FUZZY LOGIC IN ENGINEERING SEISMOLOGY PROBLEMS

V.B. Zaalishvili, A.B. Lolaev & B.A. Dzeboev
Center of Geophysical Investigations of VSC RAS & RNO-A, Vladikavkaz, Russian Federation

SUMMARY:
The new approach for reception and processing of the geological information based on fuzzy modeling is offered. The technique and methodology of presentation of variables in a logic and linguistic way in a combination to elements of the experimental planning theory is developed. The results of site investigation of the several building sites, data of calculations, as well as the results of valuation of seismic zoning as a whole based on experimental and mathematical methods are submitted. Comparison of the calculated data on model has shown its high adequacy of the experimental data of the various authors. The forecast of seismic processes in-situ on the basis of described method will allow to increase reliability of the accepted design decisions.

Keywords: fuzzy logic, soils, seismic intensity

1. INTRODUCTION

Analyzing results of the majority of tasks in ge-otechnical earthquake engineering, it is necessary to note, that they should be solved in conditions of uncertainty of the initial information, especially at forecasting of seismic activity.
The fuzziness in geophysics arises, first, be-cause of attempts to characterize the difficult versatile phenomenon or process by some quantitative characteristic reflecting it fairly relative, and, secondly, because of a vagueness of expert opinions and judgments that explains the relevance of using a fuzzy approach in geophysics because fuzzy mathematics is the device that most adequately takes into account the imprecision of data and qualitative character of experts opinion (Agayan, et al., 2005).
The analysis made in the works (Gvishiani, et al., 2003; Gvishiani et al., 2004; Zlotnicki et al., 2005) of monitoring data of geoelectric potential of La Fournaise volcano on Reunion Island - based on fuzzy logic algorithms has demonstrated the possibility of sustainable allocation in such a way abnormal areas of records (more than 95 % of signals, previously identified by the expert).
In the work (Agayan, et al 2005) the morphology of the signal on the basis of algorithms of the fuzzy logic is investigated, which allows to recommend the proposed algorithms for the analysis of complex real signals. In the work of (Klyachko, 2007) the information on the application of the theory of “fuzzy images” for assessing the vulnerability of buildings in seismically active regions is being given.
For this day a few techniques for a rating estimation of territory have been created. Some of them are applied to the territories of the cities of Vladikavkaz (Zaalishvili, et al., 2006a) and Tbilisi (Zaalishvili, et al., 2006б). The development of similar techniques is connected with a lot of difficulties both objective, and subjective in character. As a rule, it always requires a large number of various measurements, which entails both time and material costs. In addition, the final estimation at rating assessment of the territory is obtained by the simple summation of influencing factors and that do not take into account their interference. And that finally affects the accu-racy of estimation.
The new approach based on fuzzy modeling for reception and processing of the geological information is offered. The technique and methodology of presentation of variables in a logic and linguistic way in a combination to elements of the experimental planning theory is developed.

The proposed technique for territory rating can be called simultaneously the technique that estimates the increment of seismic intensity area, since both estimates of the number of points coincide. Further we shall use the term “increment of intensity”.

2. THE REASONS OF UNCERTAINTY OF INITIAL INFORMATION

The kinds of the reasons of uncertainty can be submitted as a tree (Lolaev 1998).
The top level of this tree is formed by the main reasons describing quantity (amount) of the absent information of problem elements (Fig. 1). The uncertainty of the information is defined (determined) by three components:
- By complexity of a structure of an earth massive as object of researches;
- By incompleteness of knowledge about a condition of a soils massive both on a separate site, and as a whole, that is connected with insufficiency definiteness of our knowledge;
- By illegibility of a situation, that is connected to absence of exact borders of areas of definitions or variables.

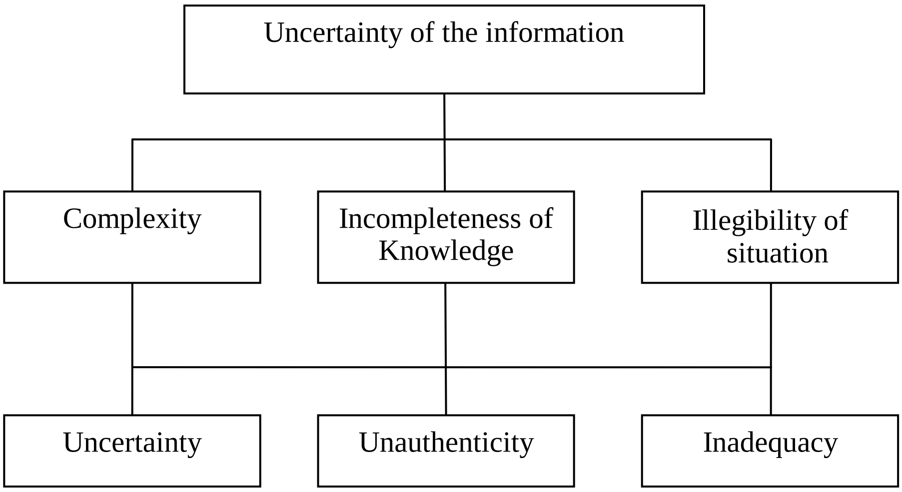

Figure 1. Classification of the reasons of uncertainty

The second level of a tree specifies the general reasons of uncertainty of the information in the field of researches:
- Uncertainty. In a situation of uncertainty, for example, at the first stages of study of a task, when the requirements to criteria of an estimation are not produced yet. When the requirements of the customer or opportunity of the executor are unknown, and also, when the information on a problem is practically absent.
- Unauthenticity. At data gathering at the first stage of researches can appear, that the assembled information has unauthenticity, as there are yet not all possible and necessary items of information, and for some elements not their unequivocal descriptions are determined, and we have only sets, to which these descriptions belong;
- Inadequacy. Inadequacy is a measure of an estimation of a degree of knowledge, in-formation, model etc. about the given phenomenon and opportunity of application them in practice. Thus the development of criteria of an estimation of adequacy and the methodology of it application is essential.

The continuation of researches should results either in the adequate description of the phenomena by models, or inadequate, when all possible information is gathered, but complete description is not present or it cannot be received by this way.
The mathematical approach of usual sets, used for the analysis, enables detailed prediction of process, and may lead to enhanced understanding of the operating system. In some instances, such detail is essential to adequately describe the processes occurring, and to achieve sufficiently accurate results.

However, it may be argued that in many cases, the inevitable requirement for high quality data and long term monitoring is not justified, either technically or financially (Plimmer 1996). The problem can be solved by using the theory of fuzzy models of logic and linguistic ones in particular.

3. FUZZY MODELLING METHODOLOGY

Use of linguistic variables (LV) is characteristic for the human activity connected to approached analysis. At creation of system, which simulates such activity, it is required to create mathematical models allowing, on the one hand representing these variables, with another - to use untraditional methods for their processing. At the same time the qualified experts reasonably precisely predict the behavior of complex systems. From this it follows that the model of a system has already existed in its consciousness as a rule only in a partially formalized kind. The similar forecasts are as a rule formulated by the expert in the fuzzy form formalized with difficulties. However it should be noted that there is the approach based on the Zadeh's fuzzy sets theory enabling to present fuzzy statements of the expert by the standard mathematical language in a kind linguistic variable (Zadeh, 1975, 1981). It should be mentioned that the application of traditional methods of extraction of knowledge of the expert comes across a number of obstacles of conceptual character:

- interdependence of the input source factors and hence infringement of the main preconditions of the regression analysis that makes problematic application of statistical methods;
- a large number of questions to the expert causes his moral and physical fatigue and increases a number of made errors;
- the adequacy of these models does not yield valuation.

To overcome all these difficulties the authors proved (Drozdov and Spesivtsev, 1994) the possibility to use the theory of planning of experiment for fuzzy sets, and formulate criterion of adequacy of received models.

As a rule it is more convenient for any expert to present knowledge in a kind of cause and effect connections, such as: ***"If ... differently (otherwise)"***. The authors have offered an orthogonal arrangement of productions in the factor space of input linguistic variables determined by the expert. The similar arrangement of productions naturally corresponds to its perception because it is difficult to define a degree of their interrelation. Orthogonality also helps experts by choosing the data which are edges of scales of input variables and this actually corresponds to the concept of Osgud's scale (Lorensen, 1957).

The algorithm of construction of fuzzy model with use of linguistic variables looks as follows:

1. Definition of factor's space of the investigated phenomenon;
2. Delimitation of opposite scale and terms under each factor;
3. Preparation of a matrix of interrogation;
4. Coding of the factors - LV (translation in to the metrics);
5. Account of polynomial factors using the method of the least squares;

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{u,j=1}^{n} \beta_{ju} X_j X_u , \qquad (3.1)$$

where $j \neq u$

6. Estimation of a mistake of numerical experiment;
7. Estimation of the importance of polynomial factors;
8. Estimation of polynomial adequacy to an expert estimation of the investigated phenomenon;
9. Estimation of adequacy of the received model to the investigated phenomenon;

The algorithm of construction of adequate forecasting model is submitted on Figure 2.

As the explanatory to algorithm of forecasting model construction we shall note, that the definition of factor's space includes:

- definition of the maximum number of the influencing factors;

- allocation of the essentially influencing factors;
- choice of linear - independent and controlled factors.

The delimitation of opposition scale includes:

- definition of quantitative estimation of the bottom and top borders of the chosen factor - LV;
- definition of quantity of divisions (term - sets) of splitting of a scale and their names;
- definition of a degree of illegibility of concept.

The preparation of a matrix of interrogation of the expert is carried out according to methods of the theory of experiment planning.

The coding of the factors - LV consists in transformation of the names of terms scale in the metrics on an interval [-1, + 1].

The account of polynomial factors consists in translation of dependent LV (Y) in a precise scale and performance of traditional actions with a matrix of interrogation accepted in the theory of experiment planning.

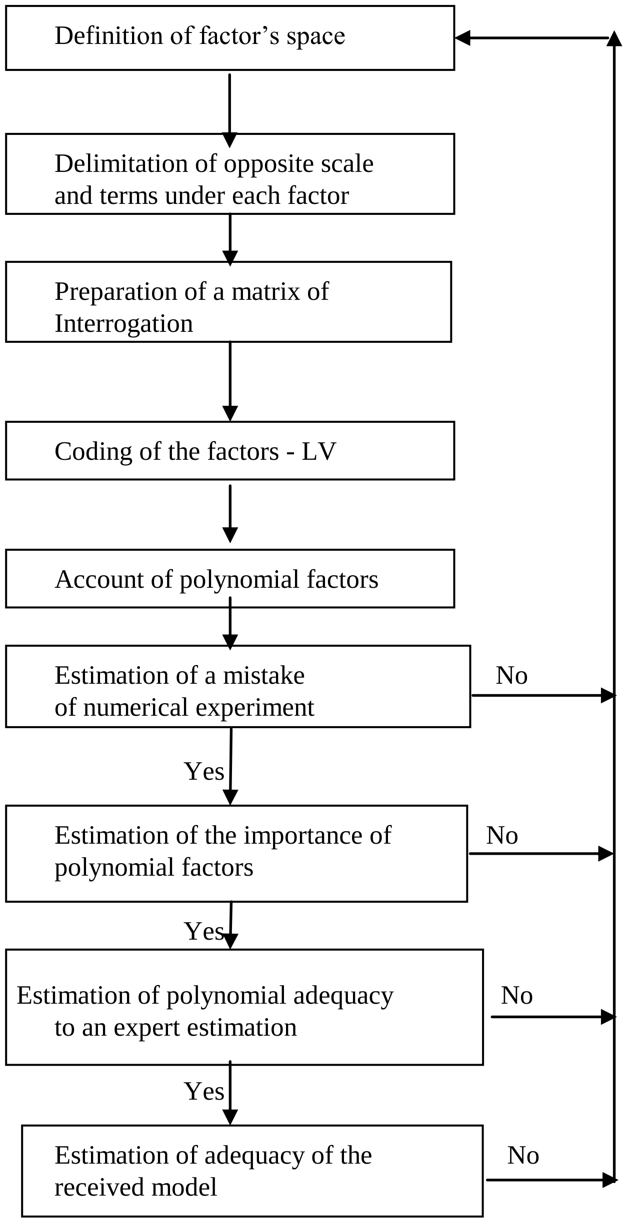

Figure 2. Algorithms of construction of forecasting model

The estimation of a mistake of numerical experiment originally consists in comparison of meaning of the polynomial's free member b_0 with an estimation of opinion of the expert at the centre of planning of factor's space of the investigated phenomenon.
The estimation of the importance of polynomial's coefficients consists in exception of those coefficients, which meaning is lower than a mistake of their definition on t - Student's criterion.
The estimation of polynomial's adequacy with important coefficients to an expert estimation of the investigated phenomenon consists in comparison of calculated polynomial factors and expert estimation among themselves (and also on algorithm "necessity - opportunity" - NEC - POS);
The estimation of adequacy of the received model to the investigated phenomenon consists in comparison of calculated and experimental data by traditional statistical methods.

4. TEST RESULTS AND DISCUSSION

The developed technique and algorithm of construction of forecasting model were used at modeling of the increment of the seismic point of territory.
Five input linguistic variables were chosen for describing of the increment of the seismic point of territory. In a fuzzy kind variables are coded as follows:
X_1 is the type of coarse-grained soil depending of there origin and determined as: $X_1 = -1$ for soils of sedimentary origin soils, $X_1 = 0$ for soils of metamorphic origin and $X_1 = +1$ for soils of igneous origin
X_2 is the density of soils and determined as: $X_2 = -1$ for porous soils, $X_2 = 0$ for medium density soils, and $X_2 = +1$ for compact soils.
X_3 is the moisture content of soils and determined as: $X_3 = -1$ for low moisture saturated soils, $X_3 = 0$ for wet soils, $X_3 = +1$ for moisture saturated soils.
X_4 is determined as the angle of slope in degrees and determined as:

$$X_4 = [X_{4(fact)} - X_{4(aver)}] / X_{4(aver)}, \qquad (4.1)$$

where X_{aver} - is the average angle of slope , degrees; $X_{fact\,-}$ is the current meaning of angle of slope, degrees.
X_5 is determined as the amount of the sandy-clay aggregation and determined as: $X_5 = -1$ for soils with sandy-clay aggregation more than 50 %, $X_5 = 0$ for soils with sandy-clay aggregation about 40 %, $X_5 = +1$ - for soils with sandy-clay aggregation less than 30 %,.
Y - is the increment of the seismic point of territory, points.
The variables are shown in Figure 2.
Matrix of interrogation in a kind of complete factor experiment of 2^5 type submitted in the form of extreme significances of input linguistic variables was generated. The results of the interrogation were processed in a coded kind. The developed method of coding and processing was carried out in (Drozdov and Spesivtsev, 1994).
The resulting equation in a coded kind was found as:

$$Y = -0{,}055\, X_1 - 0{,}227\, X_2 + 0{,}289\, X_3 + 0{,}414\, X_4 - 0{,}164\, X_5 - 0{,}008\, X_1X_2X_3 + 0.008\, X_1X_3X_4 - \\ - 0.008\, X_1X_4X_5 - 0.008\, X_1X_2X_4 + 0.008\, X_1X_2X_5 - 0.008\, X_1X_3X_5 + 0.023\, X_2X_3X_4 - \\ - 0.023\, {}_2X_4X_5 + 0.023\, X_3X_4X_5 - 0.023\, X_2X_3X_5 + 0.008X_2X_3X_4X_5 \qquad (4.2)$$

Only substantial coefficients are presented in the equation (valuation of an error has made 0.1 at a level of the substantiality of 0.05).
It should be noted, that the equation (2) has obviously a non-linear character. Even the threefold interactions having a physical sense proved to be significant. For example: $X_2*X_3*X_4$ - it is possibly interpreted as the characteristic of complex influence of the density of soil, moisture content and the angle of slope on its increment of the seismic point of territory; $X_3*X_4*X_5$ - is a parameter of complex influence of moisture content, the angle of slope and the amount of the sandy-clay aggregation on its increment of the seismic point of territory.

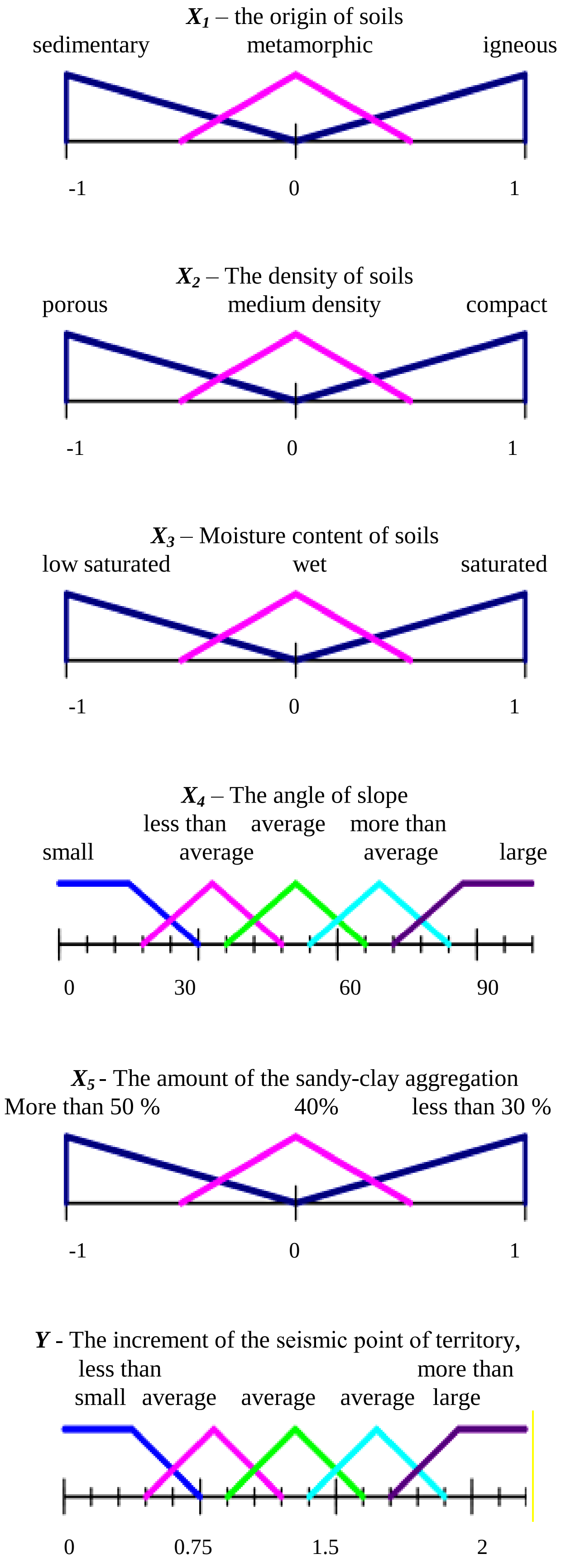

Figure 2. Characteristics of tailing dam

Cumulative action of the several factors (the double and threefold interactions) is commensurable on a degree of influence on the increment of the seismic point of territory with the linear factors, and some even surpass them.
The submitted method permits to compare the degree of the influence of the various factors on the increment of the seismic point of territory by the value of the coefficients of variables. For example, the characteristics X_2 and X_3 have the strongest effect on the increment of the seismic point of territory. It is important on the stage of design decision making. But then they have constant meaning in the equation (2).
In this case, the submitted method permits to forecast the influence of the changing factors on the increment of the seismic point of territory
The check of adequacy of an equation (1) was carried out by comparison with the results of the experiments from a test site at Vladikavkaz (Russia) (Gayfullin, 1991). The soils of test site are presented by coarse-grained soil of igneous origin, with sandy-clay aggregation more than 50 %. The soils are moisture saturated and have medium density. The angle of slope is 0.6^0. The increment of the seismic point of territory is equal 0.02 on the base of the equation (2). This result has good correlation with the result received on the base of norms (SNiP, 2000). According to the (SNiP, 2000) the soils of test site are considered to the category II with seismic point of territory is equal 0.
Application of the developed technique was executed also for the estimation of the increment of seismic intensity area with clayey soils (Lolaev & Baskaev 2008). The results of modeling have good correlation with in-situ results received for Vladikavkaz territory by Melkov (2006).

5. CONCLUSION

In this report we have presented a method of the fuzzy model creating the valuations of seismic zoning on the basis of representation of variables in a logic and linguistic kind in a combination to elements of the experimental planning theory.
Comparison of the calculated data on model has shown its high adequacy of the experimental data of the various authors.
The use of the method developed in practice of engineering and geological researches will be effective both for decreasing labor input and economic costs.
With application of the developed technique, it was possible to construct forecasting model for quantitative estimations of the increment of seismic intensity area.
The adequacy and reliability of the executed forecast is provided by independence of the used techniques and complex approach applied to study of the condition of object, with the describing occurring phenomena from the various sides both on quantitative, and at a qualitative level.
The opportunity of change of factor’s space makes the developed technique universal for study of any complex, poorly formalizable phenomena, the information about which is insufficiently exact or is absent at all.
The forecast of geoecological processes on the basis of the described method will allow increasing reliability of the accepted design decisions.

REFERENCES

Agayan, S.M., Bogoutdinov, Sh.R., Gvishiani, A.D., Graeva, E.M., Zlotniki, G., Rodkin, M.B. (2005). “Study of signal’s morphology on the base of fuzzy logics algorithms”. *Geophysical Researches*. 1, 143-155. . (in Russian)

Drozdov, A.V., and Spesivtsev, A.V. (1994). “Formalization of expert’s information using logical and linguistic kind of description of complex systems”. *Technicheskay kibernetika.* 2: 89-96. (in Russian)

Gayfullin, Z.G. (1991) “Report about territory microzonation of Vladikavkaz” *TISIZ.* Stavropol. (in Russian)

Gvishiani, A.D., Agayan, S.M., Bogoutdinov, Sh.R. (2003) “Mathematic methods in geoinformatics” *Cybernetics and systems analyses. Kiev.* 4, 103-111. (in Russian)

Gvishiani, A.D., Agayan, S.M., Bogoutdinov, Sh.R. (2004) “Algorithm FLARS and recognition of time series anomalies” *System Research and Information Technologies*. 3, 7-16.

Klyachko, A.B. (2007) “Some fundamentals of analysis and control of seismic risks on urbanized territories” *Proceedings of II Caucasian workshop of young scientists”.* Vladikavkaz. 21-38. . (in Russian)

Lolaev, A.B. (1998).” Engineering-geocryologic problems of cryolitozone economic development: Moscow. RIA Press. 150 p. (in Russian)

Lolaev, A.B., Baskaev, A.N. (2008) “Fuzzy Modelling in the Territories Seismic Risks Estimation” *Proceedings of 5th Int.Conf. “Science on a boundary of Millennia.* Tambov. 380-385. (in Russian).

Lorensen, P. (1957). “Uber die Syllogizmen als Relationen-multiplicationen”. *Archiv mathematische Logik und Grundlagen forschungen.* *1* 3-4: 112-116

Melkov, D.A. (2006). “Influence of soil condition on the natural seismic events on the base of instrumental monitoring on the urbanized territories for North Caucasus”. *Seismic Danger and Seismic Risks Control in Caucasus.* Vladikavkaz. 178-198. (in Russian)

Plimmer, B.R. (1997). “The use of a top down probabilistic modeling approach to contaminant transport”. *Proceedings of the Geoenvironmental Engineering Conference “Contaminated ground: fate of pollutants and remediation”, Cardiff,* Wales:. London: Thomas Telford. 248-253

SNiP (Stroitelnyy Normi and Pravila) (2000) “Engineering in seismic areas” *SNiP II-7-81*[*]Minstroy Rossii. Moscow (in Russian)

Zaalishvili, V.B., Melkov, D.A., Korotkaya, N.A., Dzeranov, B.V. (2006) “Rating estimation of soils condition of territories”. *Seismic Danger and Seismic Risks Control in Caucasus.* Vladikavkaz. 153-160. (in Russian)

Zaalishvili, V.B., Otinashvili, M.G., Shengelia, N.O., (2006) “Rating estimation of soils condition of territories for insurance purposes” .*Seismic Danger and Seismic Risks Control in Caucasus.* Vladikavkaz. 336-343. (in Russian)

Zadeh, L.A. (1975). “The concept of a Linguistic variable and its application to approximate reasoning”. *I, Inf. Sci.* 8: 199-249.

Zadeh, L. A. (1981). “Possibility theory and soft data analysis.” *Mathematical frontiers of the social and policy sciences,* L. Cobb and R. M. Thrall, eds., Westview, Boulder, Colo., 69-129.

Zlotnicki, J., LeMouel, J-L., Gvishiani, A.D. (2005) “Automatic fuzzy logic recognition of anomalous activity on long geophysical records. Application to electric signals associated with the volcanic activity of La Fournaise volcano (Reunion Island)”. *Earth Planet Sci.* V.234. 261-278