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PROBLEMS AND CHALLENGES IN ANALYZING MULTIPLE TERRITORIAL RISKS. METHODOLOGICAL PROPOSALS FOR MULTI-HAZARD MAPPING

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I. INTRODUCTION AND OBJETIVES

Risk analysis has traditionally been carried out from a disciplinary standpoint, according to which each type of risk is addressed, evaluated and mapped individually. However, this kind of sectoral approach is ineffective for identifying risks in complex territorial situations in which processes are expressed via tightly-linked space-time interconnections. Ignoring such interconnections and the domino effect among different types of risk within a single space can lead to an undervaluing of the synergy produced by the joint functioning of several processes.

The present article highlights the need to focus hazard mapping in an integrated, comprehensive way. This study aims to describe the main problems and necessities of multi-risk and multi-hazard mapping, proposing methodological guidelines for multiple-hazard mapping and applying them within a complex territorial context. The methodological proposals are applied to analyze a particular case on the outskirts of the city of Málaga (Spain).

II. BACKGROUND

Little has been published on the methodology of multi-risk analysis, and what there is is relatively recent. This text cites references to some approaches made from a conceptual standpoint, to others that address regulatory aspects, to studies based on applied research and, finally, to others with an institutional, national, European and global scope.

III. METHODOLOGICAL STRATEGIES FOR MULTI-HAZARD MAPPING

1. General characteristics

We propose a series of methodological guidelines for producing different types of multi-hazard maps. This mapping proposal includes different methodological strategies for grouping multiple hazards, with varying degrees of complexity as regards the spatial-temporal integration of the processes under consideration.

2. Creating individual hazard maps, by type of hazard

The following hazards, considered in multi-risk mapping, have been identified in the study area (Fig. 1):

Hydric erosion
Gravitational mass movements
River flooding by overflow and damming
Flooding due to blockage of the river mouth (sedimentation and/or marine transgression
Erosion of river banks by flood surge
Atmospheric contamination
Aquifer contamination (surface water and groundwater)
Marine contamination
Fire

Figure 1

TYPES OF HAZARDS CONSIDERED IN THE METHODOLOGICAL PROPOSAL FOR MULTI-HAZARD MAPPING

The risks of flooding, forest fire and mass movements are gauged using the intensity scales and parameters proposed in the ARMONIA Project (Delmonaco, Margottini and Spizzichino, 2006). In order to identify the risk of atmospheric and aquifer contamination, the toxicity of the substance emitted must be determined. The other hazards are then established from the spatial concurrence of potential risk factors. The overall hazard is divided into three categories, equivalent to the number of intervals proposed in the ARMONIA Project.

3. Synthetic-hazard map

The synthetic-hazard map is the most basic document in multi-hazard mapping, and is obtained from the superposition of areas of maximum risk for each hazard, with specific graphic elements identifying the geographic points where more than one type of hazard converge. This kind of multi-hazard mapping is illustrated, for example, by the map produced by the Tajikistan Disaster Management Agency for a total of nine types of natural hazard, by that used in the French Departmental Dossier Of Major Risks (DDRM) for seven types of natural and technological risks, or that published by Pita (1999) for the various hazards potentially affecting Andalusia (S Spain).

4. Aggregate hazard map

The aggregate hazard map is based on the fact that the spatial coincidence of areas liable to be affected by diverse hazards at a single point represents a geometrically-increasing progression of hazard intensity in the zone, under the assumption that the spatial connection between two or more types of hazard featuring associated processes involves not just an accumulation of risk, but the increased possibility of synergic effects between them. The aggregate hazard map was created using the following algorithm:

Aggregate Hazard = Degree of individual hazard for each type of risk * Number of coincident hazards

In drawing this map, the three levels of hazard, representing all types of risks, were superposed in order to increase the degree of joint hazard in the resulting zones, from the number of risks accumulated and the degree of risk intensity of each of the diverse hazards accumulated. Thus, the aggregate risk-calculation algorithm is summarized as follows:

$$PA = Pi * Np$$

where:
PA is the aggregate risk
Pi is the degree of individual risk for each type of hazard
Np is the number of coincident hazards

5. Map of causative and recipient areas of each hazard

The most basic document used to represent the possible repercussions within a specific area of the risk arising from other spatial points is the map of interactions within the causative area, and from this instrument, the concept of stability is deduced. Such a map shows how the hazard potential of an area may increase sharply as a result of the interactions of the hazard processes located within its causative area. This area, for each type of risk, extends throughout the continuous space in which there exists the possibility that a given action may bring about consequences at the end point. The causative area is defined from the corresponding mass and energy transfer vector, and thus is limited by the gravitational, fluid and/or atmosphere dynamics inherent to this type of hazard as a transmitter of consequences. The methodology applied by the Tajikistan Disaster Management Agency is one example by which, albeit to a rudimentary degree, this spatial dimension is addressed. The degrees of instability in the causative area used in the document were calculated from the number of hazards with associative functioning located in this area, as it was assumed that the presence of a large number of hazards in a causative area increases the probability of interactions, and thus raises the instability.

5.1. Maps showing the stability of the hazard causative area at present, and in future scenarios

The degree of instability in the causative area increases with the number of associated hazards involved, with their degree of risk and with their extension over the area. Thus, the degree of instability was calculated using the following decision-taking formula:

$$In\ AC = Nº p * Ip * (Ep\ (ce))$$

where:
In AC is the degree of instability in the causative area
Nºp is the number of associated function hazards present in the causative area
Ip is the degree of risk for each hazard
(Ep (ce)) is the extension of the risk over the causative area weighted by a coefficient for its characteristic spatial expression (extensive or at a point).

A variation of the stability map in the causative area may be achieved by taking a dynamic perspective, introducing into the analysis the foreseeable variations in hazard levels for future times or within hypothetical scenarios, such as planning for the possible consequences of climate change.

6. Map of linked accumulated risk

1. Initial assumptions

The map of chain-reaction hazard constitutes the most complex element in multiple-hazard mapping. It must reflect the topological ordering of the actions involved in different hazards, the feedback processes and consequent synergy, and the spatial and temporal transfer between causes and consequences. The evaluation of chain-reaction hazard on a territorial scale has yet to be accomplished, and the proposals made remain highly speculative, given the complexity of the question. Some limited work in this respect can be seen, however, for example in the methodology proposed by the Tajikistan Disaster Management Agency, or the Integrated Planning Decision Support System (IPDSS), designed at the University of Colorado, for hazards related to gravitational processes.

The first question to be considered in addressing chain-reaction hazard mapping is that of identifying the interactions among processes. The bibliography on the subject recommends combining into single maps the types of hazard that have a common causal agent or activator. However, the criterion followed in the methodology we propose does not follow this view. In our opinion, the link connecting certain hazard processes with others is not necessarily the cause of each, but rather it is the existence of a common mass and energy transfer vector that relates them – this could be termed a mutual consequence vector. Various cases can be cited to show that linking interactions among hazards exclusively by their origin may be insufficient and sometimes inaccurate.

Our proposal is based on the interrelations among different hazards, applying the concept of transfer vector or consequence vector, as discussed by Perles et al. (2006) and Perles, Gallego and Cantarero (2006), among others. The flows of interrelations among different hazards should be established from the transfer of consequences between some hazards and others. Such transfers have a space-time connection, and are governed by gravitational, fluid or atmospheric dynamics. The flows may be in a single direction, a two-fold single direction or may give rise to feedback. Figure 4 summarizes the lines of possible interaction among the types of hazard present in the study area.

2. Stages involved in chain-reaction hazard mapping

A map of joint risks was used as the starting point for obtaining a chain-reaction hazard map. On this basis, a series of examinations were made, using a GIS, of each of the hazard polygons obtained, to determine the following parameters:

- Number of hazards affecting the area in question. To ascertain this, note was taken of all the hazards that, on the one hand, were related via a transfer vector to the hazards in the study area and, on the other, were located in a topological position, with respect to this area, that enabled the transfer of mass and/or energy.
- Degree of danger of the hazards liable to affect the area in question.
- Extension of the area of each of the hazards liable to affect the area in question (weighted by a coefficient for the characteristic spatial expression of each hazard in the study area).

Each of these areas was assigned a value, the result of multiplying the number of accumulated chain-reaction hazards (according to the transfer vector) by the degree of intensity of each one and by its extension. . The following algorithm represents the calculation made for each step:

$$Pac = N^{o}pac \; * \; Ipac \; *(\; (Epac\,(ce))/exAC)$$

where:

Pac is the degree of linked accumulated risk thus far

$N^{o}pac$ is the number of linked accumulated risks present in the causative area of the point in question

$Ipac$ is the degree of risk for each linked accumulated hazard

Prior to this, it was necessary to confirm that these hazards were indeed connected via a vector, and that the topological position of each hazard was such that spatial connection between them was possible. As most hazard-related processes in the study area react in accordance with gravitational and/or fluid dynamics, a fundamental need for hazard mapping is the support of the “flow direction” tool provided by GIS.

IV. APPLYING MUTLI-HAZARD MAPPING TO AN AREA ON THE OUTSKIRTS OF MÁLAGA

The area chosen in which to apply this mapping proposal for multi-hazard evaluation is on the eastern outskirts of the city of Málaga (Fig. 5). The mapping results obtained reveal the great complexity of the zone, from the standpoint of inherent hazards, and comparison of the different maps created for the zone shows that the results in question may vary widely depending on the level of integration of the input information. The mapping results show a closer approach to the reality of risk production when the methods used are based on the concept of spatial transfer and linked accumulation, with respect to simpler methods of superposition *in situ*.

V. CONCLUSIONS

The proposed mapping described in this paper enables us to observe and compare the utility of mapping methods based on vertical superposition, with respect to those based on the distinction between causative and recipient areas, and with respect to the concept of the transfer vector of impacts. As concerns the more difficult question of modelling the spatial and temporal transfer of impacts, we have designed stability maps for causative areas, together with a map of linked hazards. The results derived from these provide a marked improvement over mapping documents based on vertical superposition. As an approximative proposal, this form of mapping opens up routes towards approaches that are more closely related to the spatial dynamics corresponding to the coexistence of multiple risks, and illustrates the concept of accumulated risks, although there remain some aspects to be improved. For example, in the method described, no attention has been paid to aspects such as the nonlinear nature of the incidence processes of certain risk factors over others, or to the presence of critical thresholds. Also left aside is the fact that the increase in accumulated levels of risk implies not just an increase in the intensity of risk in the recipient area, but also, in some cases, its greater extension (for example in the case of flooding, as discussed in Perles, Gallego and Cantarero, 2006). These questions have been temporarily set aside in order to develop an operative methodology applicable to a practical work scale such as that described, a scope in which risk mapping is of crucial importance.