Dealing with uncertainties in the context of post mining hazard evaluation

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DEALING WITH UNCERTAINTIES IN THE CONTEXT OF POST MINING HAZARD EVALUATION

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ABSTRACT: Risk analyses related to a past mining activity are generally performed in a strong context in uncertainties. A PhD Thesis has been undertaken in 2004 in order to draw up solutions to take into account these uncertainties in the practice. The possibility of elaborating a more quantified evaluation of risk has also been discussed, and in particular the contribution that probabilistic methods may brought to an analysis. This paper summarizes the main results of the Thesis. It particularly highlights the benefits that certain tools that have been developed may have regarding the process of expertise.

KEYWORDS: Uncertainties, Risk analysis, Probabilities.

RÉSUMÉ : Les analyses de risques liés à l'Après-mine s'ancrent généralement dans un contexte fort en incertitudes. Une thèse de doctorat a alors été entreprise en 2004 de manière à proposer des solutions permettant de prendre en compte ces incertitudes et de développer une évaluation plus quantifiée de l'aléa qu'elle ne l'est aujourd'hui, au travers notamment d'une approche probabiliste. Cet article résume les principaux apports du travail de thèse. Il insiste particulièrement sur certains outils mis au point qui permettent d'apporter une réelle aide au processus d'expertise.

MOTS-CLEFS : Incertitudes, Analyse de risque, Probabilités.

1. Introduction

Closing down mining operations has not eliminated all the risks likely to affect surface land within the geographical limits of old underground workings. Damages (surface instabilities, surface flooding, gas emission, severe environmental impacts, etc.) may indeed develop, sometimes as soon as work has ceased but also much later.

In such a context where public safety and infrastructures are at stake, *risk analysis* procedures are generally undertaken in order to study, post and manage the underground issues. In a post mining context, and more widely in the large field of rock mechanics, those *risk analyses* strongly lay on the geotechnical expert and on his experience. This characteristic is not without raising some difficulties. As he studies natural objects that are often non homogeneous, fractured, discontinuous, and so on, and because science on the topic is unachieved, the expert has to work in a context of important doubt and uncertainty.

It appears today that methods and tools that had been developed by the geotechnical expert, suffer from not bringing answers that would really allow seizing this context of uncertainty. Only few indirect methods, as the use of safety margins or of partial safety factors, allow to integrate the doubt existing of the result of any risk analysis but they remain highly insufficient. The methods and tools developed by the geotechnical expert also suffer from not being able to lead to a real quantification of the hazards related to underground issues and of their probability of occurrence.

However, a probabilistic expression of risk would perfectly fit the current statutory context, in which demands of quantification and better posting of risk issues are numerous.

In such a context, a PhD Thesis began in 2004 at the LAEGO laboratory in collaboration with the INERIS institute and the Lorraine regional Council (Cauvin, 2007). This paper will present several important results that have been obtained within the framework of this Thesis.

2. The notion of uncertainty in the context of the elaboration of a risk analysis

Before trying to deal with the uncertainty that must be faced in any risk analyses, or even to reduce it, the notion of uncertainty itself has first to be clearly introduced. This notion is defined in the framework of the Thesis as *the vagueness existing about the result of a risk analysis and which is due to the vagueness about all the parameters intervening in the process of that analysis*. The *parameters* being mentioned are identified to be the "global resources" of the study, the "expert" in charge of the analysis, the "models" used to represent the different parts of the system he studies and the "data" provided to the analysis. Those *parameters* are of very different natures. However, they own the particularity to be closely linked to each others.

The definition of "uncertainty" that is proposed might appear very general. Such a choice is however perfectly justified. The real aim of the work is indeed to allow operational solutions to be given to concrete problems. There is also a clear will in that definition to go further than a linguistic and restricted debate. The given definition thus integrates the different concepts of vagueness, variability, randomness, imprecision, indecision, subjectivity, lack of knowledge, etc. that all can have important consequences on the result of an analysis.

Using the proposed definition, the notion of uncertainty has been divided in four classes (figure 1). The so-called established *typology of uncertainty* has been built in order to reach three objectives: 1) to post the various sources of uncertainty that may be faced by the expert in an analysis, 2) to adapt to the process of realisation of a risk analysis, and more especially to the strong links existing between the *parameters* such as previously described, and 3) to allow an operational integration – and whereas possible a reduction – of uncertainties into the study.

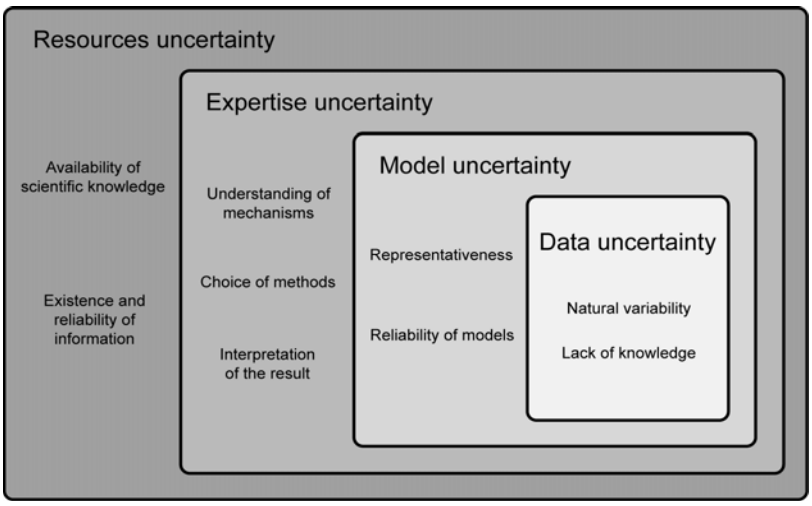

Figure 1. Typology of uncertainty (Cauvin, 2007)

"Resources uncertainties" deal with the knowledge about both the general scientific context of the study and its local particularities. More especially, it concerns the *existence of information* about the processes being investigated and the objects being studied. "Expertise uncertainty" concerns all the choices, actions or decisions that can be made by the expert while realizing the study. It mainly relies on his particular *experience* as an individual, on his subjectivity and on the way he represents and interprets the information he has gathered. “Model uncertainty” is basically induced by the use of *tools* to represent the reality. Finally, “data uncertainty” represents both the natural variability existing on data, the lack of knowledge about their exact values and the difficulty to clearly evaluate them. It is indeed particularly linked with the notion of *value* of a parameter. Concrete illustrations of those different types of uncertainty may be found in the Thesis.

Once the uncertainties he can face in his daily work are classified using the drawn-up typology, the expert must try to integrate them into his analysis. A “toolbox” has therefore been provided in the Thesis in which he will find operational solutions to help him to take into account the different categories of uncertainty (table 1). Most of the methods detailed in that toolbox have been gathered from a literature survey and their advantages and drawbacks are discussed in the Thesis.

Table 1. Several methods to deal with uncertainty, depending on the type of uncertainty

Type of uncertainty	Strategy and remarks		References and examples
Data	Use of safety margins	* deal with the problem of assessing the exact value or localisation of a parameter * qualitative method	Dejean (1981) Favre et al. (1998) Tritsch (2004)
	Use of probability functions	* deal with the problem of assessing the exact value or localisation of a parameter * quantitative method	Kim and Gao (1995) Duncan (1999) Favre (2004)
Model	Comparison between model outputs and reality	* deal with problems related with vagueness and reliability of models	Azzouz et al. (1983)
	Use of safety margins	* deal globally with problems related with vagueness of models and data * qualitative method	Favre et al. (1998)
	Integration of various models into the analysis	* deal with problems related with vagueness and reliability of models * method elaborated in the framework of the Thesis	Cauvin (2007)
Expertise	Comparison between outputs of various models	* allow a posting of uncertainty	Husein Malkawi et al. (2000)
	Use of a decision-aid approach	* allow to homogenise the expertise process	Merad (2003)
	Use of countervaluation	* limit the subjectivity that may be induced when a single expert realises the analysis	GEODERIS (2003)
	Use of technical methodological guides	* help expert in providing a wider overview of methods	INERIS (2004)
Resources	‘*as if*’ strategy	* take into account the doubt about the existence of a source of danger * implicit safety margins	
	Index of existence	* take quantitatively into account the doubt about the existence of a source of danger * method elaborated in the framework of the Thesis	Cauvin (2007)

Some specific solutions have also been developed in the framework of the Thesis when lacks in the existing methods were identified. The *index of existence* in particular appears as a powerful tool that makes it possible to deal with the problem of uncertainty related to the existence of the underground workings (figure 2). It allows to indicate how confident the expert is about the fact that a source of danger really exists at a given place. This tool may perfectly complete risk analyses as they are currently performed as it would allow a better communication of the results with the Authorities or the population (Cauvin et al., 2006).

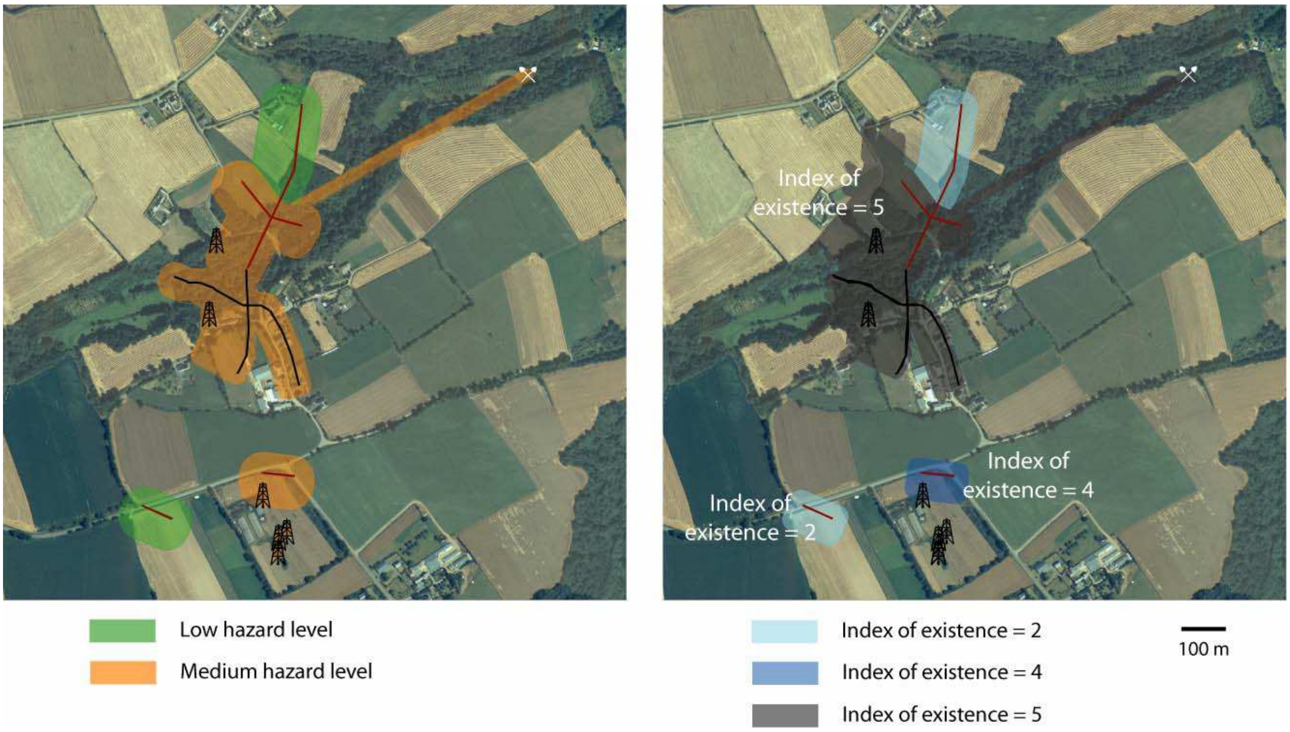

Figure 2. The *index of existence* as an excellent complement of hazard maps

When a concrete integration of uncertainty into the analysis (via a quantification for example) is not possible, the *confrontation* can be an excellent way of taking it into account. A comparison between the results induced by such or such choice, between the use of such or such tool, can thus make it possible to illustrate the influence that certain uncertainties can have in the analyses.

However, in practice, the real choice of the methods used to take into account uncertainty in an analysis strongly relies on the characterization of the whole uncertainties that are present into the analysis. The close links between the various categories of the typology actually induce these important methodological choices. An efficient method to reduce a certain type of uncertainty will therefore not be very interesting with respect to the final result of the analysis if the other types are not also taken into account. As a consequence of that remark, a qualitative treatment of uncertainty will appear particularly adapted to studies where uncertainties in the resources play an important rule.

3. The use of probabilities in risk analyses

Probabilities appear as excellent tools to manage some categories of the established typology of uncertainties. Data uncertainty, for example, can be considered and incorporated into the studies in describing parameters as probabilistic distribution functions.

In the framework of the Thesis, an original and innovative methodology was developed in order to face uncertainties related to the choice and the use of models to evaluate values of different parameters. More precisely this method allows to integrate (1) the existence of several models to represent a single feature, (2) the fact that each model combines the input data in a certain manner and that it only allows to approach reality in an approximate way, (3) the vagueness of the parameters that calibrate models, and (4) the vagueness of input data that are integrated in models. This methodology thus appears as an efficient way to integrate some expert (1), model (2 and 3) and data (4) uncertainties. It basically consists in performing Monte Carlo simulations in which data as well as models are considered as random values. The practical use of that methodology makes it possible to identify the most important sources of uncertainty present in the study and thus to help the geotechnical expert to reduce them (figure 3).

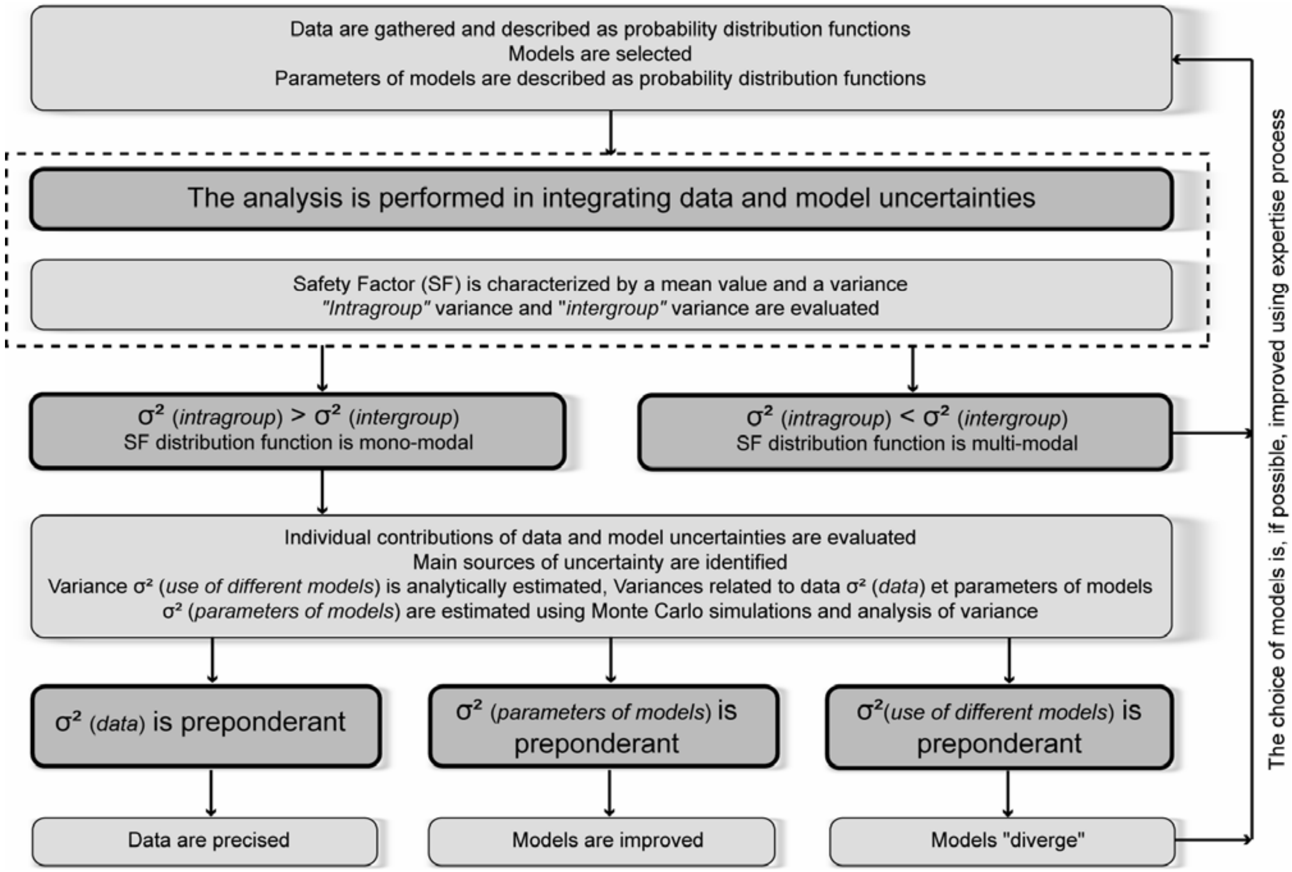

Figure 3. Methodology for a probabilistic integration of different sources of uncertainties into a risk analysis (Cauvin, 2007)

The use of probabilities in risk analyses must however be performed with a lot of vigilance. Probabilistic results may indeed be interpreted according to two different approaches. The *frequentist approach* considers probabilities as a limit of frequency. Its practical implication for the expert is that it makes it possible to indicate how frequent (over space or over time) a given phenomenon may be. On the contrary, the *epistemic approach* considers probabilities as a tool to express the lack of knowledge about a particular value. In that case, the scattering of the probability distribution function illustrates the part of the doubt existing on the parameter of concern.

In practice, each distribution function that allows characterizing the uncertainty existing on a parameter of a risk analysis generally integrates these two approaches. The scattering of the dimensions of pillars in a large mining panel can, for example, be explained partly by natural – here spatial – variability (the mining extraction process induced the fact that all pillars do not have exactly the same shape) and partly by lack of knowledge (data are not sufficient enough to evaluate precisely the modes of the probabilistic distribution of the dimensions of pillars).

Assumptions on the nature of the uncertainty of every *parameter* of the study are therefore prevailing towards the concrete meaning of the probabilistic result of an analysis. If spatial variability is preponderant in the problem, the interpretation of the result as a “spatial frequency” will appear to be possible. The likelihood that a hazard occurs at a given place could then be quantified. Figure 4 presents for example a map illustrating the frequency of sinkholes that may be expected at a given place above an old gypsum mine. This map has been obtained in combining Monte Carlo simulations to geometrical and mechanical models. The probabilistic values may be interpreted as: "*we can expect that between n_{min} and n_{max} sinkholes will occur about every 100 crossroads in an homogeneously coloured area*".

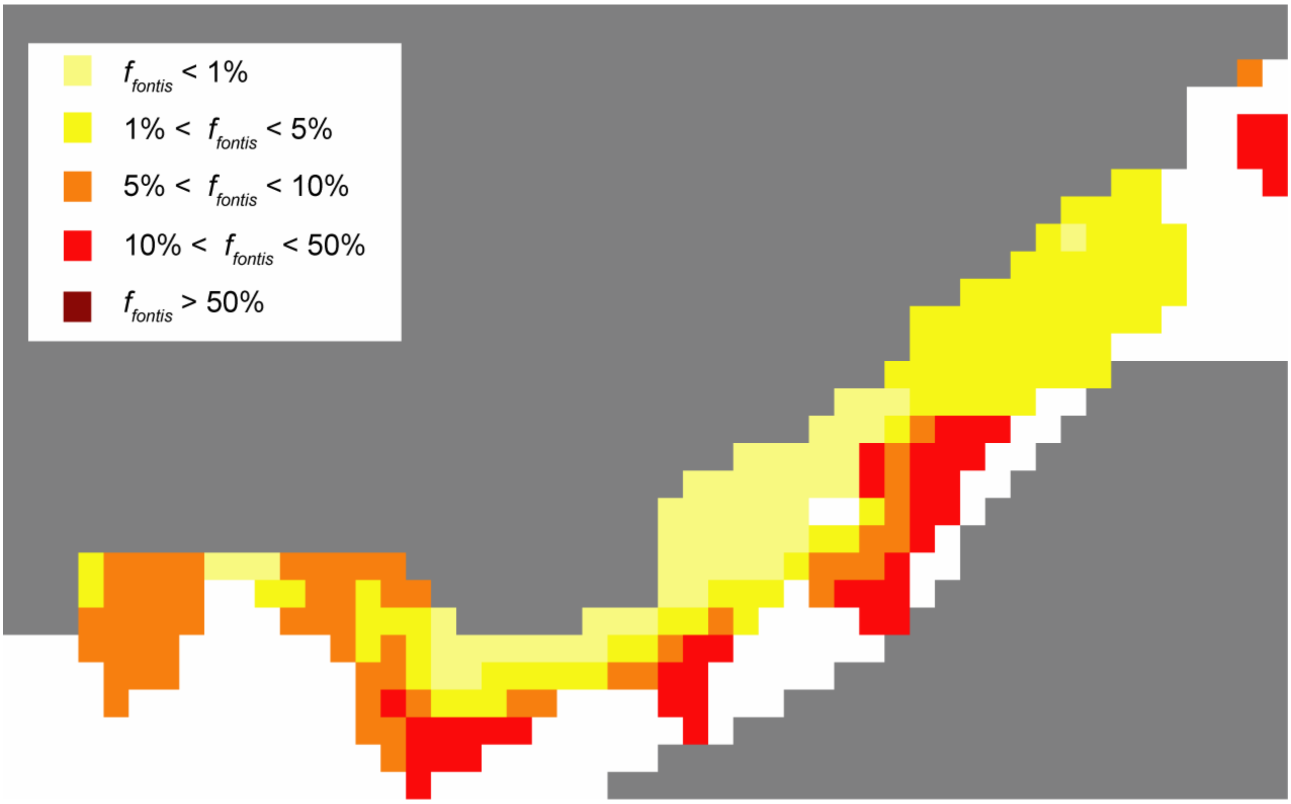

Figure 4. Probabilistic hazard map for sinkhole occurrences above an old gypsum mine (Cauvin, 2007)

Even though the obtained results allow to improve the posting of a hazard in a spatial point of view, the integration of time in the analysis still appears to be difficult. The evaluation of the probability that an event occurs at a given location during a given period of time, that is the definition of "hazard", is therefore not yet possible.

Only few works exist in the scientific literature about the integration of time in the natural risk analyses. They can basically be divided in two groups. On the one hand, some works use database in order to forecast what may occur in the future from what occurred in the past (van Besien and Rockaway (1988), Carter and Miller (1996)). On the other hand, some works focus on integrating empirically the time dimension in the mechanical models of failure, through for example the reduction of the strength properties of a rock body or of its geometrical dimensions (Kemeny (2003), van der Merwe (2003)). Even if the general philosophy of those methods is different, they both remain closely linked to the quality of the database that allows either to build the temporal model or to calibrate the mechanical one.

The integration of the time component into the analyses is nevertheless very important as it would allow a better management of risk. A methodology to evaluate the temporal occurrence of surface collapse events in large undermined areas is proposed in the Thesis and is illustrated and discussed for the mechanism of sinkholes (figure 5). The methodology basically consists in (1) performing a literature survey in order to identify the most important parameters to take into account in the problem and (2) sketching a mathematical model to represent the main trend of the evolution. Back-analyses using collapse events inventories may then be realized in order to calibrate the model and to adapt it to specific undermined sites.

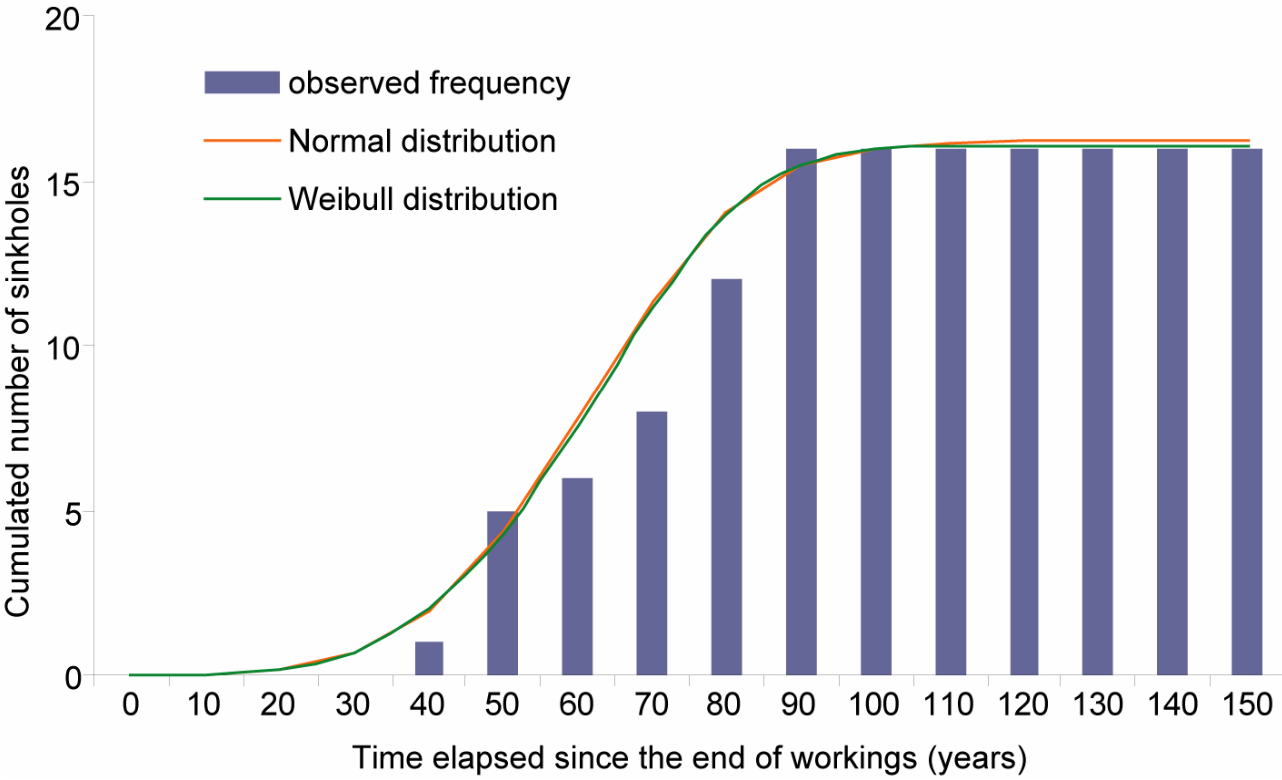

Figure 5. Adjustment of a general model for assessing the evolution of sinkhole occurrences over time to in site data

Such a work has to be seen as a first step towards the integration of time in post mining hazard analyses. It constitutes a way to reduce “resources” uncertainties due to the lack of knowledge of the expert about the real evolution of rock failure over time. This work however raises a problem of “model” uncertainties as model parameters appear difficult to be calibrated. It thus highlights the necessity of systematically developing database of events that occurred in the past. That would allow, through back-analyses for example, to improve the global knowledge about the mechanisms at stake.

4. Main conclusions

The work undertaken in the Thesis and that has been illustrated on several cases of application has arisen the fact that probabilities can constitute a powerful tool allowing to take into account uncertainties that may be encountered in a technical study. Probabilities may thus provide a real help to an expert while his following of to the process of realization of a risk analysis. They can accompany him throughout his work in insisting on particularly problematic points and, if necessary, in bringing solutions for the concrete integration of those difficulties. Moreover their adaptation to the currents methods of analysis seems possible and relatively easy to be put into practice.

Besides being a powerful expertise-aid tool, the integration of uncertainties and the use of probabilities in the studies also constitute a solution for a better risk management. The geotechnical expert has indeed the vocation of transmitting the results of his risk assessment to decision makers or to the population being concerned. The communication between the various actors involved in risk management therefore appears as a key for a good analysis. Results have to be understandable and exploitable by people whose technical and scientific culture is sometimes very different. While taking into account uncertainties in his study, the geotechnical expert may then highlight his own limits and the lack of resources he has, but he may also insist on the efforts he undertakes to reduce them. That "popularisation" of the expertise process and of the difficulties that an expert may face then constitutes a first step towards a real dialogue between the various partners of risk management. The decision following the risk assessment will thus be in that case really concerted.

An interesting prospective of the Thesis would be then to make a study in which various actors (expert, the authorities, population concerned, insurance companies, etc) would be integrated from the beginning of the work and would have presented their real expectations so that a concerted answer is obtained.

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