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Generation of a Map of Seismic Events that Occurred in Colombia during the Last Decade

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Abstract

Earthquakes are one of the natural phenomena that usually have the greatest impact on society, often generating important changes in the environment and causing great material losses and human lives. In the case of Colombia, a large part of its territory is located in the Andean mountain range area, being also the region with the highest population density in the country, which is why most of the Colombian population is exposed to the occurrence of seismic events, during some time of life. For this reason, it is of particular interest to know first-hand the frequency of occurrence of these seismic events, as well as the characteristic magnitudes, within a given region. In this work, a map of seismic events is presented as an essential result, where it can be observed how the earthquakes registered within the period 2010 - 2019 have been distributed throughout the geography of the country and earthquakes with magnitudes between 4.0 and 6.4 on the Richter scale were selected. When comparing the map obtained with the one proposed in the Reglamento Colombiano de Construcción Sismo Resistente (NSR-10), for the design of earthquake resistant constructions, some similarities could be observed in general. However, there were also some differences of interest, which is why the importance of carrying out this type of work is highlighted, in order to be able to make the adjustments that are necessary to be able to generate designs that better fit to the particular conditions of each site.

Keywords: seismic events, seismic risk zone, magnitude, Richter scale

I. INTRODUCTION

Seismology is the science that is in charge of studying the aspects related to telluric movements, shakings or earthquakes, and it is a relatively young branch, but that has made notable advances and has given great contributions to society [1], making it possible, the reduction of the damage caused by catastrophic events, but without reaching even today, to be able to predict these phenomena [2]. In any case, their contributions have been so significant that they have contributed tools, methodologies and information to have a better understanding and "control" of these natural phenomena.

Earthquakes are sudden releases of accumulated energy in rocks inside the earth; which generate seismic waves that propagate in all directions to the earth's surface, when they break. Earthquakes are considered one of nature's greatest threats to people [3]. These phenomena when are of great magnitude, can generate great damage and a strong impact on society.

In the case of Colombia, during the last years, there has been greater interest in the study and understanding of these phenomena at national and regional scale, emphasizing the evaluation of the seismic threat, which has been studied by different institutions, among them the

Servicio Geológico Colombiano (SGC). These entities have made great contributions to the knowledge and preparation of the population for these types of environmental phenomena. As an example, have the update of the Colombian Construction Code (Reglamento Colombiano de Construcción Sismo Resistente version 2010 – NSR -10), where models and calculations were applied to determine the seismic threat in a more accurate and refined way, for which made use of an important database consisting of records of seismic events [4], resulting in a more congruent regulation with the seismic characteristics of the different regions of the country.

The effort to study the country's seismic threat has paid off. Among the most representative achievements, there is the obtaining of hazard maps for the country, as well as hazard curves and uniform hazard spectra for principal cities; these results, which have been important for the definition of the seismic coefficients for the earthquake resistant design, as well as for the calculation of the seismic risk [5]. In this way, it is affirmed that studies of seismic risk and threat are of special importance for the development of the country, because they allow the design and construction of new buildings and infrastructure, as well as the reinforcement and rehabilitation of existing ones, according to with an appropriate threat level [4].

It is worth noting the importance of keeping the record of earthquakes that occurred within a geographic area up to date, as well as combining new technologies with new techniques and analysis methodologies, in order to obtain seismic hazard studies that are more in line with reality, above all, using technologies such as Geographic Information Systems [6] and new measurements of seismic activity with more precise measuring instruments.

The objective of this work is focused on making a count of the earthquakes that occurred during the last decade (2010 - 1019), in Colombia. For which, all earthquakes reported from the National Seismological Network of Colombia of the Colombian Geological Service were analyzed, with a magnitude greater than or equal to 4.0 on the Richter scale. The information was taken and organized to observe the behavior by year of the earthquakes, as well as by departments, to look at their evolution over the years and determine the places where the greatest number of them have occurred. Lastly, a map of seismic events was made, the purpose of which has been to contrast it with the seismic hazard map proposed in the Colombian Code NSR-10.

II. MATERIALS AND METHODS

The data provided with reference to the seismic events that occurred in Colombia were obtained from the public data repository of the Gobierno Nacional de Colombia. The information was collected, processed and provided by the Servicio Geológico Colombiano (SGC), which through its Red Sismológica Nacional de Colombia (RSNC) has registered the seismic activity that has occurred in the country in recent years. As of 2015, after the network was updated, it had 53 satellite stations, 13 short-term and 40 broadband [7], equipped with seismological and accelerographic measurement instruments that allow the monitoring of seismic events in all locations within the territory of the country.

The information compiled in the database contains the data on the earthquakes that have occurred in Colombia and is discriminated by hourly frequency, also categorizing them in time, in relation to the hour, day, month and year of occurrence. The data is made up of the geographic location of the seismic event, discriminated by department, municipality and geographic coordinates (latitude and longitude). Additionally, the characteristic information of the earthquakes is presented, such as the magnitude, depth, RMS, GAP and the error ranges of the measurements in latitude, longitude and depth.

For this work, the events that occurred within the period between January 2010 and December 2019 were taken as a reference. During this time interval, a total of 155,108 seismic events with intensities between 0.10 and 6.10. The seismic magnitude for these cases is measured in ML (Local Magnitude) which is defined as the quotient or difference of two algorithms as presented in Equation 1 [8].

$$ML = log\,[A(d)/AO(d)] = log\,A(d) - log\,AO(d) \quad (1)$$

Where:

ML, is the local magnitude; log A (d), is the logarithm of the maximum amplitude in mm, measured in the seismogram performed by a Wood-Anderson torsion seismograph; and log AO (d), is the logarithm of the amplitude of the same pattern (-log AO (100) = 3). Both log A and log AO are a function of the epicentral distance (distance from the epicenter to the registration site).

The above described is nothing other than the Richter scale, which is the most used in the world to measure seismic activity and receives its name in honor of the seismologist Charles Richter who designed the scale [9], with the purpose to measure the magnitude of the same from the waves registered in a seismograph. This scale increases exponentially, being that each point up the scale a represents 10 times the movement and 30 times the energy of the previous level [10]. Based on this variable, it was decided to make a choice of magnitudes from a certain value to reduce the number of seismic events to be considered in the study. For this purpose, earthquakes with magnitudes greater than 4.0 were chosen, since they are considered as earthquakes of the category “Light” and minor earquake felt by humans [11], [12], [13], as shown in Table 1.

Tabla 1. Description of magnitude classes used to describe earthquake size.

Magnitude	Class	Damage	Earthquake Effects
3.0 – 3.9	Minor	None	Usually not felt, but can be recorded by seismograph
4.0 – 4.9	Light	None/Very light	Minor earthquake felt by humans
5.0 – 5.9	Moderate	Very light	Damage may occur
6.0 – 6.9	Strong	Light	Damage can occur
7.0 – 7.9	Major	Moderate	Damage expected
8 or more	Great	Heavy	Significant damage expected

From this data separation, a total of 716 seismic events with intensities greater than or equal to 4.0 that occurred between 2010 and 2019 could be obtained.

The objective of this study is focused on the generation of a map of seismic events that occurred in Colombia, where the magnitude values are shown by geographical region of the country, which is achieved by using the tools of the Geographic Information System (GIS), in order to contrast said information with the seismic hazard maps by zones, which are presented in the Colombian earthquake resistant code NSR-10.

In Fig. 1, a map is shown where the number of seismic events with magnitudes greater than 4.0 is represented, without discriminating the magnitude. The map was constructed making the geographical delimitation by departments, in accordance with the political division of the country.

Table 2 shows the number of earthquakes that occurred during the period 2010 - 2019, showing the data by department and magnitude of seismic events, the latter being divided into four categories: 4.0 - 4.2, 4.2 - 4.5, 4.5 - 5.0 and over 5.0.

From the information filtered by magnitude of intensity of the earthquakes, some figures were built in order to observe the derivation of the earthquakes by intensity across the months and years of the study period.

Table 2. Seismic events by department and magnitude

Department	4.00 - 4.20	4.20 - 4.50	4.50 - 5.00	> 5.00	Total
Amazonas	0	0	0	0	0
Antioquia	6	5	6	2	19
Arauca	1	1	1	1	4
archipiélago de San Andrés	1	0	1	0	2
Atlántico	0	1	0	0	1
Bogotá	0	0	2	1	3
Bolívar	1	1	0	0	2
Boyacá	5	2	3	0	10
Caldas	3	0	1	1	5
Caquetá	0	0	0	0	0
Casanare	1	1	2	0	4
Cauca	2	5	3	1	11
Cesar	2	2	5	2	11
Chocó	21	21	12	5	59
Córdoba	0	2	0	0	2
Cundinamarca	3	1	1	0	5
Guainía	0	0	0	0	0
Guaviare	0	1	0	0	1
Huila	6	0	4	3	13
La Guajira	6	5	9	4	24
Magdalena	3	2	0	0	5
Meta	15	13	4	2	34
Nariño	9	8	2	5	24
Norte de Santander	2	4	4	2	12
Putumayo	3	0	0	0	3
Quindío	0	1	1	0	2
Risaralda	0	1	0	0	1
Santander	132	115	70	16	333
Sucre	2	0	0	0	2
Tolima	4	2	1	3	10
Valle del Cauca	7	9	8	2	26
Vaupés	0	0	0	0	0
Vichada	0	0	0	0	0
Outside the country	15	28	28	17	88

On the other hand, and as an essential objective, using the tools of the Geographic Information System, a map of seismic events that occurred for Colombia during the period from 2010 to 2019 was elaborated. For this purpose, the ArcMap program from Argis was used, and was able to generate a map where the seismic magnitudes for the entire Colombian terrestrial territory are interpolated and classified by color. The interpolation process used is called Inverse Distance Weighted (IDW). Interpolation using IDW, calculates spatial values through a linearly weighted combination of a set of points in a sample. The weighting is a function of the inverse distance and it is assumed that the surface to be interpolated must be that of a variable dependent on the location [14], [15]. Based on this, a map is generated where the places where geographically similar values of magnitudes of seismic intensity are represented by zones.

Based on the above information and making use of the simian hazard map of Colombia (Fig. 4), a comparison was made between the magnitudes of the earthquakes that occurred in the last 10 years, with the hazard map proposed in the NSR-10 code.

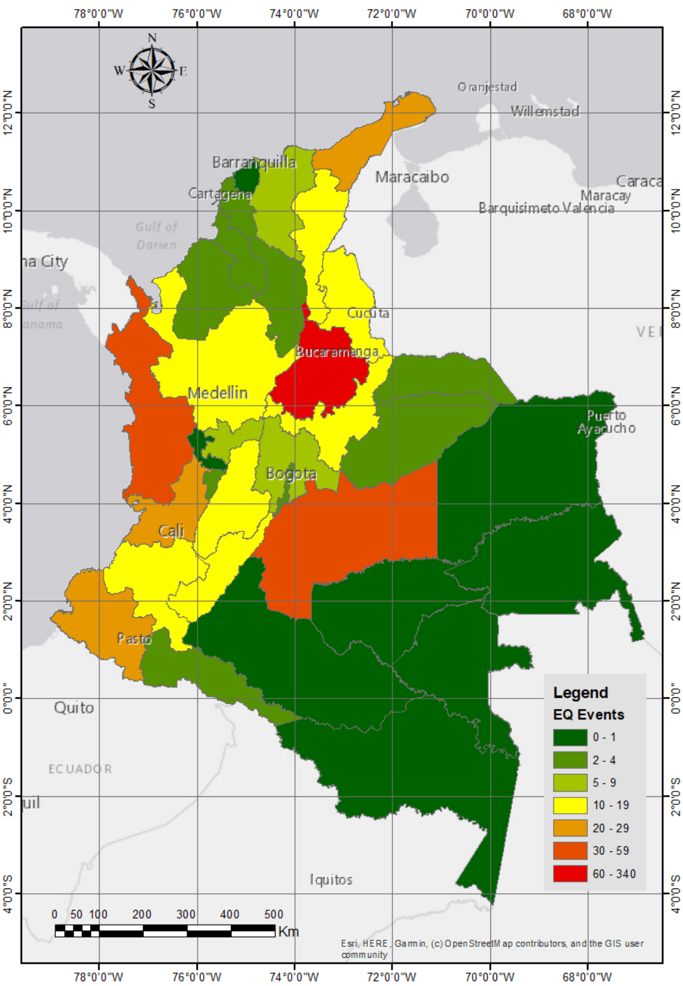

Fig. 1. Seismic events in Colombia by department

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III. RESULTS

Based on the seismic information analyzed and processed, figures were created showing the occurrence of seismic events by intensity ranges for periods of years and months during the period from 2010 to 2019. Additionally, a map of seismic events was constructed, where the seismic events are presented by intensities for the study period.

Figures 2 and 3 show the number of seismic events by ranges, which occurred per month and per year, respectively. In total, 4 ranges of earthquake magnitudes were selected, which were: 4.0 - 4.2, 4.2 - 4.5, 4.5-5.0 and over 5.

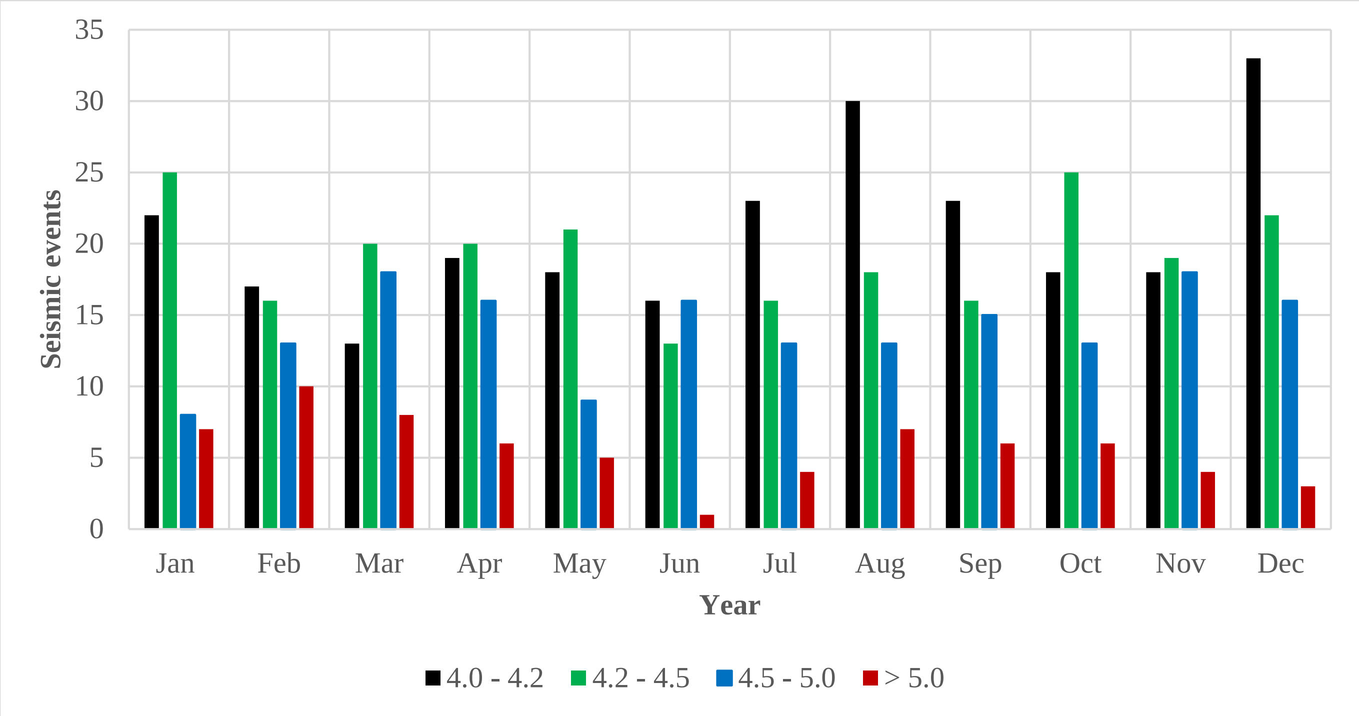

Fig. 2. Seismic events in Colombia by months

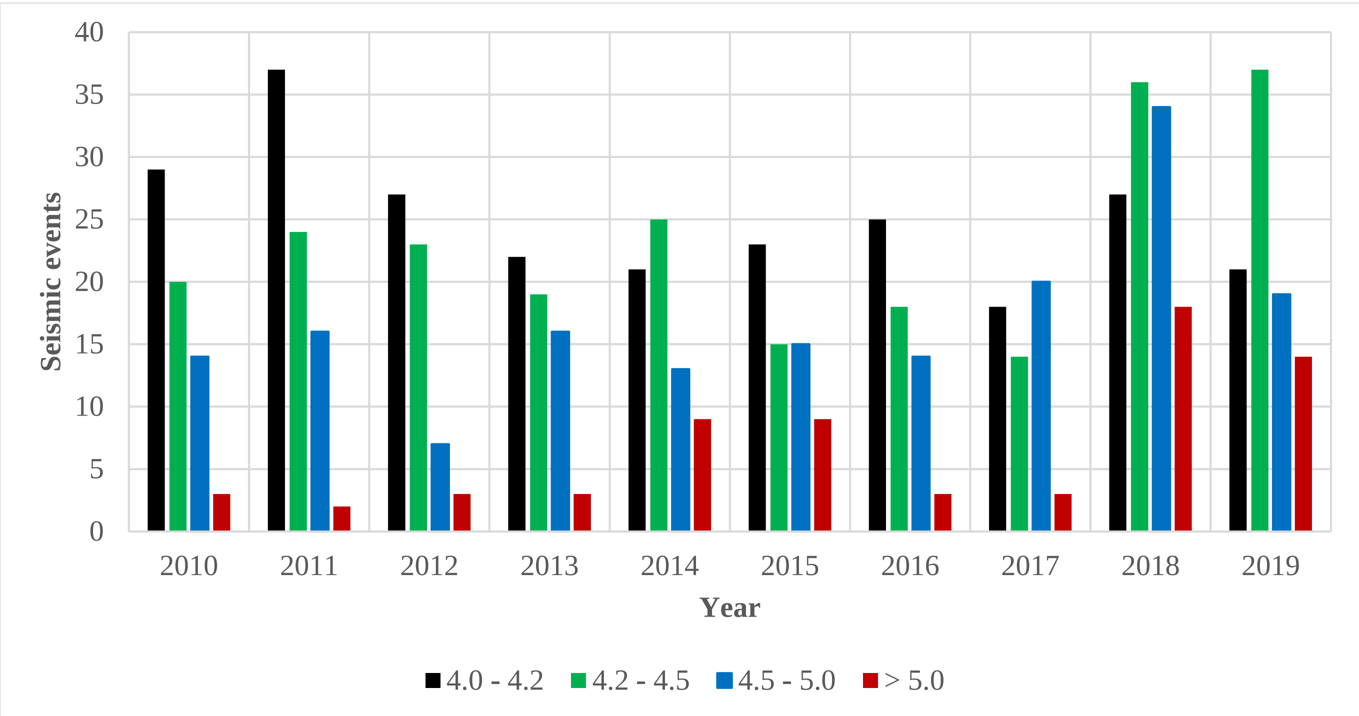

Fig. 3. Seismic events in Colombia by years

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Fig. 4 shows the seismic hazard zones in Colombia, which are those recommended in the NSR-10, for the seismic evaluation of general-use structures designed and built in the country. The norm categorizes the zones in three levels: Low, Intermediate and High; where areas with High seismic threat are more likely to present events of greater magnitude and with greater frequency than Intermediate and Low ones.

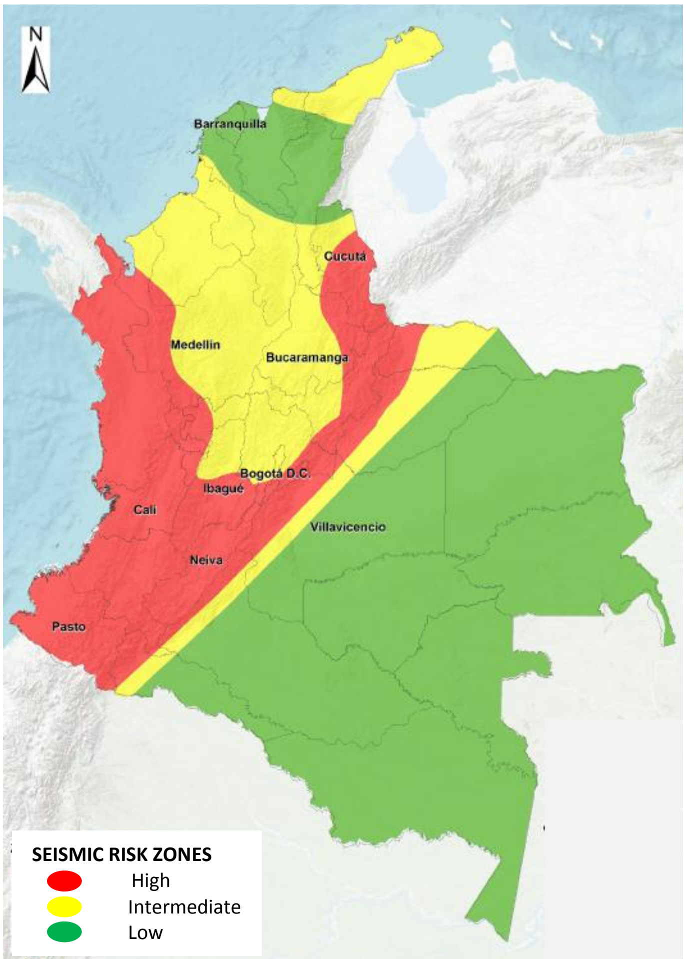

Fig. 4. Seismic Hazard Zones in Colombia – Source: Instituto Distrital de Gestión de Riesgos y Cambio Climático.

Fig. 5 graphically presents an interpolation of the magnitudes of all seismic events with a magnitude greater than 4.0 that occurred in Colombia during the period from 2010 to 2019. This map was generated, considering 716 seismic events that occurred in the Colombian territory. The IDW interpolation method was used and the limits of the ranges of the earthquakes were chosen in such a way that a comparison could be made with the seismic hazard map proposed by the NSR-10 seismic building code.

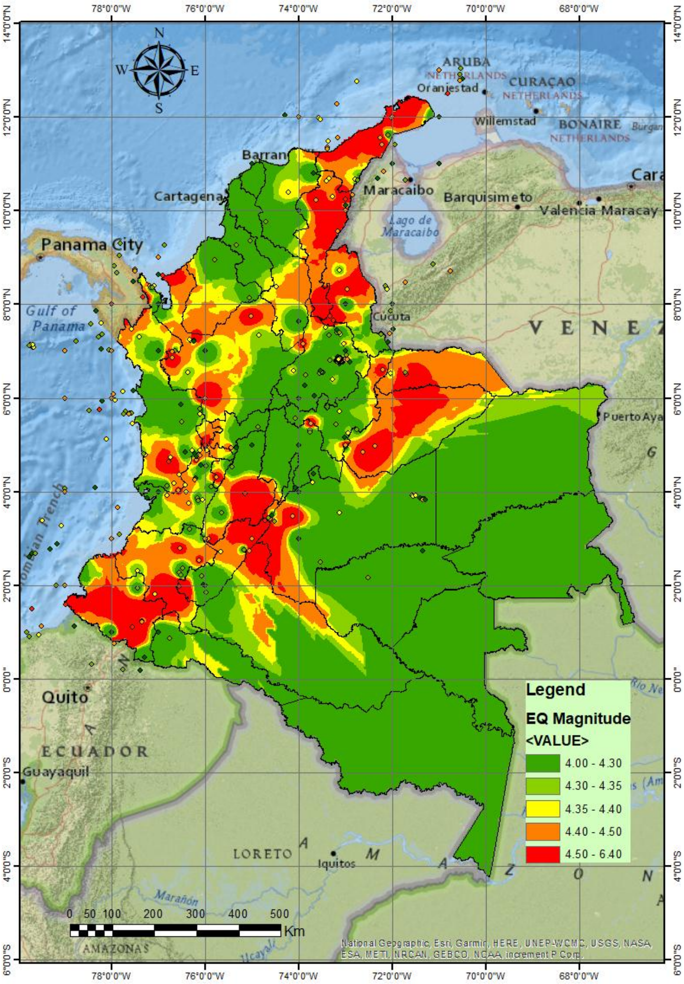

Fig. 5 Map of seismic events for the last decade

IV. CONCLUSIONS

Based on the results obtained in this work, it can be concluded:

The department where the greatest number of seismic events have occurred has been Santander, which represents approximately 47% of earthquakes with a magnitude equal to or greater than 4.0, and it is also the area of the country where the greatest number of earthquakes occur with magnitudes greater than 5.0. The departments with the highest number of recorded earthquakes, after Santander, are: Chocó, Meta, Valle del Cauca, Nariño and La Guajira, as can be seen in Fig. 1 and Table 2.

From Fig. 2, it can be concluded that during the last 10 years, for earthquakes greater than or equal to magnitude 4.0, earthquakes of greater magnitude tend to occur during the first months of the year and those of lesser magnitude at the end of the year. On the other hand, in Fig. 3 it is observed that in the first years of the study period, the earthquakes that predominated were those of the lowest magnitude, observing a clear increase in the occurrence of earthquakes of greater magnitude over the years.

Making a comparison of the Seismic Hazard Map for Colombia and the map of seismic events that occurred in the last 10 years for earthquakes greater than 4.0 (Figures 4 and 5), it can be observed that the southern part of the country, which is classified as Low, there have been few earthquakes and with small magnitudes, quite in line with expectations. The same happens for the southwestern and central-eastern part of the country, where it is classified as a risk of seismic threat High and indeed, it corresponds to the areas where the greatest number of earthquakes have occurred and with the highest intensities. The regions located further north of the country are classified in the standard as Intermediate or Low, and according to the results obtained, a similar relationship can be seen in the map of seismic events that occurred, with a slight difference for the case of the northeastern part, in the department of La Guajira, where seismic activity during the last decade has been significant and there have been several earthquakes with magnitudes greater than 5; Therefore, it would be advisable to make updated seismic hazard maps taking into consideration the earthquakes that have occurred in recent years.

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