D2.2.5 Annex – Vulnerability and exposure definitions from different perspectives (SLOD/SUOD)

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1. Introduction

The present annex has the aim to define the concepts of "vulnerability" and "exposure" and delineate eventual differentiation elements between SLOD and SUOD events in order to avoid misunderstanding in future deliverables. This necessity arose as a consequence of discussions about SLOD and SUOD variables to be involved in the next WP3. Starting to inquire about the reciprocal iteration between SLOD and SUOD events (e.g.: the possibility of the occurring of a sudden onset event during a rather constant slow onset one) and their main criticalities, some observations were advanced. A first approach has imagined considering users' vulnerability connected with exposure issues in different ways from SLOD to SUOD. But then, a literature overview and further analysis of such themes have permitted to reach the univocal solution described in this annex. Therefore, in the first part (Section 2), common and synthetic definitions of vulnerability and exposure are provided, then a distinction of these risk components between the disastrous events typologies (SUOD and SLOD) is reported and supported by further explanations, examples and references. The second part of the present annex (Section 2) regards the individuation, from experimental data analysis, (starting from D1.2.1, D1.3.1, D2.2.5 and in the view of Section 2 definitions) of the main differentiation elements between SLOD and SUOD, to move towards modelling purposes. Finally, Table 2 tries to resume SLODs and SUODs input classes for the simulation and risk assessment, by including purposes for the use of the variables. Whatever eventual modification, deriving from possible achievements of the present research, that will be believed appropriated will be taken into consideration and integrated.

Common definition of vulnerability and exposure[1]:

Vulnerability
The name given to the set of characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard is vulnerability.

Exposure
The presence and number of people, property, livelihoods, systems or other elements in hazard areas (and so thereby subject to potential losses) is known as exposure.

2. Vulnerability and Exposure distinction between SLOD and SUOD

Vulnerability, according to (Pelling 2003), is subdivided into physical vulnerability as the vulnerability of the physical environment and social vulnerability as experienced by people and their social, economic, and political systems. Social vulnerability is then subdivided into Individual vulnerability (this study mainly focuses on) and Collective vulnerability regarding the whole community.

Physical vulnerability for SUOD events mainly concerns the physical and structural features of the Built Environment. In relation to the SUODs discussed in the BE S2ECURe project, earthquakes-related disasters mainly involve the seismic vulnerabilities of buildings and all the man-made structures (e.g.: urban streets, bridges, tunnels, retaining walls and embankments) that compose the BE (e.g. see D1.2.1 and D1.2.2 and D1.2.5). In the case of terrorist attacks, the concept of physical vulnerability remains strictly related to the BE but is predominantly focused on its configuration and on the urban layout (e.g. see D1.3.1 and D1.3.2). Structural features could be evaluated for instance in case of a bombing attack (FEMA-426/BIPS-06 2011). Considering a SLOD event, the vulnerability is referred to the Built Environment configurational elements (including layout) which can alter the damaging effects (e.g. see D2.2.5). For instance, urban canyon has registered as the most vulnerable shape-related condition than other urban configurations (Zhou and Levy 2008). Applied materials for buildings facades and pavements (e.g.: high-albedo materials) can influence significatively the temperature perception, thus heatwaves, impact on the way to entrap the heat and reflecting solar radiations (Erell et al. 2014). Further urban elements presence is assessed as vulnerability-influencing factors (e.g.: green areas and tree-lined streets reducing air pollution) (Langenheim et al. 2020).

Social vulnerability, according to (Villagràn De León 2006), can include human-related factors such as physical features of individuals, their psychological and behavioural aspects, since these elements compose the "set of characteristics and circumstances" of individuals' and communities towards the damaging effects of the considered disaster hazard. Different impacts are registered in relation to the different disaster event typologies (SLOD and SUOD). People's characteristics (e.g.: age, gender, disabilities, difficulties in motion (D'Orazio et al. 2014), health fragility (Barrow and Clark 1998; Delfino et al. 2010), culture, socioeconomic status of the household (Koks et al. 2015)) and people's response to the hazard (Cardona et al. 2012) (e.g.: susceptibility, disaster preparedness, coping capacity, which also refers to their behavioural aspects and their

[1] https://www.preventionweb.net/risk/vulnerability last access 01/07/2020

reactions) can influence positively or negatively their propensity to be threatened by disaster effects (Liu et al. 2018). These elements can be evaluated for the whole disaster-prone community (*collective vulnerability*, e.g. evacuation and emergency management issues; social issues at the community scale) and for the specific individual (*individual vulnerability*, e.g. behaviours, gender, age, health fragility, other features and motion quantities). For instance, in SLOD, elderly with difficulties in motion (individual vulnerability regarding its physical features) employ major time to travel by feet, thus increasing the exposure time to pollutants; or, youngsters and elders, which having a rather fragile health, can be more affected under the same exposure time and pollutant concentration (Barrow and Clark 1998; Delfino et al. 2010). In SUOD, the same man has lower possibilities to escape from a terrorist attack than other adults without mobility impairments.

Exposure, in general, is focused on the human presence, on the number of people, on the historic and artistic heritage and to the presence of relating services (Mouroux and Brun 2006). The last two mentioned material goods are considered in the exposure assessment only in disastrous events where destroying effects can reflect on them (e.g.: earthquakes, bombing attack). The presence in stricken areas of industrial and manufacturing activities and commercial transportation systems could lead to economic losses and to the interruption of productive capacity as a consequence of disastrous events. Therefore, socio-economic issues are other factors to be encompassed in exposure (Sarabia et al. 2020). In SUODs, for instance, the exposure is strictly related to the presence of persons in a specific environment (Wardhani 2015) defined as risky for human life (e.g.: the total number of people, eventual overcrowding conditions, and how many people are in proximity to the risk sources). The same considerations are valid both for earthquakes, considering people in high seismic intensity areas, and both terrorist attacks, where one or more individuals are exposed to the risk of becoming a terrorism victim. Hence, also for SLOD events, the exposure is connected to the presence of people in a defined urban place for a certain period of time on a regular basis when their health and wellbeing are under risky conditions; or their health is slowly degrading (e.g. air pollution disease burden, see WHO (2016)). In such areas, pedestrians are exposed to Urban Heat Island and increasing temperatures[2] (that affect their body temperature) or to the inhalation of particulate matter (Luo et al. 2018) (that affect their respiratory systems). The exposure increases when citizens pass repetitively through a zone with certain critical levels registered or when they remain there for long time. Therefore, the concept of exposure can be defined in the same way for SUOD and SLOD events and it is only connected to the number and human presence in the proximity of the risk source for a specific instant (for SUODs and SLODs); or, either for a longer period or their presence factored by the recurrence of their presence (for SLODs).

Table 1 tries to offer and overview of such issues by distinguishing SUOD/SLOD conditions and given practical examples for the vulnerability and exposure-related issues.

[2] Heatwaves are another event temperature-related that can be considered as SLOD. However, their duration is around forty-eight to seventy-two hours and (only in extreme cases) longer according to (Barrow and Clark 1998) Therefore, they could not be compared with the seconds and minutes proper of SUOD events duration (earthquakes and terrorist acts).

Table 1. Short descriptions and practical examples are schematically reported for each risk factors in relation to the event typology

Disaster type	Event type	Short description	Practical examples including damaging effects	References
Physical vulnerability				
SUOD	Earthquakes	Seismic vulnerability of buildings and BE elements based on physical and structural features	Facades of masonry typologies with specific vulnerability could collapse over the urban street blocking the passage	(Ferlito and Pizza 2011)
SUOD	Terrorist attacks	Urban layout vulnerability based on spatial configurations and emergency management provisions	If no safe perimeters or standoff distances are assumed against explosion, no refuges are available	(FEMA-426/BIPS-06 2011)
SLOD	Air pollution	BE configuration in relation to traffic-related issues, presence of vegetations absorbing pollutants	An urban canyon interested by high dense traffic increases the damaging effects due to the pollutants	(Zhou and Levy 2008)
SLOD	Increasing temperature	BE configuration and surfaces features in relation to their capacity of reflecting or absorbing solar radiation	Urban canyon allowing solar radiation and high absorbing materials increase the damaging effects of Increasing temperature	(Erell et al. 2014)
Social vulnerability				
SUOD	Earthquakes/ Terrorist attacks	Pedestrian features and behavioural aspects affecting their motion toward safe areas	A person with disabilities in motion employs more time to reach safe areas	(D’Orazio et al. 2014)
SLOD	Air pollution/ Increasing temperature	Pedestrian features and behavioural aspects affecting their travel time and their clinical picture	Air pollution has a heavy impact on a pedestrian with previous respiratory disease	(Manigrasso et al. 2017)
Exposure				
SUOD	Earthquakes	Presence of people in the BE both on streets and inside vulnerable buildings	A disabled person in the middle of a wide urban square has more possibilities to survive rather than a child inside an old building	(Quagliarini et al. 2016)
SUOD	Terrorist attacks	Presence of people in the attack source proximity	People very close to the attackers are more prone to be shot because they are in the wrong place at the wrong time	(Joint Counterterrorism Assessment Team (JCAT) 2018)
SLOD	Air pollution	Repetitive inhalation of particulate matter	A person with previous respiratory disease upon a wild hill is not exposed to any pollutant	(Luo et al. 2018)
SLOD	Increasing temperature	Prolonged permanence under high temperatures effects	Increasing temperature affect pedestrian walking speed in the BE during the hot seasons	(Liang et al. 2020)

3. From differences between SLOD and SUOD to defining input data classes for risk assessment

As described in D.1.1.1 and D.2.1.1, the Slow Onset Disasters (SLODs) have a significantly different behavior compared to any other type of risk. As qualitatively shown by Figure 1, they develop in a diverse timeframe, thus frequency, intensity and duration (PreventionWeb - UNDRR). In fact, the SLODs can expose citizens adverse health conditions in different ways: to low intensity and lengthy, or to recurrent, and in certain context permanent. SLODs risk should be studied in parallel with any other SUODs risk type, over the time: it has been considered that SLODs could establish the initial conditions (time zero, t_0) from which the other risk can appear. SLODs risk will slowly determine the way the citizens behave and move under no other SUOD-related hazards, so information on citizen's exposure can be gathered. This approach is the rationale for Figure 1.

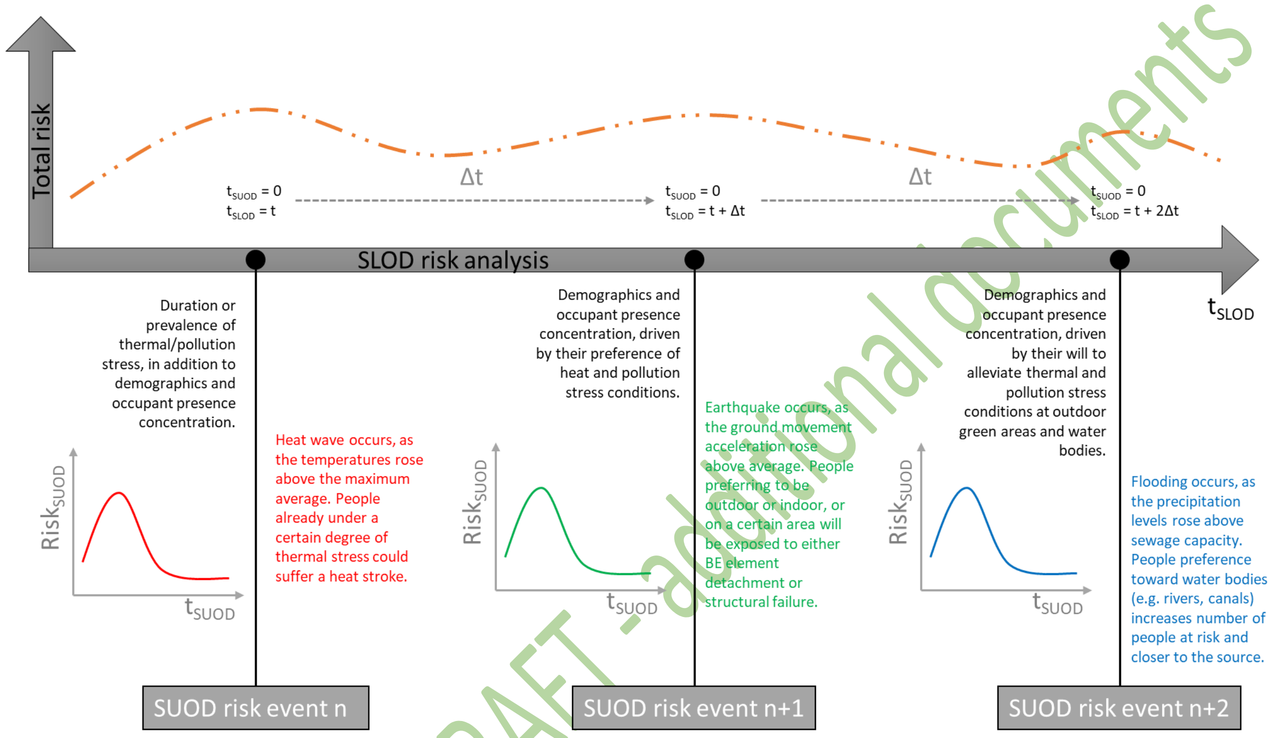

Figure 1:Representation on how the SUOD and SLOD could coexist on the same timeline with different timeframes and ranges of occurrence

Concerning the *exposure* parameter, for SUODs, the presence of individuals prone to the disaster and the occurrence of possible crowding conditions is a variable parameter (depending on the specific moment in which the event occurs and to the quickness in damaging effects manifestation). For SLODs (given the trends exposed in Section 3 of D.2.1.1), they can even be mainly considered as permanent in most urban areas (European Environment Agency 2018; Piselli et al. 2018), especially in the Open Spaces in the BE, thus having a long-term standpoint because they emerge gradually over time (World Health Organization; Reduction 2017).

Concerning the *vulnerability* parameter (i.e. *individual vulnerability*), in both SUODs and SLODs, it is associated with how "fragile" the person is when exposed to the hazard. Anyway, in addition to the general individuals' features, for SLODs, an additional fragility is associated to the individuals' health (Manigrasso et al. 2017): as citizens are constantly exposed to SLODs, what differentiates the risk is how much resistance can each individual put when subjected to the hazard stress. Moreover, SLODs are not always perceived by the citizens and when perceived, or noted, the adverse health conditions are already at their highest intensity. For instance, *increasing temperatures* are mostly perceived when a heat wave arises or recurrent heat waves do (sustained temperature intensity peak); also, smog is only perceived when the climatological conditions meet to from the fog which combines with an already present pollutant concentration.

In view of the above as well as of the risk matrixes for SUODs and SLODs (see D1.2.1, D1.3.1 and D2.2.5), different classes of input data to move towards simulation and risk assessment in the BE are provided by Table 2. For some of the reported variables regarding exposure and vulnerability, units of measure are already established, while for other a quantification will be resumed in future work programs. In any case, from the last column of Table 2 it is observable how much are various the several units of measure (e.g.: from the number of people [pp] to motion issues [m/s]). However, vulnerability and exposure issues should be interacting and affect themselves reciprocally. Therefore, a problem not still overcome emerges: establishing a dialogue between vulnerability and exposure variables that will be the objective of future metrics definition

Table 2:SLODs and SUODs input classes for the simulation and risk assessment, by including [unit of measures] of the variables and purposes for the use of the variables. "-" means not significant/not assessed

ID	Input class	Earthquake	Terrorist acts	Increasing temperatures	Air Pollution	Unit of measures (to be filled)
1	***hazard***					
1.1	*input parameters*	Event magnitude/ Seismic intensity	Type of attack considering employed weapons	Reached temperature, humidity levels, wind velocity and prevalent direction,	Exceeded time-dependent thresholds (hourly, daily, weekly, monthly or yearly), particulate matters concentrations	
1.1.1	frequency (to estimate magnitude/severity)	Return period	-	Return period of critical peak condition (depending on daily and seasonally trends)	Return period of critical conditions (depending on daily and seasonally trends)	[years]
1.1.2	Day-time	presence of the individuals	presence of the individuals	to estimate the presence of the individuals (and type of individuals); to estimate the boundary conditions to the events	to estimate traffic conditions and neighboring individuals (and type of individuals); to estimate the boundary conditions to the events	[pp]
1.2	*simulation/assessment timing*	From seconds to minutes	From seconds to hours	From hours to days	From months to years	
1.2.1	for a specific event	In mass gathering events in relation to the number of agents	In mass gathering events in relation to the number of agents	In extreme heat waves-	In extreme heat waves and traffic conditions-	
1.2.2	for all the events	Seconds/minutes	Minutes	season	years	
1.3	*early warning (to be related to 3.3)*	none	If perceived by security personnel or from ambiguous behaviours	Temperature historic and week trend. Coupled with climatological analysis on wind pressure and the water cycle.	Pollutant concentration trend, combined with solar radiation, and wind pressure analysis.	
1.4	*predictability*	none	By Intelligence Forces			
2	***BE vulnerability***					
2.1	*OS elements in the overall layout configuration*	Streets seismic vulnerability and redundant paths	BE configuration and layout	BE typologies and layout	BE typologies and layout	

2.1.1	green areas	Extension distance from buildings enclosure, fences and access points	Extension presence of elements where to refuge, enclosure, fences and access points	Extension, shading and cooling capabilities, presence of inner and alternative pathways	Extension, adsorption capabilities, presence of inner and alternative pathways	
2.1.2	low obstacles/street furniture	Obstacle presence impeding the evacuation	Obstacle presence impeding the evacuation,	Urban furniture as awning and canopy providing shading	-	
2.1.3	other low obstacles including trees	Urban furniture handholds or trees where hold on to keep balance	Low wall or vegetation where to refuges	Trees providing shading	Trees and green structures providing pollutant adsorption and/or protection from pollution source	
2.2	*building related issues*	Seismic vulnerability concerning their typologies and structural features	Building shape, facades protection measures and sheltering	Geometries, heights and facades materials (green areas present?)	Shapes, heights and facades materials (green areas present?)	
2.2.1	materials	Constructive typologies are relapsed into seismic vulnerability	Reinforced materials against bombing	Facades material property to reflect/absorb solar radiation (albedo)	Facades materials able to adsorb pollutants, surface roughness	
2.2.2	geometry	building heights vs facing Open Spaces width to estimate path blockages in the evacuation layout	building heights vs facing Open Spaces width to estimate path blockages (i.e. bombing attack) and the overall evacuation layout	building heights vs facing Open Spaces width to estimate canyon effects. Orientation.	building heights vs facing Open Spaces width to estimate canyon effects. Orientation.	[m]
2.3	*OS surfaces*	Conservation state and maintenance	Conservation state and maintenance	Reflection properties of materials	Adsorption properties of materials	
2.4	*AS/LS main elements for the disaster conditions*	Safe areas (Aerial Spaces), wayfinding signs presence (Linear Spaces) Exits and escaping routes (Aerial Spaces/Linear Spaces)	Safety measure in mass gathering events (Aerial Spaces) Exits and escaping routes (Aerial Spaces/Linear Spaces)	Lined trees for paths shading (Linear Spaces) water bodies (Aerial Spaces)	Congested intersections (Aerial Spaces) traffic lights and queues (Linear Spaces)	
2.4.1	AS function in the pre/post-disaster	Attraction areas for crowding / gathering areas	Attraction areas for crowding / gathering areas	Attraction areas for pedestrians/sunny areas to avoid	Attraction areas for pedestrians/ areas close to traffic	
2.4.2	LS function in the pre/post-disaster	Passage areas/ escaping routes	Passage areas/ escaping routes	Passage areas/ shading side of the street generates attraction	Passage areas/ passage areas to be crossed rapidly	
2.4.3	geometry	building heights vs facing Open Spaces width to estimate path blockages in the evacuation layout	building heights vs facing Open Spaces width to estimate path blockages (i.e. bombing attack) and the overall evacuation layout	Green/water areas size, height, density (lush)	Green area size, height, width, density	[m] [m^2] [m^2/m^2]
3	***Users' vulnerability***					

3.1	*individual vulnerability*	Individual difficulties and impairments in motion, behavioural response to disasters	Individual difficulties and impairments in motion, behavioural response to disasters	Individual health and wellbeing conditions, events perception and changing habits	Individual health and wellbeing conditions, events perception and changing habits	
3.1.1	motion quantities	Evacuation speed	Evacuation speed	Travel times	Travel times	[m/s]/[min]
3.1.2	health of the person	Impairment and difficulties in motion	Impairment and difficulties in motion	Compromised clinical picture and general wellbeing	Respiratory diseases	
3.1.3	age/gender	The age influences the evacuation speed	The age influences the evacuation speed	Females and males could perceive heat differently, elders suffer more for high temperatures effects	Youngers and elders are risky categories	
3.2	*(main) behavioral issues, cultural and socioeconomic status*	Pre-movement phase and evacuation choice	Pre-movement phase and evacuation choice	Reaction to sensible effects, changing habits, heat tolerance	Changing habits, context environmental quality	
3.2.1	motion issues	Paths choice, attraction and repulsion forces	Paths choice, attraction and repulsion forces	Paths choice, attraction and repulsion forces	Paths choice, attraction and repulsion forces	
3.2.2	risk perception issues	Pre-movement phase and preparedness	Pre-movement phase and preparedness	Individual perception features, preparedness	Preparedness and risk awareness	
3.3	*collective vulnerability*	Influence of crowd choices, behavioural emulations	Influence of crowd choices, behavioural emulations	Influence of others' behaviours	Influence of others' behaviours	
3.3.1	management of emergency conditions	Influence of adopted measures (e.g.: wayfinding signs, security personnel…)	Influence of countermeasures (e.g.: escape routes, security personnel…)	Previous experiences, tendency towards sheltered and conditioned spaces	Previous experiences, tendency to avoid route	
3.3.2	evacuation layout	Area division in mass gatherings, indications towards safe areas, escape routes	Shelter predispositions, area division in mass gatherings, escape routes	-	-	
4	***Exposure***					
4.1	*position of the individuals in the BE during the time*	Number of agents present in the scenario, initial position and final, timestep position, position to timesteps	Number of agents present in the scenario, initial position and final, position to timesteps	Number of agents present in the scenario, initial position and final, position to timesteps	Number of agents present in the scenario, initial position and final, position to timesteps	[pp]
4.2	*users' paths in the BE and occupancy issues*	Tracking information for each agent, occupancy and LOS in hotspots	Tracking information for each agent, occupancy and LOS in hotspots	Tracking information for each agent, occupancy and LOS in hotspots	Tracking information for each agent, occupancy and LOS in hotspots	[pp/m²]
4.3	*number of exposed individuals per individual vulnerability*	Number of agents for each user' vulnerability categories	Number of agents for each user' vulnerability categories	Number of agents for each user' vulnerability categories	Number of agents for each user' vulnerability categories	[pp]

	and behavioral issues class					
4.4	*number of exposed individuals*	Total number of agents present in the scenario	Total number of agents present in the scenario	Total number of agents present in the scenario	Total number of agents present in the scenario	[pp]
4.5	*Presence of industrial and manufacturing activities, commercial transportation systems and service to citizens*	Loss estimation and temporary interruption of such activities, damage levels influence times to restart	Loss estimation and temporary interruption of such activities, damage levels influence times to restart	Heat source	pollutant source	
4.6	*Presence of the historic and artistic heritage*	Earthquakes could cause damages to such structures and to what is contained there	In case of bombing attacks or other terrorist attack causing destruction to structures and things	-	-	

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