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INTERACTIVE DESIGN SCENARIOS FOR SPATIO-TEMPORAL EVALUATION OF SOCIAL VULNERABILITY TO SEISMIC RISKS: APPLICATION TO THE CITY OF GRENOBLE.

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1 INTRODUCTION

The development of information technologies and communication has helped to provide new opportunities in terms of tools for decision making in the field of disaster risk management. Among the tools, which have been developed, some have focused on characterizing the hazard, or the specification of regional vulnerability (Arnaud, 2009), other are more involved in crisis management. However, it seems that few tools are interested by the characterization of the population vulnerability, or deal with the definition of prevention or information policies. Different studies have shown that preventive information towards populations is a factor that can reduce the social vulnerability. However the methods and tools dedicated to the social vulnerability evaluation or to the impact of information on the population vulnerability are still poorly developed.

The aim of this paper is to present the specifications of a tool developed to design scenarios of social vulnerability to seismic risk. We consider that social vulnerability corresponds to the vulnerability of individuals related to their perception of the risks they are exposed to, their knowledge of safety measures, their experience of earthquakes, etc. Developing some scenarios for reducing social vulnerability requires two steps: the first one concerns the development of a method to quantify the social vulnerability of individuals; the second one concerns the development of a spatio-temporal information system to provide simulations to observe the impact of preventive information campaign on the social vulnerability reduction.

2 MOVISS : A METHOD FOR SPATIO-TEMPORAL EVALUATION OF SOCIAL VULNERABILITY

2.1 Social vulnerability evaluation methods

The issue of social vulnerability and its relationship with risk perception has been studied several times by geographers since the 1940s (White, 1945) and mainly in the years 1970-1980 (Burton & al. 1978; Parker & al, 1979). The so-called "qualitative" approaches (D'Ercole,1994), integrating the psycho-sociological dimension through cognitive representations, have been translated quantitatively in the years 1990-2000. These are based on the construction of indices which use depends on the scale of study and objectives. For example, some studies are mostly based on the analysis of territorial factors and do not include the individual dimension. They aim at evaluating the territorial vulnerability (Chardon, 1994; Cutter et al. 2000; Fekete, 2009) and their results can have a cartographic representation. Others used the same approach through multi-criteria analysis (Gaillard et al., 2001; Dominey-Howes &al, 2004; Paradise, 2005). D'Ercole (1996) used individuals' responses from a questionnaire. However, most social vulnerability tend to focus on residents, because, often, sampling methods are based on census data. However, considering only the resident population to assess the social vulnerability of urban space can be regarded as a reductive approach. For this reason, some studies have investigated the vulnerability of residents population but also working population (Glatron & al, 2008). Moreover, the structure and spatial distribution of population change over time, regardless of the time scale considered (day, week, year). It is the reason why it may be necessary to improve the sampling methods by taking into account the variations in the spatio-temporal distribution of the population, and to integrate the mobility of the population, which is an important vulnerability factor (Ruin, 2007).

2.2 Objective

MOVISS method is based on the hypothesis that the quantitative and qualitative distribution of the population within a city changes during the day. We consider that the population within a district at a time t consists of three groups: the “residents” (who live in the district), the “users” i.e. the individuals who are in the district for working, leisure, visiting friends, medical appointments, shopping ... and the people who transit through the district. In this study, we only considered residents and users. The functions and activities of the different urban areas also have implications for the sociological characteristics of the urban population: for example, some urban areas may be characterized by an over-representation of young people or working population during the period of 8:00 am-6:00 pm and an over-representation of non-working population in the evening. The commercial or administrative districts are characterized by high population concentration during the day but not at night.

Concerning risk management, the preventive information is distributed differently to the “users” and to the ”residents”: for the latter, information is distributed to their homes by their municipality. Users are themselves residents, but they come from another district or another municipality and they may receive different information. In principle, residents are likely to have a better knowledge of their district (depending on their residence duration). Considering that information and experiences of people influence their perception of their environment, and therefore of the risks they are exposed to (Lynch, 1960; Lindell & Perry, 2004), we can then expect to see different results, in terms of social vulnerability between users and residents.

We suggest a method to evaluate the spatio-temporal evolution of social vulnerability, integrating daily mobility data. The objective is to take into account the socio-spatial differentiation, in order to reduce the population vulnerability. The proposed approach consists in identifying the determinants of spatio-temporal vulnerability by a sociological survey and to calculate some indices in order to quantify the social vulnerability. These indices will allow designing scenarios of vulnerability reduction by changing their determinants.

2.3 Integrating daily mobility data in the study of social vulnerability

Integrating the spatio-temporal dimension into the study of social vulnerability involves the creation of a sample taking into account the residents and the users populations. The principle adopted to make the sample consists in composing a sub-population representing the variety of people present at different times of the day and in different parts of the city.

To understand the characteristics of people being in the various districts of the city, it is necessary to use the data that describe the daily displacements of individuals. In France, the most detailed investigations about the movement of people in cities are household travel surveys. These surveys usually concern several municipalities in a urban metropolitan region - corresponding to the zone of influence of the town center. These surveys are based on a representative sample of households living in study area. They describe all travels made during a weekday by the people interviewed and theirs social characteristics. By extrapolation, they allow to reconstruct the spatio-temporal distribution of the population and to identify sociological subgroups of population.

From the results of this household travel survey and using the quota method, it is possible to build a spatio-temporal sample defining the number (quantization) of people at different times of the day in different areas of the city and the types of person profiles (qualification). Two types of quotas are defined: a simple quota that shows the distribution of the age structure of population and a crossed quota based on the distribution of persons according to their resident or user status at different times of the day.

2.4 Quantifying social vulnerability

The quantification of population vulnerability to seismic risks is based on the construction of a Social Vulnerability Index (SVI) (Beck et al., 2010). This index is calculated from responses to questionnaires made by the respondents. The method requires two steps: 1) The first one is to assign a score to each question according to the responses. Then, for each group of questions that correspond to a theme (perception, knowledge or information), a sub-index is calculated. These sub-indices correspond to the average of scores. Thus, we get a sub-index to quantify the level of information, the level of risk perception and the population knowledge level. 2) Secondly, a social vulnerability index is calculated by averaging the sub-indices. A low value of the SVI indicates a low vulnerability.

A Social Vulnerability Index, and sub-indices measuring the level of perception (IP), the level knowledge (IC) and the level information (II) are obtained for each individual, but also for each territorial unit and for each studied temporal granularity.

2.5 Designing scenarios to reduce social vulnerability

In a first time, no weights are assigned to different sub-indices, as it is considered that these determinants are involved in an equivalent manner in the calculation of the IVS. However, it is possible to consider giving more weight to one or the other sub-index according to the objectives. For this reason, we propose to construct scenarios of social vulnerability by changing the value of the various sub-indices or the weights assigned to them. (figure 1)Thus, according to the results observed by simulating an information campaign that has improved the sub-index of knowledge of risks (and more generally the vulnerability), it is possible to contribute to the orientation of spatial policies of preventive information.

In case of earthquake, during the shake, what should you do?

–Stand and not move: wrong answer → score = 0

–Protect myself under a table: correct answer → score = 3

- Weighted sum of all the scores and standardisation max(I_{vt})=20:

$$I_{vt} = \frac{20}{\sum_{i=1}^{10} k_i} \sum_{i=1}^{10} k_i I_{vfi}$$

Figure 1: Rule to calculate Social Vulnerability Index

3 SPATIO-TEMPORAL INFORMATION SYSTEM SPECIFICATIONS FOR THE DESIGN OF SCENARIOS REDUCING THE SOCIAL VULNERABILITY

3.1 Methodological issues

The design of vulnerability scenarios is based on a information system to ensure the following functionalities:

– Collecting and organizing data produced from the socio-spatial survey,

– Integrating rules to calculate the social vulnerability index;

– Visualizing data related to the characterization of the spatiotemporal evolution of social vulnerability;

– Interacting on the value or the score of the determinants of vulnerability (sub-indices).

However, the idea being to assess the impact of an information campaign by varying the determinants of vulnerability, the construction of scenarios for reducing social vulnerability must be based on an exploratory approach in which the relationship "Data - Maps - User" has an important role. It may enable the user to navigate freely within the dataset using an interactive graphical interface, according to his intuition and assumptions and the results obtained via cartographic representations. This navigation capability is done using the mouse, it implies the creation of a geovisualization interface adapted to the specificity of the data handled, the other functionality necessary for the resolution of targets.

The geographical information systems are not always efficient for exploratory data analysis (Banos, 2005), in particular for managing and for representing temporal data, or for designing interfaces for the exploratory spatial data analysis. Moreover, there are few tools proposing a design method of exploratory scenarios. Usually, simulation tools are based on the design of a set of scenarios previously identified and constructed. They rely on the association of several tools such as spreadsheets, simulation software and specific geographical information system to provide a cartographic representation of the results. Also, changing a value or a parameter of the model requires taking the whole processing chain including different software and more or less complex file manipulation (changing formats, data integration in the software...). Generally, the combination of different tools involves the definition of different design and models of representation. This does not facilitate the exchange and interoperability of data and methods and does not contribute to the exploration of several scenarios.

Also, the study of social vulnerability and its evolution in time and space requires the use of multidimensional data, characterized by thematic, spatial and temporal attributes that conventional GIS do not take into account (Davoine & al 2006). It is therefore necessary to provide a computing environment that can supply a conceptual model and a representation model dedicated to the space-time analysis of social vulnerability and also to build scenarios to reduce the social vulnerability.

3.2 A problematic of information system for natural hazards

The design of an information system dedicated to the modeling of vulnerability reduction scenarios is a development issue for information systems dedicated to natural hazards. Indeed, these tools can store and manage a multidimensional and heterogeneous information (spatial, temporal, thematic and multimedia information) and offer interactive and multi-view geovisualization interfaces, allowing the user to visualize and to explore information, and to interact with it.

Among all the tools and methodologies available, we chose to use GenGHIS, a generator of Spatio-Temporal Information Systems (SIST) for Natural Hazards developed by the STEAMER team from the Laboratory of Informatics of Grenoble, (Davoine & al 2006; 2010). GenGHIS allows the creation of SIST, by supporting all stages from data modeling to the design and building of multidimensional and interactive geovisualization interfaces. The originality of GenGHIS lies in the interfaces that the tool can generate. These are based on a multidimensional view of information with different view models adapted to each dimension of information (spatial, temporal and attribute).

Thus, the interfaces generated by GenGHIS allow 1) to visualize spatial data (raster and vector) related to their temporal and thematic contexts with different interconnected views, 2) to produce interactive multimedia maps, 3) to query data using spatial, temporal, spatio-temporal and thematic criteria. Also, GenGHIS has the advantage to support a knowledge base to store data and to infer some rules, including rules of calculation. The GenGHIS environment offers all the features needed to set up an exploratory process dedicated to the construction of social vulnerability scenarios analysis.

3.3 MOVISS_SIST specifications

According to MOVISS method, the idea is to propose to the user the ability to change the values of sub-indices (IC, IP, II) and the weights assigned to them, and to analyze the spatio-temporal distribution of social vulnerability. The aim is also to give the user the ability to create as many scenarios as desired. For this, we designed MOVISS_SIST software by using the GenGHIS platform (Davoine 2010).

Mapping time raises several problems. More and more applications use animation to represent changes or evolutions (Kraak, 1999). In an exploratory data analysis method, the animation may be of interest, particularly as it applies on disaggregated data and continuous time series. In this case, animation, combined with interactivity, can help to highlight particular phenomena (Arnaud & al 2009). However, when making a thematic comparison on some periods (2 or 3), the animation does not add value to the mapping and the principle of the map collection is more appropriate. We must design a geovisualization interface which should allow the user to understand quickly:

- The spatial differentiation of vulnerability: what are the least vulnerable areas? The idea is to reveal spatial discontinuities and geographical structures;

- The temporal differentiation of social vulnerability during the day: the idea is to show the daily evolution of spatial structures, the spatio-temporal evolution of social vulnerability in a short time.

MOVISS_SIST is composed of three main modules: a knowledge base, a geovisualization interface and a scenario-designing module

The knowledge base stores the data (thematic, temporal and spatila) and calculation rules for the construction of social vulnerability indices. The calculation rules are formalized through an algebraic modeling language. The data are homogeneous and structured, issued from statistical data, and defined by homogeneous geographical units (the district) and a temporal granularity corresponding to time intervals or specific periods (morning, noon, early afternoon morning, evening and night). Several groups of thematic data are identified:

- Reference data - socio-demographic data characterizing the surveyed population;

- Produced data that correspond to the sub-indices obtained from the survey processing;

- Calculated data - the IVS;

- The weighting parameters assigned to the sub-indices.

The module to design scenarios allow to the user to easily modify the data or the parameters (weights and sub-indices) affecting the IVS. Figure 2 shows the interface that provides these features.

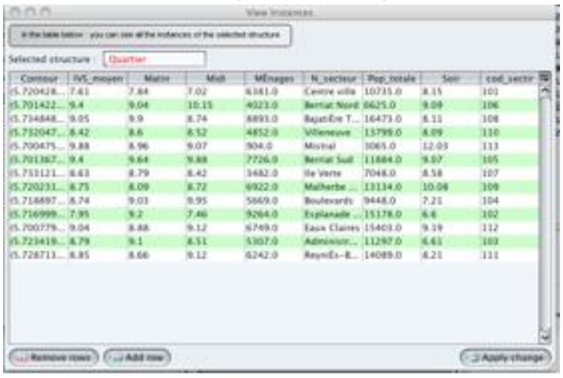

Figure 2: Interface to input scores data

The geovisualization interface is structured in several windows or views, synchronized between them. Querying data are made using visual queries, performed either on the thematic window or on the spatial window :

- A thematic window, displaying all the thematic or attribute data necessary for the evaluation of social vulnerability and to develop and to understand the scenarios. These data are displayed according to the temporal granularity defined during the survey. To explore the data set, the thematic window offers different tabs, each corresponding to a dataset. Activating a tab allows the user to view geographic information matrices for each dataset and access the corresponding cartographic representations (figure 3)

- A spatio-temporal window, displaying the geographical distribution of the determinants of vulnerability and their temporal evolution. Different maps (raster or vector) may be display

The ultimate goal is to make comparative analysis, from a spatially and temporally point of view. For this, the collection of maps, applied to a small number of maps, is a relevant mean to visualize simulation results simultaneously, both from a geographical or temporal point of view. That is why we have proposed to structure the spatial window in different views using the principle of the map collection. Each map shows the geographical distribution of social vulnerability and its determinants at a particular period of the day (morning, afternoon or evening). The synchronization between the views, associated to the interactivity with the user, offers the opportunity to visualize the daily evolution of the vulnerability according to one or several selected geographical unit(s) (figure 3).

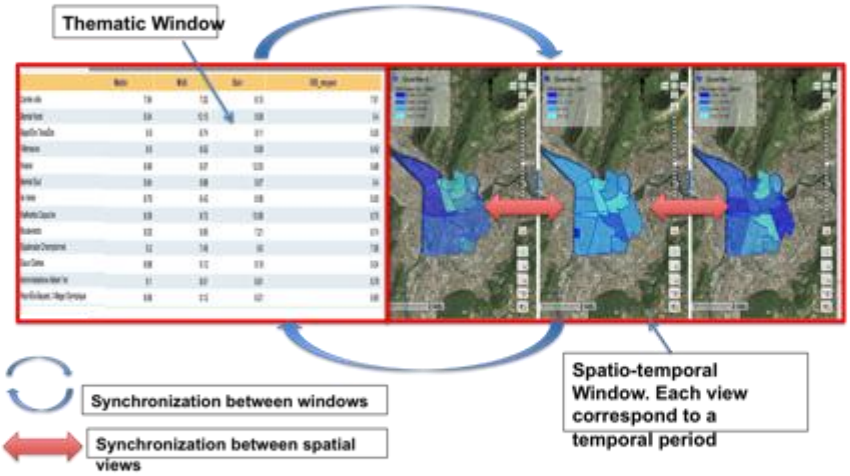

Figure 3 : MOVISS_SIST geovisualisation interface

4 APPLICATION TO THE CITY OF GRENOBLE

The city of Grenoble is exposed to various risks, including seismic risk. Seismicity is moderate, but the tectonic context may induce an earthquake of magnitude 6. In Grenoble, the population is not used to experience such events, and therefore it may be particularly vulnerable even if the municipality distributes prevention information. The municipalities located in Grenoble Metropolitan area are exposed to other different natural or technological risks. People living in these neighboring cities and who are in Grenoble for their usual activities (work, leisure, shopping...) do not receive the same information on risks. So, these individuals might be characterized by different vulnerabilities to seismic hazard. First, we evaluated the socio-spatial vulnerability of Grenoble, taking into account all the people being in the city of Grenoble during the day. In a second step, we studied the socio-spatial impact of a preventive information campaign, using the MOVISS_SIST.

4.1 Sampling and main results

The sample was designed from the results of the houselhold travel survey of the urban area of Grenoble conducted in 2002 (Andre-Poyaud et al, 2008; Tabaka, 2009). The spatial unit used for the sampling was the same as the household travel survey, which defined 13 geographical units (figure 4). The time granularity chosen defined four time periods: from 8 am to 12 am, from 12 am to 2 pm, from 2 pm to 6 pm; after 6 pm. Those time periods were aggregated into three periods (morning, afternoon, evening/night). 1004 people were interviewed in the streets of Grenoble. The number of respondents was equivalent for all geographic units. The selection of persons was based on the quota method defined in section 2.3 (Figure 4).

	Centre ville	Esplanade Championnet	Adminis-tration Albert 1er	Berriat Sud	Ile-Verte	Boulevards	Berriat Nord	Bajatière Teisseire	Malherbe Capuche	Villeneuve	Reyniès Bayard, Village olympique	Eaux claires	Mistral
Effectifs	77	77	77	77	77	77	82	77	77	78	74	77	76
classe d'âge													
15-24ans	20	19	18	17	14	16	18	15	21	21	20	23	24
25-34ans	13	16	13	16	10	12	19	14	12	12	10	12	14
35-44ans	11	10	15	16	17	16	24	13	12	15	17	14	20
45-54ans	15	14	15	12	18	17	14	10	11	16	13	12	12
55-64ans	9	8	8	7	10	5	3	11	8	8	5	8	3
65 et +	9	10	8	9	8	11	4	14	13	6	9	8	3
nombre de résidents													
entre 8h et12h	3	7	5	8	8	7	4	11	7	12	8	8	12
entre 12h et 14h	2	5	4	6	7	8	3	8	7	12	6	6	12
entre 14h et 18h	3	6	4	7	11	8	4	11	7	14	8	9	11
après 18h	4	8	6	10	10	11	8	13	9	17	12	11	16
total	12	26	19	31	36	34	19	43	30	55	34	34	51
nombre de pratiquants													
entre 8h et12h	12	12	13	10	10	11	16	7	11	3	10	9	3
entre 12h et 14h	11	8	11	7	7	7	14	6	10	4	10	8	4
entre 14h et 18h	26	18	22	16	6	13	22	13	17	9	14	16	12
après 18h	16	13	12	13	18	12	11	8	9	7	6	10	6
total	65	51	58	46	41	43	63	34	47	23	40	43	25

Figure 4 : Characteristics of the spatio-temporal sample

Figure 5 presents the main results concerning the determinants of social vulnerability. The survey results are presented in details in Beck et al.2010.

Risk perception

1- Among the natural hazards to which the respondents feel exposed, the earthquake is ranked third after the floods and storms.

2- The respondents feel moderately exposed to seismic risks.

Knowledge and behaviour

3- More than half of respondents have a good knowledge of rules to follow during and after seismic shock.

4- Young (under 24 age old) have a better knowledge about the earthquake and the guidelines to be adopted. However, they feel less exposed than older people.

5- The level of knowledge about earthquake and about the behavior to adopt are directly correlated with educational level .

6- The unemployed, retired and housewives/men do not know very well the safety measures

Information about seismic risks

8- Few people declare having received information about the seismic event to Grenoble.

9- Many people say having received information on how to behave during an earthquake.

10- Having received information (about event or safety measures) seems to improve the level of knowledge.

Social vulnerability to the earthquakes

11- The higher socio-professional categories are the least vulnerable.

12- The educational level is one of the determinants of social vulnerability to earthquakes.

Figure 5: Main results of the survey

Considering all the respondents, the average vulnerability index is 8.8. Over a scale of 0-20, this value means that the vulnerability of the sampled population is moderate (0 = low vulnerability, 20 =high). The study shows that the qualification level, the age, the profession but also the district where respondents live (or "use") constitute important determinants of social vulnerability to seismic risk. Figure 6 shows the geographic distribution of vulnerability. However, the difference between users (SVI = 8.7) and residents (SVI = 8.9) is not significant.

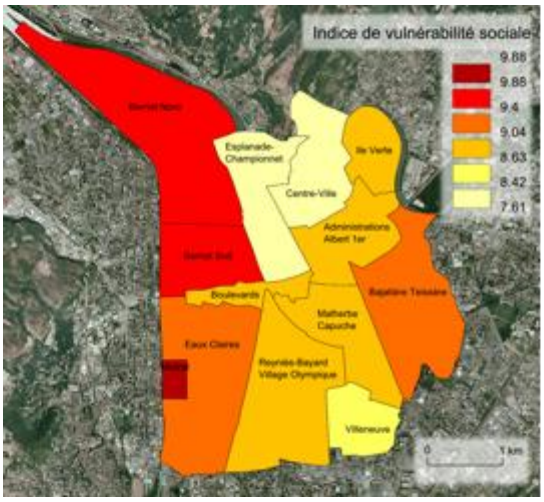

Figure 6: Social vulnerability index to earthquakes in Grenoble (average by district)

4.2 Visualization of the spatio-temporal variation of vulnerability

Data integration in the MOVISS_SIST provides a spatio-temporal approach of social vulnerability in Grenoble. Figure 7 shows temporal differentiation of social vulnerability during the day. The simultaneous display of different views allows a comparative reading of the maps, showing for each district the social vulnerability index for three significant periods: morning, afternoon and evening. These maps show that SVI changes over time and space. In some districts, the SVI is relatively stable during the day, such as in the Ile Verte, Villeneuve districts, etc. However, in other districts, social vulnerability increases during the day: in the evening (Malherbe, Capuche), or in the afternoon (Berriat, Reyniès Bayard-Village Olympique). Administrative or shopping districts, such as Grands Boulevards, Administration, Esplanade-Championnet, where the population of "users" is important, are characterized by a decrease of vulnerability in the evening.

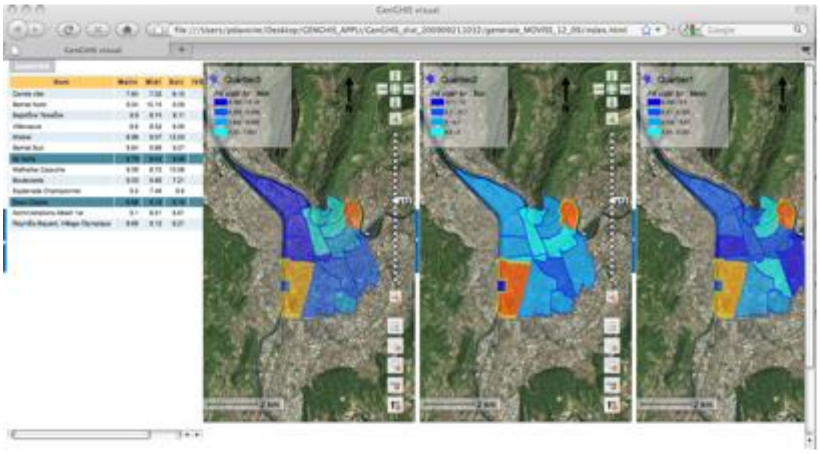

Figure 7: Spatio-temporal simulation of social vulnerability to seismic risks in Grenoble

This tool can highlight the areas where it is important to improve preventive information but also to identify groups of populations (residents or users). For example, we observe that it is important to distribute information to "users" within some districts as “Grand boulevards” or “Administration-Albert 1er”. However, it is necessary to conduct a more focussed information campaign among resident districts as “Mistrals” or “Malherbe Capuche”.

5 CONCLUSION

We have proposed a methodology and a tool (MOVISS_SIST) for evaluating and visualizing social vulnerability through the establishment of a survey and the development of a spatio-temporal information system dedicated to the theme of social vulnerability to earthquakes. This survey methodology has allowed to refine the classic studies of social vulnerability by taking into account the spatio-temporal evotution of the population during the day. We applied our methodology to the seismic hazard in Grenoble. The MOVISS_SIST has allowed to vizualize survey results according to their thematic, spatial and temporal dimensions and to design simulations in order to reduce vulnerability. MOVISS_SIST provides the user the ability to identify the main determinants affecting the IVS by visual queries and interact easily on the data to modify them. This tool finds all its interest in the simulation information campaigns. Our methodological and technological proposals are sufficiently generic to be applied to other risks, and other spatial-temporal contexts.

Several perspectives can be identified: first, the formalization of scenarios needs to be specified in order to run them and observe the results of the impact of preventive campaign over different social groups or districts. Moreover, the survey methodology could be improved by taking into account the week or season variations of population distribution.

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