

Display of the Nevado del Ruiz Volcanic Hazard Map Using GIS

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Abstract

The November 13, 1985 Nevado del Ruiz volcanic eruption that killed approximately 25.000 people was the fourth largest volcanic disaster in human history. Different versions of the volcanic hazard map of this volcano were prepared before and after the disaster, being the first map of its kind made in Colombia. Preparation of the hazard maps was not timely, and there was poor dissemination of its content. The Volcanic Hazard Map of Nevado del Ruiz Volcano was recently incorporated into a GIS, in order to make it accessible to both casual and expert users. It was simplified showing only the zones likely to be affected by given volcanic processes. For the volcano's area of influence, perspective views were generated by combining topographic data with the hazard map polygons superimposed on a Landsat TM 5 mosaic. Database visualization in 3-D enabled complex volcanic hazard data, to be more readily understood by decision makers and the general public.

Introduction

The 1980 cataclysmic eruption of Mount St. Helens in southwestern Washington, USA, began a decade marked by more worldwide volcanic disasters and crises than any other in recorded history. Volcanoes killed more than 28.500 people in the 1980s, more than during the preceding 78 years (Wright & Pierson, 1992).

The November 13, 1985 Nevado del Ruiz (Colombia, South America) volcanic eruption was the worst of the decade. When a complex sequence of hot rock-debris masses erupted, they interacted with snow and ice on the volcano's ice cap, triggering masses of water-saturated debris (lahars) that moved down the volcano slopes like wet concrete (Pierson *et al*, 1990).

The Ruiz eruption that killed approximately 25.000 people (Naranjo *et al*, 1986) was the worst volcanic disaster since the 1902 Mont Pelee (Martinique) eruption, the second worst of the 20th century and the fourth worst in human history (Voight, 1990). The town of Armero, located at the mouth of the Rio Lagunillas canyon about 74 Km downstream from Ruiz's summit crater (Fig. 1), was virtually obliterated, and 75% of its inhabitants perished (Pierson *et al*, 1990).

Volcanic hazard-zone maps are perhaps the most easily understandable form of information to help public officials and citizens plan for volcanic emergencies (Wright & Pierson, 1992). This paper presents the Nevado del Ruiz Volcano Hazard Map displayed in a meaningful format. It also shows how the map can be used, along with remotely sensed data and digital elevation models, within a geographic information system environment to make the data more comprehensible to a public unfamiliar with volcanoes.

The role of hazard maps in planning for Nevado del Ruiz volcanic emergency

The Nevado del Ruiz tragedy was another volcanic catastrophe that occurred at a volcano that erupts infrequently in a developing country, where people are not accustomed to dealing with it. Different versions of the volcanic hazard map of this volcano were prepared before and after the disaster, being the first map of its kind made in Colombia. Preparation of the hazard map was not timely, and there was poor dissemination of its content, even though the different versions were published in some of the principal newspapers of Colombia.

Hazards maps play a crucial role, yet one might question whether the precise map boundary, or the precise contour defined in these maps, should make much difference to

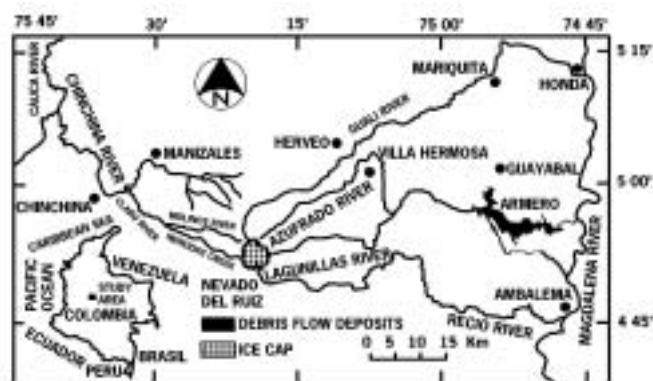


Figure 1 Geographic location of Nevado del Ruiz Volcano.

preliminary planning. Despite their value, however, the utility of hazard maps should not be overemphasized. The production and media publication of a hazard map is not synonymous with risk communication. Indeed, the map itself a familiar tool to a scientist, planner or engineer, may be virtually incomprehensible to individuals unfamiliar with the abstraction of reality on a sheet of paper. Conventional education is no guarantee of the ability to comprehend a map, a problem that becomes more acute as one moves down the communication chain and the literacy of individuals at risk cannot be assumed (Voight, 1990).

Actually, in the case of the 1985 Nevado del Ruiz catastrophe, it was not so important to foresee the beginning of the eruption as to take some simple civil-defense preparedness measures (Barberi *et al*, 1990), which are expected to be based on the map of the likely hazard produced by volcanic activity. A possible tragedy was foreseen by the government and the informed community with the publication of the first version of the hazard maps on 7 October, 1985 and the prediction that Armero ran 100% chance of being seriously affected if lahars were generated. But the map met with strong opposition from economic interests (Hall, 1990).

Besides this, preparation of the hazard maps was not timely. Under ideal emergency-management circumstances, the month-long dead time between its publication and the catastrophe might have been adequate. At Ruiz, however, the delay in producing the hazard maps impeded the mitigation effort, particularly for sites such as Armero and Chinchiná where detailed local maps were essential for the completion and refinement of local management plans and for educating local decision makers and the population on the specific nature of the lahar threat (Voight, 1990).

Hazard communication efforts

It is not easy to explain the uncertainties of volcanic hazards to people not familiar with volcanoes. Often these difficulties lead to confusion, misunderstanding, and strained relations among scientists and persons responsible for the public welfare, such as civil officials, land managers, and journalists (Peterson, 1988).

A generalized version of the October 7, 1985 map was published in color on the front page of the Bogota newspaper *El Espectador* (Fig. 2), unfortunately with errors in map symbols. Articles mentioned “a 100% probability of mudflows...with great danger for Armero, Mariquita, Honda, Ambalema and the lower part of the Rio Chinchiná” (*El Espectador*, Oct. 8, 1985 in Voight, 1990) and “lahars and floods are inevitable...Armero would be evacuated in two hours without danger”. The most notable mistakes in that map presentation are as follows (Fig. 2):

- There is no graphic scale to indicate the sizes of the hazard zones.
- The limits for lateral blasts and mudflows are not clear. The indication that appeared in the original map (Parra & Cepeda, 1990), of whether the hazard is high or moderate for such phenomena is not included.

- Everything seems to indicate that the major threat is by pyroclastic flows, not for lahars.
- Hazard zones are colored in red, blue, yellow and green, but there is no legend that could explain the meaning for each color. The newspaper reader is expected to understand that blue means moderate, although this hazard zone qualification would be more clearly represented in orange, since it appears between the red and the yellow hazard zones.
- Armero is located within the green area, which the newspaper reader is expected to assume as a non-hazard zone. This would mean that Armero was not threatened by Nevado del Ruiz volcanic activity. That differs greatly from the original map conception (Parra & Cepeda, 1990), and with the November 13, 1985 tragic results.
- All cities, towns and even the southern ice-capped volcanoes of Santa Isabel and Quindío, are shown a little too close to Nevado del Ruiz Volcano. Was it safer to represent a human settlement within a hazard zone? If that was the philosophy, why then leave Armero (the most threatened town) outside any volcano hazard zone influence?

Once again, media publication of a hazard map was not synonymous with hazard communication. What was published on the newspaper's front page differed greatly from the original map, and it was not presented in a way that could make it comprehensible to individuals unfamiliar with maps and with volcanoes.

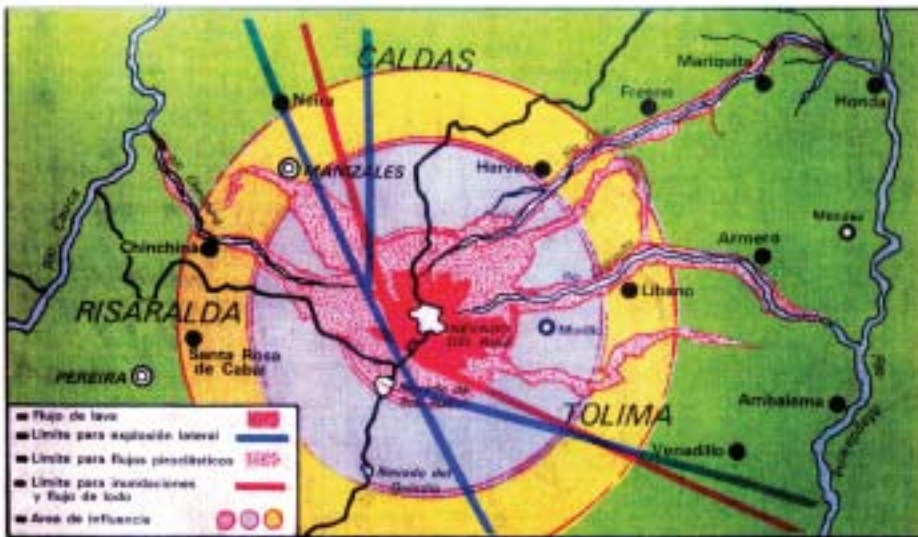
After the catastrophe, *El Tiempo*, another principal daily newspaper of Bogota and Colombia, published the Preliminary Map of Volcanic Hazards of Nevado del Ruiz Volcano in 3-D (Fig. 3). This map gave a perception of topography to the public unfamiliar with maps, allowing them to relate hazard zones to the landscape. The elaboration of this map required painstaking and artistic renderings of topography and the hazard zones. Unfortunately the final result was more artistic than scientific.

The Nevado del Ruiz Volcano hazard map

The conception of volcanic hazard assessment is based on historic and geologically recent records of eruptions, on the premise that the record of past activity provides the best basis for anticipating probable future eruptive behavior. Not taken into account are events that are possible but have not happened before at the volcano being studied or events of much greater magnitude than those in the past (Miller *et al*, 1981).

Several eruption scenarios are discussed in the explanatory text that accompanies the Nevado del Ruiz Volcano Hazard Map (Parra *et al*, 1986; Parra & Cepeda, 1990). These scenarios are based on events of the past 6200 years at the volcano, including those of November 13, 1985 (Fig. 4a). Typical scenarios were modeled after events that occurred during the following eruptions:

- (1) Scenarios involving pyroclastic flows were based on events in:



- Lava flow
- Lateral blast limit
- Pyroclastic flows limit
- Floods and mudflows limit
- influence area

Figure 2 Generalized version of the October 7, 1985 Nevado del Ruiz volcanic hazard map published on the front page of the Bogota newspaper El Espectador (after El Espectador, October 8, 1985).

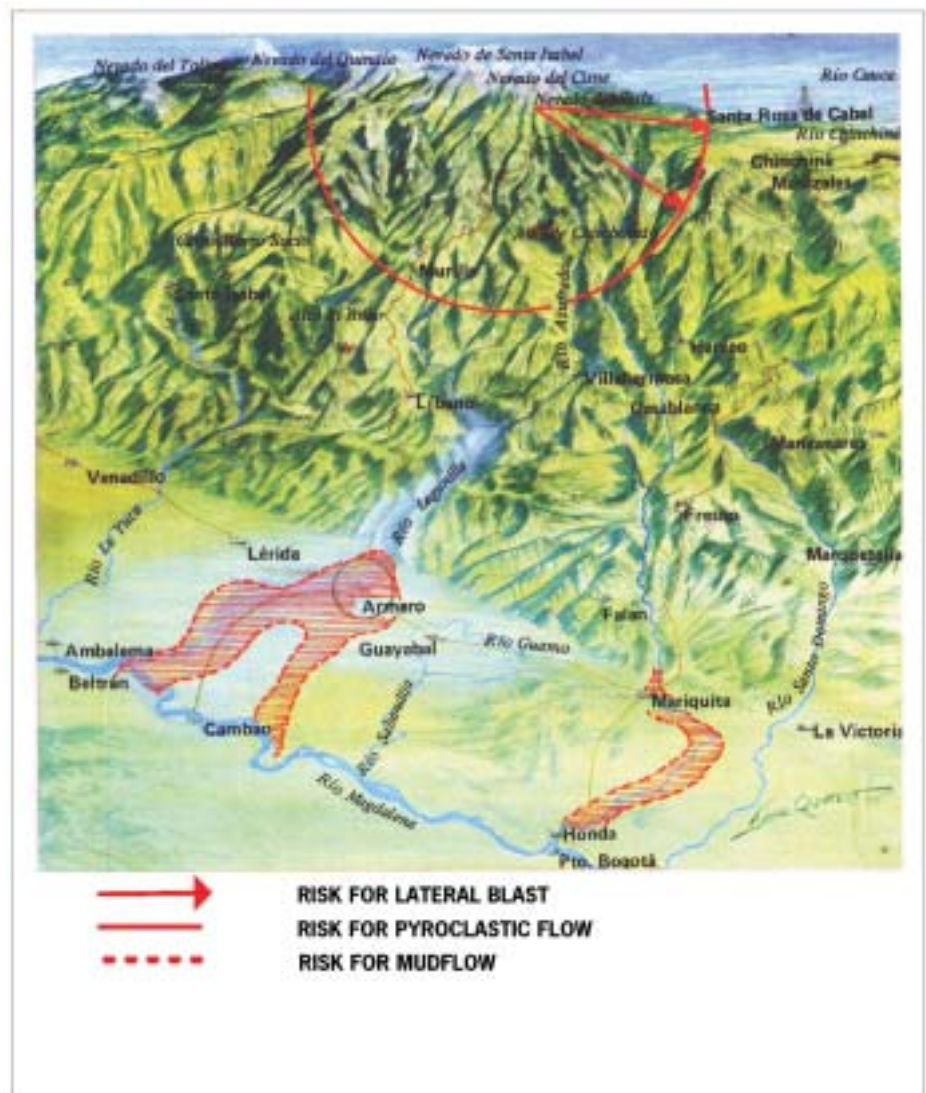


Figure 3 Pictorial perspective view of Nevado del Ruiz Volcano Hazard Map (after Tribuna Geologica, June 1986).

- 6200 years BP
 - March 12, 1595
 - November 13, 1985
- (2) Assessment of hazards from low-angle blasts was based on events during two eruptive episodes.
- 3100 years BP
 - March 12, 1595
- (3) Mudflow (lahar) hazards are based on events that occurred during eruptions on:
- February 19, 1845
 - November 13, 1985

The conceptualization of hazard and risk applied to the areas potentially affected by future volcanic activity follows definitions of UNDRO (1979) (Parra & Cepeda, 1990). A volcanic hazard refers to the potential for damage or destruction from a volcanic event, independent of the existence of inhabitants or property. A volcanic risk refers to the expected consequences of volcanic activity in terms of deaths or injury to the population, destruction of property, or other types of economic loss. These terms were used interchangeably for previous Nevado del Ruiz Hazard Maps. The 1986 version of the map showed risk areas (Parra *et al.*, 1986), but its 1990 version showed the same areas, now denoted as hazard areas, which might be affected by future volcanic activity in accordance with the recent history of the volcano. The 1990 map does not imply analysis of vulnerability and, therefore, is not as a map of risk (Parra & Cepeda, 1990).

Hazard zones on previous maps were classified into high, moderate and low (Fig. 4a). The low hazard zones are those subjected only to unlikely events (e.g. cataclysmic eruptions of the type that have occurred only once or twice in the entire history of the volcano) and to other events that are more likely but of relative low severity (e.g. minor ashfall). When areas of high hazard were immediately adjacent to areas of low hazard, they were arbitrarily separated by a zone of medium hazard 500 m wide (Parra & Cepeda, 1990). The 1990 version of the hazard map combines information on various hazardous phenomena with their relative probability of occurrence (Parra & Cepeda, *op cit.*), but the 1986 version hazard map (Parra *et al.*, 1986) remains the one with the most mass media diffusion (Fig. 4a).

Nevado del Ruiz Volcano Hazard Map in GIS environment

Geographic Information Systems (GIS) are being used by thousands of companies, government agencies, and other entities worldwide for the storage, retrieval, and manipulation of spatially referenced data. Such systems allow for the manipulation of data in a manner that is scale independent. In addition, GIS software includes utilities for placing information into a common projection and datum. This not only allows the data sets to be superimposed, but also gives them geographic content.

The Volcanic Hazard Map of Nevado del Ruiz Volcano was incorporated into a GIS, in order to make it accessible to both casual and expert users. Working in a GIS environment, data sets can be represented spatially in a variety of ways, including points, lines, and areas for so-called “vector” data sets, and grids, images, and scans for “raster” data sets. The Nevado del Ruiz Volcano Hazard Map is a vector data set, which shows different zones exposed to distinct types of volcanic phenomena (Fig. 4a).

In this map, hazard zones were classified into high, moderate and low mainly according to probabilistic criteria, although some times the separation was done arbitrarily, such as for the 500 m wide zone of medium hazard, which was placed where areas of high hazard were immediately adjacent to areas of low hazard (Parra & Cepeda, 1990). The right interpretation of these zones relates to public perception of hazard and understanding the concept of gradational hazard, and to the meaning of lines drawn around hazard zones on a map. Ideally, hazard would be equal everywhere within one zone. Actually, hazard generally increases progressively toward the volcano within any one zone and from the zone to another. Zone boundaries attempt to show points of equal hazard. Theoretically, however, to represent degree of hazard correctly, an infinite number of lines would have to be drawn, each marking successive small increases of hazard as the volcano is approached. In practice, hazard-zone boundaries are seldom more than rough approximations (Miller *et al.*, 1981).

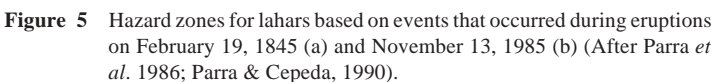
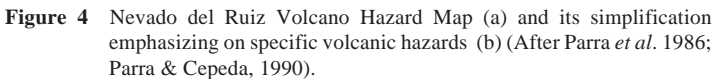
This hazard qualification was not clear to the map users, because hazard zones could be misinterpreted as risk zones (Munoz-Carmona & Monsalve, 2001). In this map, public and property exposure to specific hazards was represented by areas colored in red, orange or yellow, according to the hazard qualification of high, moderate and low, and line and dot patterns outline areas likely to be affected by specific volcanic events. Taking advantage of GIS, a first approach to make the map more useful to the general public is to simplify it, showing only the zones likely to be affected by given volcanic processes (Fig. 4b).

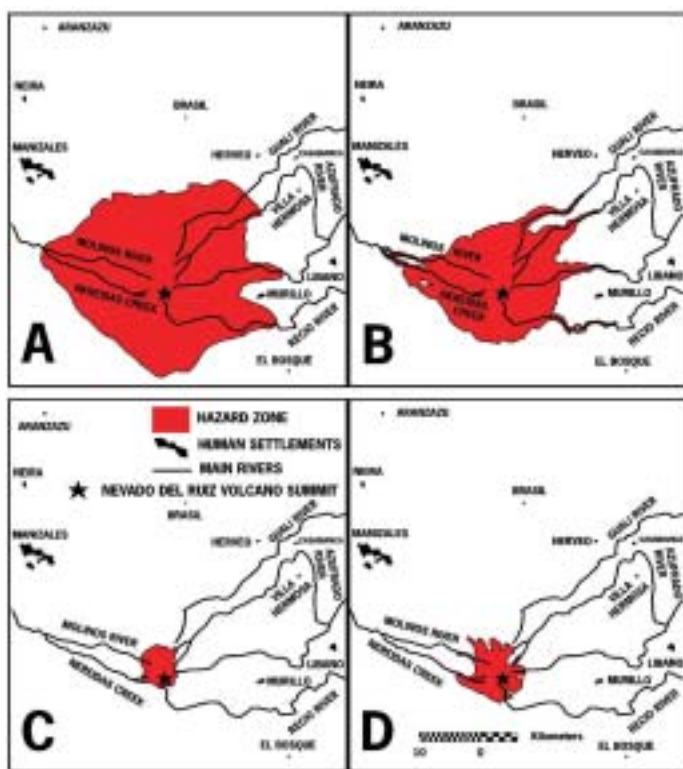
But this simplified map is not clear enough, because hazard areas corresponding to characteristic volcanic processes overlap, so that the presentation is still virtually incomprehensible to individuals unfamiliar with maps. During eruptions, different areas will be affected by various combinations of hazards. People living in different locations will face a variety of volcanic hazards. This shows why the clear identification of areas affected by specific volcanic events is of great importance. The consequences of eruptions may vary greatly, highly concentrated in some areas and barely noticeable in others (Dibben & Chester, 1999).

Volcanic hazard maps should be based on the process that generates the hazardous phenomena in question (therefore providing more elaborate eruption scenarios). Thus a volcanic hazard map (from the expert point of view) should portray the distribution of volcanic products resulting from a particular eruptive process (Munoz-Carmona, 1999). This concept meets the definition of a volcanic hazard map by

Instead of portraying overlapping areas of multiple hazards (Fig. 4b), hazard zones should be displayed individually (figs. 5, 6 and 7). It is then easier to compare different scenarios for given volcanic events. Lahars will be most dangerous for eruptions like that of February 19, 1845, because larger areas will be affected (fig. 5). Pyroclastic flows of the February 19, 1845 eruption covered a smaller area (fig. 6c) than did those of the March 12, 1595 and 6200 years BP eruptions (figs. 6a and 6b). Hazards from low angle blasts are expected to have NE trends for an event like that on March 12, 1595 (fig. 7c), but such hazards are expected to have northward and eastward trends for an eruption like the 3100 years BP one (fig. 7b).

The effective merging of raster and vector technologies was a powerful new software development in the world of GIS. Emphasis in the past centered on the advantages of either raster or vector formats. Now GIS users can have the advantages of both formats as well as the ease of passing data into either format. By combining the speed and flexibility of raster image processing and GIS analysis with relational database capabilities of vector GIS, the user has capabilities previously unavailable.





This hazard assessment provides much information about the volcanic processes that are generating hazards, to the potential users of the volcanic map. Including a more complex color composite would mean additional efforts to explain to the users about anomalous colors on snow (red, violet or blue), vegetation, clouds and water. That is the reason why the selected composite (3R 2G 1B) was considered ideal, because it makes it easy to the non-volcanologist to perceive reality. The human settlements and drainage vector layers are displayed on the mosaic for convenience (fig. 8).

Database visualization

GIS practitioners have focused their attention either on the delivery of hardcopy mapping or the presentation of the results of spatial analysis in a tabular 2-D graphical format. Even though the world around us is inherently 3-D (or 4-D, if one includes temporal aspects), only the “plan” (X & Y) data have generally been recorded into a GIS. The “2-D is good enough” paradigm is slowly subsiding in favor of a more holistic X-Y-Z requirement (Brooke, 2001).

Because most people have difficulty perceiving 3-D features, volcanic hazard maps use elevation data, line patterns, dot patterns and colors to represent 3-D features in a 2-D format. Since the third dimension (topography) used to be the most difficult to perceive, a digital elevation model was created for the study area topographic map by averaging the elevations within the cells of a grid and creating a digital matrix raster data set of these elevations.

One of the most exciting uses of digital topography is in database visualization. For the study area, perspective views for lahars of 1845 type (figs. 9a and 9b), pyroclastic flows of 6200 years BP type (figs. 9c and 9d), and low angle blasts of 3100 years BP type (figs. 9e and 9f) may be generated by combining the digital terrain data with the hazard polygons superimposed on the Landsat TM 5 mosaic. 3-D visualization enables manipulation of the position and viewing direction of a virtual observer. Several positions were emulated (fig. 10), as well as viewing parameters such as the number of meters above sea level (ASL), the angle of the field of view (FOV), the pitch of the observer to the image, and the observer's azimuth (table 1).

Table 1 Viewing parameters of perspective views showed on figure 9.

PERSPECTIVE VIEW	ASL meters	FOV degrees	AZIMUTH degrees	PITCH degrees
a	41175	60	309.03	- 52.2
b	41175	60	146.34	- 50.15
c	37892.8	60	284.65	- 48.81
d	43475.8	50	137.81	- 47.96
e	23175.2	70	269.89	- 45
f	36400	60	180.22	- 57.74

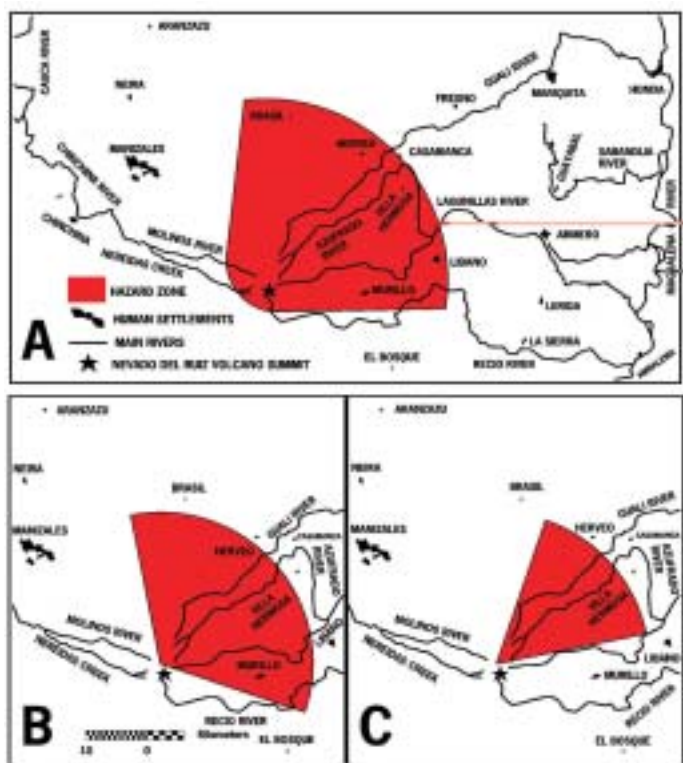


Figure 7 Hazard zones for ash fall (a) and assessment of hazards from low angle blasts based on events during the 3100 years BP (b) and March 12, 1595 (c) eruptions (After Parra *et al.* 1986; Parra & Cepeda, 1990).

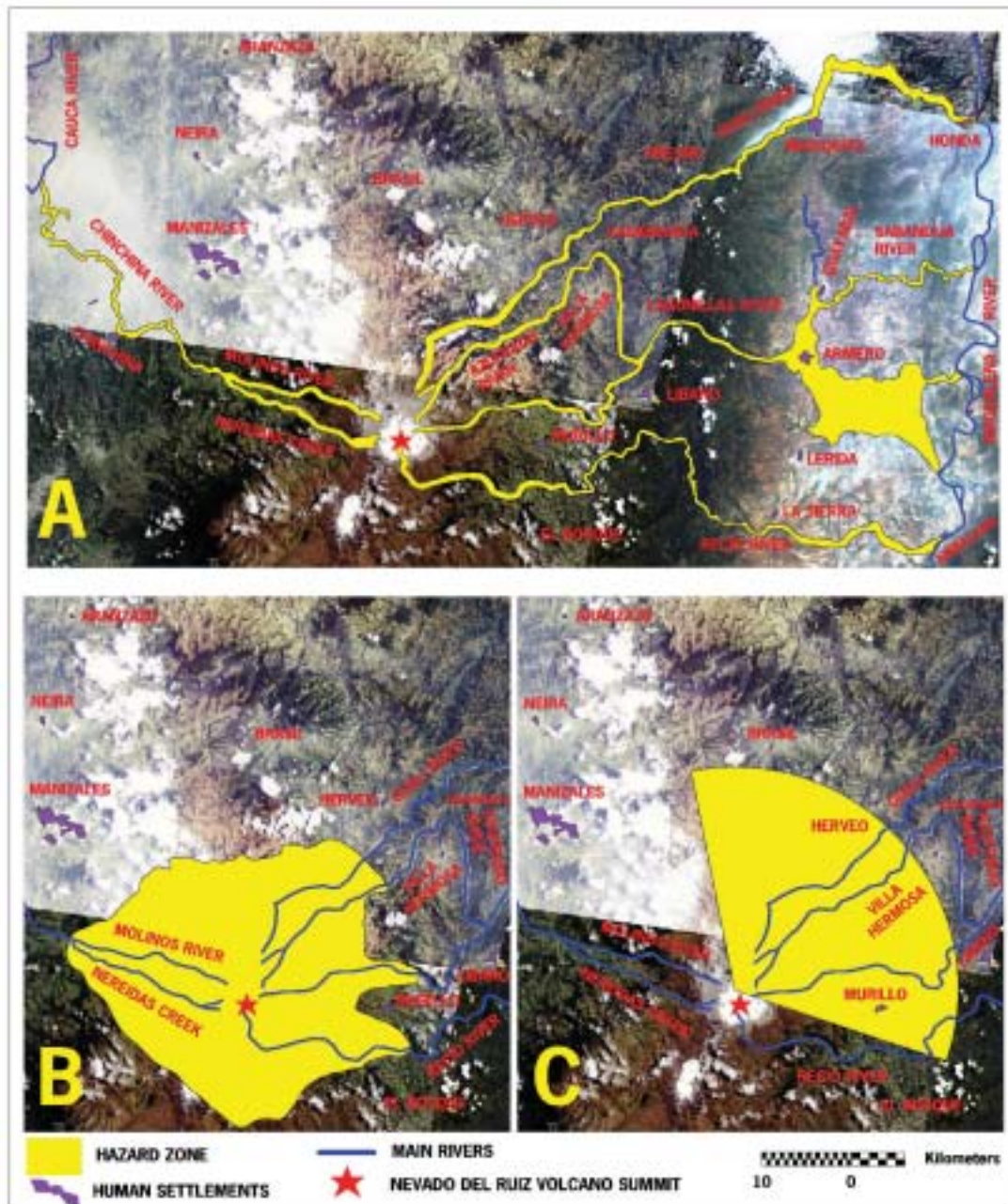


Figure 8 Hazard zones for lahars of 1845 type (a), pyroclastic flows of 6200 years BP type (b) and low angle blasts of 3100 years BP type (c) superimposed on Landsat TM 5 mosaic color composite RGB 321 (After Parra *et al.* 1986; Parra & Cepeda, 1990).

Database visualization in three dimensions has become the most common display of information, enabling hazards data for Nevado del Ruiz Volcano to be more readily understood by decision makers and the general public. Inexpensive desktop hardware and software now available commercially allow GIS, mapping and remote sensing users to “fly” or “drive” through their databases (Brooke, 2001). In the past, the process of draping different hazard zones over digital elevation models, to create perspective views of the hazard zones and simulated landscape, required painstaking, artistic renderings of topography and the hazard

map polygons (Fig. 3). Digital maps are easier to create, manipulate and modify.

Conclusions

The Volcanic Hazard Map of the Nevado del Ruiz Volcano in GIS environment offers more choices for relating hazard zones to the landscape, being specially effective in helping volcanologists communicate with the public. Database visualization in 3-D is a very good methodology to display volcanic hazard information, since it enables complex data

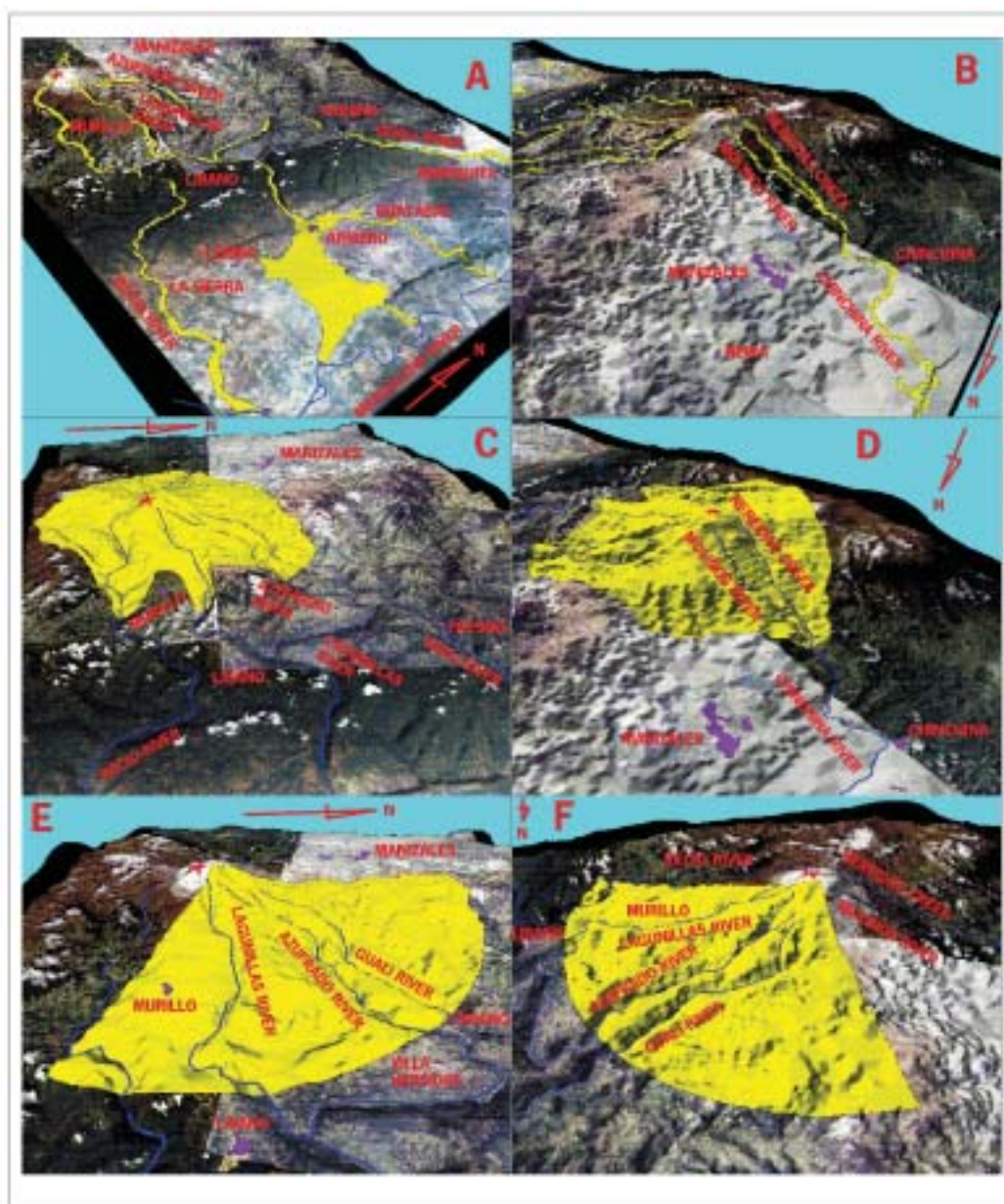


Figure 9 Perspective views for lahars of 1845 type (a and b), pyroclastic flows of 6200 years BP type (c and d), and low angle blasts of 3100 years BP type (e and f).



Figure 10 Location of perspective views showed on figure 9.

such as Nevado del Ruiz Volcano hazards to be more readily understood by decision makers and the public.

GIS can be used as a communication technology to conduct lively continuing education programs, which effectively transfer information about volcano hazards from scientists to people responsible for the public welfare and to public citizens exposed to volcanic hazard.

Acknowledgements

This work was supported by INGEOMINAS (the Colombian Geological Survey), which provided the

Nevado del Ruiz Volcano hazard map information layers, the volcano's influence area Landsat TM 5 mosaic, and remote sensing and GIS processing facilities. The author is indebted to Dr. Donald A. Swanson and two anonymous reviewers for comments on earlier versions of this paper.

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