# Forest fire risk assessment and cartography - A methodological approach

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Keywords: prevention of forest fire, risk assessment, cartography, risk definition

ABSTRACT: The difficulties to know the risk and the diversity of the needs led us to study and clarify hazard assessment. The objective of the study, presented in this paper, is to clarify the concepts relating to the risk, to appreciate the multiplicity of the existing needs, to analyze the means of risk assessment and to identify the data currently usable, as well as the processing and the information systems available. Two steps have been developed: a state of the art and a methodological proceeding.

## 1 INTRODUCTION

Forest fires is part of the ecosystem, but it becomes a risk when by its frequency or its intensity, it destroys the forest beyond what is admitted and threatens men and their activities. Forest fire risk has increased during the 20th century with the socio-economical change of our society (situation in the south of France, but available also in the Mediterranean basin). The evolution of landuse and the decrease of agricultural activity led to more forest fuel and to the multiplication of urban areas in contact with natural forest areas. These wildland/urban interfaces are all the more vulnerable to fire than man is responsible for fire departures. It becomes necessary to manage these areas with prevention devices.

However, any prevention policy is initially based on risk assessment and mapping that requires to produce knowledge on the phenomenon and its damaging consequences. But the study and analysis of risk (particularly in the field of forest fires) include difficulties linked to the complexity of the phenomenon.

To identify and localize the hazard, various methods can be implemented. Those vary according to the aims, the means and the various forms of modeling used. The methods taken into account in this paper deal with long-term hazard assessment at various scales in opposition with daily hazard estimation for operational purpose. At the present time different methods are available. The studies conducted on these topics are up to date and diverse, for example: comparative study of the risk levels in the administrative units of the European Union states, study of the fire hazard in a district (for a legal purpose), study of ignition hazard along roads in order to complete the preventive maintenance. This diversity shows a wide variety of needs.

The difficulties to know the risk and the diversity of the needs led us to study and clarify hazard assessment. The objective of the study, presented in this paper, is to clarify the concepts relating to the risk, to appreciate the multiplicity of the existing needs, to analyze the means of risk assessment and to identify the data currently usable, as well as the processing and the information systems available. Two steps have been developed: a state of the art and a methodological proceeding.

## 2 A STATE OF THE ART BASED ON THREE QUALITATIVE APPROACHES

These approaches showed below aim at collecting and condensing information to clarify the characteristics of the existing hazard assessment methods.

### 2.1 *Conduction of a survey*

The objective is to determine the hazard knowledge, the evaluation needs, the methods by different people involved in risk prevention.

The first methodological step is based on an investigation with risk cartography users. The objective is to determine the risk perception, the needs for assessment, the cartography methods shared by this people. The people constituting the sample answer various criteria. We look for representativeness in scales (from Europe to the city scale), various types of users (public or private) and concerns (from prevention to the fight).

People were contacted by telephone or by mail. We should then underline certain skews of our approach. The conditions in which the talks were made are not always the same, which involves a heterogeneity of the sources of information.

It is thus difficult to compare the answers given. Nevertheless, these talks contributed to characterize, in the broad outline, knowledge and the needs for risk assessment.

### 2.2 *To collect existing methods*

We collect the studies done on risk assessment in different organisms and locations (administration, research laboratories, …). However, it should be stressed that the sample is not quantitatively representative of what exists: we eliminate some similar studies, only some were taken into account. Finally fifty studies concerning risk assessment were listed.

Risk mapping have less than twenty years. Previously, they were rather "descriptive" approaches such as:

- the history of the last events,
- types of vegetation (inflammability, combustibility),
- the inventory of fire ignition points.

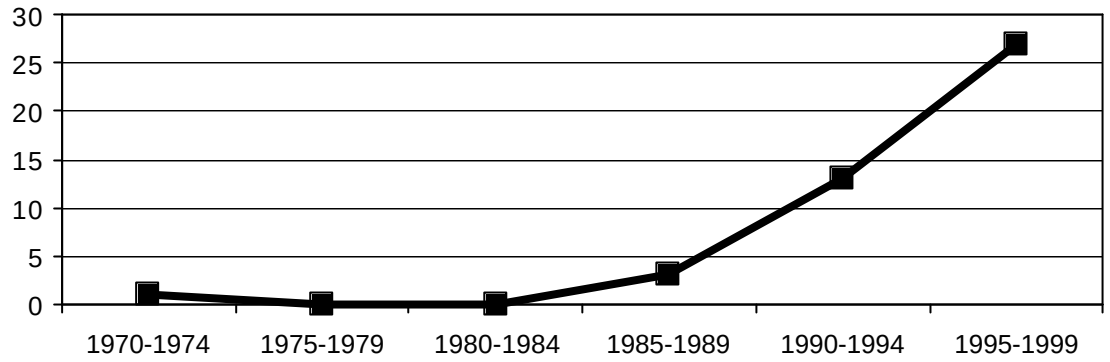


Figure 1 : Development of fire risks studies (fifty studies have been collected)

Starting from the end of the Eighties, the concept of risk started to be integrated in management plans of the forest. This way of taking into account the risk was done with very basic element, very often using a simple map of vegetation. This kind of approach did not completely disappear today (in particular for certain kind of departmental or regional approaches).

There is an increasing of studies since the beginning of the Nineties. We attend a change, the studies deal with wildland/urban interfaces (few works were conducted on this topic). Nowadays, when the concept of risk is taken into account in prevention plans (for urban planning), the methods employed "are in general more sophisticated", the authors seeking to synthesize several layers of information by using a GIS.

### 2.3 *To set up a tool to analyze these studies*

The last methodological approach has the aim of analyzing the existing methods of risk assessment. To make a distinction between these studies which have different objectives, a grid of analysis has been implemented which leads to inventory and study in depth the methods. This one allows a simplified and homogeneous reading of each study.

This technique of analysis leads to inventory and study in detail the methods employed in order to define and evaluate the risk, by considering several aspects. Thus the grid of analysis makes possible to appreciate the knowledge of risk concept which the authors of the studies have.

However the limits are the same ones as those mentioned previously, the sample does not make it possible to give an account of a homogeneous unit. Information resulting from this analysis is thus to use with precaution. The results enable us, however, to present the main current tendencies of risk assessment.

The main aspects taken into account in the grid was :

- Analyze of needs
  - General aspects (spatial, scales, …)
  - Objective of the study
- Analyze of methods set up
  - Description (definition of risk, parameters taken into account, perimeter of studies, scales)
  - Risk assessment (approach, models, tools, validation)
- Description of the data (kind of data, origin, timelessness)

## 3 METHODOLOGICAL APPROACH

The results drawn from this analysis had led us to develop a methodological process in order to assess and map forest fire hazard. The propositions are based on two steps.

- step 1: to define and express needs for cartography (objective, scale)
- step 2: determination of a method to satisfy the needs, which leads to:
  - define risk according to this needs (risk elements),
  - select the parameters required by each type of element (slope, roads),
  - chose models (probabilistic, deterministic.),
  - obtaining the data necessary (DEM, satellite images...), which requires to get the data of different types, to set up tools for spatial analysis.

### 3.1 *Main needs for forest fire mapping*

Two types of needs have been pointed out: a need related to urban planning and a need related to the protection of the forests against fires. These needs exist on a local and regional scale. Other needs were observed reading risk studies or inquiring different actor. They will be examined in the future. For example: forest policy, preventive information, and insurance.

#### 3.1.1 *Urban planning*

We can consider two levels:

- Regional level. The issue of mapping is to establish an essential zoning for future Plans for the Prevention of Natural Risks. So the local community financing will be concentrated to finance safety measures in areas subject to risk. The future urbanism needs shall have to concern on this scale probably plan projects. Those projects will have to take into account the fire risk: road infrastructures, fire management directives,
- Local level (one or several communities). The need essentially comes from prevention plan, carried out inside "risk basins". Those "risk basins" are theoretically defined on a departmental scale. An issue is to map the fire hazards and the zoning, which conforms to the regulation. Another issue consists of analyzing the present preventive and fighting systems (collectives or private equipment study, obligation to clear brushwood).

#### 3.1.2 *Protection of the forest*

We can also consider two levels:

- Regional level. The issue of mapping concerned different points : the reduction of accidental causes, the forestry massif survey, the mobilization of prevention, and fire fighting management equipment or maintenance. Financing will be concentrated on financing forest safety measures in areas where risk is induced. The future needs obligations conforming to the regulation, obligations in obtaining European aids.
- Local level (one or several communities). Inside the forest, the need is the same with more operational aspects, generally described in report as Plan for Brush and Fire management between several communities. For example these studies aid to obtain new equipment, to organize survey patrol units, to install shaded fuelbreak…

### 3.2 *Determine an approach for risk assessment*

Risk assessment is based on an approach including different forms of modeling (probabilistic, semi-probabilistic or determinist), data (depending of parameters) and tools (spatial analysis tools, GIS, simulator,...). We first define risk.

### 3.2.1 *Risk definition according to the needs*

The evaluation of Risk is the combination of the probability of an event occurrence (hazard) and its consequences (vulnerability). It is widely agreed that these two concepts are used to assess natural risks (Bachmann, 1998).

More precisely, the hazard is defined as " the probability that a forest fire might occur in a given place at a given intensity". So it depends on 2 elements: occurrence and intensity. The occurrences correspond the probability in time of a fire occurrence (based on statistic studies of past forest fires) or the probability for a certain point to be ignited or burnt (based on fire behavior models or historical data). The intensity of a forest fire is linked to the amount of energy of the fire that is directly linked to its consequences (for example Byram, 1964). The vulnerability corresponds to "the foreseeable consequences of a natural phenomenon, qualified by a certain intensity on the stakes". It depends on 3 elements: stakes, damages and fight (preventive or fighting equipment).

In wild fire field, we also consider two aspects of hazard:

- "Natural" aspect where hazard is, like for the other natural phenomenon, a combination between fire probability and fire intensity (we speak about subjected to risk hazard)
- "Technological" aspect where hazard is, like for industrial accidents, a combination between ignition probability and threatened area (we speak about induced hazard).

Risk is therefore composed of different factors.

<table>
<tr><td colspan="6">RISK</td></tr>
<tr><td colspan="4">Hazard :</td><td colspan="2">Vulnerability</td></tr>
<tr><td colspan="2">Occurrence</td><td colspan="2">Intensity</td><td rowspan="2">Stake</td><td rowspan="2">Damage</td><td rowspan="2">Prevention<br>Fire fighting</td></tr>
<tr><td>Probability of ignition</td><td>Probability of wildfire</td><td>Threatened area</td><td>Fire intensity</td></tr>
</table>

Figure 2 : the risk factors

So each need can be translated in risk factors.

To illustrate this we can consider our 2 main needs:

Urbanism example: fire probability is hazard's main characteristic to be taken into account (ignition probability is useful if calculation is integrated in it). Intensity can be taken into account at local level. Stakes have to be listed at local level as precisely as possible. We can take into account reply to determine defensible areas.

Fire management example: ignition probability calculation is essential. Indeed the potential sources of ignition areas are a very high-risk factor to obtain departmental priorities or to deal with forest management. The probability of wildland fire can be used to define equipment ratio at departmental level. The threatened area is also a factor adapted to this need when management strategy is to prevent ignition and to control fires from beginning. It is useful to consider the present prevention and fire-fighting system in hazard evaluation when areas aren't equipped enough

### 3.2.2 *Selection of components and parameters which are required for each element*

The objective is to define the parameters taken into account in the risk assessment (influence of parameters on the intensity and spatial occurrence of a fire).

The parameters are natural and human factors, which influence fire ignition, propagation and intensity and its development. For example the main topographic parameters used in hazard studies are slope and exposure.

The groups of parameters are called components. There are five components: vegetation (fuel bed, flammability, biomasses…), topography (slope, exposure,), climate (moisture content, sunlight, rainfall,), human activities (soil occupation, land, watersource,), fire history (threatened

area, ignition source). The human activity component can be used for 3 risk factors: ignitions source, stakes (people, possessions...) and fire fighting activity.

### 3.2.3 *Different kind of models*

We can distinguish 3 type of modelling (Dupuy, 1997):

- The probabilistic mode. This mode is based only on statistics to represent a risk element. For example we will use only historical data to estimate ignition probability. Very often historical data have geographical references on administrative boundary lines; that define their representation mode: generally by district or community at departmental level, by community at local level.

- The semi-probabilistic mode. This representation mode uses only historical data with a view to "adjusting" the non-historical components but also results from expertise or experimentation. Some fire aspects can be taken into account without knowing completely physical fire mechanisms. For example we will use available statistics to know ignition probability of each vegetation type or human activity type.

- The deterministic mode. This one supposes that we know the fire mechanism very well: ignition, propagation, reply...The current knowledge isn't sufficient to modelize all risk factors.

### 3.2.4 *Obtaining different data types*

We list 6 data types more or less easy to be used.

- Data ready to use. There are specific and digital data which can be easily transformed to parameters: for example, the Digital Elevation Model (DEM) gives parameters like slope, exposure and altitude.

Those data exist generally on big areas and in a homogeneous way.

- Data on maps. The information has to be selected and/or interpreted, then digitalized (digitalisation of boundaries on a special table to digitalize, or using a plan scanner and vectorisation on the screen). The descriptive information is added in a second time (thematically map).
- Spatialized data to interpret. There are aerial photographs and satellite imagery and recently orthophotos. Information is continuous and gives a global vision of space occupation, obtaining components such as vegetation, topography and human activities.
- Limited located data. An interpolation is useful to obtain a continuous representation on the study areas. For example with the meteorological data, the climatic parameter variations can be mapped.
- Statistics. There are listing files. Their first aim is to propose statistical information on certain area, and then another aim is to be able to obtain digitalized information. It supposes that those data belong to a determined area(For example community). The French database Promethee is often used to describe historical data.
- Data more or less located. There are no spatial references but only qualitative information. It can be bibliography, archives or abbacies. Experimentation is also a high way to get data: Laboratory experimentation or field experimentation (real fire, prescribed burning). The most often described parameters in experimentation are fire physical characteristics such as flammability, combustion.

### 3.2.5 *Spatial analysis tools*

There are many techniques of spatial analysis and a lot of functional software. Four different techniques are used to map fire risk.

Data layers combination

This combination makes use of analytic geometry tools. All the data are brought together and analyzed in a Geographical Information System (GIS). Each parameter is described in a specific data layer. Data layer combination can be carried out in different ways:

- Using experts (ponderation, cross tabulation,…),
- Using deterministic mathematical relations between parameters (for example slope effect,…),

In this category there are methods of factors' classical combination: combination is made in RASTER format. All the pixels belonging to a same geographical area are combined.

Spatial interaction

It corresponds to a topological analysis, which puts "objects" (vector or raster) in a spatial structure coming into contact each other. Notion of proximity, adjacent situations, connectivity are used.

The fire propagation simulation is well known. One or several starting points of fire are simulated inside a risk basin. Then we observe where and how fire is propagating. The more used models are semi-empirical models: in the same time they take into account experimental or real fire observations, or laboratory experimentation and physical and chemical fire behaviour.

There are other spatial interactions: definition of influence area, interpolation, distance or proximity notion.

Extraction of data

The original and very detailed information has to be synthesized to characterize a parameter or a risk factor. There are two ways to simplify:

- In gathering together classes (some forest tree types to describe combustion parameters)
- In using remote sensing images (gathering together image reflectance values in accordance with a known soil occupation).

Classical statistical analysis

Several parameters describe the same "object" (for example the boundary lines). Analyses are carried out this "object": algebraic operation, typology to distribute situations in different classes, multivariable regression...The GIS isn't always useful. In this category we find methods to calculate the annual medium risk, or the annual medium pressure (number of fire starting points per surface unit-frequency).

## 4 CONCLUSION

The main goal of this research is to point out the difficulties linked to long-term forest fire hazard assessment and clarified this situation to improve the risk knowledge.

There are a diversity of existing fire risk assessment and mapping methods. There is no common place between each one. In this field, the needs expressed are often confused. The concepts used can have very different meanings. This observation points out the variety of the objectives that influences the elaboration of a method.

Nowadays, two types of needs are dominant:

- Urbanism needs because of urbanism problems in risk areas
- Fire management needs.

They exist at local or departmental scales.

Thus research has taken a direction towards the appropriateness of needs, methods and data.

A new process based on expressed needs is proposed. So each need in risk assessment can be analyzed and defined in risk factor, which have to be modelled. (Probabilistic, semi-probabilistic or deterministic model). Those models take into account parameters obtained with data and spatial analysis tools (combination, simulation, interpolation, influence area,).

## 5 ACKNOWLEDGEMENTS

This study is financed by French Ministry of Environment and by French Ministry of Agriculture. This study was conduct within the framework of the "Scientific Interest Group on forest fire".

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