Methodology for zoning by earthquake threat in the department of Cordoba (Colombia), using Geographic Information Systems

Metodología para zonificación de amenaza por Sismos en el Departamento de Córdoba (Colombia), utilizando Sistemas de Información Geográfica

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Abstract

Earthquakes are one of the most unpredictable natural phenomena and once they have occurred, they generate impacts on the population and infrastructure in relation with its magnitude. Therefore, analyzing the territory to know the areas threatened by this natural event is very useful in order to take the measures to minimize those impacts. In this sense, this study identifies areas with seismic hazard in the department of Cordoba, using Geographic Information Systems and the use of heuristics, which are implemented from weighting and rating according to the application of the fundamental scale of Saaty [8], to each of the analysis variables: seismic inventory, geological faults, slopes, and soil texture. Results found that areas with high seismic hazard are located on the east, northeast and south of the department, the medium threat are located towards the western, central and northern part and finally the low threat are distributed throughout the department.

Keywords: Earthquakes, Natural hazards; heuristic.

Resumen

Los sismos son uno de los fenómenos naturales más impredecibles y una vez ocurren generan impactos sobre la población y la infraestructura, acordes con su magnitud. Por lo tanto, analizar el territorio para conocer las zonas de amenaza por este evento natural es muy útil para tomar las medidas que minimicen dichos impactos. En este sentido, el estudio permite identificar las zonas con amenaza sísmica en el departamento de Córdoba, empleando los Sistemas de Información Geográfica y el uso del método heurístico; que se implementa a partir de ponderaciones y calificaciones acorde a la aplicación de la escala fundamental de Saaty [8], a cada una de las variables de análisis: inventario sísmico, fallas geológicas, inclinación de las pendientes y textura del suelo. Encontrándose como resultado que las zonas con amenaza sísmica alta se localizan en la parte este, noreste y sur del departamento; las de amenaza media se ubican hacia la parte oeste, centro y parte norte y por último, las de amenaza baja, están distribuidas por todo el departamento.

Palabras claves: Sismos; Amenazas naturales; Método heurístico.

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Introduction

In Colombia, the study of natural hazards by seismic events is of great interest, because this phenomenon has left human and material losses and very unfortunate complex social situations. In recent decades there have been reports on different scales to estimate damage and occurrences of this phenomenon conducted by different organizations and institutions working hand in hand to obtain reliable and effective results. The Department of Córdoba is no stranger to this natural phenomenon, it is located in an area of high and intermediate threat according to the seismic hazard map by INGEOMINAS published in 2007 [6]. This situation conditions and represents danger for the population of the department, which is why this work is developed in order to implement a methodology which allows the zoning of seismic hazard, to a more detailed level parting from correlated factors.

Methodology

The development of this research consists of the following stages:

1. Data collection. For each of the layers of information the following data was consulted and obtained:
   - Seismic inventory: Earthquakes reported in the seismic catalog by the Seismological National Network[4] from June 1, 1993 and located in the Department of Cordoba, which contain information on the magnitude and intensity of the event.
   - Fault report: geological faults reported by the Colom-bian Institute of Geology and Mining - INGEOMINAS and available from the website of the Geography Institute Agustin Codazzi -IGAC from the link SIGOT[5]. This layer of information was updated from the report of the Autonomous Corporation for the Valleys of Sinu and San Jorge [1], which details the activity of some faults present on the Department of Cordoba.
   - Digital Elevation Model: terrain heights calculated from stereoscopic pairs using the Aster system, with a pixel size of 30 meters.
   - Soils: Information of the General Soil Survey and Land Zoning - Department of Cordoba [5].

2. Data weighting. According to the methodology for studies on the evaluation of natural threats, heuristics was used, which is based on knowledge of the terrain, the compilation, and evaluation of information. The application of this method parts from establishing the subjective ratings to cartographic units of each parameter and weights to the variables to be integrated. For the establishment of the weighting the method for hierarchical analysis proposed by Thomas Saaty [4], which compares the criteria according to the importance of each one of them with others, providing a quantitative measure of the judgments among the factors.

3. Spatial processing. Once the information defined by the analysis was collected, we proceeded to standardize the information and design the database. Using functions to spatial analysis and using the tools for the Geographic Information Systems the data was classified and integrated in raster format, resulting in intermediate layers and the final stage of the zoning of the natural threat of earthquakes.

Results - Discussion

Rating for the cartographic units of analysis. Criteria and quantitative analysis were defined for each of the data layers. The ratings were established on a scale of 1 to 5, in which the value 1 corresponds to a low degree of importance and the value 5 to the largest degree.

Table 1 shows the rating for each seismic event according to the degree of magnitude. A greater degree of energy releases further qualification.

[4]http://seisan.ingeominas.gov.co/RSNC/
[5]http://sigotn.igac.gov.co/sigotn/default.aspx

Table 1. Rating for each seismic event.

MAGNITUDE OF THE QUAKE	RATING
<3,5	2
>=3,5	5

Table 2 represents the ratio of influence or effect that an active fault can present, according to the study conducted by the Venezuelan Foundation for Seismological Research (FUNVISIS for its acronym in Spanish) [7] and the rating established according to its activity.

Table 2. Influence around of the fault and rating.

TYPE OF FAULT	INFLUENCE	RATING
ACTIVE	15 km	5
INACTIVE	100 m	1

According to the steepness of the slope ratings were established in accordance with the effect to a seismic wave and possible action triggered by other natural phenomena, such as the case of landslides [2], see Table 3.

Table 3. Rating for the steepness of the slope.

PENDING	RATING
0 -3%	1
3-7%	2
7-12%	3
12-25%	4
> 25%	5

Soils play an important role in the analysis of seismic hazard, since certain properties such as the case of the water table, soil depth, the constituent material and its texture facilitate its movement because of the seismic wave. More clayey textured soils tend to have a higher degree of incidence or susceptibility to the threat by seismicity [3]. Table 4 presents the ratings defined.

Table 4. Rated by soil texture.

TEXTURE	RATED
Loamy sand	2
Sand	2
Silt loam	3
Sandy Loam	3
Frank	3
Silty clay loam	4
Sandy clay loam	4
Clay Loam	4
Clay loam	5
Sandy clay	5
Clayey	5

For the final analysis of the information the percentages given in Table 5 were defined, according to the importance of each of the variables.

Table 5. Weights to each of the factors of analysis.

INFORMATION	WEIGHT
Seismic Inventory	30%
Faults	15%
Soils	30%
Pending	25%

Spatial integration of data. Once the database was standardized and implemented we applied spatial functions, which are presented in Figure 1, resulting in rated areas with degrees of susceptibility to seismic threat in low, moderate and high, from the weighted sum of each one of the rated factors.

According to the results the following zones are identified and classified as seismic hazard areas in the department of Córdoba (see Figure 2):

- **Areas classified as high threat:** are located in the east, north and south of the Department of Cordoba; includes the municipalities of San José de Uré, Montelibano, Puerto Libertador, Buenavista, La Apartada, Planeta Rica,

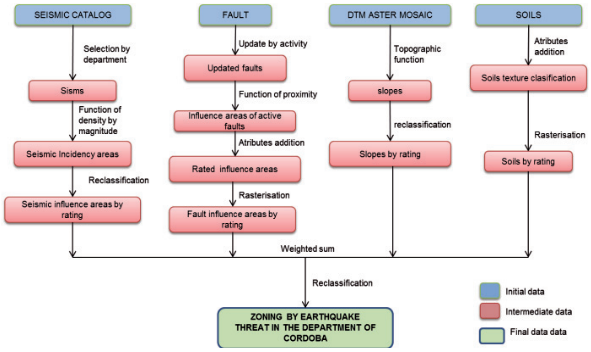

Figure 1. Functional cartographic model.

Ayapel, Pueblo Nuevo, Sahagun, Chinu, San Andres de Sotavento, Tuchin, Purisima, Momil, San Antero, Chima, Lorica, Moñitos, Puerto Escondido, San Pelayo, Monteria, Cerete, and Tierralta. Some of these municipalities despite having teluric movements, are not highly affected for appearing in areas with little infrastructure.

- **Medium threat areas:** are located to the western, central and northern part, includes the municipalities of Valencia, Canalete, Los Cordobas, The northeastern part of Montelibano, the northwestern part of Ayapel, with exception to Montería and its northern part, San Bernardo del Viento, Eastern Lorica and Cienga de Oro and the southeastern part of Chima. These municipalities have clayey textured soils, low slopes and low faulting.

- **Low risk areas:** these areas are distributed throughout the department, especially in the municipalities of Valencia, Canalete, Los Cordobas, the northwestern part of Montelibano, the northwestern part of Ayapel, with exception to Northern Monteria, San Bernardo del Viento, east of Lorica, east of Cienaga de Oro and the southwest tof Chima. These municipalities are characterized by clayey textured soils, low slopes and low faulting.

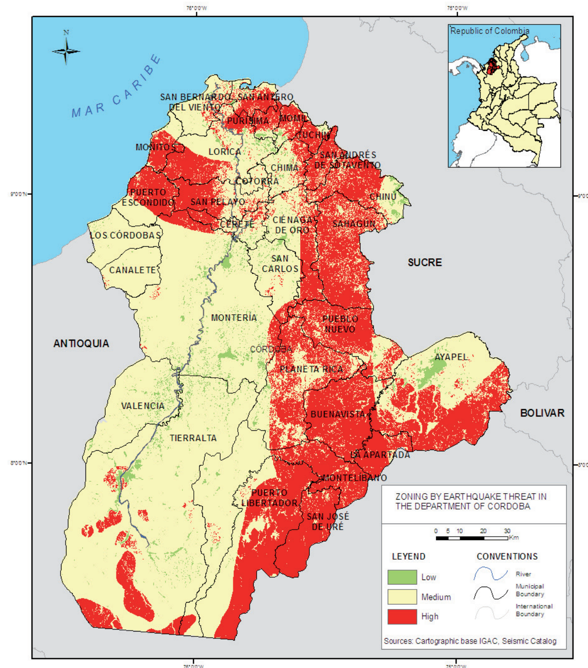

Figure 2. Zoning threatened by earthquakes in the Department of Córdoba.

Conclusions

From the results it can be concluded that the high threat areas, comprise 25% of the department, which are along the fault lines of Romeral, Cauca Almaguer fault and the fault of Santa Rita, associated to such a large number of seismic events of different magnitudes. The soils in this area are, for the most part, clay texture, which have increased susceptibility to seismic events, just as the percentage of Slopes are between 12 and 25%, ranking well in the municipalities of: San José de Ure, northeast of Montelibano, Puerto Libertador, Buenavista, La Apartada, Planeta Rica, southeast of Ayapel, Pueblo Nuevo, Sahagun Chinú, San Andres de Sotavento, Tuchin, Purisima, Momil, San Antero, north of Chima, north and southwest of Lorica, Moñitos, Puerto Escondido, west of San Pelayo, north and west of Monteria Cerete, in the municipality of Tierralta areas are located in the southern part which combines the high percentage of slopes and the large number of seismic events recorded.

The medium threat covers an area of 67% of the depart-ment, which has no active fault records, the degree of inclination of the slope is between 3 and 7%, the seismic records are lower, but still soils in large Most clay, are part of this area the municipalities of Valencia, Paddle, Los Cordobas, the northwestern part of Montelibano, the northwestern part of Ayapel, Monteria except its northern San Bernardo del Viento, east of Lorica, the the Cienaga de Oro and southwest of Chima.

Low threat area covers an area of 8% of the department, in which the slopes have a slope percentage of 0 and 3%, have no active faults, low seismic events recorded, in the same way, soils in these areas are the least susceptible to seismic events, are in this area: southern Monteria Ayapel northern, northeastern Valencia, Tierralta northern, eastern Chinu, Cerete southern, northern San Carlos, western Cienaga de Oro, Chima northwest, and east of Lorica.

Bibliography

[1] CVS. (2005). Diagnostico ambiental de la cuenca hidrográfica del Río San Jorge. Capítulo 10: Amenazas Naturales.

[2] CVS, (2004). Diagnostico ambiental de la cuenca hidrográfica del Río Canalete.

[3] Flórez, H. (1993). Zonificación sísmica preliminar de Barrancabermeja. Universidad de los Andes. Santafé de Bogotá.

[4] Geoff Coyle, 2004. The analytic hierarchy process (AHP). Pearson Education Limited.

[5] IGAC. 2009. Estudio general de suelos y zonificación de la tierra - Departamento de Córdoba.

[6] INGEOMINAS, (2007). Mapa de zonificación de amenaza por sismos a nivel nacional.

[7] Liberal, L, et al. (2005). FUNVISIS. Universidad Central de Venezuela.

[8] Zanazzi, J. (2003). Anomalías y supervivencia en el método de toma de decisiones de Saaty. Editorial Universitaria. Universidad Nacional de Córdoba.