International Journal of Operations Management

ResearchLEAP

Volume 1, Issue 1, October 2020, Pages 19-26
DOI: 10.18775/ijom.2757-0509.2020.11.4002
URL: http://dx.doi.org/10.18775/ijom.2757-0509.2020.11.4002

Measuring Societal Vulnerability to Critical Infrastructure Failure due to Extreme Weather Events

[1] Maria Luskova, [2] Bohus Leitner
[1] University of Zilina, Faculty of Security Engineering Slovakia
[2] University of Zilina, Faculty of Security Engineering Slovakia

Abstract: Climate change and the associated more frequent and unpredictable occurrence of extreme weather events are according to the Global Risk Report (2020), published by the World Economic Forum, among the top five risks today. Although the effects of extreme weather vary around the world and in regions, their effects on social – economic and natural systems are becoming increasingly important and require an active solution. In this context, it is important to address the individual areas of human society vulnerability, as their assessment is the basic information necessary for improving risk reduction and preparedness to extreme weather events. The paper underlines the importance of critical infrastructure as an asset or system whose disruption or destruction could have a range of serious implications for the performance of economic and social functions of the state and thus on the inhabitants in terms of their life, health, security, property and environment protection. It provides selection of past cases of extreme weather events having impacts on critical infrastructure in sector energy and transportation throughout Europe and their impacts on society. Subsequently own approach to measuring societal vulnerability due to impact of extreme weather event on critical infrastructure is presented. In conclusion recommendations supporting the proactive approach to building resilient critical infrastructure which contributes to resilient society are presented.

Keywords: Critical infrastructure, Extreme weather, Resilience, Risk, Society, Vulnerability

1. Introduction

The security, economic and social stability of the state, its functionality, as well as the protection of citizens' lives and assets depend on the proper functioning of many state infrastructure systems. Based on current security risks, the need to define critical infrastructure as a part of infrastructure, the destruction of which will cause serious political and economic consequences, has been arisen in highly - developed countries. In the Slovak Republic, critical infrastructure is defined as the part of national infrastructure (selected organizations and institutions, objects, systems, facilities, services and systems), whose disruption or destruction should adversely affect the performance of economic and social functions of the state; thus on the quality of life of residents in terms of the protection of their lives, health, safety, property, as well as the environment (Act No. 45/2011).

Critical infrastructure as a concept has an interdisciplinary character as it crosses many areas of human society. It therefore requires a wide cooperation and partnership between many sectors and actors, whether they are forming or using the infrastructure. Disruption of key critical infrastructure objects due to a major natural or technological disaster or terrorist attack on the territory of the Slovak Republic would always entail large losses on life and property (nuclear power plant, dam), moral damages (objects with significant symbolic value) or would lead to disorganization of the society as a whole (headquarters of the central authorities, damage to the network of health facilities, waste water treatment plants, supply network, etc.) (MI SR, 2008).

Extreme weather events are no longer perceived as possible future threats but are considered to be one of the biggest environmental problems of the day. The uncertainty associated with their predicting leads to serious impacts on society. The Intergovernmental Panel on Climate Change defines extreme weather or climate event as „The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. An extreme weather event (e. g. a flood) is associated with changing weather patterns within timeframes of less than a day to a few weeks. An extreme climate event (e.g. a drought) is associated with longer timeframes, and can be the accumulation of several weather events (IPCC, 2012).

According to the Global Risks Report 2018 published by the World Economic Forum, the extreme weather events are ranked as the top global risk in terms of the likelihood and the second top global risk in term of the impact (WEF, 2018). This report is based on work with experts and decision-makers across the world participating in identification and analysis of the most pressing risks that people face.

In accordance with the World Meteorological Organization (WMO, 2015) the most frequent and damaging extreme events are storms, floods, droughts, and heatwaves. They cause disasters which are on the rise worldwide. Their devastating impact is due to their increasing occurrence, severity and also to the growing societal vulnerability especially people living in less developed countries. The Atlas of Mortality and Economic Losses from Weather and Climate Extremes 1970-2012 which presents a worldwide analysis of extreme weather, climate, and water events states that „Storms and floods accounted for 79 per cent of the total number of disasters due to weather, water and climate extremes and caused 54% of deaths and 84% of economic losses. Droughts caused 35% of deaths, mainly due to the severe African droughts of 1975, 1983 and 1984' (WMO, 2015). Table 1 provides selection of past cases of extreme weather events having impacts on critical infrastructure in sector energy and transportation throughout Europe and their impacts on society (Groenemeijer, P. et al., 2015).

Extreme weather events affect society in a variety of ways. They include social and economic impacts such as:

- morbidity and mortality of the population,
- deepening social problems, including poverty and poor quality of life,
- deterioration of the quality of natural waters and soil and the overall environment of humans and animals,
- damages to movable and immovable property,
- power supply outages,
- damage to road infrastructure,
- lack of water and food, etc.

Table 1: Selection of past cases of extreme weather events (Groenemeijer, P. et al., 2015)

Event	**Date**	**Location**	**Total damage**	**Fatalities**	**Damage to critical infrastructure in sector energy and transportation**
Windstorm Lothar and Martin	December 1999	West and Central Europe	€ 9 billion	140	Broken power lines, blocked roads, railways
Windstorm Kyrill	January 2007	West, Central and East Europe	€ 4 - 7 billion	47	Falling trees leading to blocked roads and railways; damage to power lines
Flash flood	February 2010	Madeira, Portugal	€ 1.5 billion	45	Blocked roads, disrupted electricity and telecommunication, closed airport, cut water supplies
River flood	May and June 2013	Central Europe	€ 12 billion	25	Road and rail closures, erosion of embankments and streets, damage to bridges, landslides blocking railways
Coastal flood	February 2010	Vendée and Charente-Maritime departments, France	€ 2.5 billion	41	Direct damage and destruction by floodwater and strong wind, cessation of services.

The most notable are the negative consequences of extreme weather events for the most vulnerable population. In our conditions, they are old people, lonely living, children, low-income people and people suffering from a disability.

Since the societies are not resilient to the extreme weather events it is necessary to effectively reduce the impact of and build resilience. A great deal of excellent work has been already done and now it is needed to synthesise all knowledge and information. It requires also joint work and responsibility at local, national and international levels with participation from the individual or household to the international community (The Royal Society, 2014)

2. Research Objective and Methods

Reducing societal vulnerability is one of the main principles of society functioning. Societal vulnerability is a part of the disaster risk assessment and key information needed to assess relevant threats and mitigate their adverse effects.

The aim of the paper is to present the own approach to measuring societal vulnerability due to impact of extreme weather event on critical transport infrastructure developed within solution of the FP7 project RAIN – Risk Analysis of Infrastructure Networks in Response to Extreme Weather (Project Reference: 608166, 2014-2017).

To achieve this aim, a large-scale analysis of the knowledge from domestic and foreign scientific and professional literature, published either in book or in the form of articles, research reports, legal and technical standards, European Commission documents, interviews, processed statistical data, which are in close connection with the issues of measuring and assessing the vulnerability of society, was carried out. By selection, comparison and synthesis of knowledge, the basic concepts, key elements and dimensions of societal vulnerability were defined. In interpreting the results obtained on the basis of study and analysis of vulnerability assessments applied in the Slovak Republic and abroad, the method of induction was applied. The development of own approach to measuring vulnerability was done by the deduction method. A structured set of indicators for measuring and assessing the societal vulnerability as well as the conditions and principles for addressing emerging crisis events were defined and processed based on the synthesis and comparison of the acquired knowledge.

3. Results

In year 2017 the researchers of the Faculty of Security Engineering, University of Žilina participating in the FP7 project RAIN – Risk Analysis of Infrastructure Networks in Response to Extreme Weather developed Methodology for measuring societal vulnerability due to failure of critical land transport infrastructure elements. This Methodology is divided into two basic parts.

The first part “Research of the societal vulnerability concepts and societal vulnerability components” is dealing with theoretical aspects of vulnerability. It includes defining vulnerability, vulnerability concepts, core factors and key dimensions of vulnerability, resilience and survey of some models of risk and vulnerability assessment.

The second part “Development of approach to measure societal vulnerability” includes results of our research in the form of proposed methodology for measuring societal vulnerability due to extreme weather impacts on critical transport infrastructure..

3.1 Research of the Societal Vulnerability Concepts and Societal Vulnerability Components

The concept of vulnerability has been emerged, discussed and continuously developed over the almost past five decades. In the 1970s and early 1980s vulnerability was associated especially with physical fragility (e.g. the likelihood of a building to collapse due to the fire). During the last two-three decades the concept of vulnerability has been continuously developed and broadened towards a more comprehensive approach encompassing susceptibility, exposure, coping capacity and adaptive capacity, as well as different thematic areas, such as physical, social, economic, environmental and institutional vulnerability (Luskova, 2015).

Now the term “vulnerability” is used very loosely in dependence on an individual’s background and the applied context (Luskova et al, 2017). The scientific communities and stakeholders apply different vulnerability definitions. According to Birkmann (2013), the current literature encompasses more than 30 different definitions, concepts and methods to systematize vulnerability.

Concerning the core factors of vulnerability, various authors and scientific communities define core factors of vulnerability differently, e.g.:

• Birkmann (2013) includes among core factors of vulnerability: susceptibility, sensitivity or fragility, coping or adaptive mechanisms.
• Institute for Environment and Human Security of the United Nations University incorporates among the core factors except susceptibility and coping capacities also exposure (Renaud, 2013).
• In IPCC concept the exposure is considered as own factor next to vulnerability. It is defined as the presence of people, livelihoods, environmental services and resources, infrastructure, economic, social, or cultural assets in places that could be adversely affected. Vulnerability is briefly defined as the propensity or predisposition to be adversely affected (IPCC, 2012).

Based on the study of professional sources and their analysis we have defined vulnerability as a function of three elements:

• exposure to extreme weather events,
• susceptibility to change,
• capacity to adapt to that change.

Systems that are highly exposed, susceptible and less able to adapt are vulnerable (Allen Consulting Group, 2005).
Exposure is the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected (IPCC, 2012).

Susceptibility (called also sensitivity or fragility) characterizes the predisposition and likelihood to suffer harm when a hazard strikes a community or a system is exposed.

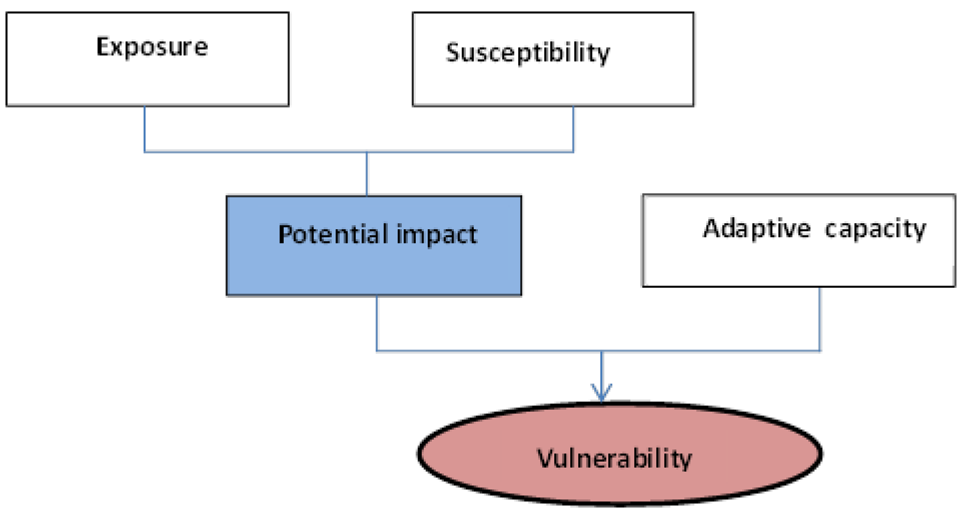

Figure 1: Vulnerability and its core factors (Adapted from Allen Consulting Group, 2005)

In addition to the key factors of vulnerability there are also key dimensions that usually encompass social, economic and environmental aspects.

The social dimension of vulnerability includes aspects such as justice, social differentiation, societal organization, individual strength, poverty, social marginalization, powerlessness, demography, social networks, education, health and well-being, gender, culture, migration, risk perception, etc. (Adger and Kelly, 1999, Adger, 2006, O´Brien et al., 2008, Few, 2007, Cutter et al., 2003).

Economic dimension of vulnerability can be understood as the susceptibility of an economic system (public and private sectors) to potential disaster damage and loss (Mechler et al., 2010). Economic vulnerabilities at macroeconomic level can be analysed e.g. by CATSIM model or the Disaster Deficit Index (Cardona et al, 2009).

The environmental dimension of vulnerability deals with the fragility of ecological and biophysical systems and their different functions under a hazardous condition, to suffer damage and deterioration (Birkmann et al, 2014).

3.2 Development of Approach to Measure Societal Vulnerability

The developed methodology is based on multilevel approach to societal vulnerability measuring. It was formed by gradual splitting of Societal Vulnerability into lower levels (Figure 2):

- Vulnerability Core Factors (3 factors).
- Vulnerability Societal Categories (9 categories).
- Vulnerability Indicators (31 indicators).

The measure of Societal Vulnerability is expressed through Vulnerability Index (VI) calculated on the basis of selected vulnerability indicators.

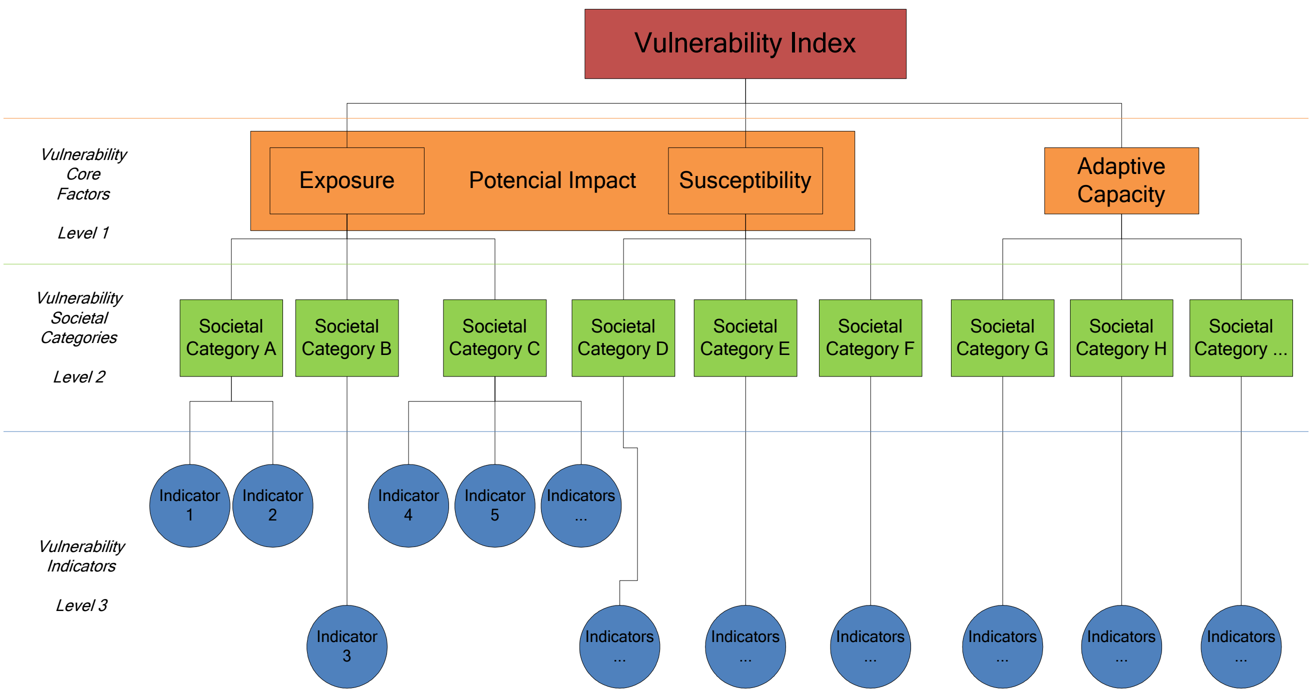

Figure 2: Multilevel approach to the Vulnerability Index identification (Luskova et al, 2017)

In total 31 indicators of societal vulnerability related to the failure of the critical land transport infrastructure elements were identified and described. They were selected based on the study of scientific literature and they were also discussed with subject matter experts in the RAIN consortium. Each indicator is given a value from 1 to 5 in accordance to the assessment table which is part of the description of every indicator (Luskova et al, 2017).

EXPOSURE considers the societal categories: Society, Infrastructure, and Transport Services and the list of indicators is available in Luskova et al, 2017.
SENSITIVITY considers the societal categories: Society, Infrastructure, and Transport Services and the list of indicators is available in Luskova et al, 2017.
ADAPTIVE CAPACITY considers the societal categories: Rescue services, Economic sources, Preparedness/Prevention and the list of indicators is available in Luskova et al, 2017.
By summing the values of Vulnerability Indicators and considering indicator weights, values of the Vulnerability Societal Category were calculated according to equation (1):

$$SC_x = \sum_{n=1}^{i} w_{I_n} I_n \qquad (1)$$

SC= Societal Category
x = designation of Societal Categories
i = number of indicators within Societal Category (from 1 to n)
w_I=weight of Indicators
I_n = value of Indicators

Similarly, values of Societal Categories were added to the value of the Core factor. As in the case of other indicators, Societal Categories needed their weight (w_{SC}**)** to be assessed. The aggregated value of Core Factor is calculated according to equation (2):

$$CF_y = \sum_{n=1}^{j} w_{SC_n} SC_n \quad (2)$$

CF = Core Factor

y = designation of Core Factors

j = number of Societal Categories within Core Factor (from 1 to n)

w_{sc}= weight of Societal Category

SC_n = value of Societal Category

The resulting value of VI is obtained in a similar way. The final calculation of VI is preceded by one extra step which lies in the calculation of Potential Impact **(**PI). Potential Impact represents possible level of impacts on society after considering all aspects which can be in danger (Exposure) and after considering all societal groups, which are more sensitive to extreme weather impacts (Susceptibility). The weights of Exposure and Susceptibility (w_E, w_S) are also included. The Potential Impact is calculated according to equation (3):

$$PI = w_E E + w_S S \quad (3)$$

PI =Potential Impact

E= Exposure

S = Susceptibility

w_E = weight of Exposure

w_S = weight of Susceptibility

The resulting value for VI is the sum of the PI weight value and weight value of Adaptive Capacity (4):

$$\boldsymbol{VI} = w_{PI} PI + w_{AC} AC \quad (4)$$

VI = Vulnerability Index

AC = Adaptive Capacity

w_{PI}= weight of PI

w_{AC}= weight of Adaptive Capacity

A higher VI value indicates higher societal vulnerability. The index and related interpretations (Luskova et al., 2017) serve for evaluation of the current state in specific region as well as for decision making purposes.

4. Discussion

Within our research in the RAIN project focused on societal vulnerability measuring, we have applied conceptual framework that is widely used in research community (Fig. 1).

Societal vulnerability is composed of various dimensions and is affected by vast number of factors. These dimensions and factors are so different that it is not possible to use them for direct Societal Vulnerability measurement. On the other hand, these dimensions and factors have some characteristics and aspects in common, hence, it is possible to assort them into groups. This way we can gradually define the overall level of societal vulnerability. Therefore, we suggest the use of multilevel approach for the measurement of societal vulnerability (Fig. 2) which, by gradual defining of concrete levels, will lead to the determination of overall Societal Vulnerability

It is also important to remind that vulnerability is dependent on specific hazard. Hence, target region can be more vulnerable to a certain kind of threat but much more resistant, i.e. less vulnerable to another kind of threat. We incline to this idea and therefore it is necessary to evaluate vulnerability for each threat or danger separately.

There could be significant differences between vulnerabilities of the same area to the same hazard with different intensity, e.g. windstorm with speed of 70km/hour or 140km/hour; flood with probability of occurrence 1 in 10 years, and flood with probability of occurrence 1 in 1000 years. Therefore to address the intensity of hazard within vulnerability analysis, it is important to identify the indicators which can vary based on the hazard intensity.

Our research work was concentrated on development of an understanding how failure of critical land transport infrastructure leads to societal vulnerability. From a literature review, dealing with measuring vulnerability to extreme weather events, follows that a common methodology to identify and measure risk and vulnerability to extreme weather events in order to define disaster-risk management and disaster-relief priorities is still not sufficiently developed. Also for this reason our effort was concentrated on research how to measure vulnerability to be usable for improving risk reduction and preparedness to extreme weather events and how to propose and develop relevant indicator approaches for specific purposes.

5. Conclusion

Extreme weather and climate events as a phenomenon of the 21st century are becoming one of the biggest challenges of environmental policy. Although their exposes across the world and regions are different, their adverse consequences for socio-economic and natural systems are increasingly important and require active solutions.

One such solution that helps minimize the risks and negative consequences of extreme events is to reduce vulnerability and to adapt people and ecosystems to lower economic, environmental and social costs.

From the point of view of protecting and defending critical infrastructure, one of the main tasks of the Slovak Republic's security policy is a continuous assessment of risks and threats at national as well as international level. Risk analysis is a prerequisite for understanding threats in the world of globalization. This task includes also the assessment of the effectiveness of the protection and defense of critical infrastructure as well as the assessment of the preparedness and capability of the individual actors involved in the protection and defense of critical infrastructure. Integrated systems are in place to enable the individual units to be able to cooperate and to engage operationally in crisis situations, to combine their efforts according to the extent and nature of the threat.

Recommendations for all stakeholders participating in critical infrastructure protection for the purpose to support the proactive approach to building resilient critical infrastructure which contributes to resilient society include:

• Effective cooperation between the critical infrastructure owners/operators and state administration authorities supporting mutual confidence and reliability.
• Measuring societal vulnerability due to critical infrastructure failure.
• Building resilient organisations which are able to absorb an event, to adapt and continue in their activities.
• Assistance of state administration authorities to critical infrastructure owners /operators in identifying, analysing and managing cross-sectoral dependencies.

Acknowledgement

This paper was supported by VEGA grant No. 1/0240/15 “Process model of critical infrastructure safety and protection in the transport sector and by the European Union within the FP7 project No. 608166 “Risk Analysis of Infrastructure Networks in response to extreme weather”.

References

- Act No. 45/2011 Coll. about Critical Infrastructure. (2011). 9p. Retrieved 15.07.2018 from http://www.zbierka.sk/ CrossRef
- Adger, W.N., Kelly, P. M. (1999). Social vulnerability climate change and the architecture of entitlements. Mitigation and Adaptation Strategies for Global Change. Volume 4, Issue 3-4, pp 253-256. Retrieved 18.07.2018 CrossRef
- Adger, W.N. (2006). Vulnerability, Global environmental change, 16: 268-281. Retrieved 18.07.2018 from https://www.geos.ed.ac.uk/~nabo/meetings/glthec/materials/simpson/GEC_sdarticle2.pdf
- Allen Consulting Group. (2005). Climate Change, Risk and Vulnerability. Report to the Australian Greenhouse Office, Department of the Environment and Heritage. Published by the Australian Greenhouse Office, in the Department of the Environment and Heritage. ISBN: 1 920840 94 X.
- Birkmann, J. (2013). Measuring vulnerability to natural hazards: towards disaster resilient societies. United Nations University Press. Tokyo. Japan. ISBN 978-92-808-1202-2.
- Birkmann, J., Kienberger, S., Alexander, D., (2014). Assessment of vulnerability to natural hazards. A European perspective. 2014. Elsevier Inc. USA. ISBN: 978-0-12-410528-7

- Cardona, O.D., Ordaz, M.G., Marulanda, M.C., Barbat, A.H. (2009). Use of the disaster deficit index in the evaluation of the fiscal impact of future earthquakes. Article No.1, Intersections/Intersecţii, Vol.6, 2009, No.2. ISSN 1582-3024. Retrieved 20.07.2018 from http://intersections.ro/archive/2009/No02/Intersections_V06_No02_01.pdf
- Cutter, S. L., Boruff, B. J., Shirley, W. L. (2003). Social Science Quarterly. Social Vulnerability to Environmental Hazards. Vol. 84, No. 2. pp.242-261. Retrieved 19.07.2018 CrossRef
- Few, R. (2007). Health and climatic hazards: Framing social research on vulnerability, response and adaptation. Global Environmental Change. Volume 17, Issue 2, May 2007, pp. 281-295. Retrieved 19.07.2018 from CrossRef
- Groenemeijer, P. et al. (2015). Past Cases of Extreme Weather Impact on Critical Infrastructure in Europe. Project RAIN - Past Cases of Extreme Weather Impact on Critical Infrastructure in Europe. Deliverable 2. 2. Retrieved 17.07.2018 from http://rain-project.eu/
- IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Special Report of the Intergovernmental Panel on Climate Change (ed. Field, C. B, Barros, V, Stocker, T. F., Qin, D, Dokken, D. J, Ebi, K. L, Mastrandrea, M. D, Mach, K J, Plattner, G.K, Allen, S K, Tignor, M & Midgley P. M). Cambridge University Press.
- Lusková, M. (2015). Approaches to risk and vulnerability assessment caused by extreme weather events/In: Riešenie krízových situácií v špecifickom prostredí: 20. International scientific conference: 20. - 21. May 2015, Žilina. [2. Part]. - Žilina: Žilinská univerzita, 2015. - ISBN 978-80-554-1022-7. - p. 335-341.
- Luskova, M., et al. (2017). Methodology for measuring societal vulnerability due to failure of critical land transport infrastructure elements. D3.4. Retrieved 18.07. 2018 from http://rain-project.eu/
- Mechler, R., Hochrainer, S., Pflug, G., Lotsch, A., Williges, K. (2010). Assessing the Financial Vulnerability to Climate-Related Natural Hazards. Background Paper to the 2010 World Development Report. Policy Research Working Paper 5232. Washington, DC: World Bank. Retrieved 20.07.2018 from https://openknowledge.worldbank.org/bitstream/handle/10986/3718/WPS5232.pdf?sequence=1
- Ministry of Interior of the SR (MI SR). (2008). National Program for the Protection and Defence of Critical Infrastructure in the Slovak Republic. Retrieved 15.07.2018 from https://www.mhsr.sk/uploads/files/c2CSdqQ5.pdf
- O'Brien, K. et al. (2008). Disaster Risk Reduction, Climate Change Adaptation and Human Security A Commissioned Report for the Norwegian Ministry of Foreign Affairs. University of Oslo. Report 2008:3. ISSN: 1504-5749. Retrieved 19.07.2018 from https://www.unisdr.org/files/7946_GECHSReport3081.pdf
- Renaud, F.G. (2013). Environmental Components of Vulnerability. In: Birkmann, J. (Ed.): Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. United Nations University Press, Tokyo. pp. 109-126.
- The Royal Society. (2014). Resilience to extreme weather. The Royal Society Science Policy Centre report 02/14. Issued: November 2014 DES3400. ISBN: 978-1-78252-113-6
- World Economic Forum (WEF). (2018). The Global Risks Report 2018. Retrieved 16.07.2018 from https://www.weforum.org/reports/the-global-risks-report-2018
- World Meteorological Organization (WMO). (2015). Atlas of Mortality and Economic Losses from Weather and Climate Extremes 1970-2012. Geneva. Retrieved 16.07.2018 from https://drive.google.com/file/d/0BwdvoC9AeWjUd1RwQW5Ld2hqTDQ/view