actually, we consider that this five-year-interval is the most relevant, since the majority of all papers found were published during this period (Table 1).

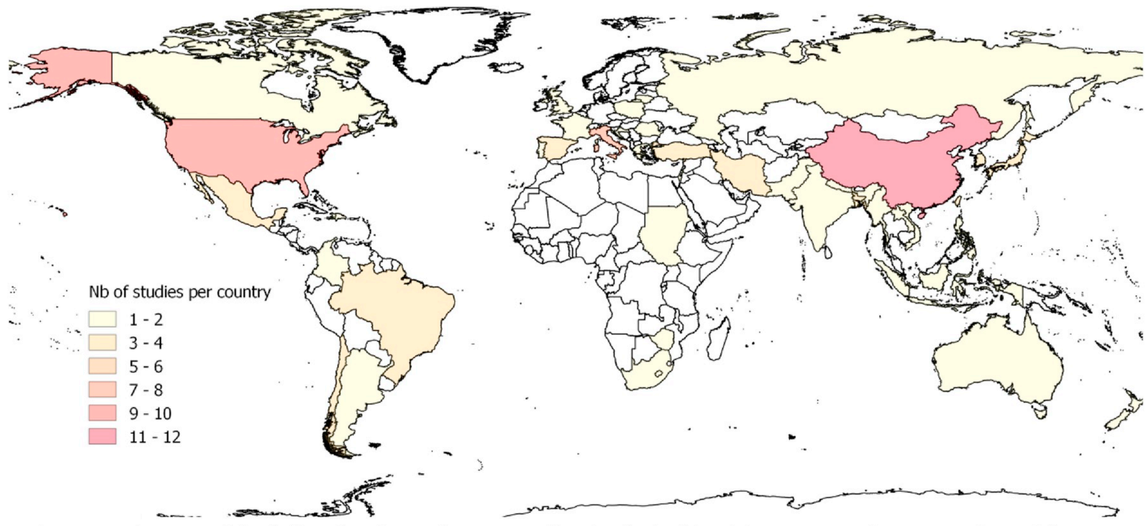


**Fig. 1.** Geographical distribution of case studies included in this survey. The countries with most case studies are China (11), USA (9) and Italy (7).

Since the amount of sampled papers is unlikely to be the sum of the three searched terms due to overlapping, the next step was therefore to identify those that belong to the three different sets, representing an intermediate set of articles.

The papers were studied bearing in mind the three following questions:

(1) Are the constructed indicators globally or locally oriented and are those choices justified?
(2) Which indicators are used and are they in line with UNISDR recommendations?
(3) What is the approach in using indicators for dealing with different time scales?

## 3. Results

Among 250 studies, we focused on natural hazards and excluded those related to human health and diseases, biodiversity of flora and fauna, fishing and industrial pollution issues. Those papers including the term "indicator" in their title were considered a priority (33 articles), expecting that such articles should be narrowly focused on its usage in risk management (listed in Table 2).

Furthermore, from the period of interest (2013–2017), the case studies were allocated according to the main topic of research and to their region of study. We decided to further focus on three different groups of natural hazards: earthquakes and seismic risk, floods and inundation risk, and coastal risk (tsunamis, coastal storms, erosion), for their interconnections and nature of being large catastrophic events. Among them, 26 case studies were related to seismic risk, dealing with geographical areas that are notorious for large and/or frequent earthquakes, with significant number of victims and economic losses: the Caribbean Sea (Dominican Republic and Haiti), Chile, Italy, Romania, Turkey, Iran, China, Japan and New Zealand. Secondly, 37 case studies were related to flood risk spread over all continents. Finally, among 37 articles dealing with coastal risks, most of them were related to North and South America and Asia, which made a total of 100 case studies. The geographical distribution of case studies is presented in Fig. 1.

Finally, to maintain a certain geographical consistency and aiming at finding a generalized approach in dealing with indicators, 35 out of 100 geographically widespread studies were chosen, to keep the survey within manageable proportions. Some of the studies included several countries at the same time or were at a broader regional level. However, our focus was on those case studies dealing with more than one risk. These 35 case studies plus the 33 initially retained papers on indicators gave us a final set of 68 studies.

### 3.1. Indicators used in natural hazard assessment

#### 3.1.1. On adopted terminology while using the indicators in natural hazard assessment

Although indicators are key tools for measuring vulnerability since the Hyogo Framework for Action (2005) and although there is a broad theoretical reasoning on the usage of indicators, different authors may define indicators differently [8], and our database reflects this general current situation. There is an overlap of the terms "indicator" and "index", as well as terms that serve in constructing indicators, such as "variable", "factor", and "parameter" (Table 2). For example, in the study [95] the authors construct composite drought vulnerability index/indicator using seventeen variables/factors/indicators, which noticeably demonstrates the overlapping of these terms. The absence of universal definition of indicators is theoretically discussed in Ref. [34], with a proposed definition of indicators from Ref. [32] being "quantifiable variables that represent a selected characteristic of resilience […]", with the equivalence between "indicator" and "concept". A substantial number of studies also considers indicators as "variables" (e.g. Refs. [20,21,26]). For example, in Ref. [27], it is specified that "the indicators become variables when taken from the literature, modified and applied to the empirical study", and in Ref. [33] that the "25 variables were selected […] that served as indicators of resilience". In some studies, "indicator" is a higher term than "variable", and is described by a set of variables, like in Refs. [15,35] or [40].

#### 3.1.2. Seismic risk

Earthquakes are one of the best assessed natural hazards in terms of physical vulnerability, with recent efforts to improve the social vulnerability as well [20,41]. The hazard indicators used for seismic risk assessment are related to the structural characteristics of the active faults (length, segmentation, seismogenic depth) or expected, maximum magnitude, recurrence time between two events, date of the last event (instrumental, historical or paleo-seismological). In addition to seismicity (seismic risk categories, disaster probabilities, number of hazards), other hazard indicators used are related to terrain (terrain landslide susceptibility) [42,43].

The vulnerability indicators are related to the state of buildings (i.e., age, material used, number of floors, walls area, thermal rehabilitation, the state of the structure), and systemic indicators (building density, distance to hospitals and emergency services) [42]. The final group are socio-economical indicators, which are demographic, with a focus on how to integrate social vulnerability into the seismic risk analysis [44]; how to characterize the specific risk based on economic and human loss [45]; how to include the community participation and environmental policies in community disaster resilience [43]; and how to combine physical risk with social fragility and lack of resilience in an composite indicator of urban seismic risk index [46].

#### 3.1.3. Risk of inundations

Floods are climate-change related natural hazards which vary in spatial and temporal scales according to river basin size and climatologic dynamics [47]. In the light of the population and economic changes, the societal vulnerability is increasing (the worldwide expenses for weather-related hazards and human losses from storms and floods have increased in the last 40 years and it is expected that 1.3 billion people will be living in the 1/100-year flood zone in 2050 due to population growth). Within this context, space and time relationships should be considered for any efficient evaluation of the flood (or other climate-change related) risks [48,49,98]. In addition, according to the IPCC 2014 report, climate change and sea-level rise are likely to intensify flood risk in the future. What remains a major challenge is the adjustment of vulnerable populations to new flood risk evaluation under different climate change and the sea-level rise scenarios [48]. Finally, research on floods is one of the positive examples of interdisciplinary gap reduction between social and natural sciences. Indeed, socio-hydrology integrates hazard and vulnerability paradigm in order to move forward in understanding of socio-natural interactions, all for an objective of improved impact of the UN Sendai Framework and of disaster risk reduction in general [97,99].

The hazard indicators are related to rivers (the generic environmental flow indicator, the floodplain inundation indicator and the river habitat availability indicator) [49], rainfall (the number of days with rainfall, the total rainfall, the maximum intensity, the average intensity, the rainfall intensity and the accumulated rainfall) [50] and the return interval of floods and the erosion (the mean annual soil loss) [53]. On the other hand, the vulnerability indicators are related to flood exposure (the number of people in an area at risk, the land cover, the density of exposed assets, the share of exposed assets) [47,51,103], the maximum possible damage of flooding [52] and the expected annual damage of flooding [54], and finally there is also a need to include human decision making as part of an updated flood risk analysis [48].

#### 3.1.4. Coastal risk

Coastal risk is both non-climate and climate related, the former in the form of tsunamis (as a consequence of an earthquake offshore, related to volcanic activity or submarine landslides), the latter as a consequence of coastal storms and flooding, sea-level rise and erosion [28].

The hazard indicators related to coastlines are: geomorphology, erosion rate, sediment budget [55,59], coastal slope, as well as elevation and distance to the sea [56–58]. In addition, the indicators of coastal storm hazards are: storm waves effects [55], distance to sea [56,58], relative sea-level rise, mean tidal range, mean significant wave height [57], depth and extent of inundation and overwash [59], highest storm surge level, exceeding value of warning water level, and average slope of the storm surge landfall position [61]. Finally, hazard indicators could be even more specifically constructed, such as indicators of shoreline (the previous high tide high-water level, the wet/dry line or run-up maxima) [60].

On the other hand, the vulnerability indicators are social and demographic [55–58], related to building and tax assessment [58], land use and cover [55,58], artificial beach nourishment and beach control structures [57], and finally experience and perception of risk, as well as the household and communal risk adaptation strategy [56].

### 3.2. Indicators are more often used on a global space scale than on a local one

As far as logical argumentation of indicators is concerned, the majority of 33 selected studies do specially argue their usage as a key management tool, stating that the proposed indicators are found in the existing literature or coming from the own authors' expertise. As asked in Ref. [13], the question is whether or not the common indicators that are used nowadays correspond to managers' needs? In the review [15], the authors underline that only a few studies tried to validate the used indicators of social vulnerability. As stated in Ref. [39], the used indicators are based on existing literature and on experience of the authors, which is in line with the remark by Ref. [28] that selection of indicators is seldom based on objective criteria and mainly on the common sense of the authors. As shown in the review [13], the majority of selected disaster resilience assessments are developed based on a non-participatory method. This is confirmed in an African case study [37] where the authors showed that there is a gap between top-down and bottom-up perception, inviting a closer collaboration between them by putting more emphasis on local knowledge, and drawing the justification that the world needs a local scale for each and every unique case [37]. A similar call for local approaches comes from the Brazilian and Swiss case studies, where the latter resolutely states that it is impossible to make global indicators that actually work [22,35]. In addition, the Canadian case study proposes the Hazard Vulnerability Similarity Index which uses the local knowledge by comparing similarity between different sites, since learning is of key importance to resilience [29]. Finally, the traditional knowledge, possessed by local communities, should be merged with scientific tools to bring better understanding of local risks and more efficient risk management [90].

The examples from the additional case studies confirm that the local community is an indispensable agent in post-disaster reconstruction, as in the Chinese earthquake-related study focused on the NGOs collaboration [62]. To integrate psychological and governance indicators with the traditional ones [63], included only those factors that local decision makers have a direct influence on, that is to say focusing on community and household levels. Case studies from Romania [64], Laos [65], Bangladesh [66] and Saudi Arabia [67] all implemented the local scale dimensions of vulnerability or resilience in their studies. Additionally, three parallel studies from Canada, the UK and Spain [68] demonstrated that local environmental context is the main contribution to the perception of environmental risks. Similarly to this study's [37] conclusion that the global and local approach have to be more coupled, in Ref. [69] the authors analyzed one top-down and another bottom-up case study and summarized that the local aspects are equally as important as global approaches for trustworthy scenarios of vulnerability.

Other important remark comes from the way case studies are held. If we look at the sample of 33 articles on indicators, there are 9 reviews and 24 case studies. However, among those case studies there are only two studies that actually included fieldwork on terrain (Greece [17] and Romania [18]), and three studies whose fieldwork was in the form of practical workshop with different managers and experts (Australia [23], USA [30], West Africa [37]). The other case studies were focused on a theoretical approach by using indicators in risk management, like statistical analysis of the available data and modeling.

### 3.3. Indicators are predominantly related to vulnerability and not to hazards

Following UNISDR, the improved criteria for disaster risk management include built resilience of communities to disasters [70], where the constant monitoring of risk is required and where the progress has to be measured in terms of changes in risk [71]. Among the targeted articles only six studies dealt with UNISDR Sendai lines and advices. The study [22] focused on understanding of disaster risk in Brazil (Sendai's

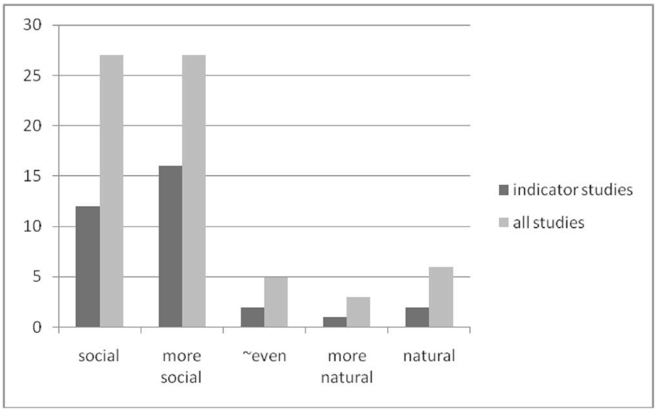


**Fig. 2.** Social indicators are significantly more frequently used than natural indicators, which is evident both from the initial "indicator" set of articles (in dark), and from the set enlarged by additional case studies (in light).

priority 1), the review [32] identified 27 disaster reduction assessment approaches according to Sendai policy, and the review [20] updated the practice by new approaches, offering improvements in both earthquakes and flooding by comparing their vulnerability indicators. The study [90] hopes that its risk index would be useful in addressing some of Sendai's priority areas related to drought and health [89], that the combination of approaches to assess physical vulnerability to debris flows would contribute to the resilience of mountain areas, and [40] is the only case study implementing Sendai regulative, carrying out the study of climate adaptability in the city of Beijing, China. In addition, the case studies of Ischia island [72], Venice [73] and Saudi Arabia [67] used definitions of vulnerability, risk and resilience proposed by UNISDR. These are the minority of studies from our analyzed sample that consider UN's promotion of a resilient territorial system's development.

The used indicators are mainly related to the vulnerability component of risk (dark columns of Fig. 2). Twelve out of 33 studies (36%) consider only social dimensions of risk. Among 19 studies considering both social and natural component (58%), it is again the social dimension of risk that was mainly considered: 4/5 in Ref. [14], 4/7 in Ref. [20], 32/36 in Ref. [22], 10/13 in Ref. [24], 3/4 in Ref. [29], 4/5 in Ref. [40] and 4/15 in Ref. [91], to state some of them. Only one study [94] is based mainly on natural indicators (three sub-indices out of four), and two among the studies [18,89] are based exclusively on natural or physical indicators (6%).

Similarly, among the additionally analyzed case studies, there is a predominant social dimension of risk (15 of 35 studies use only social indicators, 43%). Four studies (11%) are based on natural hazards only: two of them being modeling cases [72,74], whereas the other two are reviews of methodologies [75] and risk assessment framework [73]. The rest of the papers (16 of 35, 46%) consider both hazard and vulnerability. The most balanced studies are [55,77] with even distribution of social and environmental indicators, and one study [78] considers geomorphologic attributes of beach erosion vulnerability (three attributes) more than the social attributes (one attribute). If we consider our full sample of 68 studies, we again find a similar distribution of usage of social and natural indicators (light columns of Fig. 2).

### 3.4. *While researching the temporal scale, the main phase to work on is the post-disaster one*

The temporal scale is of equal importance as the spatial one. There are three indicator studies that have their objective to research about temporal phases of disaster. A case study from Thailand [33] created a new disaster resilience index to better understand pre-disaster conditions, the Greek case study [17] worked on pre-disaster and disaster part of the disaster cycle, which is of importance for the cultural heritage management, and the Australian review offered a new outline in all three temporal phases for better social resilience [23].

Almost all case studies focused on resilience time scale were interested in a post-disaster stage of the following events: the 1999 Taiwan earthquake [79], the 2004 Indian Ocean tsunami [80], the 2005 hurricane Katrina in the USA [81], the 2008 China's earthquake in Sichuan [62], the 2010 New Zealand's earthquake [82], the 2011 earthquake in Japan [83], and a theoretical case in Saudi Arabia [67]. One work was also a meta-analysis of flood disasters, considering all three disaster stages [84]. In this last study, thematic indicators are sorted by proportion of citations within the three stages of disaster, and it concluded that the social vulnerability varies noticeably within the different temporal stages.

### 3.5. *Learning outcomes and risk perception are keys for the future research*

The level of education is often cited as an important indicator of vulnerability to natural disasters and [85] showed it had a bigger effect on reducing disaster vulnerability than wealth, based on the example of communities in Nepal that face floods and landslides. Study [79] on learning outcomes from disaster-preparedness training in Taiwan underlines the need of an annual follow-up on learning satisfaction indicators. The objective is to establish standards that have to be attained, in order to improve the level of education related to disasters. It seems that knowledge produced by scientists and policy makers is not fully understandable for general population [86] and that local knowledge is not used to enrich the existing scientific tools [90]. The initial step to enlarge human awareness are the established precise definitions of multi-risk concepts [75].

Secondly [68], confirmed the strong relation between community's adaptive capacity and the human perception of environmental risks, and [84] found in its meta-analysis of flood disasters that the risk perception and coping capacity are weakly reflected in many social vulnerability indicators. Finally, as underlined in review [36], 82% of all studies use methods whose theoretical requirements are rarely satisfied in the context of indicator-based vulnerability assessment.

## 4. Discussion

Risk indicators used in the studies included in this review are mainly globally oriented, they are based more on social variables than on natural ones, and there therefore still remains a lot of space for improvement of the Sendai's framework for disaster risk reduction.

### 4.1. *Spatial and temporal scales*

Previous studies have already addressed a dire need to improve the risk management methodology based on the usage of indicators, with the question raised as to whether or not they correspond to managers' needs in the first place [13]. They are usually chosen based on literature reviews and authors' own experience, which means that accurate criteria are generally missing while choosing the indicators [28,39].

Concerning the spatial scale, although indicators for vulnerability evaluation range from local to national or global level, and given that lots of indicators depend on characteristics of sites or hazards, there is a major issue in including more indicators determined at the local scale [22,35,37,69] and reducing the existing gap between bottom-up and top-down approaches [37]. Just a glance at the map (Fig. 1) shows the absence of case studies in many countries (e.g. vast area of Africa) that could be partly because there are few publications on the Web of Science and also because there is little planning policy that uses the concept of integrated risk management with indicators.

Acknowledging the specific contexts of studied sites will necessarily draw a much clearer figure of general population's perception of risk [68], and consequently improve the framework of local and national

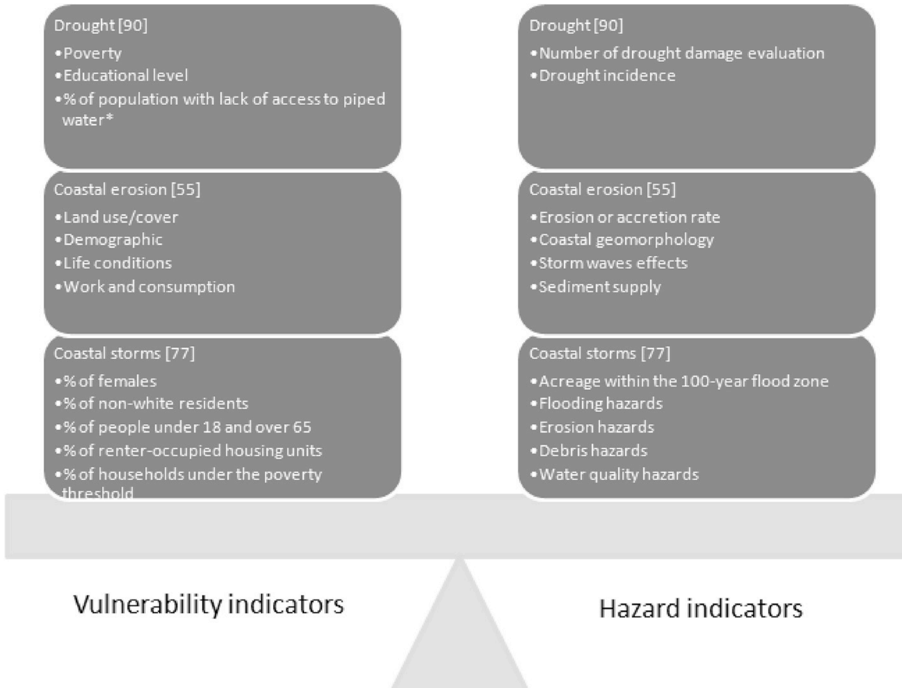


**Fig. 3.** Examples of case studies with balanced social (vulnerability) and natural (hazard) indicators (*originally in paper considered as exposure indicator) from studies [55,77,90].

governance. More local studies, with a direct fieldwork, are therefore needed, since the main approach so far has been a theoretical reasoning on indicators. Merging of field studies based on natural and social variables [ex. 17, 18], and of fieldwork based on participative approach [ex. 23, 37] will result in better contextualization of indicators, with a developed interdisciplinary language between the natural and social sciences.

Secondly, in order to improve the social resilience, research on pre-disaster and disaster phase has to be continued, because until now these temporal scale phases are under-represented compared to the post-disaster phase [23,84]. Since one of the seven targets of the Sendai framework for disaster risk reduction is to increase the number of countries with national and local disaster risk reduction strategies [71], there is an evident need to increase the local approach to resilience. Finally, an interesting remark on scale and meeting the Sendai's objectives comes from the study [105] in which the author concludes that the current approaches in disaster research are mostly custom-made to individual contexts. It could therefore pose a barrier in achieving the Sendai Framework where agents have to agree on indicators to measure performance towards set objectives [105], which calls for further research on disaster risk indicators.

### 4.2. More natural and improved combination of natural and social indicators needed

The indicators used in the papers included in our dataset are predominately related to vulnerability and not to hazards, that is to social and not to natural or environmental components of risk (Fig. 2). Additionally, social vulnerability indicators do not always include risk perception and coping capacity [84] and the justifications for their usage are often limited [20,87]. Since risk is the product of hazard and vulnerability, it may be that one should not be considered without the other. We claim that corresponding indicators used from both hazard and vulnerability should be included and valued in a balanced way, as it is the case of studies from Brazil [90], Argentina [55] and the USA [77] (Fig. 3). If the indicators are used methodologically, and didactically like in these studies, then we can say that they are user-friendly tools for risk management, and clearly transmitting integrative scientific information to risk managers. Finally, the review [36] poses huge methodological issues that need to be additionally addressed in the future, since we

**Table 3**
The ideas of making indicators more dynamical, some examples.

| | Vulnerability (pre-disaster) | Impact (response, during disaster) | Resilience (recovery, post-disaster) |
|---|---|---|---|
| climatology | the number of people living in an area at risk (basic indicator of flood exposure) | flooding (frequency, intensity) | the number of people moved out from the area after an educational campaign |
| geology | fault length | earthquake (magnitude scale) | stability (period between two earthquakes) |
| sociology-anthropology | risk perception | societal response | changes in behavior |
| management-policy | cost-benefit analysis of the actual policy | investments | cost-benefit analysis of the new policy |
| economics-infrastructure | number of high-school pupils educated on risk | number of affected | number of resilient pupils (psychological recover) |
| | added value of tourism | marine erosion, cost-lost | added value of new infrastructure |
| | number of anti-seismic houses | number of destroyed houses | number of reconstructed houses (organizational resilience) |
| | land cover as an indicator of the financial damage | economic valuation of land loss | Investments |


**Fig. 4.** The scheme of the key gears in a mechanism for improved risk management policy, where indicators present the grounds of an accessible and sound framework.

cannot expect an efficient risk assessment if we use methods whose theoretical requirements do not satisfy the context of assessment based on usage of indicators.

### *4.3. Limitations and policy implications*

One of the limitations of this study is that some papers may have been left out and not enlisted by our Web of Science research. Similarly, there could be many case studies missing from the set, with even different outcomes, partly due to low publication capacity of some countries and partly due to the incompleteness of Web of Science research tool. In addition, our focus on large catastrophic events should be extended with studies on slow-onset disasters for broader view on interconnections, coupled hazards and cascading, as in recent works by Pescaroli and Alexander [106]. Furthermore, although one may argue that the presence of term "indicator" in the keyword list is enough, we claim that it is reasonable to give the priority to those papers validating and critically valuing indicators, and therefore having the key term "indicator" in the title.

Moreover, since indicators are usually modeled through statistics (i.e. % of women, per capita income), the question is whether we are able to create dynamical indicators by considering them on a time scale? Additionally, would it be technically and conceptually possible to pair resilience indicators with vulnerability indicators, and how? The policy implications of this study are the possible changes that we recommend for the community, which could be developed following some ideas from Table 3.

To sum up the requisites for ameliorated policy and more successful approach in risk management we again have to start from the indicators. More case studies with clear methodology and with equal attention dedicated to both social and natural indicators [55,77,90], with local participation [37,92,107] and information on risk perception [68,84] will advance the framework of local governance. In addition, the human decision making with liable hazard mitigation actions is needed for improved risk management [97,103]. Finally, continuous research for indicators that could measure performance towards Sendai's objectives is required [105]. Those objectives will be attained only with permanent knowledge flow from research to practice and if backed by strong, global political commitment [104] (Fig. 4).

### *4.4. Are indicators beneficial to general population?*

It is expected that the general population benefit from successful risk management plans that are developed using numerous indicators. Since indicators give information to policy makers and local managers whether they should act or not confronting some of the risks they face, indicators are not directly, but indirectly useful for broad public. General population surely has to profit from the transmitted information from scientists to managers via indicators, vectors of risk information. If those indicators are clear, straightforward and, therefore, user-friendly, then they will be beneficial to final users. This need for more efficient knowledge transfer is underlined in some of the analyzed studies [97, 103] and it should not be neglected in the future research. Nevertheless, the reverse direction of learning is of utmost importance, where local knowledge and perception on risks indeed nourish the risk management strategies [84,92,99]. General population is, therefore, not an object, but both subject and object, dynamic actor in an efficient risk management strategy.

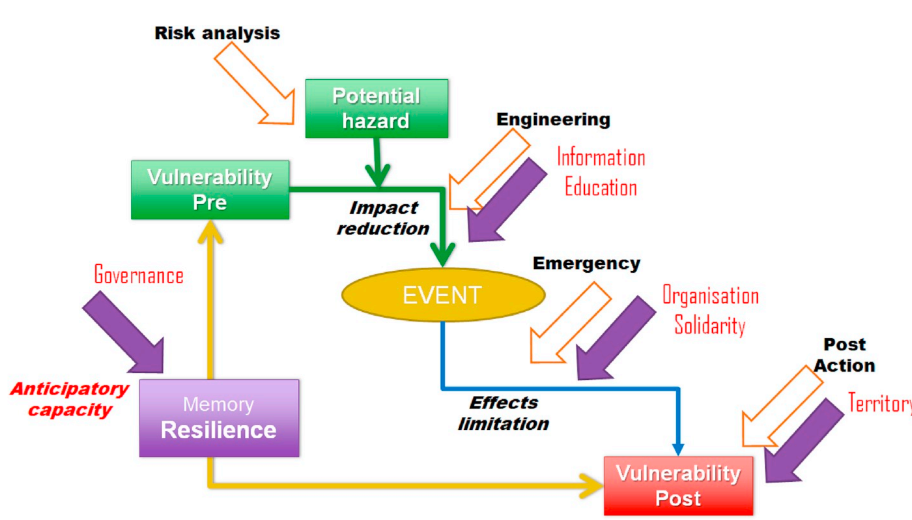


**Fig. 5.** To make a move from less vulnerable to more resilient society, indicators should be used to collect information on every single step of the process before, during and after the disastrous event.

### 4.5. Indicators' terminology should be standardized

As previously exposed in the introductory section, UNISDR recommends the use of a defined terminology related to disaster risk reduction, where the term *indicator* is not elaborated. The possible reason for not doing so is that it was considered that this term is technical and comprehensible to those that should understand it and use it. We therefore call for the standardization of term *indicator* and of following terms like *index, variable, factor*, or *dimension* as well. In order to illustrate this need it is enough to look at our three exemplary case studies (Fig. 3). What is considered as variable that builds an indicator in one study [55], in other study that variable is considered as indicator itself [77], and in study [90] there is a mixed usage of indicators and variables. Even better example of overlapping of terms is the study [95], where the composite drought vulnerability index/indicator is constructed by using seventeen variables/factors/indicators. Although majority of policy makers and local managers understand what is the meaning and expected content of those terms, standardized definition (i.e. index > indicator > variable) could put an end to another ambiguity.

### 4.6. Conclusion

The evident conclusion is the need to use social and natural indicators in risk assessment equally. Also, indicators taken from the literature to be used in future studies should be valorized in interviews with different stakeholders in order to justify their usage. Furthermore, indicators should be developed using a bottom-up sense because the local practice differs from the top-down measures valid for large scales. In addition, as every region is specific, based on its basic environmental and social characteristics, there is a rising need to increase the number of case studies based on fieldwork studies that would contribute to fundamental knowledge on natural risk management. On the other hand, since indicators and risk assessment on large scales are useful for different objectives than local ones, mainly for comparison across countries, they should both be used in a complementary way.

The information transmitted by indicators and the vocabulary used while managing natural risks should be clear and comprehensible by the broad, non-specialist population and they should be directly adapted to management needs. If they are not used for monitoring and risk assessment, then they fail not only to attain Sendai's objectives but to tackle the increasing human and economic loss worldwide. It would be useful to develop indicators to be followed up for each phase of the temporal scale: pre-disaster, response and recovery (post-disaster). In an improved risk management, indicators should be used to collect and gather information on every phase of the disaster management cycle, building society that is less vulnerable and more resilient (Fig. 5). The indicators would, in that sense, become more dynamical measures of the changes they are supposed to depict by their definition and would be more resilience oriented, contributing to improved risk management.

The responses on our three initial questions and the additional remarks are important to underline the need for further research on indicators. We do not have enough studies that not only use indicators, but that also critically discuss and validate them. This lack could be due to limitations of this study where some key papers may have been left out and not enlisted by our Web of Science research; therefore further study to test our conclusions is needed. If this lack of studies on Sendai Framework is due to fact that the Framework's goals and objectives may not have inspired the researchers, but mainly managers, then it is possible to raise a question about the utility of the indicators for the managers, and also about the communication interface between scientists and managers. In a nutshell, an improved dialogue and participatory approach between the scientists, managers and civil society has to be enhanced by all means. The risk for societies could be tackled both on the basis of scientific and local knowledge and on the basis of institutional adaptations (i.e. new risk management strategies) and social adaptations resulting from them. It is, therefore, important to address the physical phenomena of hazards as well as how they are socially constructed, not only by developing more natural indicators, but also to associate them with social components in a combined index. This construct of index permits different cultural, economic and demographic contexts with a participatory approach to be involved in the process of building scientific knowledge. Scientific knowledge must therefore be both consolidated and made accessible to society. Different sources of knowledge - scientific, local, and institutional knowledge - are available and must be solicited to strengthen the resilience of territories. The constant knowledge flow between those sources will contribute to Sendai's priority areas for action and it is a crucial condition for a step towards a more responsible disaster risk reduction policy. Finally, the knowledge flow and interdisciplinary approach used in the process of the indicators' construction between the natural and social scientists will result in a common vocabulary of risk management elements, comprehensible to local authorities, managers and institutions, as well as to the final users of the improved risk management strategy, the general population itself.

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