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PEOPLES: a Tool to Measure Community Resilience

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ABSTRACT

This paper provides a novel method to quantitatively assess the resilience of communities at various scales. The proposed method is based on the PEOPLES framework and it takes an indicator-based approach as an engine for its algorithm. PEOPLES is a framework for identifying the different resilience aspects of a community and for providing new ways through which the decision makers can take actions. The framework comprises seven dimensions, each of which is the collection of more specific components and indicators. Each indicator is accompanied with a measure allowing the analytical computation of the indicator's performance. The measures are presented in the form of continuous functions whose parameters can be analytically obtained. The output of the methodology is a performance function for each indicator and a resilience index for the whole community. A case study illustrating the application of the methodology is also provided in the paper.

INTRODUCTION

Community resilience has become one of the primary concerns for decision makers due to the increasing number of natural and man-made disasters. Resilience itself is not limited to one disciplinary but rather it is a multidisciplinary subject. According to Bruneau et al. (2003), the resilience of a system depends on its serviceability performance. The serviceability performance (Q) ranges from 0 % to 100 %, where 100% and 0% imply full availability and non-availability of services, respectively. The occurrence of a disaster at time t_0 causes damage to the system and this produces an instant drop in the system's serviceability (ΔQ). Afterward, the system is restored to its initial state over the recovery period (t_1-t_0). The loss of resilience is considered equivalent to the quality degradation of the system over the recovery period. Mathematically, it is defined as:

$$LOR = \int_{t_0}^{t_1} \left[100 - Q(t)\right] dt \quad (1)$$

where *LOR* is the loss-in-resilience measure, t_0 is the time at which a disastrous event occurs, t_1 is the time at which the system recovers to 100% of its initial serviceability, *Q(t)* is the serviceability of the system at a given time *t*.

In a highly interconnected world, impacts from events are significantly amplified. This makes measuring resilience one of the most demanding tasks. Several solutions for measuring resilience are available in the literature (Cimellaro 2016; Cimellaro at al. 2016; Cimellaro et al. 2014). Liu et al. (2017) introduced a method that combines dynamic modelling with resilience analysis. Interdependent critical infrastructures have been analyzed using that method by performing a numerical analysis for the resilience conditions in terms of design, operation, and control for a given failure scenario. Kammouh et al. (2017b) have introduced a quantitative method to assess the resilience at the state level based on the Hyogo Framework for Action (UNISDR 2011). The approach introduced was an evolution of the risk assessment concept. The resilience of 37 countries has been evaluated and a resilience score between 0 and 100 has been assigned to each of the countries (Kammouh et al. 2017a).

Cutter et al. (2014) reported that research on measuring community resilience is still in the early stages of development (Cutter et al. 2014). Although many attempts have been made to consolidate research on community resilience (e.g. (Twigg 2009), (Norris et al. 2008), (Cutter et al. 2010)), no accepted method exists so far and there are still difficulties in developing concrete assessment approaches (Abeling et al. 2014). This paper introduces an indicator-based method to compute the resilience of urban communities based on the PEOPLES framework (Cimellaro et al. 2016). PEOPLES is a multilayered framework composed of a large set of components and indicators. The proposed method is deterministic and requires data on past earthquake events for its implementation. The result of the method is a resilience index and a performance function for the community. As a case study, the resilience of the physical infrastructure aspect of the city of San Francisco city has been evaluated using the proposed tool.

THE METHODOLOGY: INDICATOR-BASED APPROACH TO MEASURE COMMUNITY RESILIENCE BASED ON THE PEOPLES FRAMEWORK

PEOPLES is a holistic framework for defining and measuring disaster resilience for a community at various scales. The framework is composed of seven *dimensions* covering all community aspects. Each dimension comprises a set of *components* that tackle the details of the dimension. In its current version, PEOPLES does not identify a clear procedure to quantitatively compute resilience, but rather a qualitative assessment and description of resilience. The goal of this paper is to use the structure of PEOPLES framework to come up with a quantitative framework that allows evaluating the resilience of communities. To do so, a large number of *indicators* available in literature have been collected and then allocated to the PEOPLES' components, creating a condensed list of 115 indicators. The full list of the components and indicators is provided in Appendix A. A quality control has been performed to insure the consistency of the used indicators. A single *measure* is assigned to each indicator to make it quantifiable. Each measure is normalized with respect to a fixed quantity, the standard value (*SV*). The standard value is an essential quantity that provides the baseline to measure the resilience of a system (or indicator). The system's existing serviceability at any instance of time is compared with the standard value to know how much serviceability deficiency has been experienced by the system. In addition, two types of measures are identified: *static measures (S)*, assigned to the measures that are not affected by the disastrous event, and *dynamic measure* (*D*) or event-sensitive measures, assigned to the measures whose values change after a disaster takes place. Each measure is defined using a continuous function to allow identifying the performance of the corresponding indicator during an interval of time following a disaster event. Finally, the indicators are weighted according to their relevance and importance, and then aggregated into a single serviceability function for the whole community. The community resilience is then evaluated by simply integrating the area below the serviceability function for a given period of time.

Weighting factors

Each of the components, sub-components, and indicators is given an importance factor (*I*) ranging from 1 to 3, where 1 means low importance and 3 means high importance. This factor represents the extent to which a variable (component, sub-component, or indicator) contributes towards achieving resilience. There are several ways to choose the importance factor of a measure: it can be an expert decision or it can come from an interdependency analysis.

For the purpose of the study, the variables of PEOPLES are classified into three major groups as follows:

1. Indicators that fall within a component are considered as a group;
2. Components classified under a dimension are taken as a group;
3. PEOPLES seven dimensions fall in one group.

Eq. (2) translates the importance factor (*I*) into a weighting factor (*W*). It is applied to each group independently:

$$W_i = \frac{I_i}{avg(I_1, I_2, \cdots, I_j)} = \frac{I_i}{\sum_1^j (I_i)} j \qquad (2)$$

where W_i is the weighting factor of element i, I_i is the importance factor of element i, j is the number of elements in the studied group.

Deriving the final resilience curve

After obtaining the weighting factors, a serviceability function is built for each variable: uniform function for event-sensitive measures “static measures”, and non-uniform function for event-non-sensitive measures “dynamic measures”, as shown in Figure 1. The serviceability function can be defined using a set of parameters that mark the outline of the serviceability function (e.g. initial serviceability q_0, post disaster serviceability q_1, restoration time T_r, recovered serviceability q_f). These parameters can be obtained from the past events and/or by performing a hazard analysis specific to each variable. Afterwards, all serviceability functions are weighted based on their contribution in the resilience assessment using the weighting factors described before. Figure 2 provides a schematic representation of the introduced methodology. The average of the weighted serviceability functions of the variables in the same group is considered to move to an upper layer. That is, to obtain the serviceability function of component i, the average of the weighted serviceability functions of the indicators under component i is considered. Similarly, to obtain the serviceability function of dimension i, the average of the weighted serviceability functions of the components under dimension i is considered. Finally, the serviceability function of the community is the average of the weighted serviceability functions of the seven dimensions. The resilience index of the community is then evaluated as the area under the final serviceability function using Equation 1.

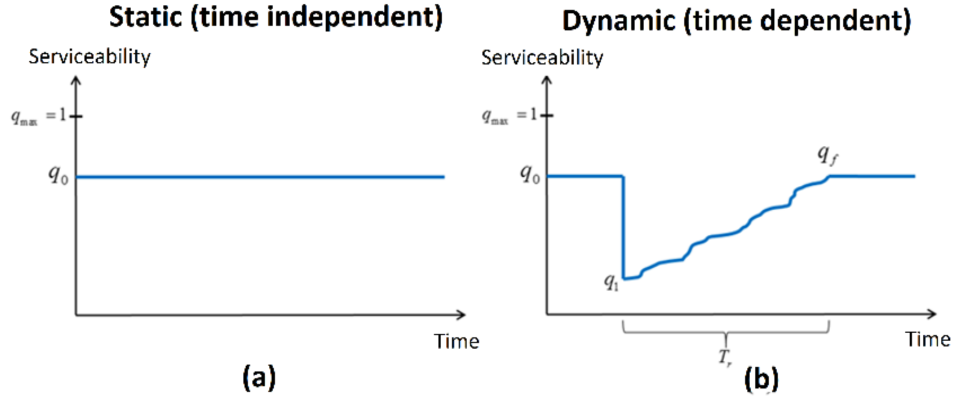

Figure 1. Example of (a) static and (b) dynamic indicators

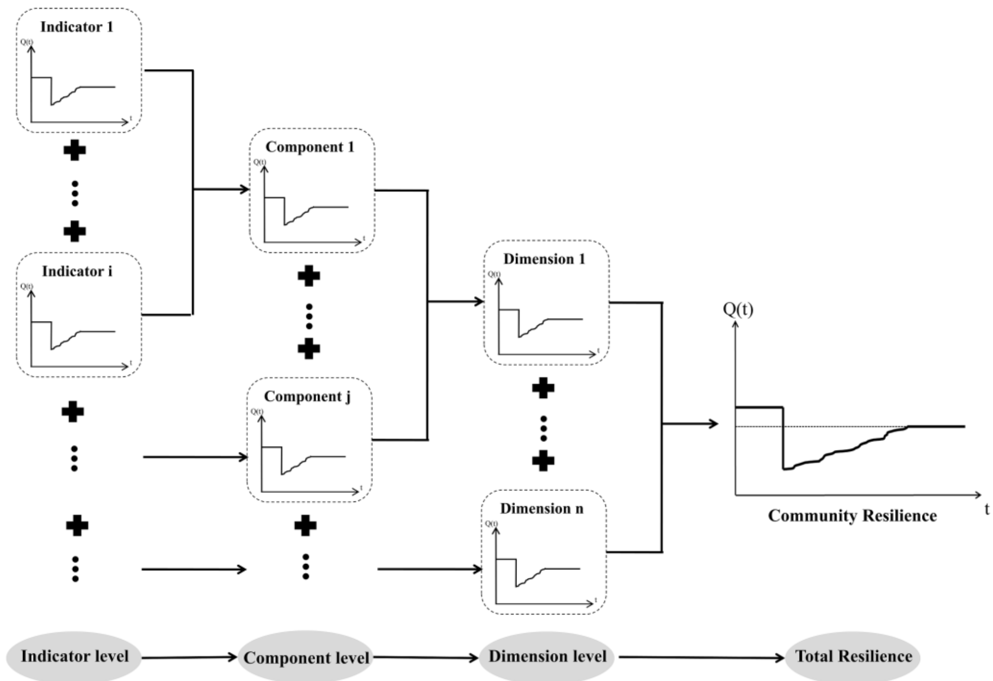

Figure 2. Hierarchical scheme of the proposed methodology

CASE STUDY

The resilience of the city of San Francisco is evaluated using the proposed resilience method. The case study intends to show the applicability of the proposed methodology and not the actual evaluation of the resilience of San Francisco. The 1989 Loma Prieta earthquake, with a moment magnitude of 6.9, has been considered as the disaster event.. Only one of the PEOPLES dimensions, namely Physical Infrastructure, has been considered for the sake of simplification. Table 1 shows the extended list of the components and indicators within the dimension ‘Physical Infrastructure’. Each indicator is linked to a measure that describes the indicator numerically. Each measure is defined using a set of parameters:

- Importance factor (I): a value between 1 and 3 representing the contribution of the indicator towards the resilience output;
- Indicator nature (Nat): the indicators are classified according to their nature: “Static (S)”, assigned to the measures that are not affected by the disastrous event, and “Dynamic (D)” or event-sensitive measures, assigned to the measures whose values change after a hazard takes place;
- Un-normalized serviceability before the event (q_{0u}): is the un-normalized initial serviceability of the measure;

- Standard value (*SV*): represents the optimal quantity for the indicator in order to be considered as fully resilient;
- Normalized serviceability before the event (q_0): is the normalized initial serviceability of the measure. It is obtained by dividing the un-normalized serviceability q_{0u} over the standard value *SV*;
- Serviceability after the event (q_1): The residual serviceability after the disaster. This quantity should be normalized with respect to *SV*;
- Serviceability after recovery (q_r): it is the recovered serviceability, which can be equal, higher, or lower than the initial serviceability (q_0). In this paper, the recovered serviceability q_r is assumed equal to the initial serviceability q_0;
- Restoration time (T_r): it is the time needed to finish the recovery process. This value is usually determined using probabilistic or statistical approaches.

In this study, the parameters were determined using open database sources (see notes under Table 1), which offer data for all cities across the US. Restoration fragility curves recently developed by Kammouh and Cimellaro (2017) have been used to determine the restoration time for the different variables. In their work, they have introduced an empirical probabilistic model to estimate the downtime of lifelines following an earthquake. Different restoration functions were derived for different earthquake magnitudes using a large earthquake set that contains data on the downtime of affected infrastructures.

Data collection was the most challenging part of the analysis since data about the serviceability of community systems is scares and not shareable with the public. However, this does not imply that data is not available but rather is not accessible. Interested parties, such as decision makers and authorities, can use the framework with its full potential since data is usually available to them.

Table 1. Serviceability parameters of the indicators within the Physical Infrastructure dimension for the city of San Francisco after the Loma Prieta earthquake

4- Physical infrastructure (I=3)									
Component /indicator	**Measure**	***I***	**Nat**	q_{0u}	***SV***	q_0	q_1	q_r	T_r (days)
4.1 Facilities	-		-						
4.1.1 Sturdy (robust) housing types	% housing units that are not manufactured homes	3	D	1	1	1	0.599	0.998	120
4.1.2 Temporary housing availability	% vacant units that are for rent	3	D	2.68	5	0.536	0.050	0.536	620
4.1.3 Housing stock construction quality	100-% housing units built prior to 1970	3	D	0.241	1	0.241	0.145	0.241	700
4.1.4 Community services	%Area of community services (recreational facilities, parks, historic sites, libraries, museums) total area ÷ SV	2	D	0.16	0.2	0.800	0.480	0.800	430
4.1.5 Economic infrastructure	% commercial establishments outside of	2	S	0.85	1	0.850	-	-	-

exposure	high hazard zones ÷ total commercial establishment								
4.1.6 Distribution commercial facilities	%Commercial infrastructure area per area ÷ SV	3	D	0.13	0.15	0.867	0.520	0.867	160
4.1.7 Hotels and accommodations	Number of hotels per total area ÷ SV	3	D	102	128	0.797	0.478	0.797	130
4.1.8 Schools	Schools area (primary and secondary education) per population ÷ SV	3	D	134	140	0.957	0.574	0.957	90
4.2 Lifelines									
4.2.1 Telecommunication	Average number of Internet, television, radio, telephone, and telecommunications broadcasters per household ÷ SV	3	D	5	6	0.833	0.500	0.833	90
4.2.2 Mental health support	number of beds per 100 000 population ÷ SV	2	D	69	75	0.920	0.644	0.920	35
4.2.3 Physician access	Number of physicians per population ÷ SV	2	S	2.5	3	0.833	-	-	-
4.2.4 Medical care capacity	Number of available hospital beds per 100000 population ÷ SV	3	D	544	600	0.907	0.635	0.907	35
4.2.5 Evacuation routes	Major road egress points per building ÷ SV	2	S	0.67	1	0.670	-	-	-
4.2.6 Industrial re-supply potential	Rail miles per total area ÷ SV	3	D	5412	6000	0.902	0.631	0.902	45
4.2.7 High-speed internet infrastructure	% population with access to broadband internet service	3	D	0.9	1	0.900	0.450	0.900	300
4.2.8 Efficient energy use	Ratio of Megawatt power production to demand	3	D	0.8	1	0.800	0.160	0.800	25
4.2.9 Efficient Water Use	Ratio of water available to water demand	3	D	1	1	1.000	0.240	1.000	60
4.2.10 Gas	Ratio of gas production to gas demand	3	D	0.1	1	0.100	0.050	0.100	70
4.2.11 Access and evacuation	Principal arterial miles per total area ÷ SV	3	D	172138	200000	0.861	0.602	0.861	45
4.2.12 Transportation	Number of rail miles per area ÷ SV	3	D	5412	6000	0.902	0.631	0.902	72
4.2.13 Waste water treatment	Number of WWT units per population ÷ SV	3	D	3	4	0.750	0.300	0.750	65

- Note: q_{0u} = the initial serviceability; *SV* = the standard value; q_0 = the initial normalized serviceability; q_1 = post disaster serviceability; q_r= the recovered serviceability; T_r = the restoration time.
- Source: City Data, Census Data, This Study, City Assessor's Data, Dept of Numbers, SF Indicator Project, Data World Bank, Dot Ca, SF Bos, Arcadis, SF Wáter, Energy Ca.

The serviceability functions of the measures under a certain component are combined point by point into a single serviceability function, taking into account their weighting factors. The weighting factors of the analyzed components are presented in Table 1. The serviceability function of each component (i.e. facilities and lifeline) is obtained by computing the average of the derived serviceability functions of all measures that belong to the underlying component. Similarly, the serviceability function of the dimension 'physical infrastructure' was derived by computing the average of the weighted serviceability functions of the corresponding components (i.e. facilities and lifelines). The loss of resilience of the physical infrastructure has been evaluated using Eq. (1). The time interval for the resilience evaluation was considered from the time that the event occurs (t_0=0) until the end of full recovery (i.e. the time corresponding to the instance where the curve reaches its pre-disaster level; t_r=700 days). The control time T_c can take any value and is determined based on the user's period of interest. In this example, T_c is assumed equal to t_r.

The loss of resilience *LOR* is computed as the area above the serviceability curve for the time interval (0 to 700 days), normalized with respect to T_c. The *LOR* value obtained is 25.6%, which corresponds only to the physical infrastructure dimension of the community. In order to have a resilience index for the whole community, the serviceability functions of other dimensions have to be similarly evaluated and to be combined in the same way. It is also interesting to compare the resilience of the two components facilities and lifelines. From Figure 3, it is clear that the city of San Francisco has more problems in facilities (*LOR*=31.29%) than lifelines (*LOR*=21.85%). In this case, it is suggested that the authorities focus more on enhancing the facilities as the benefit they would get is higher.

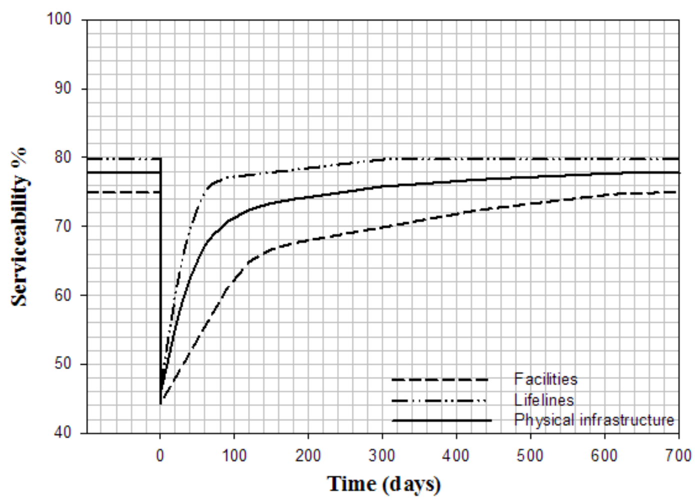

Figure 3. Serviceability curves of the components "Facilities" and "Lifelines" and the dimension "Physical Infrastructure"

CONCLUSION

This paper introduces a novel indicator-based method to compute the resilience of communities. The significance of the proposed methodology lies in its graphical representation that helps authorities take proper actions to improve their resilience. While all previous works generally provide a single index to measure community resilience, the proposed method indicates in details whether the resilience deficiency is caused by the system's lack of robustness or by the slow restoration process. The proposed method identifies where exactly resources should be spent to efficiently improve resilience. The proposed resilience assessment method can serve as an initial tool for decision makers to evaluate the disaster resilience of their communities. Future work will focus more on the interdependency between indicators.

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REFERENCES

Abeling, T., Huq, N., Wolfertz, J., and Birkmann, J. (2014). "Interim Update of the Literature. Deliverable 1.3, emBRACE project."

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., and Winterfeldt, D. v. (2003). "A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities." *Earthquake Spectra*, 19(4), 733-752. doi:10.1193/1.1623497.

Cimellaro, G. P. (2016). *Urban Resilience for Emergency Response and Recovery*, Springer.

Cimellaro, G. P., Renschler, C., Reinhorn, A. M., and Arendt, L. (2016). "PEOPLES: a framework for evaluating resilience." *Journal of Structural Engineering, ASCE*. http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001514.

Cimellaro, G. P., Solari, D., and Bruneau, M. (2014). "Physical infrastructure interdependency and regional resilience index after the 2011 Tohoku Earthquake in Japan." *Earthquake Engineering & Structural Dynamics*, 43(12), 1763-1784. 10.1002/eqe.2422.

Cutter, S. L., Ash, K. D., and Emrich, C. T. (2014). "The geographies of community disaster resilience." *Global Environmental Change*, 29, 65-77.

Cutter, S. L., Burton, C. G., and Emrich, C. T. (2010). "Disaster resilience indicators for benchmarking baseline conditions." *Journal of Homeland Security and Emergency Management*, 7(1).

Kammouh, O., Dervishaj, G., and Cimellaro, G. P. (2017a). "A New Resilience Rating System for Countries and States." *Procedia Engineering*, 198, 985-998. https://doi.org/10.1016/j.proeng.2017.07.144.

Kammouh, O., Dervishaj, G., and Cimellaro, G. P. (2017b). "Quantitative Framework to Assess Resilience and Risk at the Country Level." *ASCE-ASME Journal of risk and uncertainty in engineering systems, part A: civil engineering*.

Kammouh, O., and Cimellaro, G. P. (2017). "Downtime Estimation and Analysis of Lifelines After Earthquakes." In review.

Kammouh, O., Zamani-Noori, A., Cimellaro, G. P., and Mahin, S. A. (2017c). "Resilience Evaluation of Urban Communities Based on Peoples Framework." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, under review.

Liu, X., Ferrario, E., and Zio, E. (2017). "Resilience Analysis Framework for Interconnected Critical Infrastructures." *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering*, 3(2), 021001-021001-021010. 10.1115/1.4035728.

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., and Pfefferbaum, R. L. (2008). "Community Resilience as a Metaphor." *Theory, Set of Capacities*.

Twigg, J. (2009). "Characteristics of a disaster-resilient community: a guidance note (version 2)."

UNISDR (2011). "Hyogo Framework for Action 2005-2015 mid-term review." <http://www.preventionweb.net/files/18197_midterm.pdf>.

APPENDIX A

PEOPLES' dimensions, components, indicators, and measures with corresponding indicators' nature (Nat.)

Dimension/ component/indicator	**Measure (0 ≤value ≤1)**	**Nat.**
1- Population and demographics		
1-1- Distribution\ Density		
-Population density	1-(Average number of people per area ÷ TV)	D
-Population distribution	% population living in urban area	D
1-2- Composition		
-Age	% population whose age is between 18 and 65	S
-Place attachment-not recent immigrants	1-(% population not foreign-born persons who came within previous five years)	S
-Population stability	1-% population change over previous five year period	S
-Equity	% nonminority population – % minority population	S
-Race/Ethnicity	1-Absolute value of (% white – % nonwhite)	S
-Family stability	% two parent families	S
-Gender	1-Absolute value of (%female–%male)	S
1-3- Socio- Economic Status		
-Educational attainment equality	% population with college education – % population with less than high school education	S
-Homeownership	% owned-occupied housing units	D
-Race/ethnicity income equality	1-Gini coefficient	S
-Gender income equality	1-Absolute value of (% male median income – % female median income)	S
-Income	Capita household income ÷ TV	D
-Poverty	1-% population whose income is below minimum wage	D
-Occupation	Employment rate %	D
2- Environmental and ecosystem		
2-1- Water		

-Water quality/quantity	Number of river miles whose water is usable ÷ TV	D
2-2- Air		
-Air pollution	1-(Air quality index (AQI) ÷ TV)	D
2-3- Soil		
-Natural flood buffers	% land in wetlands ÷ TV	S
-Pervious surfaces	Average percent perviousness	S
-Soil quality	% land area that does not contain erodible soils	S
2-4- Biodiversity		
-Living species	1-% species susceptible to extinction	S
2-5- Biomass (Vegetation)		
-Total mass of organisms	Harvest index (HI) the ratio between root weight and total biomass	S
-Density of green vegetation across an area	Normalized difference vegetation index (NDVI)	D
2-6- Sustainability		
-Undeveloped forest	% land area that is undeveloped forest ÷ TV	S
-Wetland variation	% land area with no wetland decline	S
-Land use stability	% land area with no land-use change ÷ TV	S
-Protected land	% land area under protected status ÷ TV	S
-Arable cultivated land	% land area that is arable cultivated land ÷ TV	S
3- Organized governmental services		
3-1-Executive/ Administrative		
-Health insurance	% population under age 65 with health insurance	S
-Disaster aid experience	Presidential disaster declarations divided by number of loss-causing hazard events ÷ TV	S
-Local disaster training	% population in communities with Citizen Corps program	S
-Emergency response services	% workforce employed in emergency services (fire-fighting, law enforcement, protection) ÷ TV	S
-Schools	Number of schools per 1000 students ÷ TV	S
3-2- Judicial		
-Jurisdictional coordination	Governments and special districts per 10,000 persons ÷ TV	S
3-3- Legal/ Security		
-Performance regimes-state capital	Proximity of county seat to state capital ÷ TV	S
-Performance regimes-nearest metro area	Proximity of county seat to nearest county seat within a Metropolitan Statistical Area ÷ TV	S
3-4- Mitigation/ Preparedness		
-Mitigation spending	Ten year average per capita spending for mitigation projects ÷ TV	S
-Nuclear plant accident planning	1-% population within 10 miles of nuclear power plant	S
-Effective mitigation plans	% population covered by a recent hazard mitigation plan	S
-Exposure to hazards	% building infrastructure not in high hazard zones	S
-Protective resources	% land area that consists of windbreaks and environmental plantings	S
-Financed activities for risk reduction	% governmental financial resources to carry out risk reduction activities ÷ TV	S
-Essential infrastructure robustness	% of local schools, hospitals and health facilities that remained operational during emergencies in past events	S
-Essential infrastructure assessment	% essential infrastructures that are under regular assessment programs	S
-Accuracy of building codes	% designed structural damage – % actual structural damage (from past events)	S
-Training programs for officials	% of officials and leaders who are under regular training programs	S
-Availability of early warning centers	Average number of early warning centers per each independent zone ÷ TV	S
-Citizen disaster preparedness and response skills	Red cross training workshop participants per 10,000 persons ÷ TV	S
3-5- Recovery/ Response		
-Money dedicated to supporting the restoration	Microfinancing, cash aid, soft loans, loan guarantees available to affected households after disasters to restart livelihoods ÷ TV	S
-Ecosystem support plans	Local government plan to support the restoration, protection and sustainable management of ecosystems services (0 or 1)	S
-Local institutions access to financial reserves to support effective disaster response and early	1 (there is access), 0 (no access)	S

recovery		
-Local government access to resources and expertise to assist victims of psycho-social impacts of disasters	1 (there is access), 0 (no access)	S
-Disaster risk reduction measures integrated into post-disaster recovery and rehabilitation activities	1 (if there is), 0 (otherwise)	S
-Contingency plan degree including an outline strategy for post-disaster recovery and reconstruction	1 (if there is), 0 (otherwise)	S
4- Physical infrastructure		
4-1- Facilities		
-Sturdier housing types	% housing units not manufactured homes	D
-Temporary housing availability	% vacant units that are for rent	D
-Housing stock construction quality	100-% housing units built prior to 1970	D
-Community services	%Area of community services (recreational facilities, parks, historic sites, libraries, museums) total area ÷ TV	D
-Economic infrastructure exposure	% commercial establishments outside of high hazard zones ÷ total commercial establishment	S
-Distribution commercial facilities	%Commercial infrastructure area per area ÷ TV	D
-Hotels and accommodations	Number of hotels per total area ÷ TV	D
-Schools	Schools area (primary and secondary education) per population ÷ TV	D
4-2- Lifelines		
-Telecommunication	Average number of Internet, television, radio, telephone, and telecommunications broadcasters per household ÷ TV	D
-Mental health support	number of beds per 100 000 population ÷ TV	D
-Physician access	Number of physicians per population ÷ TV	S
-Medical care capacity	Number of available hospital beds per 100000 population ÷ TV	D
-Evacuation routes	Major road egress points per building ÷ TV	S
-Industrial re-supply potential	Rail miles per total area ÷ TV	D
-High-speed internet infrastructure	% population with access to broadband internet service	D
-Efficient energy use	Ratio of Megawatt power production to demand	D
-Efficient Water Use	Ratio of water available to water demand	D
-Gas	Ratio of gas production to gas demand	D
-Access and evacuation	Principal arterial miles per total area ÷ TV	D
-Transportation	Number of rail miles per area ÷ TV	D
-Waste water treatment	Number of WWT units per population ÷ TV	S
5- Lifestyle and community competence		
5-1- Collective Action and Decision Making		
-Authorities interdependency	Less than 3 parties are involved in the decision-making process (1), otherwise (0)	S
5-2- Collective Efficacy and Empowerment		
-Creative class	% workforce employed in professional occupations ÷ TV	S
-Scientific services	Professional, scientific, and technical hour services per population ÷ TV	S
5-3- Quality of Life		
-Means of transport	% households with at least one vehicle	S
-Safety	1-Crime rate	D
-Quality of homes	Sustainability rating systems (LEED, BREEAM) ÷ maximum index number	S
-Quality of neighborhood	Sustainability rating systems (LEED, BREEAM) ÷ maximum index number	S
6- Economic development		
6-1- Financial Services		
-Hazard insurance coverage	% housing units covered by National Insurance Program	S
-Crop insurance coverage	Lands areas which are covered by Crop insurance program ÷ total area of cultivated lands	S
-Financial resource equity	Number of lending institutions per population ÷ TV	S
-Tax revenues	Corporate tax revenues per 1,000 population ÷ TV	S
6-2- Industry- Employment Services		
-Employment rate	% labor force employed ÷ TV	S
-Business size	% large businesses	S

-Professional and business services	1-% population that is not institutionalized or infirmed	D
-Economic stability	% employment rate	D
-Economic diversity	% population not employed in primary industries ÷ total employed population	S
-Households insurance	% households covered by National Insurance Program policies	S
-Research and development firms	Number of research and development firms ÷ TV	S
-Business development rate	Business gain /total business	S
6-3- Industry- Production		
-Food provisioning capacity	Food security rate	D
-Large retail-regional/national geographic distribution	Large retail stores ÷ total number of stores	S
-Local food suppliers	Farms marketing products through Community supported Agriculture per 10,000 persons ÷ TV	S
-Manufacturing	Mean sales volume of businesses ÷ TV	S
7- Social-cultural capital		
7-1- Child and Elderly Services		
-Child and elderly care programs	1 (if there is a program), 0 (if no)	S
7-2- Commercial Centers		
-Social capital-civic organizations	Number of civic organizations per population ÷ TV	S
-Commercial establishments	Area of commercial establishments per population ÷ TV	S
7-3- Community Participation		
-Pre-retirement age	% population below 65 years of age	S
-Non-special needs	% population without sensory, physical, or mental disability	D
-Political engagement	% voting age population participating in presidential election	S
-Female labor force participation	% female labor force participation	S
-Population participating in community Rating System	% population participating in Community Rating System (CRS)	D
-Emergency community participation	% community participation in case of warning systems	D
7-4- Cultural and Heritage Services		
-Cultural resources	National Historic Registry sites area per population ÷ TV	S
7-5- Education Services/ Disaster Awareness		
1-English language competency	% population proficient English Speakers	S
2-Adult education and training programs	Number of yearly adult education and training programs per population ÷ TV	S
3-Education programs on DRR and disaster preparedness for local communities	Number of education programs on DRR and disaster preparedness per each local community by local government per year ÷ TV	S
4-Integration of disaster risk reduction in educational curriculum	Number of courses in disaster risk reduction as part of the educational curriculum per schools and colleges ÷ TV	S
5-Citizens awareness of evacuation plans or drills for evacuations	Average number of maneuver per institution ÷ TV	S
7-6- Non-Profit Organization		
1-Social capital-disaster volunteerism	Red cross volunteers per 10,000 persons ÷ TV	D
7-7- Place Attachment		
-Social capital-religious organizations	Persons affiliated with a religious organization per 10,000 persons ÷ TV	S

(Note: the references for the listed indicators can be found in (Kammouh et al. 2017c)