Evaluation of physical and functional vulnerability of populations in the surrounding area of Galeras volcano. (Nariño, Colombia).

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ABSTRACT: This paper presents the evaluation's results in terms of the physical and functional vulnerability of populations in the area surrounding the Galeras Volcano. This volcano is located in the state of Nariño, southwest Colombia. It reaches a height of 4276 meters and is one of the most active in the country. Its influence area covers approximately 888 km ²; with a population over 500. 000 inhabitants, 30% of this are located in rural areas, while the other 70% is in urban areas. With the Galeras volcano activation in 1989, the country installed a state policy of evaluation and prevention for volcanic hazards. As a result of the Galeras' continuous activity and the declaration of disaster area (2005), Colombia's National Disaster Prevention and Attention Bureau started a program called 'Proceso Galeras'. As part of this program the study, which is a pioneer in the country because of the large-scale (11 municipalities) coverage and the complexity of the variables related to the volcanic phenomenon, was developed. The methodology used was semi-quantitative, identifying common vulnerabilities by sectors, areas and systems' components. We evaluated 12 types of exposed elements consisting of: electric power systems, communications, water sources, waste water, solid waste, roads and transportation, fuel supply, population, housing, essential buildings, agriculture, livestock, industrial sectors; natural and ecological. Inputs from the vulnerability study are transverse to the planning policies for future development of the region. One product of this study was the creation of a GIS (http://osso.org.co:8000/) free access for making available to the community at large, skilled and unskilled population, and the testing results with the purpose of helping to the development planning and land management. The results and lessons learned from studies of this kind seek to consolidate a comprehensive process for volcanic risk reduction, with a regional perspective in the Volcano's influence area, a process that is currently ahead in the area. The main challenge is to change the perception of the communities and authorities of the risk establishment along with the creation of possible strategies and actions necessary for damage reduction.

Keywords: vulnerability, volcano, Galeras, Nariño, Colombia

1.INTRODUCTION

After a long story of negation and trivialization of the threads and risk, along with the Galeras Volcano's actual activation period, which started in 1989, Colombia installed a state policy. This policy, involves the evaluation and damage prevention (short threat assessment - monitoring - and long term - volcanic hazard map, initial assessment of vulnerability). Perhaps coinciding with the tragedy of Ruiz and the creation of the National System for Disaster Prevention and Attention - SNPAD. Later, as a result of the continued Galeras activity and the declaration of disaster area (2005), the program starts SNPAD 'Proceso Galeras' with measures to facilitate the exposed areas evasion on imminent situations (shelter construction). We also included measures to avoid the most threatened areas by a project that identifies potential development areas and resettlement of those with the biggest risk, as well as current advances in studies of physical and functional vulnerability basis for the implementation of other strategies and reduction measures.

The study had two main objectives: (1). In Zone 1, inside the oval, defined in INGEOMINAS' volcanic hazard map with an area of 888 km ², physical and functional elements vulnerability assessment exposed to medium hazard, and low (lifelines, essential buildings , population and housing sectors, agriculture and industrial, natural and ecological areas) and high threat zone, only those elements such as lifelines and water supply systems for current and future population resettlement. (2) Zone 2, for all that is outside the oval, was sought to characterize and evaluate the functional vulnerability of potentially suitable areas for future development (in the Figure 1 shows the study area in the observed Zone 1 (Z1) and Zone 2 (Z2)). The used hazard scenario was specified in the latest hazard map for Galeras volcano (INGEOMINAS, 1997), which defines likely phenomena associated with volcanic processes, for which there is information. These were: lava flows, pyroclastic falls (volcanic ash), mud flows, ballistic projectiles, shock waves, and cloud accompanying pyroclastic flow. The concentration of gases and acid rain, to be secondary phenomena, were taken into account generally for analysis

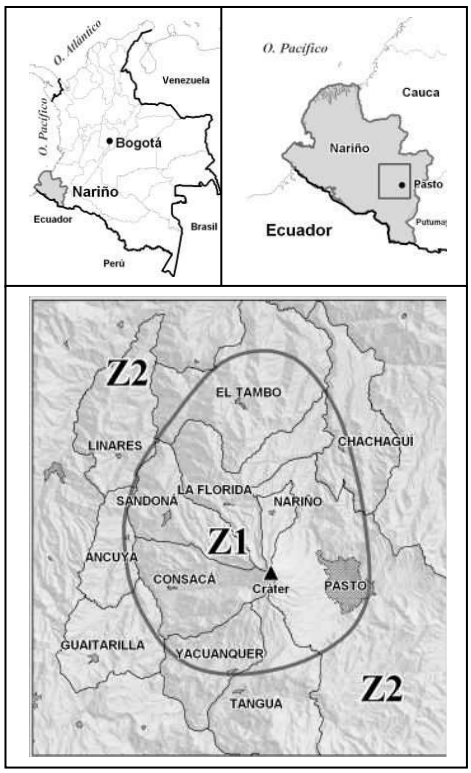

Figure. 1. The interest area corresponds to contained in the Volcanic Hazard Map (INGEOMINAS, 1997). Physical and functional vulnerability studies were conducted in the area called Z1, which corresponds to the area where INGEOMINAS reported historical volcanic eruptions. In Z2 were identified areas with lower environmental and functional restrictions and useful for potential future resettlement.

The methodology was intermediate, semi-quantitative, without detailed numerical analysis of the exposed elements' structural behavior (eg., Individual buildings, lifelines, urban systems and community, etc.). But, seeking to identify generic and common vulnerabilities by sectors, areas and systems' components, this exercise was based on a combination of direct observations on the types of terrain, composition, genesis and geomorphology and their spatial location in relation to building typologies, genesis, density, urban and community systems, their strengths and weaknesses against the volcanic phenomena. The set of vulnerability defined variables that took into account both the type and severity of the impact on the site or area of exposure and the nature of the submitted information. This sets up a complex picture of events that cause mechanical impact, thermal and chemical on humans, animals, buildings, infrastructure, agricultural land use, water resources and natural environment.

Thus, from the knowledge of the different threat levels associated with each of the volcanic phenomena, the most representative elements were identified and evaluated set by higher priority and importance to intervene their vulnerability, it was taken into account: population accessibility and information's availability. The inventory of all the evidence presented in the study area was conducted with diverse techniques, from the collection of documentary and cartographic information from primary sources (institutions, municipalities, etc..), secondary (documents, studies, press, etc.), satellite images interpretation, aerial and spatial high resolution photographs, up to field work, which included the characterization and georeferencing of the exposed elements.

In the context of this survey, it was identified a need to develop a cartographic model that would allow online access to all layers of spatial information of the project with the aim of providing, decision makers and the wider community, with a clear perception of the elements outlined in the territory that could be affected by a volcanic eruption. To answer this need a Geographic Information System - GIS was designed complying with the following characteristics: (i) it may be updated, (ii) dynamic and (iii) it should allow changes (both attributes and elements in their roles.) The main objective of this study was to publicize and make available to technical expertise and wider community, for consultation and download through the Internet, spatial and non spatial information generated in the study (see http://osso.org . co: 8000 /).

The results and learnings about the vulnerability lead to the consolidation of a comprehensive process for reducing volcanic risk in the Galeras Volcano's area of influence, from a regional perspective, because the volcanic phenomena does not distinguish municipal boundaries. The results are transverse and longitudinal inputs that allow creating planning policies for the future development of the region, framed in the dimensions of sustainability: physical - environmental, political - administrative, socio - cultural and economic - productive. The main challenge would be then altered the communities' perception - but also the authorities' themselves - on the risk establishment (vulnerability is controllable!) the strategies and measures necessary for feasible reduction.

2. THEORICAL FOUNDATION

The vulnerability is not an intrinsic property of the exposed elements and it is defined in relation to a specific phenomenon type and intensity. Because of the diversity of volcanic phenomena (pyroclastic flows, ash falls, gases, pressure wave, avalanches, etc.), it is required - ideally - a set of vulnerability functions for each type of vulnerable element, which quantify the relationship between a possible solicitation response range (resistance) of the exposed element. The physical vulnerability concept used in the study also covers the functionality, especially in those elements or systems that are vital for normal development of activities in the population (productive, commercial, cultural, service and some other relationships) as well as critical systems for emergency cases (roads, services, etc.). It should be clear that although physical vulnerability often contains the functional, the functional does not necessarily contain the physical, for that reason, the estimation of vulnerability was carried out in two ways, both physically and functionally.

3. MATERIALS AND METHODS

State the general procedure for evaluation of physical vulnerability is relatively simple, however, in the practice emerge complexities and constraints, as - in this case - the occurrence possibility of various phenomena, with different types of impact, the lack of fundamental empirical information, as the record of disastrous eruptions and their effects on habitat in the Galeras' region, etc.

The methodology considers the two components that must exist in order to configure a vulnerability scenario: (1) threatening phenomena characterization, specified in terms of 'solicitation' (possible range of intensities in a specific location) and (2) Inventory of exposed elements, characterized in its range solicitation resistance.

Each of the above components were assigned indicators (qualitative and quantitative) to characterize and relate them logically and topologically. Thus, the component 'phenomena' left of qualitative indicators of the solicitation severity (High, Medium, Low). Similarly, each exposed element was assigned with qualitative indicators that would realize their vulnerability (on the specific phenomenon) in terms of their spatial relationship to the phenomena, its provision on the ground or some sort of protection against them. By the normal processes of the GIS tools - spatial analysis - the phenomena are interrelated with each of the elements set out from a binary exposure indicator, which spatially allowed to determine what events are, their exposure and their severity level. The results of these tests show new data elements with qualitative attributes, ie, indicators of damage depending on the severity of the phenomenon that affects (severe, moderate, mild or no) and quantitative parameters respecting to their space and their georeferenced elements (length, area, unit quantities, distances, percentages, topology, etc.). Finally, the methodology allowed the production of basic data in different presentation formats (thematic maps, lists, tables, graphs, etc...) That is reviewed by experts in various areas in order to generate useful information in decision making.

However, there is an exception in this methodology: vulnerability per load of ashes. In this case, the most important in the low volcanic hazard area, the level of knowledge and analysis capabilities is greater. On the other hand, solicitation - the ash layer's weight - is quantifiable, and secondly, the resistance of elements exposed to possible damage from overuse, is valuable to a certain level of resolution. That is, in this specific case - ash load on items with limited resistance to vertical forces - the vulnerability and damage functions are more quantifiable. It was reached, from the characteristic of vulnerability function values, the calculation of 'damage functions', expressing the likelihood of damage to the respective type . For other phenomena types, the solicitation range is much less known and measurable, for example in the case of pyroclastic flows and the dynamic pressures generated horizontally.

4. RESULTS

The results are expressed and represented in two ways: first, according to the variables that describe the physical and functional vulnerability, based on analysis of impact scenarios for volcanic phenomena (unbundling INGEOMINAS' hazard model of Galeras volcano), which are expressed in matrices of vulnerability for the most exposed elements and functions covered by defining the variables that make up the mathematical model. And, secondly, in terms of mapping and GIS model. It also identifies priorities for detailed analysis involving modeling and quantitative analysis point, which would be the subject of future studies.

On the other hand, based on the results of the evaluation of physical and functional vulnerability of the exposed elements, an example of risk assessment was constructed, based on the calculation of a scenario of direct losses for the event (ash fall) maximum probable, derived from the information on the hazard's map at Ingeominas third version (1997) for the municipality of Nariño, in order to serve as a starting point for strengthening local authorities in taking decisions against the associated phenomena the threat of the Galeras volcano. There were identified and proposed the most appropriate measures, depending on the levels of physical and functional vulnerability found in each of the above elements, which involve strategies within a wide range of action-control, avoidance, evasion, resistance,

training, redundancy and risk transfer ", in order to generate the conceptual basis to complement the actions so far used in the Galeras volcano, to control and / or reduce volcanic risk.

The increased reliance on systems that generate greater territorial and functional vulnerability are the Fuels and Electricity Storage and Transportation. The first is associated to the strong dependence on the land routes system that pass by Galeras Circunvalar way, which has high indicators of physical vulnerability, and dependence on sources supply located in the center of the country and the lack of redundancy. The electrical system also has a high vulnerability functional dependence on external generating sources and the lack of redundancy in the networks of regional and local distribution

The territorial analysis shows that *Nariño* is the municipality with higher levels of functional vulnerability, followed by *Florida* and *Consacá*, and *Linares* is the municipality with the lowest functional vulnerability, the other municipalities show similar levels of functional vulnerability.

The functional vulnerability, although it depends on the physical vulnerability of the systems, i.e. elements that are affected with severe and moderate damage, are more influenced by the availability of elements to provide redundancy. Systems such as Liquid and Solid Waste, Electrical and Aqueduct, are most vulnerable due to lack of redundancy factors. According to the spatial influence criteria, the most vulnerable systems are the Electrical, Water Resources and Solid Waste, i.e. those with more elements exposed to severe damage and / or moderate and that would affect more land in case of failure.

Finally, the study outlines the main vulnerabilities, by municipality and by the system, it describes the various measures reduction practices that have arisen from volcanic disaster experiences in various countries, it details the various strategies and measures to reduce risk and analyzes them in their effectiveness in volcanic phenomena. It describes what makes the reduction of likely impacts of a complex volcanic phenomena, proposes concepts and techniques of selection and prioritization of strategies and appropriate measures to manage this complexity and reach the decision-making - which must include other factors besides vulnerability - a proposal with the favorable relationship of cost / benefit.

5. CONCLUSIONS

The results of an evaluation of physical and functional vulnerability can be applied to several purposes: a risk estimate (probability of loss), together with a hazard model, the design of plans and actions to reduce vulnerabilities of the exposed elements currently exposed, design measures to control the vulnerabilities of future elements in exposed areas.

The recommendations from the study results are intended to be accessible to all sectors of the population (communities, institutions, academia, etc..). Which allows each actor to have a series of knowledge and evidence to verify itself the vulnerability conditions, with respect to the volcanic phenomena which it is exposed and thus identify mitigation measures, defining powers and responsibilities, i.e. who is responsible for what. In addition, to identify the most appropriate measure, depending on levels of physical and functional vulnerability found in each of the elements exposed. It seeks to implement actions to prevent, control, manage and / or reduce volcanic risk in the influence area of Galeras volcano, which may involve different strategies within a range of actions such as: control, escape, evasion, avoidance, preparedness, redundancy, transfer of risk, among others.

Finally, the Geographic Information System vulnerability study of Galeras - SIGVULGALERAS is an useful, efficient and modern in response to the need for timely access to spatial information in the areas that are exposed to volcanic hazard in the Galeras volcano region. It is also a source of reference that can guide and / or support community processes, such as politic decisions, necessary to ensure the reduction of the probability (or potential) of losses from volcanic eruption in the Galeras region.

6. REFERENCES

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