Improvement of an index oriented methodology for consequence analysis of natural hazards: application to the Upper Guil Catchment (Southern French Alps)

Benoît Carlier [1], Anne Puissant [2], Constance Dujarric [1], Gilles Arnaud-Fassetta [1]

[1] Université Paris-Diderot (Paris 7), Sorbonne Paris Cité, UMR 8586 PRODIG, 5 rue Thomas Mann, 75013 Paris, France.

[2] Université de Strasbourg, UMR 7362 LIVE, 3 rue de l'Argonne, 67000 Strasbourg, France.

Correspondence to: Benoît Carlier (carlierbenoit@hotmail.fr) and Anne Puissant (anne.puissant@live-cnrs.unistra.fr)

Abstract

Vulnerability is a complex concept involving a variety of disciplines from physical and socio-economic sciences. Currently, two opposite trends exist: the physical approach in which vulnerability is analysed as potential impacts on the exposed elements; and the social approach in which vulnerability is viewed as a combination of socio-economic variables determining people's ability to anticipate before a catastrophic event, to react during it, and to recover after it. Finding a way to combine these two approaches is a key issue for a global vulnerability assessment. The objective of this paper is to improve the *Potential Damage Index* (Puissant *et al.*, 2013) originally developed to assess the physical, structural and functional consequences of landslide hazard, by including social and institutional criteria. These criteria, derived from INSEE French census data and risk perception survey were selected to represent the three main phases of risk management: preparedness, crisis management and recovery. The new *Global Potential Damage Index* is then applied on the Upper Guil Catchment to assess torrential floods. Results of the PDI are compared with the GPDI and show significant differences. GPDI scores are globally lower than PDI scores indicating that resilient population may qualify results obtained for physical consequences.

Introduction

In mountainous area, local communities are particularly exposed to natural hazards due to some characteristics inherent to the physical and socio-institutional environment (Zingari and Fiebiger, 2002; Hewitt & Metha, 2012). This leads to important costs for communities with often limited resources and have significant impacts on public opinion (Barroca *et al*., 2005). In a context a global changes (i.e. climatic, socio-economics and institutional) this concern is growing up (Pachauri *et al*., 2007; Alcántara-Ayala *et al*., 2015) and thus, communities request for studies on risk assessment are increasing too.

However, studies on risk assessment at regional or local scale are frequently hazard centred and consequently the vulnerability component is often limited (Reghezza, 2006; Reghezza & Rufat, 2015; Zahran *et al*., 2008; Jeffers, 2013). Even when vulnerability is taken into account, few multidisciplinary studies apprehending the overall components of vulnerability (social, institutional, physical, structural and functional aspects) exists

(Fuchs, 2009; Barroca *et al*., 2005). Vulnerability is a complex concept involving a variety of disciplines from both physical and socio-economic sciences (Fuchs, 2007, Fuchs *et al*., 2009). If the number of vulnerability components is also debated (Tapsell *et al*., 2010), two main research approaches dominate: the "physical approach" and the "social approach". For environmental researchers and engineers, vulnerability is viewed as the total potential consequences of a process impacting on human stakes (Glade, 2003; Fuchs *et al*., 2007; Kappes *et al*., 2012). In this approach, the emphasis is focused on structural and functional consequences on building, network and landcover/use (Puissant *et al*., 2006; 2013). For social scientists, vulnerability is mainly considered as a combination of socio-economic variables determining people's ability to anticipate a catastrophic event, to react during it, and to recover after it (Blaikie *et al*., 1994; 2003; Clark *et al*., 1998; Cutter *et al*., 1996; 2003; Wu *et al*., 2002; Chakraborty *et al*., 2005). In that case, social vulnerability refers to socio-economic and demographic factors that may affect the resilience of communities (Flanagan *et al*., 2011).

Reducing susceptibility to hazard and create disaster-resilient communities, necessitate to combine these two theories (Fuchs, 2009; 2012). For Rygel *et al*., 2006, and Birkmann, 2006, the more effective solution to assess vulnerability is to create an index from a suite of indicators. This approach provides many advantages: it is flexible enough to be adjusted to different hazards and places (Kappes *et al*., 2012) and it permits the analysis of all the relevant types of consequences without monetary measures (Meyer *et al*., 2009). Furthermore, the improvement of GIS technology with its ability to integrate information from various fields makes it easy to develop high resolution vulnerability index with an operative perspective (Wood & Good, 2004; Nelson *et al*., 2015).

In the context of the French funded ANR project SAMCO (*Society Adaptation for coping with Mountain risks in a global change Context*), we applied these principles to set up a systemic analysis of mountain risk including elements of all the components of vulnerability (i.e. structural, functional, social, economic and institutional). To achieve this, we proposed a modified version of the *Potential Damage Index* (PDI) originally developed by Puissant *et al*. (2013) to estimate the total potential consequences of natural multi-hazards on elements at risk (building, network and land occupation). In its first version, the PDI was obtained by combining three indices representing direct (physical injury and structural and functional impacts) and indirect consequences (socio-economic impacts). In order to include elements of social and institutional vulnerability from census data and risk-perception surveys we proposed to replace the physical injury component by adding several elements of the three phases of risk management: preparedness, crisis management and recovery. The new index called *Global Potential Damage Index* (GPDI) is tested to map consequences of multi-hazards in the Upper Guil catchment (torrential flood, landslide and avalanche).

In the first section of this paper, the physical and socio economic context of the study area is exposed. Then, the second section present the data and methods used to obtain PDI and GPDI and explain the different tests made to evaluate the influence of the new variables introduced. After an exposition of SIVI results, the third section show a comparison between PDI and GPDI.

1. Study area

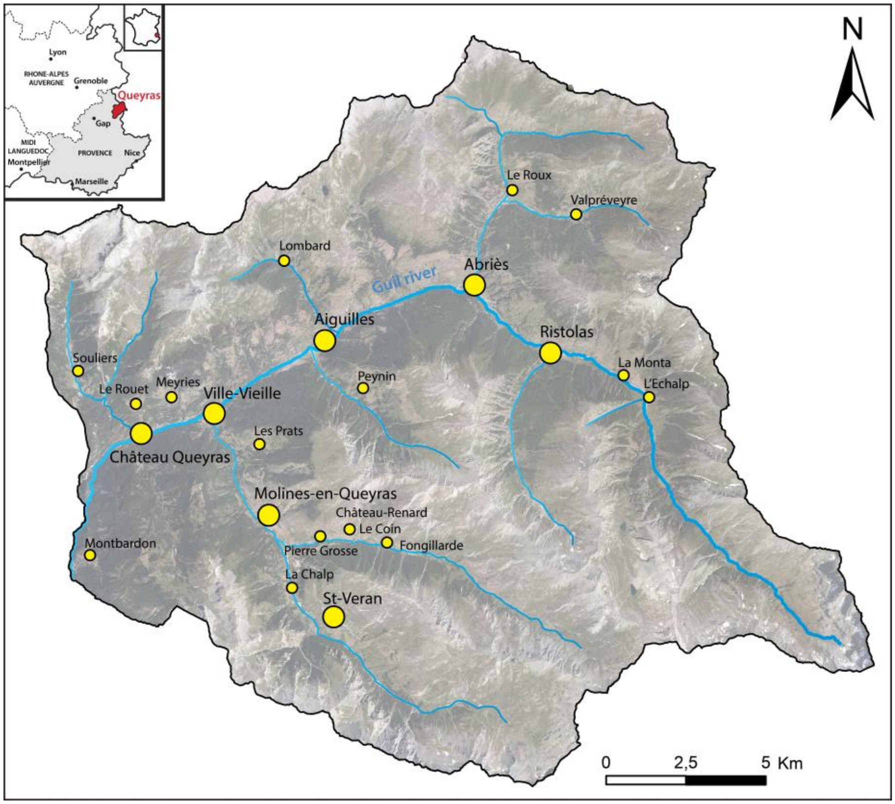

Figure 1: The Upper Guil catchment and its six communities.

The area of interest is the Upper Guil catchment, a 366 km² area covering 6 small municipalities (< 400 inhabitants): Ristolas, Abriès, Aiguilles, Château-Ville-Vieille, Molines-en-Queyras and St-Véran. It broadly corresponds to the historic territory of Queyras, a landlocked area located in the "Hautes-Alpes" French department, near the Italian border (Fig. 1). The altitude ranges from 1200 m.a.s.l. at the outflow of the River Guil to over 3300 m.a.s.l. along the highest summits surrounding the catchment.

1.1 Physical context

Due to some predisposing (schist bedrock supplying abundant debris, structural opposite slopes, strong hillslope channel connectivity) and triggering (summer and winter Mediterranean rainstorms) factors, the Upper Guil catchment is particularly prone to hydrogeomorphic hazards such as torrential floods, debris flows, landslides, rockfalls or avalanches (Fort *et al*., 2002, 2014; Arnaud-Fassetta *et al*., 2004, 2005, 2014). These hazards frequently impact the local population (fatalities, destruction of buildings and infrastructures, loss of agricultural land, road closures) causing difficulties for local managers, who also have to cope with the legislation and management procedures of the Parc Naturel Régional du Queyras (PNRQ) (Arnaud-Fassetta *et al*., 2004, 2005). Most catastrophic episodes are related to torrential flood as in 1957, 2000, 2002, 2008 and 2011 (PNRQ, 2016). The two main events described in the literature took place in June 1957 (> 100 year R.I., 15 million euros damage) and June 2000 (30 year R.I., ≈ 5 million euros damage) (Arnaud-Fassetta *et al.*, 2004; Tricart, 1958). These catastrophic episodes have severely impacted the mentalities and entailed considerable expenses in terms of risk management and protective structures (dykes, embankments, thresholds etc.). Due to the obsolescence of protective measures and local planner needs in new studies, it was necessary to reassess vulnerability and risk in this area.

1.2 Socio-economic context

Currently, the permanent population of the area reach 1770 inhabitants (Insee, 2012) and thus, it's one of the less populated districts in France (<5 inhabitants km^2). However, during the peak of touristic season (summer and winter holidays), the resident population can be multiplied by a factor of 10 (Insee, 2006). Since the second half of the 20th century, the territory has experienced significant changes concerning its land cover/uses and economic activities. The progressive decline of agro-pastoralism and the development of skiing tourism activities led to a concentration of human stakes in areas that are particularly exposed to several natural hazards (described above). The current land cover/use is hence the result of a combination of these important changes in human activities together with the impacts of past catastrophic events. Actually, land cover classes count 29 % of forest, around 30 % of bare rocks and alluvial deposits, 38 % of grassland, 3 % of agricultural lands and less than 1 % of building areas. Apart from houses, major stakes are public services/administration (city-hall, schools, hospital, fire station etc.), industrial/artisanal parks and, of course, touristic infrastructures (shops, hotels, museum, ski resorts etc.). The departmental road (D947) is the most important lifeline ensuring the link with the nearest urban centres (Guillestre, Embrun, Gap). These relatively recent stakes are mostly located on endangered areas and cause an increase of vulnerability for the communities (Arnaud-Fassetta *et al.*, 2004).

2. Methods and data

2.1 General Framework of the GPDI

Our *Global Potential Damage Index* is proposed in order to assess social and institutional consequences together with physical, structural and functional consequences. As the PDI, it consists in an empiric semi-qualitative and semi-quantitative analysis of the total potential consequences (i.e. structural, functional, social and institutional) for a considered hazard. It is also index based method which combines spatial analysis (GIS) and statistical modelling (linear combination). In order to focus our attention on the method improvement, we choose to only consider torrential floods in this paper.

Potential Damage Index (PDI) was obtained by combining three indices: the *Physical Injury Index*, the *Structural and Functional Index* and the *Socio-Economic Index*. In the proposed GDPI, the Physical Injury (PI) Index is replaced by a *Social and Institutional Vulnerability Index* (SIVI) – (Fig. 2). The SIVI was itself obtained by a sum of three score based on the three main phases of risk management: *Preparedness Index* (PI), *Crisis Management Index* (CMI) and *Recovery Index* (RI) – (Fig.3). These indices are built by using national and municipal French census data (INSEE) at community scale and data derived from a risk perception surveys made in the frame of the SAMCO project (Table 2).

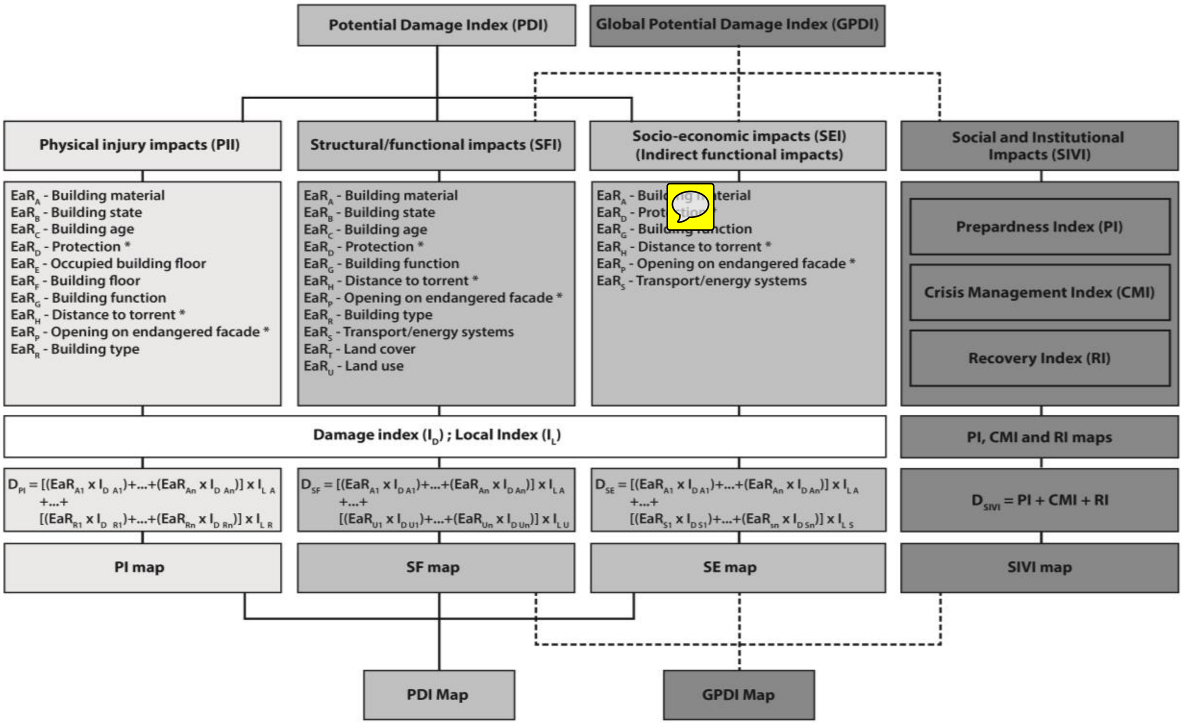

Figure 2: General framework of the Potential Damage Index (PDI) compared to the Global Potential Damage Index (GPDI).

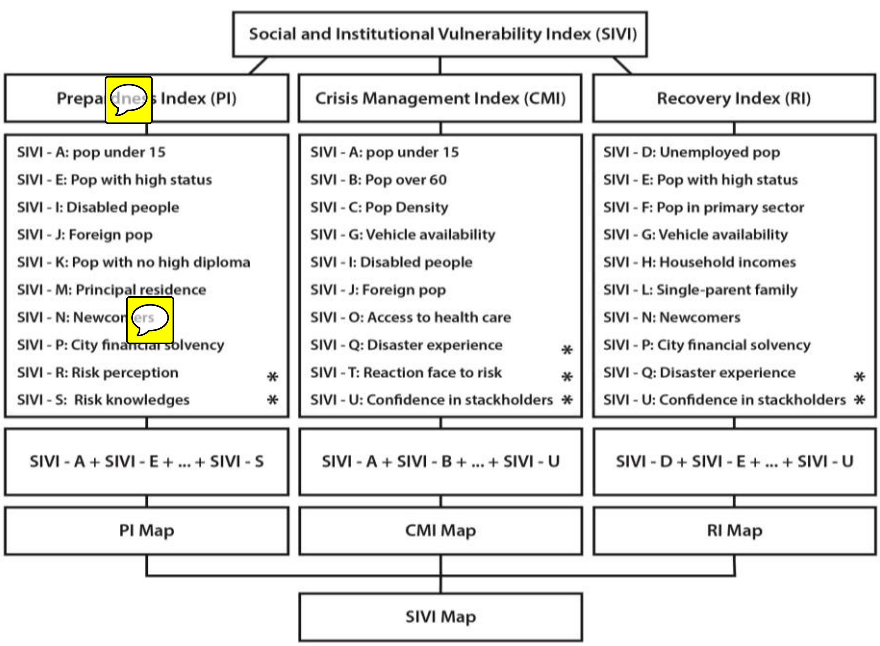

Figure 3: Framework for the calculation of the Social and Institutional Vulnerability Index (SIVI). Criteria with an * are those derived from the risk perception survey.

After the identification of the major stakes, the second step consisted in assigning a weigh to each modality of the considered variables. The value of each modalities is standardized on a scale from zero to one, with higher index values indicating higher potential consequences. A complete description of the considered variables and associated weights are shown in Fig. 4 and 5.

Then, direct (i.e. physical injury, structural and functional impact) and indirect consequences (socio-economics) were modelled using linear combination. In this step, minor modifications of the originally presented model were integrated to its adaptation for flooding (see * in Fig.2 and 4). *Preparedness Index*, *Crisis Management Index* and *Recovery Index* were calculated and combined to obtain the *Social and Institutional Vulnerability Index* for the six studied municipalities. PDI and GPDI were finally calculated for each stakes combining the index scores of previously calculated indices (Fig. 2).

2.2 Database on elements at risk, census data and risk perception survey

As described in Puissant *et al*. (2006, 2013), the first step consisted in elaborating a complete database for elements at risk (i.e. buildings, networks and land cover/uses) on GIS. As support for this work, data sets from *Institut National de l'Information Géographique et forestière* (IGN, BD ORTHO, 2009; BD TOPO, 2009) were used. To fill this database, an intensive field investigation in association with the use of *Google Street View*® and *OpenStreetMap*® software was realized. Land cover and land uses maps were produced on GIS by combining photo interpretative work with data on natural protected areas (DREAL PACA, 2016), agricultural land (RPG, 2012) and touristic infrastructures (prospectuses, touristic maps etc.).

Census data used for the social and institutional vulnerability assessment were provided by the *Institut National de la Statistique et des Etudes Economiques* (INSEE) or were calculated from data collected by the INSEE. When this work started, the 2014 census data were not fully accessible. Therefore, we used data from the 2012 and 2006 Census to complete our data. All the data used are available in the statistical database on the INSSE website, and in a publication of the 2014 Legal Population Census of France. Information related to the communities' financial solvency came from the different websites of the studied communities.

A risk perception survey consisted in a questionnaire (38 questions) carried out on the six studied municipalities have been done during the autumn 2014 and the summer 2015/2016. It was focused on 3 main issues: (1) inhabitant perception of the different risks, (2) inhabitant knowledges about preventive and protective measures and (3) inhabitant confidence in stakeholders. One hundred questionnaires were collected (abou[illegible]% of the total population): 8 in Ristolas, 22 in Abriès, 22 in Aiguilles, 16 in Château-Ville-Vieille, 17 in Molines-en-Queyras and 15 in St-Véran. People were surveyed by an interviewer in-person or by paper questionnaires delivered in person. Special attention was made in order to have a representative view of the socio-economic characteristics of local population. In the second and third campaign, surveyed people were selected for their demographic and socio-economic characteristics according to INSEE census data.

EaR-A	Building material	
	Concrete	0,8
	Wood	1
	Mixture (wood & concrete)	0,8
	Metal	0,4
	Stone & wood (traditional)	0,8
	Natural	0,4
	Coated, asphalted surfaces	0,2
EaR-B	Building State	
	Good	1
	Moderate	0,7
	Bad	0,2
	Very bad (ruin)	0
EaR-C	Building Age	
	<1900	0,3
	1900-1950	0,5
	1950-1970	0,7
	1970-1990	0,9
	1990-2000	1
	2000-2010	1
	>2010	1
EaR-D	Building protection *	
	Absence	1
	Sparsed hedge	0,9
	Dense hedge	0,8
	Wire fence	0,8
	Low wall (dry stone)	0,7
	Low wall (masonery)	0,7
	Wooden fence	0,6
	Mixed (low wall & hedge or fence)	0,5
	Wall >1,5m	0,3
	Shutter on opening exposed to hazard	0,4
	Building protecting other building	0,1
	Snow supporting structure	0
EaR-E	Occupied floors	
	>6	1
	3 - 6	0,7
	<3	1
	0	0
EaR-F	Number of floors	
	>3	0,5
	3	0,5
	2	0,7
	1	1
EaR-G	Building Function	
	Education	1
	Emergency	0,95
	Trade	0,9
	Industry/Craft	0,9
	Public administration	0,7
	Accommodation	0,8
	Agricultural	0,4
	Tourism	0,8
	Religious	0,2

EaR-H	Distance to torrent *	Torrentiality
	<10m	1
	10m to 20m	0,8
	20m to 30m	0,6
	30m to 40m	0,4
	40m to 50m	0,2
	>50m	0
EaR-I	Opening on endangered facade *	Torrentiality
	Absence	0
	1 - 3	0,6
	4 - 6	0,8
	>6 (or glass wall)	1
EaR-J	Building type	Torrentiality
	"Sensitive" building (city hall, hospital, fire station)	1
	Housing	1
	Tourism activity	0,8
	Cultural heritage	0,3
	Shed and warhouse	0,5
	Car park	0,2
	Hut	0,1
	Cemetery	0
EaR-K	Transport & energy systems	Torrentiality
	Main road	1
	Secondary road	0,8
	Gravel road	0,6
	Track	0,1
	Ski lift	0,7
	High-voltage line	1
EaR-L	Lancover	Torrentiality
	Urban	0,6
	Farming/pasture	0,35
	Forest	0,2
	Grass	0,15
	Water surface	0,1
	Alluvium	0,05
	Bare rock & colluvium	0,05
EaR-M	Land use	Torrentiality
	Urban	1
	Arable land	0,25
	Winter tourist activities	0,8
	Summer tourist activities	0,5
	Protected area	0,15

Figure 4: Detail of weights assigned to the attributes of the physical stakes in PDI. Criteria with an * have been added in order to adapt the model for flooding.

2.3 Construction and organisation of the SIVI

As previously mentioned, the SIVI is structured on three indices representing the main phases of risk management: preparedness, crisis management and recovery. Using this type of approach requires the selection of specific criteria that unequivocally represent the different forms of social and institutional vulnerability (Rygel *et al*., 2006). The literature on vulnerability identifies many elements contributing to differential ability to cope with hazards. An intensive review of published data on social vulnerability indices was performed in view to select a set of pertinent indicators (Table 1).

Actually, most of analyses use data from national census to build social vulnerability indices (Cutter *et al*. 2000; Wu *et al*. 2002; Chakraborty *et al*., 2005; Fekete, 2009; Guillard-Gonçalves *et al*., 2014, Frigerio *et al*., 2016). Some indicators repeatedly appear in these analyses such as poverty, age, ethnicity and disabilities (Table 1). In agreement with these existing published references, socioeconomic data were collected for the six studied municipalities. 15 criteria were selected in the INSEE census database (Insee, 2012; 2015) (Table 2) and 5 from the risk perception survey realized in the frame of the SAMCO project (2014-2015) (see * in Table 2). 2 other criteria were calculated with derived data (Insee, 2015) bringing the total number of criteria to 2[illegible] (Table 2).

	Chakrabortyet al., 2005	Clarket al., 1998	Cutter et al., 2003	Fekete, 2009	Flanaganet al., 2012	Frigerioet al., 2016	Johnsonet al., 2012	Nelson et al., 2015	Schmidtleinet al., 2008	Wu et al., 2002	Zahranet al., 2008	Zhang & You, 2014	Total
Age	■	■	■	■	■	■	■	■	■	■		■	11
Income	■	■	■	■	■		■	■	■	■	■	■	11
Race and ethnicity		■	■	■	■	■	■	■	■	■	■		10
Gender		■	■	■		■	■	■	■	■		■	9
Education level	■	■	■	■	■	■	■		■			■	9
Employment		■	■	■	■	■		■	■				7
Special need population	■	■	■	■	■	■		■					7
Family structure		■	■			■	■	■		■			6
Mobility	■	■			■	■		■				■	6
Equipement	■	■	■		■							■	5
Medical service			■	■		■		■				■	5
Population (number/density)	■			■		■				■			4
Employed in primary sector		■							■			■	3
Recent arrival		■		■				■					3
Municipality budget				■								■	2
Owner/tenant			■							■			2

Table 1: Synthesis of the criteria usually used for social vulnerability assessment.

The three indices representing the phases of risk management were then constructed using the selected criteria (Fig. 3). The first one, the *Preparedness Index* (PI), is focused on inhabitant experiences about risks and deployed preventive measures. The second one, the *Crisis Management Index* (CMI), insists on people abilities to react aptly facing a catastrophic event. The third, the *Recovery Index* (RI), concerns the people capacities to recover after a disaster, thus it is mostly constructed with economic criteria.

According to PDI methodology, weights among 0 to 1 were affected at each proxy of the 22 criteria used in the SIVI model (Fig. 5). PI, CMI, and RI were then calculated using linear combinations on GIS (raster calculator tool on ArcGIS). SIVI was finally calculated by summing the index scores of the three indices and included in the PDI to obtain GPDI (Fig. 2).

Variable code	*Variable*	*Increase (+) or decrease (-) social vulnerability if high*
SIVI - A	Percent of children15 and under	+
SIVI - B	Percent of population 60 years or older	+
SIVI - C	Population density (in habs / km^2)	+
SIVI - D	Percent of unemployed people	+
SIVI - E	Percent of population with high socioeconomic status*	-
SIVI - F	Percent of population employed in primary sector	+
SIVI - G	Percent of household with no vehicle available	+
SIVI - H	Household incomes / average national household incomes	-
SIVI - I	Percent of population which is mentally disabled	+
SIVI - J	Percent of foreign population	+
SIVI - K	Percent of population with no high diploma (> BAC)	+
SIVI - L	Percent of single-parent family	+
SIVI - M	Percent of principal residence	-
SIVI - N	Percent of the population which moved in less than 2 years ago	+
SIVI - O	Distance to nearest medical centre (in decimal h)	-
SIVI - P	Communities financial solvency (cash flow = operating charges - debt annuity /incomes)	+
SIVI - Q	Percent of IP who never experienced a catastrophic event**	+
SIVI - R	Percent of IP considering risk as low**	+
SIVI - S	Percent of IP considering themselves as sufficiently informed on risk**	-
SIVI - T	Percent of IP who responded not knowing what to do if a catastrophic event occurs**	+
SIVI - U	Percent of IP who have not confidence in local planners**	+

IP: investigated population

**Artisant, Commercant et Chef d'Entreprise ou Cadres et Profession Intellectuelle Supérieur*

*** Data from SAMCO risk perception survey*

Table 2: Criteria selected for the calculation of SIVI and their impacts on social and institutional vulnerability.

2.4 Test runs and comparisons between PDI and GPDI applied to torrential floods

To evaluate the pertinence of our model, we proceeded to different test runs. First, we declined the SIVI in two versions: standardized and adapted to our field. The classical version (CV) correspond to the "theoretical SIVI" with standardized modalities and weighting. It is mostly constructed on average national data, and so give us an estimation of social and institutional vulnerability comparable to other French communities. The adapted version (AV) correspond to a SIVI adapted for our study area and dataset. It permit to qualify the social and institutional vulnerability comparing to proximal communities. The aim of this test was to establish the flexibility of our model and its possible transposition to a specific study area. Modalities and weighting are thus, quite different (Fig.5).

A second run was computed to test the influence of the variable coming from risk perception surveys. To achieve this, PI, CMI, RI and SIVI score were calculated without the data from questionnaires and compared with original model scores. Complete comparison of the two versions of SIVI is showed in Fig. 8.

Last, a comparison between the *Potential Damage Index* and the two version (classical and field adapted) of the *Global Potential Damage Index* was made for flooding (Fig. 9 and 10).

Variable code	Variable	Modality for a normal distribution	Modality for an asymmetric distribution	Weighting for a normal distribution	Weighting for an asymmetric distribution
SIVI-A	Percent of children15 and under	Less than 20% 20-30% 30 -40% 40-50% More than 50 %	Less than 15% 15-20% 20-25%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8
SIVI-B	Percent of population 60 years or older	Less than 20% 20-30% 30 -40% 40-50% More than 50 %	Less than 20% 20-25% 25-30% More than 30%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-C	Population density (in habs / km^2)	Less than 25 habs/km^2 25-50 habs/km^2 50-100 habs/Km^2 10-200 habs/km^2 More than 200 habs/km^2	Less than 1 habs/km^2 1-5 5-10 More than 10 habs/km^2	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-E	Percent of unemployed people	Less than 8% 8-10% 10-12% More than 12%	0% 0-5% More than 5%	0,1 0,4 0,7 1	0,1 0,4 0,8
SIVI-F	Percent of population with high socio-economic status*	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 10% 10-15% 15-20% More than 20%	1 0,8 0,6 0,4 0,1	1 0,7 0,4 0,1
SIVI-G	Percent of population employed in primary sector	Less than 5% 5-10% 10-15% 15-20% More than 20%	0% 0-5% 5-10% More than 10%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-H	Percent of household with no vehicle available	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 5% 5-10% More than 10%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8
SIVI-I	Household incomes / average national household incomes	Less than 60% 60-70% 70-80% 80-90% 90-100%	Less than 80% 80-90% 90-100%	1 0,8 0,6 0,4 0,1	0,8 0,4 0,1
SIVI-J	Percent of population which is mentally disabled	Less than 5% 5-10% More than 10%	Less than 10% 10-15% More than 15%	0,1 0,5 1	0,1 0,5 1
SIVI-K	Percent of foreign population	Less than 5% 5-10% 10-15% 15-20% More than 20%	Less than 1% 1-2% More than 2%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8

Figure 5: Detail of weights assigned to the attributes used in SIVI calculation. Criteria with an * are those derived from the risk perception survey.

SIVI-L	**Percent of population with no high diploma (> BAC)**	Less than 25% 25-50% 50-75% 75-100%	Less than 70% 70-75% More than 75%	0,1 0,4 0,7 1	0,1 0,4 0,8
SIVI-M	**Percent of single-parent family**	Less than 10% 10-15% 15-20% 20-25% More than 25%	Less than 10% 10-15% 15-20%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8
SIVI-N	**Percent of principal residence**	Less than 25% 25-50% 50-75% 75-100%	Less than 20% 20-30% More than 30%	0,1 0,4 0,7 1	0,1 0,4 0,8
SIVI-O	**Percent of the population which moved in less than 2 years ago**	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 10% 10-15% More than 15%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8
SIVI-P	**Distance to nearest medical centre (in decimal h)**	Less than 0,25 h 0,25-0,50 h 0,50-0,75 h 0,75-1,00 h More than 1,00 h	0-0,10 0,10-0,20 h 0,20-0,30 h More than 0,30 h	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-Q	**Communities financial solvency (cash flow = operating charges - debt annuity /incomes)**	Less than 0,50 0,50-0,75 0,75-1 1-1,25 More than 1,25	Less than 0,90 0,90-1,00 1,00-1,10 More than 1,10	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-R	**Percent of interogated population who never experienced a catastrophic event****	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 15% 15-20% 20-25% More than 25%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-S	**Percent of interogated population considering risk as low****	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 25% 25-50% 50-75% More than 75%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-T	**Percent of interogated population considering themselves as sufficiently informed on risk****	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 20% 20-30% 30-40% More than 40%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1
SIVI-U	**Percent of interogated population who responded not knowing what to do if a catastrophic event occurs****	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 25% 25-50% More than 50%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,8
SIVI-V	**Percent of interogated population who have not confidence in local planners****	Less than 10% 10-25% 25-50% 50-75% 75-100%	Less than 20% 20-25% 25-30% More than 30%	0,1 0,4 0,6 0,8 1	0,1 0,4 0,7 1

***Artisant, Commercant et Chef d'Entreprise ou Cadres et Profession Intellectuelle Supérieur**
**** Data from SAMCO risk perception survey**

Figure 5 (continuation): Detail of weights assigned to the attributes used in SIVI calculation. Criteria with an * are those derived from the risk perception survey.

3. Results and discussion

3.1 Classical and adapted version of SIVI

Using the different methods previously described (Fig. 3), SIVI was calculated for the six municipalities of the Upper Guil catchment. PI, CMI, RI and SIVI scores were obtained and classified for classical (CV) and adapted versions (AV) of the model (Fig. 6). Due to the limited number of studied communities, all the indices were represented in three classes. Because statistical series are symmetric, classification was made using, median and standard deviations.

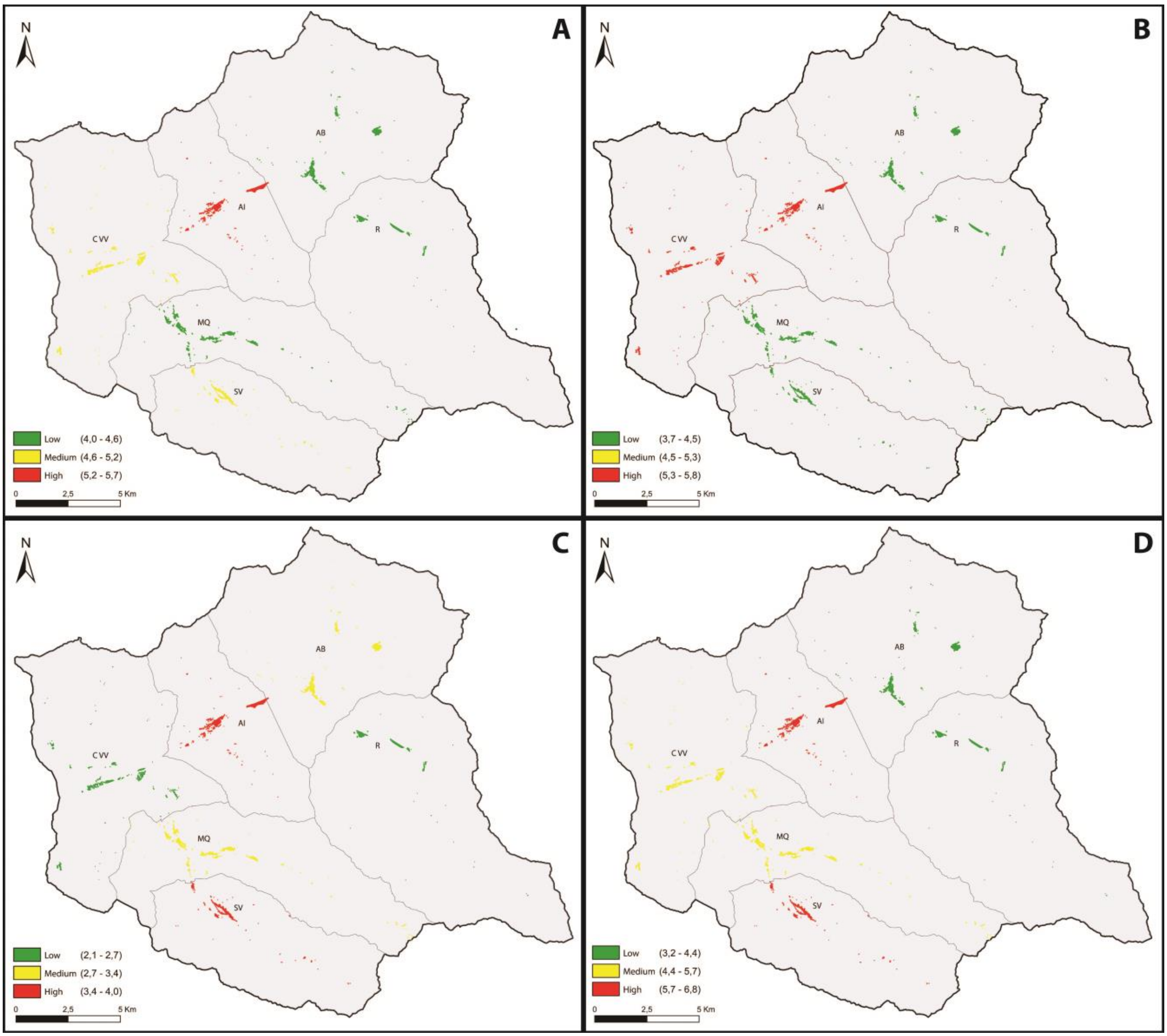

Figure 6: Indices maps for classical version (CV) and adapted version (AV) of the Social and Institutional Vulnerability Index (SIVI):

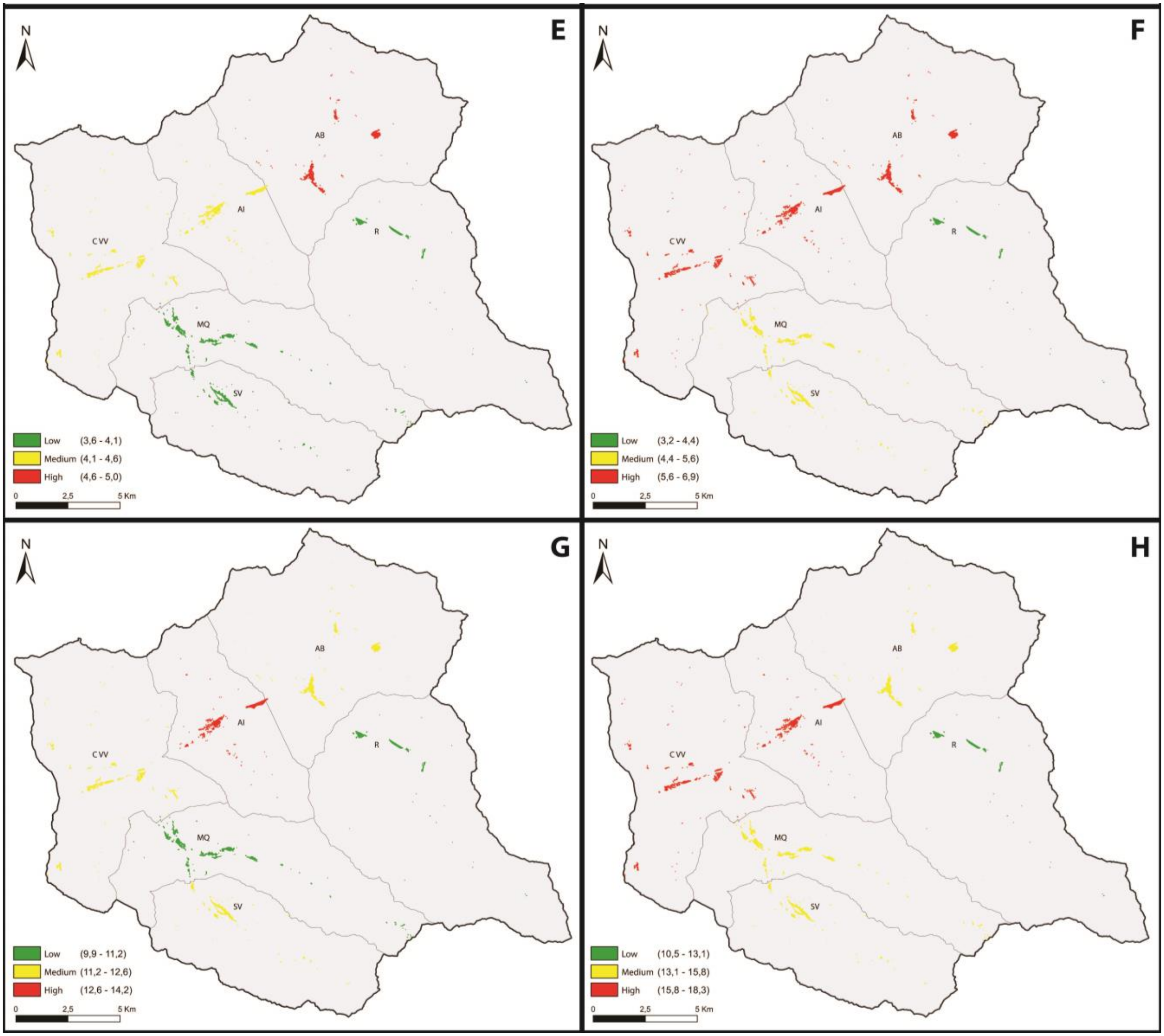

Figure 6 (continuation): Indices maps for classical version (CV) and adapted version (AV) of the Social and Institutional Vulnerability Index (SIVI): (A) Preparedness Index map for CV, (B) PI map for AV, (C) Crisis Management Index map for CV, (D) CMI map for AV, (E) Recovery Index map for CV, (F) RI map for AV, (G) Social an Institutional Vulnerability map for CV, (H) SIVI map for AV.
R= Ristolas, AB = Abriès, AI = Aiguilles, CVV = Château-Ville-Vieille, MQ = Molines-en-Queyras SV = St-Véran.

Looking for produced maps (Fig. 6), some first elements can be pointed out: (1) Index scores are globally higher for the adapted version than for the classical version, (2) intervals between extremes are more important for AV and, (3) there are more communities in the higher vulnerability class in AV maps than in CV maps. These first results are in conformity with those expected. Because CV is mostly constructed on national averaged data's, some modalities of its variable components are not represented here. In fact, there is only few studied communities and their proximity make them broadly similar in terms of vulnerability. Inversely, AV was constructed in order to have its all modalities expressed. As a result, indices scores are generally lower in CV than in AV. Furthermore, we note that, between the two versions, *Preparedness Index, Crisis Management Index* and *Recovery Index* don't have the same importance. In CV, *Preparedness Inde*x is the more influent component of SIVI while in AV it is the *Recovery Index* followed by *Crisis Management Index*. These elements apart, similar tendencies are observed for normal and adapted versions of PI, CMI, RI and SIVI maps (Fig.6).

Preparedness Index maps are closed and extremes are preserved from CV (Fig.6, A) to AV (Fig.6, B). AV give us complementary information's on Château-Ville-Vieille and St-Véran villages indicating in which direction tends their vulnerability. Here, communities with better index scores are those which are the well prepared, with a great proportion of their population living here for long time and having experienced various catastrophic events. They are also those managed by local councillors particularly involved in developing preventive measures (communication on risk, security planning, crisis simulation exercises etc.).

Crisis Management Index maps (Fig.6, C and D) are similar too. Differences between CV and AV are related to Château-Ville-Vieille and Abriès villages. These two communities have similar scores. Because these scores are close to a class limit (between "low" and "medium" vulnerability class) we observe a reversal between the ranking of Abriès and Château-Ville-Vieille village. Communities with highest scores actually have the highest proportion of people unable to aptly react to a catastrophic event. Concerned people include those recently settled, or isolated or/and dependant (children, elderly, disabled persons etc.) populations. People who develop the less confidence in local authorities to protect them against risks are also included here

In *Recovery Index* maps the same organisation is observed for CV (Fig.6, E) and AV (Fig.6, F). In both case, there is a partition between a group with a high index scores (Château-Ville-Vieille, Aiguilles and Abriès villages) and a lowest index score group (Ristolas, Molines-en-Queyras and St-Véran villages). In these maps, communities with lower scores are those more able to recover quickly their functionalities after a catastrophic event. Their population have, globally, a better social status and are richest than those of the other communities. These municipalities have also a better fiscal health and thus have more chances to quickly repair damage caused by hazards.

Social and Institutional Vulnerability Index represents a synthetic view of the vulnerability issued from the 3 identified phases of risk management. Here, communities with low score are theoretically the more resilient. Their populations are well prepared, know how to react to a catastrophic event, have confidence in local authorities for risk management and are more able to recover quickly if they are directly impacted. Associated maps for classical version (Fig.6, G) and field adapted version (Fig.6, H) display similar results. Aiguilles village that has high scores for all the indices of two versions appears as the less resilient community. Conversely, Ristolas, which has the lower scores, can be considered as the more resilient. Abriès village has high scores for *Recovery Index* but low scores for the other indices, consequently it is in the medium vulnerability class. St Véran village has high scores for *Crisis Management Index* but this is partially counterbalanced by its relatively low scores for *Preparedness Index* and *Recovery Index*. Its social and institutional vulnerability is so, medium in both versions. Molines-en-Queyras and Château-Ville-Vieille communities appear as those having experienced the more important weight changes between the two versions. Respectively classified as low and moderately vulnerable in classical version they are, in fact, classified as moderate and high in field adapted version.

3.2 SIVI with and without questionnaires data

The second test was made to evaluate the influence of criteria coming from the risk perception survey. *Social and Institutional Vulnerability Index* was calculated without the data from risk perception survey and compared with complete SIVI (Fig. 7). For the sake of readability, we only presented here the test for the adapted version of the model.

Removing the variables from risk perception survey necessarily imply changes in SIVI results. At first reading, vulnerability appears as higher in the truncated version for *Preparedness Index* (Fig. 7, B) and *Crisis Management Index* (Fig. 7, D) and lesser for *Recovery Index* (Fig. 7, F). Considering indices scores, changes are more consequent for the *Crisis Management Index* since it's the index containing the most of perception survey variables. At the opposite smaller changes are observed for *Recovery Index*. In both version, *Recovery Index* have the highest score and remain the one, which mostly influence SIVI results. Paradoxically, *Recovery Index* experienced the most important change in terms of vulnerability class between the version with and without questionnaire data's.

The low importance of *Crisis Management Index* comparing to *Preparedness Index* and *Recovery Index* is illustrated by truncated SIVI map (Fig. 7, H). For instance, despite high *Crisis Management Index* scores for St-Véran and Molines-en-Queyras, the two communities are classified as low vulnerable in SIVI. Therefore, the loss of information resulting of the removing of survey variables is reflected by clear-cut results. There is, in fact, a strong opposition between the more active and populated communities (Abriès, Aiguilles and Château-Ville-Vieille) and the modest ones (Ristolas, Molines-en-Queyras and St-Véran). Based only on classical socio-economics data, main villages appear as highly vulnerable while the other villages appear as low vulnerable.

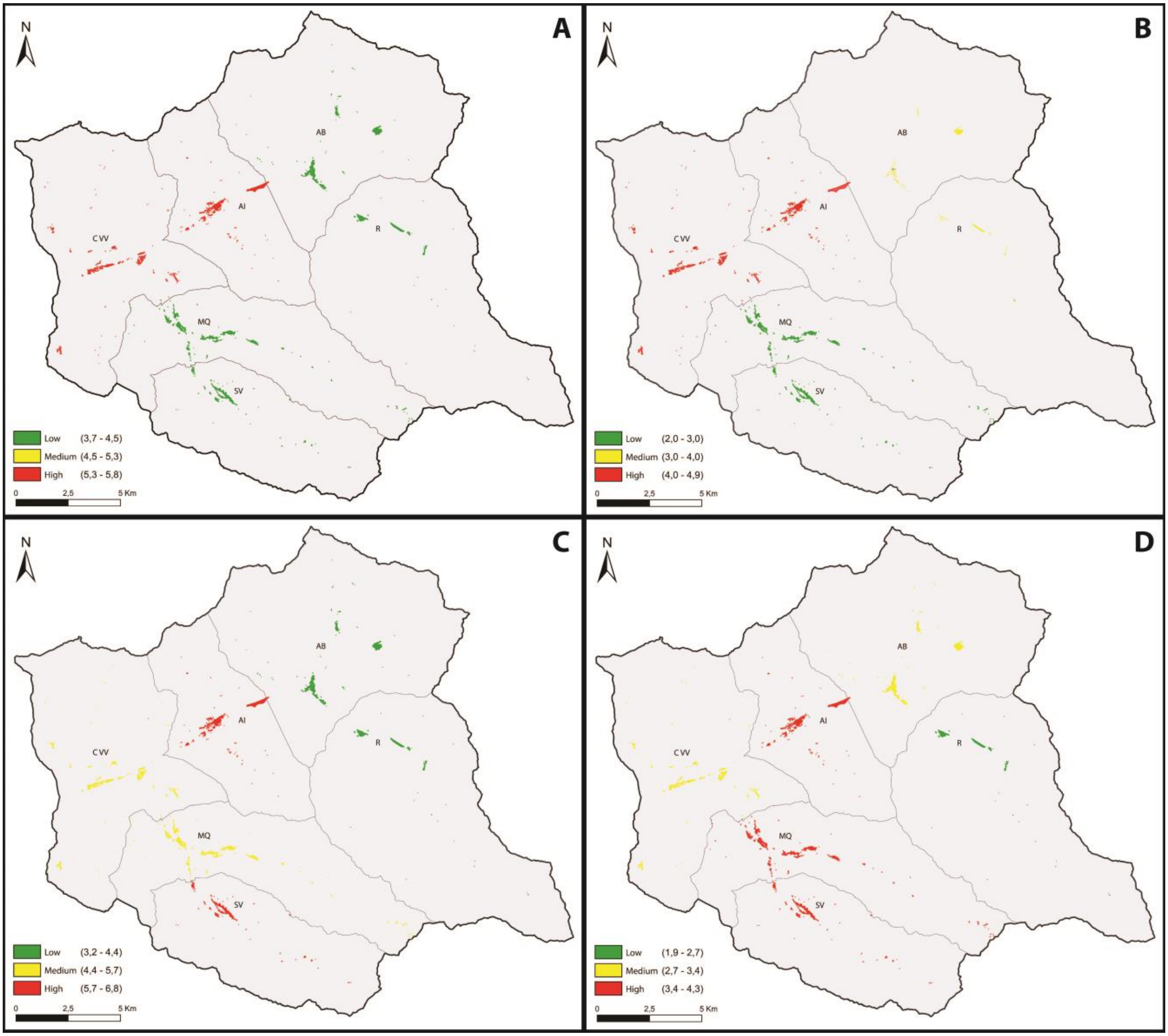

Figure 7 (continuation): Indices maps for adapted version with and without criteria derived from risk perception survey: (A) PI map with survey criteria, (B) PI map without survey criteria, (C) CMI map with survey criteria, (D) CMI without survey criteria, (E) RI map with survey criteria, (F) RI map without survey criteria, (G) SIVI map with survey criteria, (H) SIVI map without survey criteria. R= Ristolas, AB = Abriès, AI = Aiguilles, CVV = Château-Ville-Vieille, MQ = Molines-en-Queyras and SV = St-Véran.

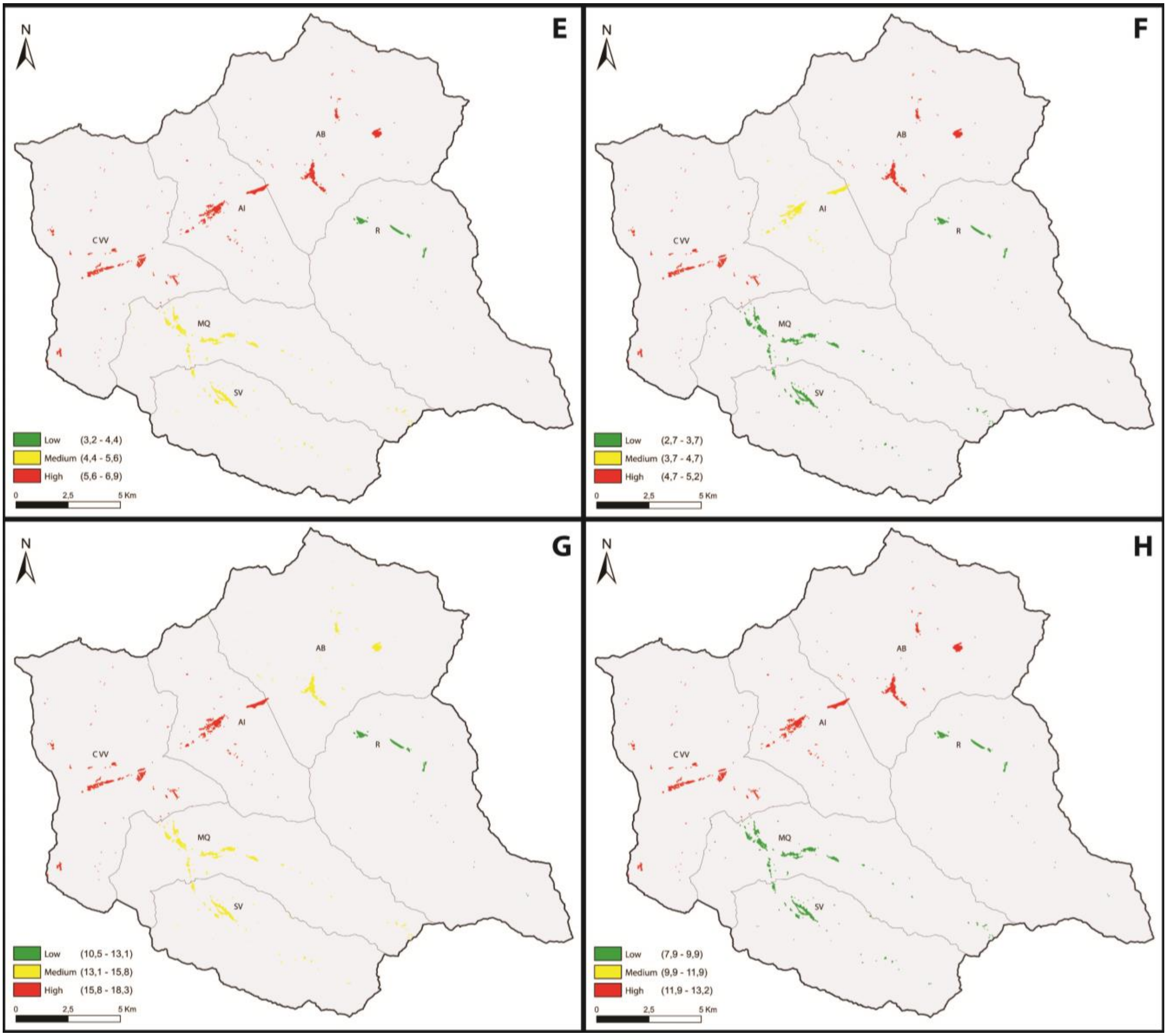

Figure 7 (continuation): Indices maps for adapted version with and without criteria derived from risk perception survey: (A) PI map with survey criteria, (B) PI map without survey criteria, (C) CMI map with survey criteria, (D) CMI without survey criteria, (E) RI map with survey criteria, (F) RI map without survey criteria, (G) SIVI map with survey criteria, (H) SIVI map without survey criteria. R= Ristolas, AB = Abriès, AI = Aiguilles, CVV = Château-Ville-Vieille, MQ = Molines-en-Queyras and SV = St-Véran.

3.3 Comparison between PDI and GDPI

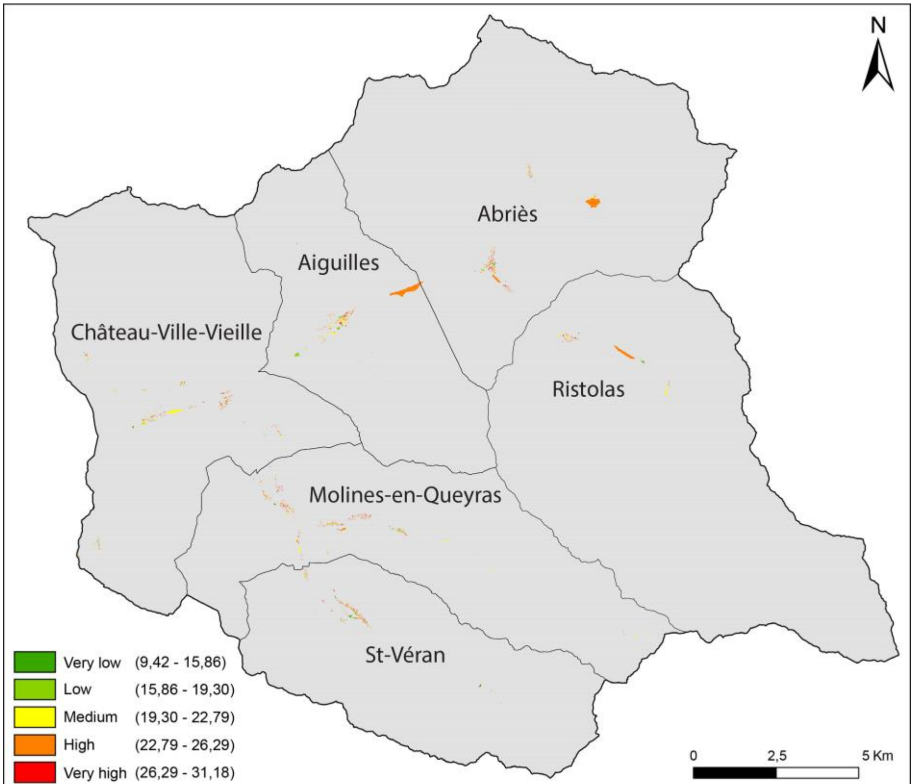

Figure 8: Original PDI map for the Upper Guil catchment

PDI model is an efficient tool to estimate potential physical consequences on human stakes. In this part, we investigate the possibility to adapt it in order to estimate social and institutional consequences too. Original PDI map for flooding was obtained for the Upper Guil catchment (Fig. 8) by summing the classified *Physical Injury Index (PII)*, *Structural and Functional Index (SFI)* and *Socio-Economic Index (SEI)*. Here, the three indices have symmetric distributions, thus, they are ranked in five classes using median and standard deviations. For buildings, highest scores are generally observed for *Physical Injury Index* (median: 12.5) and lowest for *Socio-Economic Index* (median: 4). *Structural and Functional Index* scores are comprised between the both (median: 8.7). Zooms on Aiguilles and Abriès villages are shown in Fig. 10, A and B.

Two versions of GPDI were then calculated using classical (Fig. 9, A) and adapted versions (Fig. 9, B) of SIVI. Zooms on Aiguilles and Abriès village are shown in Fig. 10. To highlight differences between PDI and the two GPDI versions, networks and land cover/uses are ignored in this part of the analysis.

Original PDI map for flooding (Fig. 8) displays a majority of buildings with moderate to high scores of total potential consequences for the all studied communities. Buildings with highest PDI scores are mainly located in close proximity to the Guil River or one of its main tributaries (Fig. 10, A and B). Major stakes such rescue centres (hospital, fire-station etc.), town-halls, schools and purification plant have a high degree of potential consequences because of their important function in local life. Conversely, churches, car parks, sheds and warehouses have low degree of potential consequences. In town centres, buildings with trading or touristic function are generally classified as high beside those with housing function are classified as moderate. Sparse housing areas, on the heights have a high degree of total potential consequences. They were, in fact, not constructed to resist to floods because of their remoteness to streams.

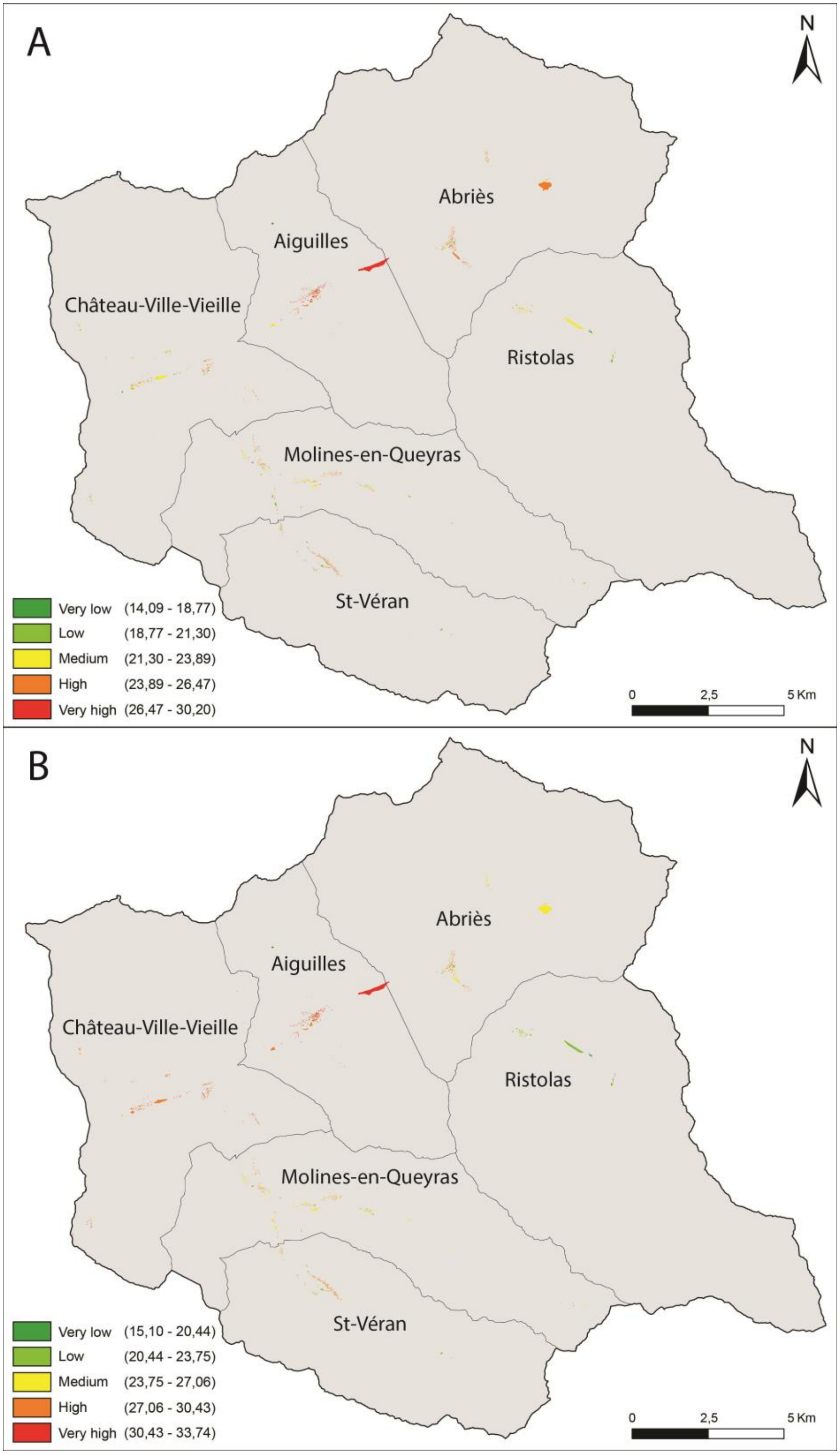

Figure 9: GPDI maps with classical and adapted version of SIVI: A) GPDI map with classical SIVI, (B) GPDI map with adapted version of SIVI.

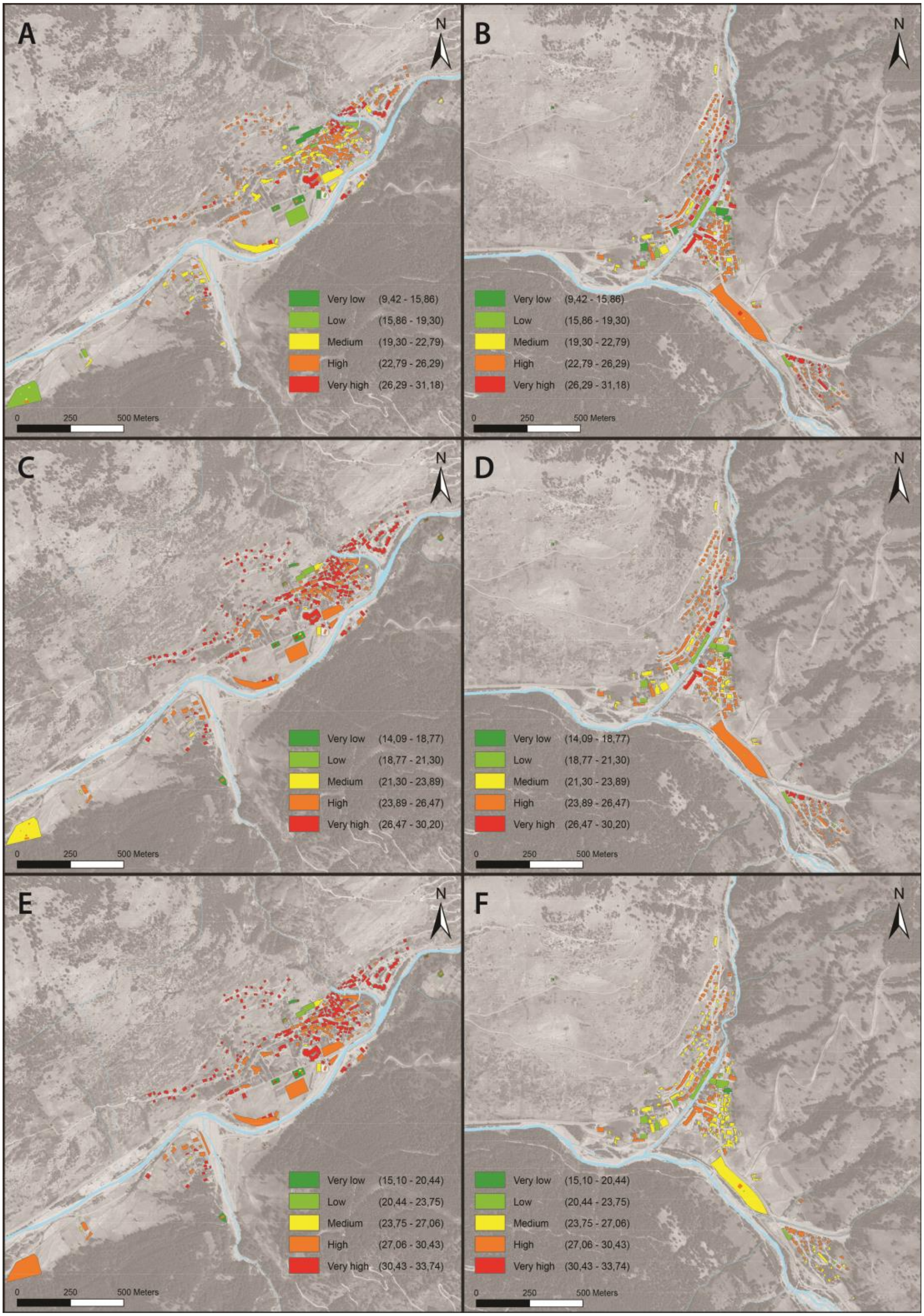

Figure 10: Zoom on Aiguilles and Abriès villages for PDI and GPDI map: (A) PDI map for Aiguilles village, (B) PDI map for Abriès village (C) GPDI map with classical SIVI for Aiguilles village, (D) GPDI map with classical SIVI for Abriès village, (E) GPDI map with adapted version of SIVI for Aiguilles village, (F) GPDI map with adapted version of SIVI for Abriès village.

GPDI maps for flooding displays result different from a community to another. This is due to the influence of SIVI, which is equally applied for the all buildings of a same community. This tend to homogenise GPDI score by uplifting minimum values. Despite these scores variations, we observe some similarities between PDI and GPDI at community scale. Maximum scores for PDI and GPDI are in the same order of magnitude and buildings with high scores are in the vicinity of the Guil Rivers and its main tributaries or are major stakes (hospital, fire station, town hall etc.). Conversely to PDI, GPDI scores mapping at regional scale tend to highlight the differences between the studied communities. GPDI scores mapping are globally lower than those of PDI for both classical (Fig. 9, A) and adapted version (Fig. 9, B). The main exception is Aiguilles village (Fig. 10, C and E) because of it high SIVI score. This indicate that resilient population may qualify results obtained for physical consequences.

Conclusions and perspective

Looking for results some remarks can be made concerning the uses of the GPDI model. Classical version appears as more efficient to estimate and compare social and institutional vulnerability at a large scale. Because it is mostly based on national averaged data, it gives us a level of vulnerability, which must be compared to results obtained in different places of a same country. Adapted version allows to detail the results of classical version highlighting the similarities and differences of nearby communities. AV is fine at county or regional level but, conversely to CV, it is not directly transposable to all areas. However, all these elements require a confirmation due to the short number of studied communities in this analysis.

One of the originality of SIVI is its sub-division in three indices representing the main phases of risk management: *preparedness*, *crisis management* and *recovery*. This organization get the advantage to display information easily interpretable by risk managers or local decision makers. Furthermore, it allow developing mitigation measures adapted to local population indicating the most relevant vulnerability aspect to analyse. Until now, *Social and Institutional Vulnerability Index* is calculated by summing *Preparedness Index*, *Crisis Management Index* and *Recovery Index*. This may introduce an imbalance in the representability of each index into SIVI. Using a qualitative matrix to obtain SIVI will possibly solve this problem.

Another original aspect of SIVI is the integration of data derived from risk perception survey. This makes possible to qualify results which are usually obtained with only census data. However, because questionnaire surveys take time and require consequent fieldwork, it is clear that use of SIVI model at large scale will be quite difficult. If removing the data from survey implies necessarily a loss of information, the model appears as sufficiently robust to be used without these data.

Originally, SIVI was developed as an add-on for the *Potential Damage Index*. Until now, results are still mitigated yet encouraging. The main problem remains that a unique value of SIVI is applied for the overall building of a same community. By proceeding so, SIVI has a great influence on PDI and tends to homogenize it. While, the simplification of the information which results from it highlight the more vulnerable areas and thus, make results easily understandable for local manager.

Some elements which may improve GPDI model will be investigated later. First of all, we will enlarge the scale of our study by including other communities of Southern French Alps studied in the frame of the SAMCO project. Located in the Ubaye valley, near our study area, these communities display similar structural and socio-economics characteristics. So, their inclusion will provide a more representative selection for statistics investigations. In addition, we will simplify the SIVI and reduce its importance into GPDI by reducing the number of its variables. Doing that, the information on structural and functional consequences will be brought out more clearly. Another lead will be an adaptation of the survey protocol in order to get data at finer scale such as district scale. Another solution to gain in precision will be the use of a desegregation model to distribute SIVI at building scale.

The method presented in this paper will be a source of significant progress for vulnerability assessment. By considering the two main component of vulnerability, the physical one and the socio-economic one, this work may provide an important tool for local authorities. GPDI will help them to better understand their strength and weakness and thus will be useful to develop appropriated mitigation measures.

Author contribution

Benoît Carlier and Anne Puissant designed the experiments and carried them out. Benoît Carlier developed the model and performed the simulations. Benoît Carlier and Constance Dujarric realised the questionnaire survey. Gilles Arnaud-Fassetta supervised Benoît Cralier and Constance Dujarric works. Benoît Carlier prepared the manuscript with contributions from all co-authors.

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgement

This paper is part of a larger research project (SAMCO Project ANR-12-SENV-0004.) bringing together research centres (BRGM, IPGS, IRSTEA), laboratories (LIVE-UMR7362, PRODIG-UMR8586, GEODE-UMR5602) and a technologically advanced SME (GEO-HYD) to evaluate mountain risk in a context of global changes (i.e. socio-economic and climatic).

This research is a part of the PhD research work of B. Carlier (*Evaluation, cost and management of torrential and gravitational risk in mountainous environment*; defence thesis in 2018).

We would like to thank Bérengère Charnay from the Parc Naturel Régional du Queyras and the municipality councils of Ristolas, Abriès, Aiguilles, Château-Ville-Vieille, Molines-en-Queyras and St Véran for their hospitality, their help and their interest for our works.

References

Alcántara-Ayala, I., Altan, O., Baker, D., Briceño, S., Cutter, S., Gupta, H., Holloway, A., Ismail-Zadeh, A., Jiménez Díaz, V., Johnston, D., McBean, G., Ogawa, Y., Paton, D., Porio, E., Silbereisen, R., Kuniyoshi, T., Valsecchi, G., Vogel, C., Wu, G., Zhai, P.: Disaster Risks Research and Assessment to Promote Risk Reduction and Management, ICSU- ISSC AD- HOC Group on Disaster Risk Assessment, March 12, 2015, 1-47, 2015.

Arnaud-Fassetta G., Cossart E., Fort M.: Hydro-geomorphic hazards and impact of man-made structures during the catastrophic flood of June 2000 in the Upper Guil catchment (Queyras, French Alps). Geomorphology, 66, 41-67, DOI:10.1016/j.geomorph.2004.03.014, 2005.

Arnaud-Fassetta G., Fort M.: La part respective des facteurs hydro-climatiques et anthropiques dans l'évolution récente (1956-2000) de la bande active du Haut-Guil, Queyras, Alpes françaises du Sud, Géosystèmes méditerranéens et montagnards. Un mélange offert à Maurice Jorda. Méditerranée, 1-2, 143-156, DOI: 10.3406/medit.2004.3350, 2004.

Arnaud-Fassetta G., Fort M.: Hydro-bio-morphological changes and control factors of an upper Alpine valley bottom since the mid-19th century. Case study of the Guil River, Durance catchment, southern French Alps, The Little Ice Age in the Mediterranean, Méditerranée, 122, 159-182, DOI: 10.4000/mediterranee.7245, 2014.

Barroca, B., Pottier, N., Lefort, E.: Analyse et évaluation de la vulnérabilité aux inondations du bassin de l'Orge aval, Septièmes Rencontres de Théo Quant, janvier 2005, 1-12, 2005.

Birkmann, J.: Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies, New York: United Nations Publications, 2, 55-77, 2006.

Blaikie, P., Cannon, T., Davis, I., Wisner, B.: At Risk: Natural Hazards, Peoples' Vulnerability and Disasters, London: Routledge, 1994.

Blaikie, P., Cannon, T., Davis, I., Wisner, B.: At Risk, Second edition: Natural Hazards, Peoples' Vulnerability and Disasters, London: Routledge, 2003.

Chakraborty, J., Tobin, G.A., Montz, B. E.: Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards, Nat. Hazards Rev, 6, 23-33, DOI: 10.1061/(ASCE)1527-6988(2005)6:1(23), 2005.

Clark, G.E., Moser, S.C., Ratick, S.J., Dow, K., Meyer, W.B., Emani, S., Jin, W., Kasperson, J.X., Kasperson, R.E., Schwarz, H.E.: Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA., USA, Mitigation and Adaptation Strategies for Global Change 3, 59-82, DOI: 10.1023/A:1009609710795, 1998.

Cutter, S.: Vulnerability to environmental hazards, Human Geography, 20, 4: 529-539, DOI: 10.1177/030913259602000407, 1996.

Cutter, L.S., Boruff, B.J., Lynn Shirley, W., (2003). Social Vulnerability to Environmental Hazards, SOCIAL SCIENCE QUARTERLY, 84, 2, 242-260, DOI: 10.1111/1540-6237.8402002, 2003.

Fekete, A.: Validation of a social vulnerability index in context to river-floods in Germany, Nat. Hazards Earth Syst. Sci., 9, 393-403, DOI:10.5194/nhess-9-393-2009, 2009.

Flanagan, B.E., Gregory, E.W., Hallisey, E.J., Heitgerd, J.L., Lewis, B.: A Social Vulnerability Index for Disaster Management, Journal of Homeland Security and Emergency Management, 8, 1, Article 3, DOI: 10.2202/1547-7355.1792, 2011.

Fort M., Arnaud-Fassetta G., Cossart E., Beaudouin B., Bourbon C., Debail B., Einhorn B. : Impacts et signification hydromorphologique de la crue du Guil de juin 2000 (Haut Queyras), Geomorphology: from Expert Opinion to Modelling. A tribute to Professor Jean-Claude Flageollet. Proceedings of the Symposium held in Strasbourg, France, April 26-27 2002, CERG Editions, 159-166, 2002.

Fort M., Arnaud-Fassetta G., Bétard F., Cossart E., Madelin M., Lissak C., Viel V., Bouccara F., Carlier B., Sourdot G., Tassel A., Geai M.-L., Bletterie X., Charnay B.: Sediment dynamics and channel adjustments following torrential floods in an upper Alpine valley (Guil River, Southern French Alps), Engineering Geology for Society and Territory. Volume 3: River Basins, Reservoir Sedimentation and Water Resources, Chapter 65. Springer, Cham, Heidelberg, New York, Dordrecht, London, 313-317, DOI: 10.1007/978-3-319-09054-2_65, 2014.

Frigerio, I., Ventura, S., Strigaro, D., Mattavelli, M., De Amicis, M., Mugnano, S., Boffi, M.: A GIS-based approach to identify the spatial variability of social vulnerability to seismic hazard in Italy, Applied Geography, 74, 12-22, DOI: 10.1016/j.apgeog.2016.06.014, 2016.

Fuchs, S., Heiss, K., Hübl, J.: Towards an empirical vulnerability function for use in debris flow risk assessment, Nat. Hazards Earth Syst. Sci., 7, 495-506, DOI: 10.5194/nhess-7-495-2007, 2007.

Fuchs, S.: Susceptibility versus resilience to mountain hazards in Austria - paradigms of vulnerability revisited, Nat. Hazards Earth Syst., 9, 337-352, DOI: 10.5194/nhess-9-337-2009, 2009.

Fuchs, S., Birkmann, J., Glade, T.: Vulnerability assessment in natural hazard and risk analysis: current approaches and future challenges, Nat. Hazards Earth Syst., 64, 1969-1975, DOI: 10.1007/s11069-012-0352-9, 2012.

Glade, T.: Vulnerability assessment in landslide risk analysis, DIE ERDE 134 (2), Beitrag zur Erdsystemforschung, 123-146, 2003.

Guillard-Gonçalves, C., Cutter, S.L., Emrich, C.T, Zêzere, J.L.: Application of Social Vulnerability Index (SoVI) and delineation of natural risk zones in Greater Lisbon, Portugal, Journal of Risk Research, 24 p, DOI: 10.1080/13669877.2014.910689, 2014.

Hewitt, K., & Metha, M.: Rethinking risk and disasters in mountain areas. Journal of Alpine Research, 100-1, DOI: 10.4000/rga.1653, 2012.

IGN: Bd ORTHO/Bd TOPO, Hautes-Alpes, 2009.

IGN: Registre Parcellaire Graphique, RPG, Hautes-Alpes, 2012.

IGN: Reseau Natura 2000, documents d'objectif, BdCarto/BdCarthage, DREAL PACA, 2016.

INSEE: Recensement de la Population 2006, Hautes-Alpes, exploitation principal, 2008.

INSEE: Recensement de la Population 2012, Hautes-Alpes, exploitation principal, 2014.

INSEE: Recensement de la Population 2014, Hautes-Alpes, exploitation principal 2014.

Jeffers, J.M.: Integrating vulnerability analysis and risk assessment in flood loss mitigation: An evaluation of barriers and challenges based on evidence from Ireland, Applied Geography, 37, 44-51, DOI: 10.1016/j.apgeog.2012.10.011, 2013.

Kappes, M.S., Papathoma-Köhle, M., Keiler, M.: Assessing physical vulnerability for multi-hazards using an indicator-based methodology, Applied Geography, 32, 577-590, DOI: 10.1016/j.apgeog.2011.07.002, 2012.

Meyer, V., Scheuer, S., Haase, D.: A multicriteria approach for flood risk mapping exemplified at the Mulde River, Germany, Nat. Hazards Earth Syst. Sci., 48, 17-39, DOI: 10.1007/s11069-008-9244-4, 2009.

Nelson, K.S., Abkowitz, M.D., Camp, J.V.: A method for creating high resolution maps of social vulnerability in the context of environmental hazards, Applied Geography, 63, 89-100, DOI: 10.1016/j.apgeog.2015.06.011, 2015.

Pachauri, R. K., Allen, M., Barros, V., Broome, J., Cramer, W., Christ, R., *et al*.: Climate change 2007: Synthesis report. Contribution of working groups i, ii and iii to the fifth assessment report of the intergovernmental panel on climate change, 2007.

Parc Naturel Régional du Queyras, PNRQ : Diagnostic de vulnérabilité du bassin versant du Guil aux inondations. Rapport définitif, Avril 2016, 1-48, 2016.

Puissant, A., Malet, J.P., Maquaire, O.: Mapping landslide consequences in mountain areas: a tentative approach with a semi-quantitative procedure, SAGEO, 1-16, 2006.

Puissant, A., Van Den Eeckhaut, M., Malet, J.P., Maquaire, O.: Landslide consequence analysis: a region-scale indicator-based methodology, Landslides, 1-16, DOI: 10.1007/s10346-013-0429-x, 2013.

Rygel, L., O'Sullivan, D., Yarnal, B.: A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country, Mitigation and Adaptation Strategies for Global Change, 11, 741-764, DOI: 10.1007/s11027-006-0265-6, 2006.

Tapsell, S., McCarthy, S., Faulkner, H., Alexander, M.: Social vulnerability to natural hazards, CapHaz-Net Consortium, WP4, .D4.1, 4-56, 2010.

Tricart, J.: Etude de la crue de la mi-Juin 1957 dans la vallée du Guil, de l'Ubaye et de la Cerveyrette, Revue de géographie Alpine, 4, 565-627, DOI: 10.3406/rga.1958.1846, 1958.

Reghezza, M.: Vulnérabilité et risques: L'approche récente de la vulnérabilité. Responsabilité et environnement, 43, 9-13, 2006.

Reghezza M. Rufat S.: The Resilience Imperative: Uncertainty, Risks and Disasters, Elevier-ISTE, 262 p, 2015.

Wood, N.J., & Good, J.W.: Vulnerability of Port and Harbor Communities to Earthquake and Tsunami Hazards: The Use of GIS in Community Hazard Planning, Coastal Management, 32:3, 243-269, DOI: 10.1080/08920750490448622, 2004.

Wu, S.Y., Yarnal, B., Fisher, A.: Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA, Clim Res 22, 255-270, DOI: 10.3354/cr022255, 2002.

Zahran, S., Brody, S.D., Peacock, W.G., Vedlitz, A., Grover, H.: Social vulnerability and the natural and built environment: a model of flood casualties in Texas, Disasters, 32 (4), 537-560, DOI: 10.1111/j.1467-7717.2008.01054.x, 2008.

Zingari, P.C., & Fiebiger, G.: Mountain risks and hazards, Unasylva 208, 53, 71-77, 2002.