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► To cite this version:

Ante Ivčević, Hubert Mazurek, Lionel Siame, Abdelkhalak Ben Moussa, Olivier Bellier. 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. *International Journal of Disaster Risk Reduction*, 2019, 41, pp.101301. 10.1016/j.ijdr.2019.101301 . hal-02283000

HAL Id: hal-02283000

<https://amu.hal.science/hal-02283000v1>

Submitted on 10 Sep 2019

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

3 Ante Ivčević*¹², Hubert Mazurek¹, Lionel Siame², Abdelkhalak Ben Moussa³, Olivier Bellier²

4 Abstract

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

20 Key words: indicators; risk management; natural hazards; societal response; Sendai

21 1. Introduction

22 Every year the world feels new burdens due to either climate-related or telluric natural hazards with
23 strong societal, economic, and environmental issues. In 2017 alone there were 318 disasters
24 recorded, with 9503 deaths, 96 million people affected, together with 314 billion dollars of economic
25 damage, making it the second most costly year ever [1]. For decades, it has broadly been
26 acknowledged that the disasters that cause human and economic losses are not only natural, but
27 depend on the social conditions of the areas where natural hazards occur [2]. In order to make
28 society respond more efficiently, and to tackle the increasing losses, the United Nations (UN)

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29 developed disaster risk management plans to set goals and objectives for reducing risks associated
30 with natural hazards. After the International Decade for Natural Disaster Reduction (1990-1999),
31 disaster risk and risk management expectedly attracted more attention worldwide. One of the
32 frameworks developed was that from the “Program for Latin America and the Caribbean”, which, in
33 addition to relative indicators at the national level, included a limited number of aggregate
34 indicators to serve policy makers. Four composite indicators were used to measure each country’s
35 progress in risk management and its proposed monitoring tool for risk management is still used in
36 modified form on national levels [9, 100, 101]. On a larger, global scale, the first framework for
37 disaster risk reduction, i.e., the *Hyogo Framework for Action 2005-2015*, was adopted. The five
38 priorities for action were: ensure that disaster risk reduction is a national and local priority with a
39 strong institutional basis for implementation; identify, assess, and monitor disaster risks and
40 enhance early warning; use knowledge, innovation, and education to build a culture of safety and
41 resilience at all levels; reduce the underlying risk factors; strengthen disaster preparedness for
42 effective responses at all levels [108]. Among its identified shortcomings was the need to encourage
43 a mutual responsibility for disaster resilience at all levels [88], which was hopefully overcome in the
44 most recent plan, i.e., the *Sendai Framework for Disaster Risk Reduction 2015-2030* [3].

45 The Sendai Framework aims at achieving a significant reduction of disaster risk and losses during a
46 15-year-period and consists of seven global targets, which are proposed to reach the goal by using
47 appropriate indicators. There are four priority areas for action: better disaster risk knowledge,
48 improved risk governance and management, new research into resilience practices, and improved
49 post-disaster and recovery phase. The missing gap on mutual responsibility from the Hyogo
50 Framework is now addressed, but with subsisting doubts on how to implement it [88]. The Sendai’s
51 flaws are the lack of the targets that specify a measure of improvement in disaster risk to be made,
52 first five years are meant to serve as period to put together disaster risk reduction strategies, and
53 sometimes the objectives are expected to be attained on a global level [71]. The proposed indicators
54 mainly apply to the monitoring of national policies and carrying out the Sendai policy, rather than
55 the implementation of local strategies [4, 105]. The key objective of adapting the framework for
56 local contexts has recently been addressed [88, 92], coming from the positive example of increased
57 resilience to floods and droughts in Peru, where the teams of locals worked together with external
58 researchers to identify vulnerabilities and possible solutions [92]. Similarly, measuring societal
59 resilience at country level (Germany) is underlined as problematic for local level assessment since
60 demographic information cannot be profound [107]. These examples of governance and institutional
61 arrangements put back on stage the bottom-up arrangements (participatory approach derived from
62 a common work of a group of involved members of society, conversely to top-down arrangement

63 decided from above) for management that better suits different local contexts [92]. Finally, seeking
64 for Sendai's framework to succeed, the open-source knowledge transfer of reviewed information on
65 disaster risk reduction from researchers to practitioners has to be established [104].

66 The UN also calls for a better dialogue between experts and civil society (the community flow) and,
67 since the key terms like *disaster risk*, *hazards*, *vulnerability* and *resilience* used in the literature are
68 sometimes differently defined, it recommends the use of a defined terminology related to disaster
69 risk reduction as it follows. The UN defines *hazards* as processes that may negatively affect humans
70 physically, socially and economically or through an environmental degradation, with either natural,
71 anthropogenic or socio-natural origins. *Vulnerability* is the condition that increases the human
72 susceptibility to the impacts of hazards. *Disaster risk* is determined probabilistically as a function of
73 hazard, vulnerability, exposure and capacity. Complimentary to vulnerability, *resilience* is the ability
74 to recover from and adapt to the impacts of a hazard in a timely and efficient manner. Surprisingly,
75 among 38 defined terms in the UNISDR report on indicators and terminology relating to disaster risk
76 reduction, the term *indicator*, widely understood and used by the risk managers, is not among them
77 [3]. Therefore, we decided to pay attention to indicators themselves as a key tool in disaster risk
78 management.

79 The term indicator is widely used by different branches of science, from mathematics and economics
80 to natural sciences, but also in engineering or policy-making. For example, indicators are common in
81 territorial and environmental planning, standing for a measure of environmental properties [5]. For
82 instance, vulnerable species are an indicator allowing evaluating the quality of a marine environment
83 [6]. To use indicators as a clear basis for decision-making, it is needed to precisely define what the
84 term "*indicator*" means in our specific context of research [5]. As stated in the book edited by Jörn
85 Birkmann [8], different authors would define indicators differently. Birkmann defines the
86 vulnerability indicator for hazards of natural origin as "a variable which is an operational
87 representation of a characteristic or quality of a system able to provide information regarding the
88 susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event
89 linked with a hazard of natural origin" [8]. Additionally, in risk management, every measure of
90 environmental, social or economical phenomena used to evaluate or to set environmental, social or
91 economical changes and goals could be considered as an indicator [5,9].

92
93 But an indicator is not only a variable; it is also often a combination of variables. An indicator is
94 above all the quantitative or qualitative translation of the state of a concept or a phenomenon. The
95 main characteristic of an indicator is to "simplify" the information, to make it more compact to allow
96 a better understanding of the phenomenon, especially for a non-specialist audience. The indicator is

97 also a replicable element that can be used to track a phenomenon in time and space. In the field of
98 natural hazards, the composite characteristic is of special importance, since it makes it possible to
99 combine physical, social and economic variables to evaluate a state, like for example the level of risk,
100 and the recovery after the risk. It thus allows better preparing systems for much more effective
101 surveillance and warning. Nowadays, managers need control instruments. Since indicators
102 somewhat guarantee decisions' fairness and rationality, thus allowing negotiation, their control
103 constitutes one of the main stakes of risk management [7, 76].

104 To take into account human welfare, disaster risk management should, however, be parameterized
105 using more sensitive and sensible indicators [10]. Within this context, since indicators are designed
106 to comply with the application of the Sendai Framework [11], the question is whether or not they
107 respond to the societal need of serving as decision tools, that is to say, to reduce impacts and to
108 facilitate the resilience of societies. Do they remain useful to policy makers to inform and attend the
109 well-being of general population, as they are meant to? Since risk is a cross-sectoral domain
110 between natural and social sciences, there is indeed a dire need to integrate different parameters
111 into a global approach that should be comprehensive for all the actors involved, and allowing
112 identifying reliable indicators related to multiple risks [12], which are not just the sum of single
113 hazards [96]. It is, thus, important to clearly define which risk components are used in the analysis
114 [93], and it would be necessary to include all multiple dimensions of risk in the assessment. Different
115 societies face different risks and, although they sometimes face the same hazard (i.e., floods),
116 societies do not have the same level of vulnerability and resilience confronting it (e.g., Bangladesh
117 versus the USA [97]). This contributes to plenitude of indicators used in description of hazards, and
118 even more of indicators describing societal vulnerability. The rising questions are, therefore,
119 whether the indicators are useful, how are they used and is it rational to seek holistic or universal
120 indicators.

121

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

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130 2. Methods : data source and papers selection

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

142 Table 1: Articles dealing with indicators and vulnerability or resilience, and additional alternating
 143 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%)

144
 145 Since the amount of sampled papers is unlikely to be the sum of the three searched terms due to
 146 overlapping, the next step was therefore to identify those that belong to the three different sets,
 147 representing an intermediate set of articles.

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

149 (1) Are the constructed indicators globally or locally oriented and are those choices justified?

150 (2) Which indicators are used and are they in line with UNISDR recommendations?

151 (3) What is the approach in using indicators for dealing with different time scales?

152

153 3. Results

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

158

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

170

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

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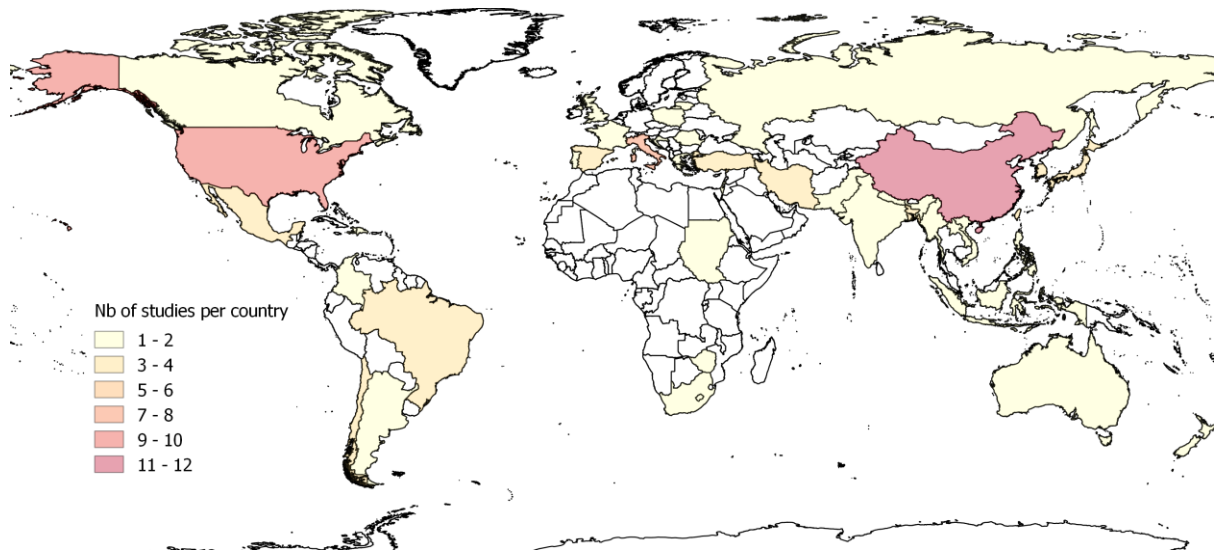


Figure 1: Geographical distribution of case studies included in this survey. The countries with most case studies are China (11), USA (9) and Italy (7).

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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	Discusses 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 operationalization; 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	Case study	25 variables grouped in four factors; variables selected	floods

	et al., 2015 [33]	(Thailand)	to serve as indicators of resilience; factors (indicators) ~ variables	
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

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188

3.1. Indicators used in natural hazard assessment

189

On adopted terminology while using the indicators in natural hazard assessment

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Although indicators are key tools for measuring vulnerability since the Hyogo Framework for Action

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(2005) and although there is a broad theoretical reasoning on the usage of indicators, different

192

authors may define indicators differently [8], and our database reflects this general current

193 situation. There is an overlap of the terms “indicator” and “index”, as well as terms that serve in
194 constructing indicators, such as “variable”, “factor”, and “parameter” (Table 2). For example, in the
195 study [95] the authors construct composite drought vulnerability index/indicator using seventeen
196 variables/factors/indicators, which noticeably demonstrates the overlapping of these terms. The
197 absence of universal definition of indicators is theoretically discussed in [34], with a proposed
198 definition of indicators from [32] being “quantifiable variables that represent a selected
199 characteristic of resilience [...]”, with the equivalence between “indicator” and “concept”. A
200 substantial number of studies also considers indicators as “variables” (e.g. [20, 21, 26]). For example,
201 in [27], it is specified that “the indicators become variables when taken from the literature, modified
202 and applied to the empirical study”, and in [33] that the “25 variables were selected [...] that served
203 as indicators of resilience”. In some studies, “indicator” is a higher term than “variable”, and is
204 described by a set of variables, like in [15], [35] or [40].

205

206 *Seismic risk*

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

214

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

223

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225

226 *Risk of inundations*

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

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

250

251 *Coastal risk*

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

255 The hazard indicators related to coastlines are: geomorphology, erosion rate, sediment budget [55,
256 59], coastal slope, as well as elevation and distance to the sea [56, 57, 58]. In addition, the indicators
257 of coastal storm hazards are: storm waves effects [55], distance to sea [56, 58], relative sea-level
258 rise, mean tidal range, mean significant wave height [57], depth and extent of inundation and

259 overwash [59], highest storm surge level, exceeding value of warning water level, and average slope
260 of the storm surge landfall position [61]. Finally, hazard indicators could be even more specifically
261 constructed, such as indicators of shoreline (the previous high tide high-water level, the wet/dry line
262 or run-up maxima) [60].

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

267

268 *3.2. Indicators are more often used on a global space scale than on a local one.*

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

288 The examples from the additional case studies confirm that the local community is an indispensable
289 agent in post-disaster reconstruction, as in the Chinese earthquake-related study focused on the
290 NGOs collaboration [62]. To integrate psychological and governance indicators with the traditional

291 ones, [63] included only those factors that local decision makers have a direct influence on, that is to
292 say focusing on community and household levels. Case studies from Romania [64], Laos [65],
293 Bangladesh [66] and Saudi Arabia [67] all implemented the local scale dimensions of vulnerability or
294 resilience in their studies. Additionally, three parallel studies from Canada, the UK and Spain [68]
295 demonstrated that local environmental context is the main contribution to the perception of
296 environmental risks. Similarly to this study's [37] conclusion that the global and local approach have
297 to be more coupled, in [69] the authors analyzed one top-down and another bottom-up case study
298 and summarized that the local aspects are equally as important as global approaches for trustworthy
299 scenarios of vulnerability.

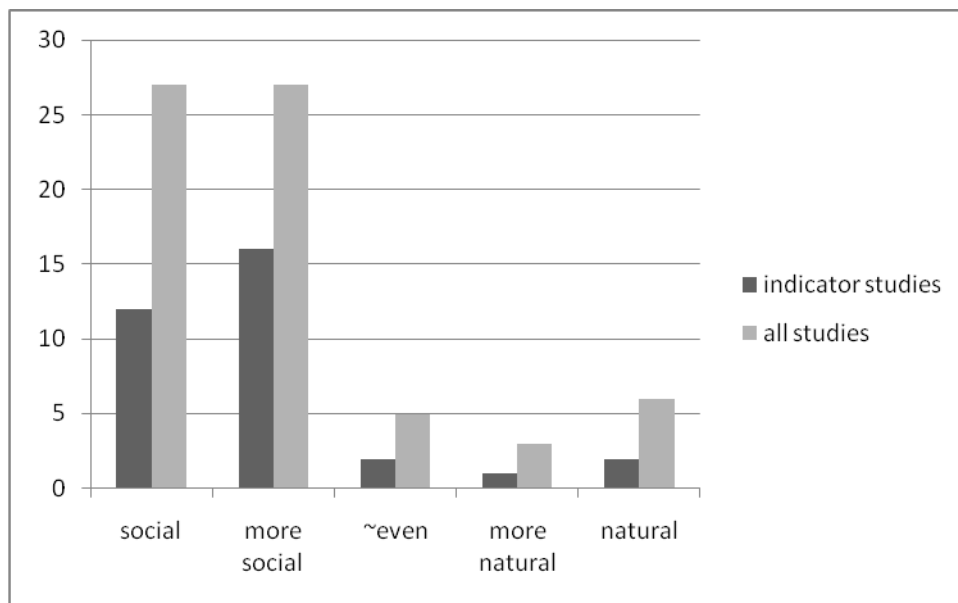
300 Other important remark comes from the way case studies are held. If we look at the sample of 33
301 articles on indicators, there are 9 reviews and 24 case studies. However, among those case studies
302 there are only two studies that actually included fieldwork on terrain (Greece [17] and Romania
303 [18]), and three studies whose fieldwork was in the form of practical workshop with different
304 managers and experts (Australia [23], USA [30], West Africa [37]). The other case studies were
305 focused on a theoretical approach by using indicators in risk management, like statistical analysis of
306 the available data and modeling.

307 *3.3. Indicators are predominantly related to vulnerability and not to hazards.*

308 Following UNISDR, the improved criteria for disaster risk management include built resilience of
309 communities to disasters [70], where the constant monitoring of risk is required and where the
310 progress has to be measured in terms of changes in risk [71]. Among the targeted articles only six
311 studies dealt with UNISDR Sendai lines and advices. The study [22] focused on understanding of
312 disaster risk in Brazil (Sendai's priority 1), the review [32] identified 27 disaster reduction assessment
313 approaches according to Sendai policy, and the review [20] updated the practice by new approaches,
314 offering improvements in both earthquakes and flooding by comparing their vulnerability indicators.
315 The study [90] hopes that its risk index would be useful in addressing some of Sendai's priority areas
316 related to drought and health, [89] that the combination of approaches to assess physical
317 vulnerability to debris flows would contribute to the resilience of mountain areas, and [40] is the
318 only case study implementing Sendai regulative, carrying out the study of climate adaptability in the
319 city of Beijing, China. In addition, the case studies of Ischia island [72], Venice [73] and Saudi Arabia
320 [67] used definitions of vulnerability, risk and resilience proposed by UNISDR. These are the minority
321 of studies from our analyzed sample that consider UN's promotion of a resilient territorial system's
322 development.

323 The used indicators are mainly related to the vulnerability component of risk (dark columns of Figure
 324 2). Twelve out of 33 studies (36%) consider only social dimensions of risk. Among 19 studies
 325 considering both social and natural component (58%), it is again the social dimension of risk that was
 326 mainly considered: 4/5 in [14], 4/7 in [20], 32/36 in [22], 10/13 in [24], 3/4 in [29], 4/5 in [40] and
 327 4/15 in [91], to state some of them. Only one study [94] is based mainly on natural indicators (three
 328 sub-indices out of four), and two among the studies [18, 89] are based exclusively on natural or
 329 physical indicators (6%).

330



331

332 Figure 2 : Social indicators are significantly more frequently used than natural indicators, which is
 333 evident both from the initial “indicator” set of articles (in dark), and from the set enlarged by
 334 additional case studies (in light).

335

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

345

346 *3.4. While researching the temporal scale, the main phase to work on is the post-disaster*
347 *one.*

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

354 Almost all case studies focused on resilience time scale were interested in a post-disaster stage of
355 the following events: the 1999 Taiwan earthquake [79], the 2004 Indian Ocean tsunami [80], the
356 2005 hurricane Katrina in the USA [81], the 2008 China's earthquake in Sichuan [62], the 2010 New
357 Zealand's earthquake [82], the 2011 earthquake in Japan [83], and a theoretical case in Saudi Arabia
358 [67]. One work was also a meta-analysis of flood disasters, considering all three disaster stages [84].
359 In this last study, thematic indicators are sorted by proportion of citations within the three stages of
360 disaster, and it concluded that the social vulnerability varies noticeably within the different temporal
361 stages.

362 *3.5. Learning outcomes and risk perception are keys for the future research*

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

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

377

378 4. Discussion

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

382 *4.1. Spatial and temporal scales*

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

388 Concerning the spatial scale, although indicators for vulnerability evaluation range from local to
389 national or global level, and given that lots of indicators depend on characteristics of sites or
390 hazards, there is a major issue in including more indicators determined at the local scale [22, 35, 37,
391 69] and reducing the existing gap between bottom-up and top-down approaches [37]. Just a glance
392 at the map (Figure 1) shows the absence of case studies in many countries (e.g. vast area of Africa)
393 that could be partly because there are few publications on the Web of Science and also because
394 there is little planning policy that uses the concept of integrated risk management with indicators.

395 Acknowledging the specific contexts of studied sites will necessarily draw a much clearer figure of
396 general population's perception of risk [68], and consequently improve the framework of local and
397 national governance. More local studies, with a direct fieldwork, are therefore needed, since the
398 main approach so far has been a theoretical reasoning on indicators. Merging of field studies based
399 on natural and social variables [ex. 17, 18], and of fieldwork based on participative approach [ex. 23,
400 37] will result in better contextualization of indicators, with a developed interdisciplinary language
401 between the natural and social sciences.

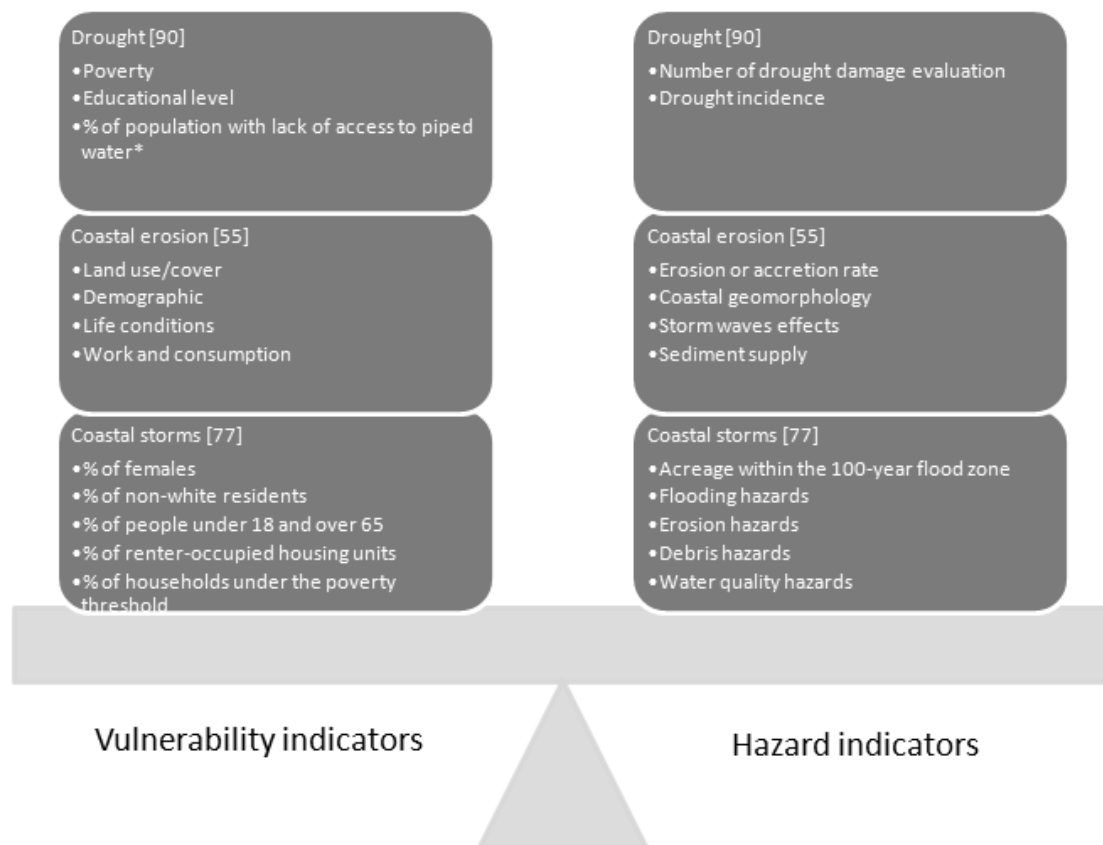
402 Secondly, in order to improve the social resilience, research on pre-disaster and disaster phase has
403 to be continued, because until now these temporal scale phases are under-represented compared to
404 the post-disaster phase [23, 84]. Since one of the seven targets of the Sendai framework for disaster
405 risk reduction is to increase the number of countries with national and local disaster risk reduction
406 strategies [71], there is an evident need to increase the local approach to resilience. Finally, an
407 interesting remark on scale and meeting the Sendai's objectives comes from the study [105] in which
408 the author concludes that the current approaches in disaster research are mostly custom-made to

409 individual contexts. It could therefore pose a barrier in achieving the Sendai Framework where
410 agents have to agree on indicators to measure performance towards set objectives [105], which calls
411 for further research on disaster risk indicators.

412 *4.2. More natural and improved combination of natural and social indicators needed*

413 The indicators used in the papers included in our dataset are predominately related to vulnerability
414 and not to hazards, that is to social and not to natural or environmental components of risk (Figure
415 2). Additionally, social vulnerability indicators do not always include risk perception and coping
416 capacity [84] and the justifications for their usage are often limited [20, 87]. Since risk is the product
417 of hazard and vulnerability, it may be that one should not be considered without the other. We claim
418 that corresponding indicators used from both hazard and vulnerability should be included and
419 valued in a balanced way, as it is the case of studies from Brazil [90], Argentina [55] and the USA [77]
420 (Figure 3). If the indicators are used methodologically, and didactically like in these studies, then we
421 can say that they are user-friendly tools for risk management, and clearly transmitting integrative
422 scientific information to risk managers. Finally, the review [36] poses huge methodological issues
423 that need to be additionally addressed in the future, since we cannot expect an efficient risk
424 assessment if we use methods whose theoretical requirements do not satisfy the context of
425 assessment based on usage of indicators.

426



427

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

430

431 *4.3. Limitations and policy implications*

432 One of the limitations of this study is that some papers may have been left out and not enlisted by
 433 our Web of Science research. Similarly, there could be many case studies missing from the set, with
 434 even different outcomes, partly due to low publication capacity of some countries and partly due to
 435 the incompleteness of Web of Science research tool. In addition, our focus on large catastrophic
 436 events should be extended with studies on slow-onset disasters for broader view on
 437 interconnections, coupled hazards and cascading, as in recent works by Pescaroli and Alexander
 438 [106]. Furthermore, although one may argue that the presence of term “indicator” in the keyword
 439 list is enough, we claim that it is reasonable to give the priority to those papers validating and
 440 critically valuing indicators, and therefore having the key term “indicator” in the title.

441 Moreover, since indicators are usually modeled through statistics (i.e. % of women, per capita
 442 income), the question is whether we are able to create dynamical indicators by considering them on

443 a time scale? Additionally, would it be technically and conceptually possible to pair resilience
 444 indicators with vulnerability indicators, and how? The policy implications of this study are the
 445 possible changes that we recommend for the community, which could be developed following some
 446 ideas from Table 3.

447 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

448

449 To sum up the requisites for ameliorated policy and more successful approach in risk management
 450 we again have to start from the indicators. More case studies with clear methodology and with equal
 451 attention dedicated to both social and natural indicators [55, 77, 90], with local participation [37, 92,

452 107] and information on risk perception [68, 84] will advance the framework of local governance. In
453 addition, the human decision making with liable hazard mitigation actions is needed for improved
454 risk management [97, 103]. Finally, continuous research for indicators that could measure
455 performance towards Sendai's objectives is required [105]. Those objectives will be attained only
456 with permanent knowledge flow from research to practice and if backed by strong, global political
457 commitment [104] (Figure 4).



458

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

461

462 *4.4. Are indicators beneficial to general population?*

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

474 *4.5. Indicators' terminology should be standardized.*

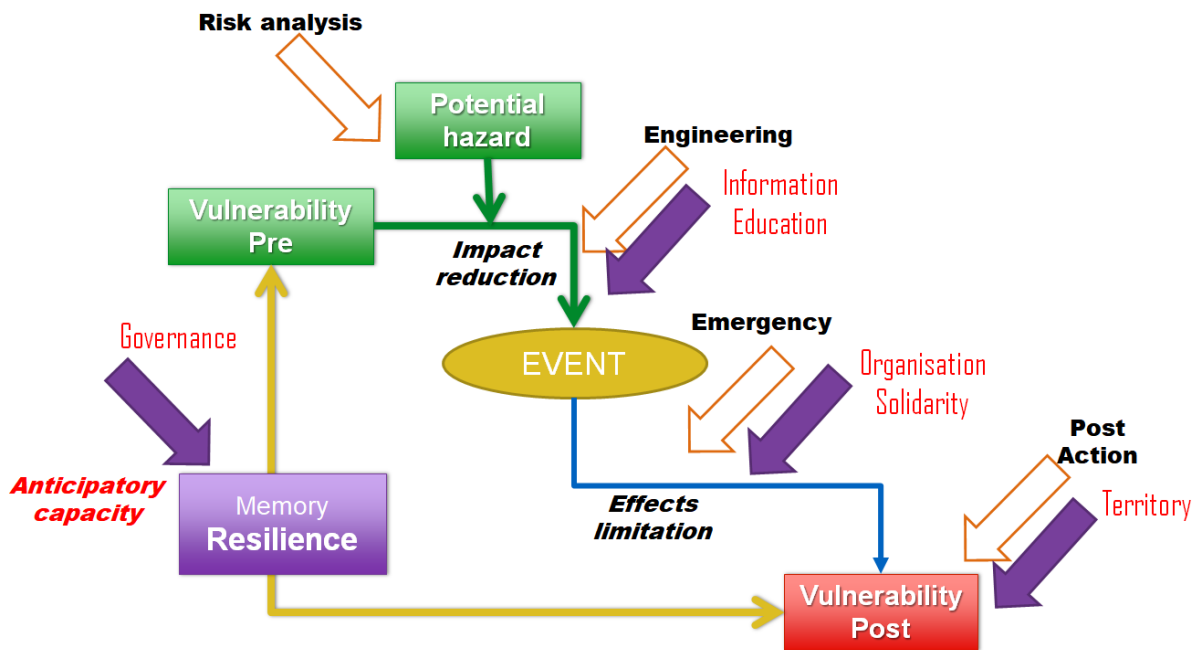
475 As previously exposed in the introductory section, UNISDR recommends the use of a defined
476 terminology related to disaster risk reduction, where the term *indicator* is not elaborated. The
477 possible reason for not doing so is that it was considered that this term is technical and
478 comprehensible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

488 *4.6. Conclusion*

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

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

508 to depict by their definition and would be more resilience oriented, contributing to improved risk
 509 management.



510

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

513

514 The responses on our three initial questions and the additional remarks are important to underline
 515 the need for further research on indicators. We do not have enough studies that not only use
 516 indicators, but that also critically discuss and validate them. This lack could be due to limitations of
 517 this study where some key papers may have been left out and not enlisted by our Web of Science
 518 research; therefore further study to test our conclusions is needed. If this lack of studies on Sendai
 519 Framework is due to fact that the Framework's goals and objectives may not have inspired the
 520 researchers, but mainly managers, then it is possible to raise a question about the utility of the
 521 indicators for the managers, and also about the communication interface between scientists and
 522 managers. In a nutshell, an improved dialogue and participatory approach between the scientists,
 523 managers and civil society has to be enhanced by all means. The risk for societies could be tackled
 524 both on the basis of scientific and local knowledge and on the basis of institutional adaptations (i.e.
 525 new risk management strategies) and social adaptations resulting from them. It is, therefore,
 526 important to address the physical phenomena of hazards as well as how they are socially
 527 constructed, not only by developing more natural indicators, but also to associate them with social
 528 components in a combined index. This construct of index permits different cultural, economic and

529 demographic contexts with a participatory approach to be involved in the process of building
530 scientific knowledge. Scientific knowledge must therefore be both consolidated and made accessible
531 to society. Different sources of knowledge - scientific, local, and institutional knowledge - are
532 available and must be solicited to strengthen the resilience of territories. The constant knowledge
533 flow between those sources will contribute to Sendai's priority areas for action and it is a crucial
534 condition for a step towards a more responsible disaster risk reduction policy. Finally, the knowledge
535 flow and interdisciplinary approach used in the process of the indicators' construction between the
536 natural and social scientists will result in a common vocabulary of risk management elements,
537 comprehensible to local authorities, managers and institutions, as well as to the final users of the
538 improved risk management strategy, the general population itself.

539

540 Acknowledgements

541 This project has received funding from the European Union's Horizon 2020 research and
542 innovation programme under the Marie Skłodowska-Curie grant agreement No713750. Also, it
543 has been carried out with the financial support of the Regional Council of Provence- Alpes-Côte
544 d'Azur and with the financial support of the A*MIDEX (n° ANR- 11-IDEX-0001-02), funded by the
545 Investissements d'Avenir project funded by the French Government, managed by the French
546 National Research Agency (ANR).

547 This work has also been funded by the Labex OT-Med (ANR-11-LABEX-0061) supported by the
548 Investissements d'Avenir, French Government project of the French National Research Agency
549 (ANR) through the A*Midex project (ANR-11-IDEX-0001-02).

550 The authors highly appreciate the comments, critics and suggestions of four anonymous referees
551 on an earlier draft of this paper.

552

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