Vulnerability assessment for mining subsidence hazard

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VULNERABILITY ASSESSMENT FOR MINING SUBSIDENCE HAZARD

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ABSTRACT: After the last mining subsidence events, which occurred in the iron-ore field in Lorraine (France) in 1996, 1997 and 1999, and because of the thousand hectares of undermined areas, the assessment of vulnerability of buildings and territories became necessary for risk management. The ten last years highlight evolutions of the vulnerability concept and its assessment method between the first risk management decisions and current risk assessment. These evolutions reveal a lot about the complexity of the vulnerability concept and about difficulties to develop simple and relevant methods for its assessment.

The objective of this paper is to present this evolution and to suggest different improvements compared to other concepts and methods developed in other countries (USA, Poland...) and for other hazards (flood, industrial...). These improvements take into account more various kinds of elements in the vulnerability meaning (buildings, people, roads, public facilities and public functions) as well as they deal with method of assessment in relation to the subsidence intensity and vulnerable elements.

KEYWORDS: Vulnerability, Subsidence, Stakes, Assessment Methods.

RESUME : Depuis les affaissements miniers survenus en Lorraine en 1996, 1997 et 1999, et en raison des milliers d'hectars souminés, l'évaluation de la vulnérabilité des habitations et des territoires est devenu une nécessité pour permettre une meilleure prévention des risques. Les dix années écoulées depuis les premières décisions prises en réaction au risque d'affaissement minier montrent une évolution importante des méthodes employées. Ces évolutions sont révélatrices de la complexité du concept de vulnérabilité et de la difficulté à trouver des méthodes pertinentes et opérationnelles pour l'évaluer.

Cet article a pour objectif de présenter cette évolution et de donner des perspectives d'amélioration au vu des méthodes employées dans d'autres pays (Etats-unis, Pologne) et vis-à-vis d'autres aléas (sismique, inondation, accidents industriels). Ces perspectives portent sur les différents enjeux qui contribuent à la vulnérabilité (personnes, bâtiments, infrastructures, équipements publics...) et sur les méthodes de caractérisation de la vulnérabilité en fonction des enjeux et de l'intensité de l'affaissement.

MOTS-CLEFS : Vulnérabilité, Affaissement, Enjeux, Méthodes d'Evaluation.

1. Introduction

"La Lorraine" is a French territory, which has important underground natural resources of iron, coal and salt. The industrial need for large quantities of raw materials at an acceptable cost has led to large underground mines, especially between 1900 and 1990. Because of the extraction methods, such underground mining works create underground voids, which may cause mining subsidence phenomena, i.e. significant movements at surface. These may then result in serious damage to structures built in the area of influence of such movements. Subsidence is planned, during mining works, in the case of total extraction mining methods ("caving-in" method in coal mines, for example). Such methods are the most profitable and were used in the iron-ore field when no build elements exist on the ground surface. On the other hand, mining subsidence is of a highly accidental nature when it takes place over mines that use abandoned rooms and pillars method even though this method should have allowed an endless ground stability. Indeed, in the latter case, the operator has deliberately left in place natural or artificial pillars sized to withstand the weight of the overburden. Such a method is less profitable and is used under urbanized areas in order to avoid subsidence and damages to structures. Recent cases of mining subsidence (1996, 1997 and 1999) that have taken place in the Lorraine iron mining area denote the hazard of such mining works when left abandoned.

The cases of subsidence in Lorraine led public authorities to carry investigations over the entire Lorraine iron-mining field in order to assess hazard, vulnerability and risk of the whole territory. The first investigations highlighted the existence of about 20 km^2 of urbanised areas undermined by abandoned works consisting of rooms and pillars.

The first part of this paper is a presentation of the last subsidence phenomena and on the identification of damage.

The second part deals with different aspects of the vulnerability concept through a bibliography study. It is then proceeded to a description and a discussion, in a third part, of evolutions of methods used in the iron-ore field for the vulnerability assessment.

The last part deals with possible evolutions of the vulnerability and risk assessment methods for mining subsidence hazard. Some improvements can be carried out with an explicit split of the vulnerability components and some others with careful considerations about influence attached to the different vulnerability and risk components.

2. Mining subsidence in the iron-ore field

Mining subsidence often produces significant horizontal and vertical movements at the ground surface (Table 1). The maximum value “Sm” of the vertical subsidence is usually considered as a characteristic of the trough. This parameter is relatively easy to estimate for undermined areas. However, the horizontal strain of the ground “ε”, its curvature and its slope “T”, are the three main causes of structural damage. The maximum values observed for these parameters (“εm”, “Tm”) can be disastrous for a structure if the movements are imparted integrally. The measurement of these parameters entails significant difficulties either when a site of mining subsidence is instrumented, or in a case where cave-in has not yet taken place and prediction is regarded. The real measurements of movement often reveal that the vertical movement is in agreement with its theoretical value, but the slope and the horizontal strain deviate slightly from theory and the curvature even more.

Table 1: Description of the five last subsidences in the iron-ore field and the associate damage.

	Subsidence characteristics[2]	Physical damage	Cost	Others consequences
Auboué (Metz street) 1996	Sm = 1.7m $\varepsilon m \approx 15\ 10^{-3}$	130 buildings[2] roads, pavements,	13,9 millions € Erreur ! Signet non	150 families evacuated[1]

	Tm = 2.5%	sewerage system1	défini.	300 peoples left their village for good[1] Nursery school closed[1]
Auboué (Coinville city) 1996	Sm = 1m $\varepsilon m \approx 8.5\ 10^{-3}$ Tm = 3.5%	100 buildings[2] roads, pavements[1]		
Moutiers (high quarter) 1997	Sm = 1.4m $\varepsilon m \approx 18\ 10^{-3}$ Tm = 1.2%	70 buildings[2]		A pub is closed[1]
Moutiers (near the stadium) 1997	Sm > 0.5m $\varepsilon m > 6\ 10^{-3}$ Tm = ?	60 buildings[2]		
Roncourt 1999	Sm = 0.65m $\varepsilon m \approx 6.5\ 10^{-3}$ Tm = 1%	18 buildings[2]		
[1] Zihri (2004) ; [2] Deck (2002)				

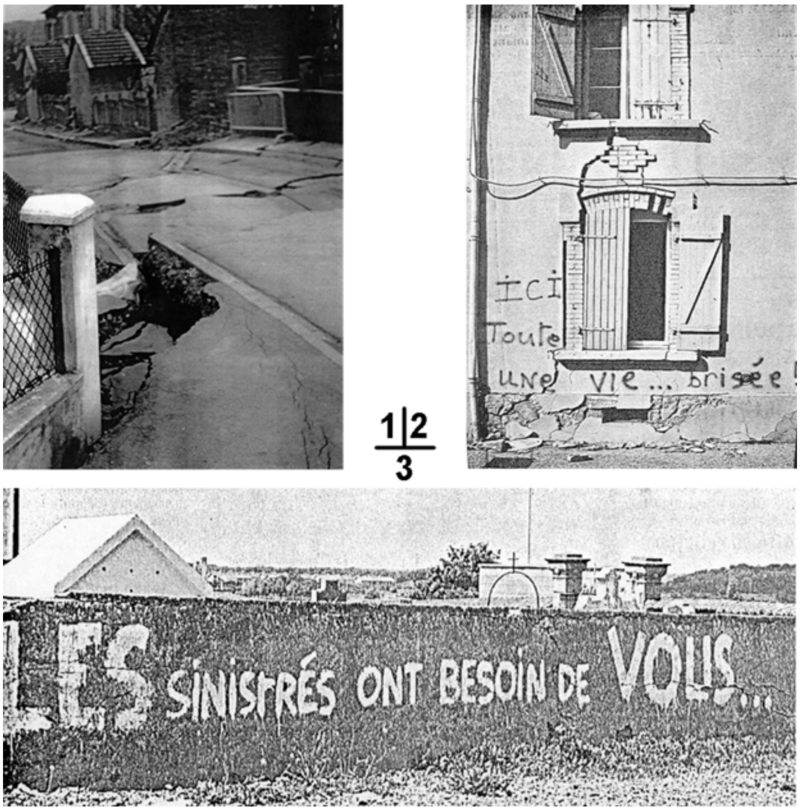

Figure 1: Example of mining damage in the iron-ore field (1: Road damage in Auboué, 1954; 2: Building and social damage in Auboué, 1996 “*Here, all a life is broken!*”; 3: Social damage in the iron-ore field *« Disaster victims need you...* »

Prediction of building damage may be performed on the basis of threshold values for ground movements (especially horizontal ground strain) and buildings characteristics (especially length and structural strength). But an accurate building damage prediction is difficult in the light of uncertainties about the real ground and structure behaviour.

Consequences induced by subsidence are various (Table 1, Figure 1):

- physical, with buildings, roads, pavements and networks damage;
- economical with the cost of physical reparations and compensations;

- social with important psychological impact on both disaster victims and other people of the area who suffer from an impression of a lack of public support and answer to their fears;
- political and media related because the whole territory became a key point for a political debate and media reports for many months.

3. The vulnerability concept in the scientific litterature

The concept of vulnerability is usually used in many definitions of risk. A comparison of these definitions is useful to grasp whole the notions included in this term.

The Vulnerability is a component of Risk. The United Nations, through the International Strategy for Disaster Reduction define Risk as “the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions » (UN/ISDR 2004). They adopt the classical convention expressed by the notation: Risk = Hazards x Vulnerability. Vulnerability is then defined by « the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. »

In France, the Ministry of Environnement and Sustainable Development, defines the vulnerability by the « level of foreseeable consequences of one natural phenomenon upon stakes » in which stakes are « people, goods, activities, means, heritage... likely to be affected by a natural hazard » (MATE, 1997). In case of industrial risk, the same Ministry suggests a slightly different definition: « the vulnerability of an area or a place is the appreciation of target sensibility against particular effects. » (MEDD, 2003).

Griots and Ayral (2001) make an inventory of 17 definitions of vulnerability, which lead to split the vulnerability concept into two elementary notions: the notion of damage, consequences, losing level... and the notion of sensibility, susceptibility, weakness, predisposition... This last notion is also highlighted by Bogardi (2004, United Nations University), who underlines the “stochastic” nature of vulnerability.

In the seismic field, the European Macroseismic Scale used the vulnerability in the strict sense of the buildings strength: it “incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake generated shaking (vulnerability) has been employed in order to give a robust way of differentiating the way in which buildings may respond to earthquake shaking. The Vulnerability Table is an attempt to categorise in a manageable way the strength of structures, taking both building type and other factors into account. This is a development from previous scales, which used only construction type as an analogue of vulnerability. » (EMS, 98). Nevertheless, the seismic field has a strong foothold in the evolution of the vulnerability term. Recent studies show an increase of assessment of both social and material vulnerability. Balandier (2004) lists different kinds of elements at risk (urbanized areas, roads, networks, power plants, community facilities), which are relevant for social vulnerability.

Still in the seismic field, Teramo et al. (2005) introduce a methodology of urban and territorial seismic vulnerability related both to engineering studies and social priority levels. They first highlight the impossibility for administrations to plan suitable prevention interventions due to the use of usual approaches based on the building weakness and the earthquake loss estimate (as in the EMS 98 case). They identify different vulnerability related to three kinds of elements:

- the vulnerability related to the “morpho-typological characters of buildings” (as the EMS 98 vulnerability);

- the vulnerability related to “the collective or public system” (distribution of services, productive stakes, public buildings...);
- the vulnerability related to “the critical spatial elements” (streets, safety routes, strategic structures...).

Each vulnerability is assessed with two functions, which model the seismic weakness/reliability and the social or strategic priority levels within the system.

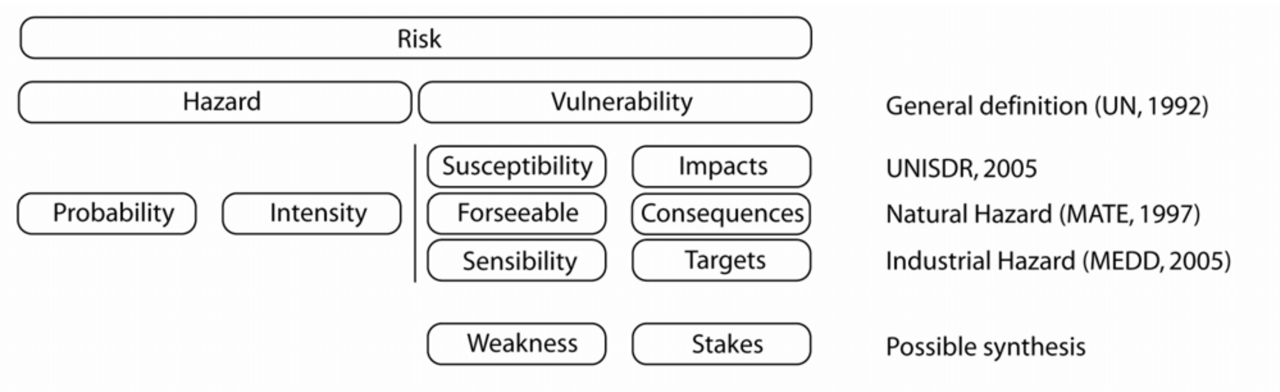

Figure 2: Synthesis of different definition for the Vulnerability term.

Studying vulnerability means to make the assessment of damage upon different kinds of stakes: human physical and psychological integrity, goods (buildings, roads, factories, properties...), economic (cost of reparations, decrease of activities, lost of stocks...), environmental (induced pollutions, ecosystems damage...)... The study of vulnerability requires identifying all the stakes, which may be damaged in case of natural phenomena or industrial accidents. But this step of the analysis is not sufficient to perform a real damage assessment since stakes may be damaged with varying level depending on accident intensity. For this reason, we choose a possible synthetic definition of vulnerability, which highlights the necessity to combine identification of stakes and the study of their weakness (Figure 2). This synthesis is in agreement with the vulnerability assessment methodology presented by Teramo et al. (2005).

On the basis of similar considerations, Bogardi (2004) still reveals uncertainties due to several points:

- the question of “how far should vulnerability be seen as the “susceptibility” alone or being rather the product of hazard exposure and that very susceptibility?”
- the question of the “proper scale (national, regional, community, household or individual) to capture and to quantify vulnerability”;
- the question of “whether (social) vulnerability can adequately be characterized without considering simultaneously the response (coping) capacity of the same social entity”

The first question can be clarified with help of the Figure 2 where the “weakness” is assumed to be quite similar to susceptibility. From a theoretical point of view, weakness of stakes may be dependant from the intensity of Hazard. Considering that this intensity may be very different, regarding to its probability, the study of vulnerability might lead to as many elementary studies as the number of various hazard intensities. Because of the number of studies that this theoretical point of view would lead, engineers used to make a single assessment of vulnerability and thus make the hypothesis of the independence of weakness and hazard intensity.

The second question is also considered by Balandier (2004) and highlights that a same risk element has not the same importance depending on the kind of hazard and the surface area (country, city, district...) because of their relative importance.

The last question refers to the "resilience" concept, which is largely discussed by Klein et al. (2003). On the basis of several definitions they suggest to restrict this term to describe:

- "the amount of disturbance a system can absorb and still remain within the same state or domain of attraction;
- the degree to which the system is capable of self organisation;
- the degree to which the system can build and increase the capacity for learning and adaptation."

In conclusion, the vulnerability term has many different meanings. The most important is then to clearly define the held meaning before any study. It is important to notice that the vulnerability is always a subjective concept, due to the number of different stakeholders, administration or insurance companies who have to support the consequences of hazard occurrences. The results of the vulnerability studies are then dependant on the end user.

4. Evolution of the vulnerability concept and its method of assessment in the iron-ore field between 1996 and 2005

4.1. The first hierarchy

In reaction to recent subsidences, in 1996 (Auboué), 1997 (Moutiers) and 1999 (Roncourt) and sinkholes in 1998 (Moyeuvre), public authorities ordered investigations to become aware of the extent of the problem.

Because of the lack of knowledge regarding to the subsidence phenomena, a first hierarchy was based upon two main considerations:

- the subsidence probability, through the value of the extraction ratio;
- the subsidence intensity, through the value of the maximal subsidence.

This first hierarchy was in agreement with the regulations of the French urban code (article R111-2 and R111-3). It defines three kinds of areas, depending on the maximal possible subsidence, and associates recommendations for building projects (Table 2; Kouniali, 2001).

Table 2: First hierarchy of risk in the iron-ore field and its associate recommendations.

Maximal subsidence < 1m	Surface of building < 400 m2, Maximal length < 25m, Number of floors ≤ ground floor + 3
Maximal subsidence < 2.5 m	Surface of building < 150 m2, Maximal length < 15m, Number of floors ≤ ground floor + 1
Maximal subsidence > 2.5 m	Forbidden

This first hierarchy is called step 1 in the **Erreur ! Source du renvoi introuvable.**. It mainly deals with urban side of vulnerability and was unsuitable for other side of vulnerability, especially human, social and economical.

4.2. The multicriteria hierarchy

Supplementary investigations were necessary to both go deeper into the hazard assessment and the human vulnerability assessment. Merad and al. (2004) developed a method, based upon a multicriteria analysis. Because of mathematical functions included in the method, it allows to manage with a « complex decision-making problem where the available information is uncertain and imprecise and where knowledge is incomplete » (Merad and al., 2004). This method uses weight factors for all criteria, which allow to highlight their relative importance in the risk assesment.

One of the main goals was to identify areas requiring specific surveillance because of the importance of existing stakes. This leads to the second step of **Erreur ! Source du renvoi introuvable.**, which deals with identifying stakes.

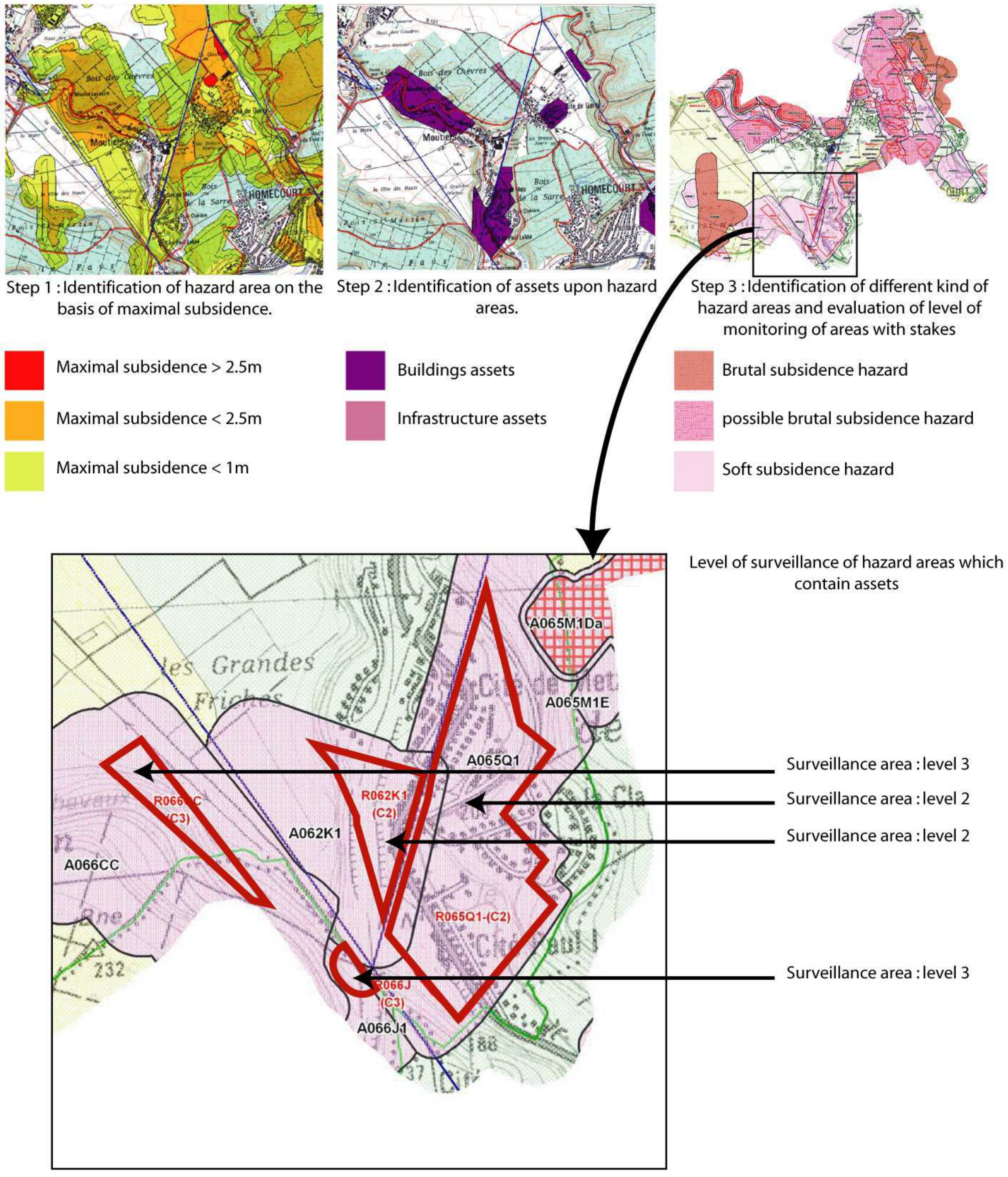

Figure 3 : Evolution of risk assessment in the iron-ore field.

Two kinds of stakes were identified: buildings stakes and infrastructure stakes. The Figure 4 shows the methodology used to determine the vulnerability of each kind of asset. In case of buildings stakes, no other stakes are taken into account. Buildings stakes are assessed through 5 levels from « business park » which induce a small vulnerability level because of its single daily activity to « city » which induce the strongest vulnerability level because of its both daily and nightly activities and because of the number of concerned people. This typology is mainly devoted to the population safety and to a lesser degree to the economic or structural vulnerability although those kinds of vulnerabilities are indirectly taken into account since they increase with the population numbers. The associated recommendations are listed in the Table 3.

The choice to distinguish between two kinds of stakes (buildings stakes and infrastructure stakes) shows a will to favour human vulnerability upon others kinds without an explicit weighting.

The weights linked with the probability, intensity and vulnerability criteria raise an important question connected with the previous definition of risk. If the risk is the outcome of hazard and vulnerability, do weight for each component have to be equals? In this case, weight of hazard reach a sum of 46 while vulnerability weight factors reach « only » between 2 and 14, depending on the stakes. This difference leads to results, which are more dependent on hazard than on vulnerability, that is focuses on prevention rather than crisis management

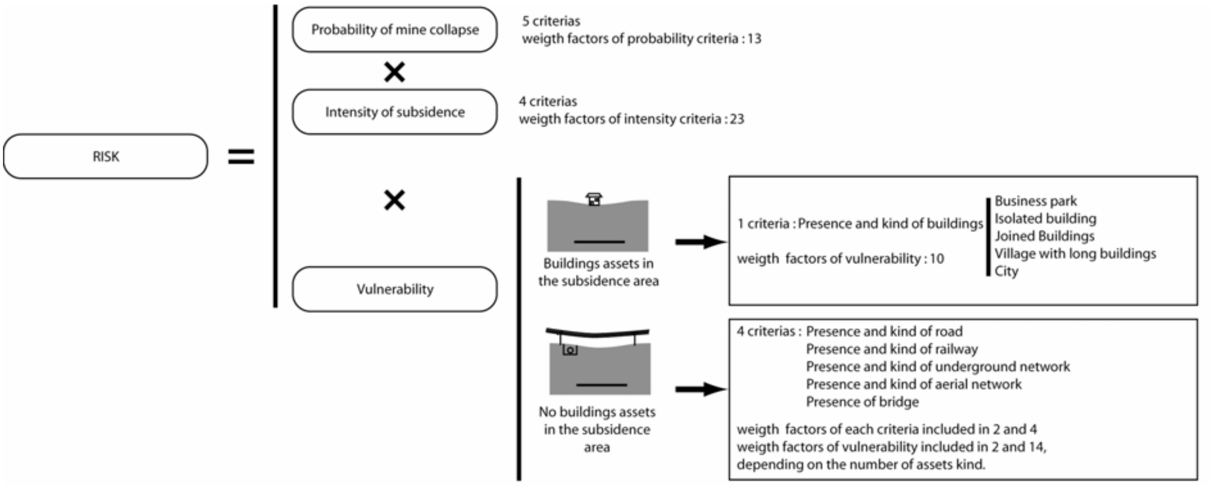

Figure 4: Description of criteria and weight factors used in the actual assessment of risk, hazard and vulnerability in the iron-ore field.

Table 3: Second hierarchy of risk in the iron-ore field and its associate recommendations.

Level 1 of surveillance area	Real-time monitoring.
Level 2 of surveillance area	Regular monitoring which will become a real-time one at the first forewarning.
Level 3 of surveillance area	Supplementary are required to assess the need of regular monitoring.
Level 4 of surveillance area	No monitoring is required. Levelling measurements are only made.

This methodology has been applied to constructed areas (civil security objective). An extension of the methodology has been applied to non urbanised areas in a perspective of land use planning

4.3. The Mining Risk Prevention Plan (MRPP)

The last step for the mining risk assessment and management is currently in completion stage. MRPP will provide a legal framework for all municipalities to both identify hazards and their current or foreseen stakes upon their territory. These plans aim to identify most sensitive areas with regards to risk development and establish rules for a proper management of territories according to post-mining constraints. MRPP are introduced by Didier (2005). They consist of four steps :

- Mining exploitation data collection and structuring ;
- Hazard assessment ;
- Stakes assessment ;

- Rules and regulations for existing and future constructions.

The “stakes assessment” step aims to identify all existing stakes within studied territories as well as possible future projects. It enables to identify threatened populations and most sensitive infrastructures. This step ends with a map of stakes. Several maps may be carried on to fit the goal of the study (civil security, land use planning…).

The MRPP framework is intended to be applied over potentially hazardous mining field. Its construction is based on the experience of already existing prevention plans for other hazards (flood, fire…). MRPP global methodology is the result of the experience of former REP (Risk Exposition Plan) that applied in 80’s. Within REP, vulnerability had to be assessed through an exhaustive study of susceptibilities. At the scale of a town, this task appeared to be too complex and long. This led to define MRPP methodology with a requirement for simplicity and quick results.

In Lorraine, MRPP will lead to a third hierarchy with no significant difference in term of vulnerability assessment compared to the previous one. More generally, the application of the MRPP will not give methods to asses the vulnerability. Consequently, the next part presents a possible improvement of the current method for a better assessment of vulnerability

5. Improvements for a better vulnerability assessment

In a report for the Ministry of Environment and Sustainable Development and for the Ministry of Industry, Economy and Finance, Deck (2003) suggested some evolution to improve the current taking into account of the vulnerability in the French iron ore field. These proposals take into account the further remarks about the previous sections:

- Before any vulnerability study, it is obviously necessary to define the meaning of the term vulnerability. In the case of the iron-ore field, we saw that the objective was both the safety of citizens and the mitigation of risk with the prescription of rules for new buildings. The studied area is the whole iron-ore field, which is composed of more than one hundred small cities and villages. The scale of this study is far greater than the town one. Proposals for a better assessment of the vulnerability need to be related to this scale. They must allow a better hierarchy of every urbanized area (small villages or districts) in comparison with one another and especially guarantee the homogeneity of the evaluation of towns vulnerabilities ;
- Previously presented hierarchies underestimate the societal consequences and do not take into account the “resilience”;
- Current hierarchy appears to give more importance to the hazard criteria than to the vulnerability ones (Figure 4). This situation is probably the reflection of the skills of experts who made this analysis. It is clear that the risk analysis is made by engineers, who are more keen on hazard concept than on the vulnerability one because of the number of its different dimensions: social, politic, economic... Giving exactly the same weight to vulnerability and hazard criteria comes from a theoretical point of view of the risk problematic. The increase of the vulnerability weight factors lead to direct safety measures towards vulnerable areas, although no certitude exist about the hazard occurrence. Conversely, a decrease of the vulnerability weight factors leads to limit safety measures to the highly probable hazard areas. The difference is equivalent to favour preventive cost or to favour compensation cost.

Proposals are synthesised on Figure 5 and discussed afterwards. They are mainly connected with the first two remarks.

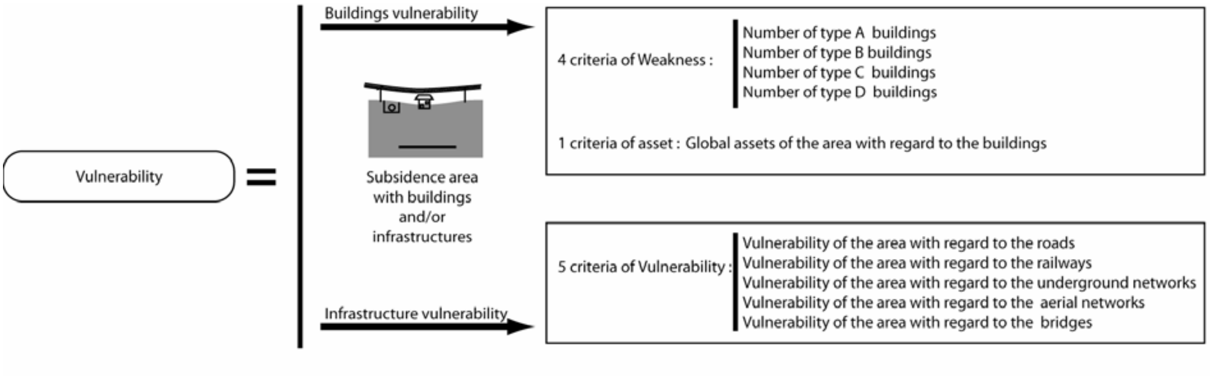

Figure 5: Propositions for a better assessment of the vulnerability in the iron-ore field.

For a more accurate vulnerability assessment, the every weak elements must simultaneously be considered into the analysis. In accordance with the section, which deals with literature, it may be useful to split vulnerability into different components.

For buildings, the current method assesses vulnerability through one criterion that identifies the nature of the building. We propose to split building vulnerability into two components: **weakness** and **stakes**. For networks, we choose to keep a single criterion but with a quite different definition than previously. These choices are in agreement with the problematic because most of urbanized areas are small one and previous subsidences show that buildings were the most critical constructions due to their weakness and stakes. Secondly, the use of explicit criteria for the weakness allows to consider results of the seismic field as a model for these criteria.

Figure 6 shows a classification of different kinds of buildings into four classes of **weakness**. This classification is modelled on the one used in the EMS 98. We based our proposal on statistical studies performed on the iron-ore damaged buildings (Deck, 2003) and on a architect study about the typology of buildings for one typical village in Lorraine.

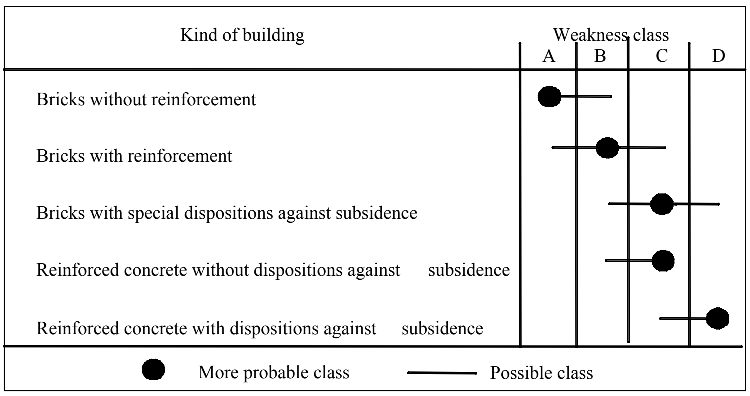

Figure 6 : Classification of buildings into 4 classes of weakness.

The Figure 6 can then be used to determine the number of buildings in each weakness class. This lead to consider 4 criteria to assess the weakness of buildings : number of class A, B, C and D buildings. These criteria are directly connected with the economic consequences of subsidence because the class A buildings will be more damaged than those of class B for similar subsidence phenomena. These four criteria are neither connected with social or environmental consequences dues to building damage, nor to the resilience.

For this reason, we define another criterion **(stakes),** which allows a qualitative assessment of stakes connected with building and to take into account the resilience, and mainly the degree to which the village is capable of self organisation. The Table 4 describes three possible levels for this criterion.

Table 4: Indicators of stakes connected with buildings.

Slight	Medium	Strong
Individual consequences due to a slight importance of stakes or a slight quantity of possible damaged buildings.	Collectives consequences due to a strong importance of stakes or a big quantity of possible damaged buildings. Consequences over the society running are possible (social and economic equilibrium).	Collectives consequences with possibility of series of accidents: In addition to the collectives consequences previously described, a possibility of a series of accidents exist due to the very strong importance of stakes (hospital, emergency services...) or because some problems are identified in the hazard area (chemical factories, petrol station...).

For the infrastructure vulnerability assessment, we choose to keep the same number of criteria (five) than for the current method, but with a different meaning in order to take into account both the weakness and the stakes asset. Because of the lowest importance of the infrastructure vulnerability compared to the building's one, and because of the necessity to keep a relevant method for risk assessment, it is necessary to synthesize weakness and asset assessment into a single vulnerability criterion for each of the five kinds of infrastructure (roads, railways, underground networks, aerial networks, bridges). Table 5 describes five possible levels for each of these five criteria. The reference to the scale of consequences follows the thesis of Zihri (2004). This evaluation way allows to integrate both the weakness, the stakes assets and the resilience concept seeing that the social, economical and political response of the community is required and then assessed.

Table 5: Indicators of damage levels due to the infrastructure weakness and stakes.

Null	Slight	Medium	Strong	Very Strong
No infrastructure in the area	Combination of weakness, stake asset and resiliance of the infrastructure lead to think that damage will only affect...			
	...a few people (individual consequences)	...people, economy, running of whole a village.	...people, economy, running of whole an administrative region.	...people, economy, running of whole a state or of administrative region of different states

The Table 6 shows a comparison for a theoretical area between the current method of vulnerability assessment and the proposed one. On the basis of one area with 50 buildings, 1 main road, 2 shops, with no possibility to rehouse people for less than 10 Km and with a public debate and many information given to population about the risk of subsidence.

Table 6 : A exemple of comparaison between the currently method of vulnerability assessment and the proposal one

Current method		Proposal method	
1 criterion for building vulnerability	The whole area is classed as village one	4 criteria for building weakness	The four criteria of building weakness allow the assessment of possible economic damage : 5 buildings in class A 15 buildings in class B 22 buildings in class C 8 buildings in class D
		1 criterion for building stakes	Medium value of stakes connected with buildings due to the important number of concerned buildings and due to the difficulty to rehouse people.
5 criteria for infrastructure vulnerability	The 5 vulnerability criteria of infrastructures (bridge, road, railway, aerial netwok, underground	5 criteria for infrastructure vulnerability	Medium value for road infrastructure vulnerability. Null values for railway and bridge infrastructure

	network) are not taken into account because of the presence of buildings.		vulnerability because there is no such infrastructure. Sligth values for aerial and underground network because few of them might be damaged

6. Conclusion

The study of vulnerability with the prospect of risk assessment appears to be sensitive because of the gap between the social expectations and the difficulty to formalize a coherent and unbiased methodology.

A bibliographic approach allows to identify different concepts, which may be included in the vulnerability term. We choose to split this term into two elementary components: the weakness and the stakes. The weakness allows to characterize the possible structural damage to physical elements like buildings and infrastructures. The weakness is directly connected to the economic loss due to reparations. The stakes allow to characterize the importance of other damage due to the social, economical, civil... use of the damaged physical element.

Both of these two components are really subjective. Several preliminary considerations are necessary to precise the meaning of the vulnerability before using it in a risk assessment study.

- What is the scale of the study (national, regional, community...)?
- What is the balance between the weight factors for hazard criteria and for vulnerability criteria? An upper weight factor for vulnerability leads to favour civil protection, an upper weight factor for hazard leads to favour land use planning.
- Does the social vulnerability have to be taken into account? In this case, the concept of resilience need to be incorporated in the analysis. Improvements suggested for the vulnerability assessment in the iron-ore field show a pragmatic but subjective way to take into account the resilience concept. Nevertheless, It is necessary to be very cautious with this resilience assessment method because this term and its proper meaning is still uncertain.

These questions need to be answered before any vulnerability study. They all refer to the question of who is the end user and what does he want to do with the result? Much confusion may be raised because of an inappropriate use of vulnerability assessment study : some of its aspect may be relevant for one objective or one kind of end-user but not for other ones. In a single hazard area, the vulnerability will be very different for one citizen with an individual worry, for the municipality with collective worry or for the insurance companies with business worries.

The case of the Lorraine iron-ore field reveals the complexity of the vulnerability assessment, which may need several consecutive studies to go deeper in the analysis with the increase of stakes and knowledge about the present hazard. A consequence of these consecutive studies is the evolution of the hierarchy and the necessity to explain it both to citizens and end-users. This highlights the necessity to clarify the objectives of the study, so that results should not be interpreted in a different way than the expected one.

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