Macroseismic intensity-based catalogue of earthquakes in Ecuador

David Cajamarca-Zuniga1,2, Oleg Kabantsev2, Christopher Marin1

1Catholic University of Cuenca, Cuenca, Republic of Ecuador
2National Research Moscow State University of Civil Engineering, Moscow, Russian Federation

Abstract. Earthquake magnitude catalogues and peak ground acceleration (PGA) maps for Ecuador may be found in several studies, however, there are rare works on the characterisation of the epicentral macroseismic intensities associated with earthquakes. In view of the concept that macroseismic intensity enables us to categorise the extent and severity of damage to buildings and structures caused by an earthquake, this study aims to compile a macro-seismic intensity-based catalogue of earthquakes in Ecuador, characterise the epicentral macroseismic intensities associated to seismogenic sources and perform a comparison with the National Seismic Hazard Map. This paper is the first that presents a catalogue of earthquakes with macroseismic intensities ≥VII and a series of maps of earthquake epicentres according to intensity, focal depth, data and magnitude of seismic events in Ecuador, based on the study of historical and instrumental records from 1900 to 2021. The obtained data shows that 95% of the territory of Ecuador has a PGA > 0.1 g, which corresponds to seismic intensities greater than VII, while regions with seismicity >VIII (ag = 0.2 g) constitute 86%, and 3.8% of the territory of Ecuador has very high seismicity (>IX), where the PGA exceeds 0.5 g. This information suggests that the normative National Seismic Hazard Map of Ecuador underestimate the hazard mainly in the south-east and in the Central Andes of Ecuador, and require an actualization.

Keywords: earthquake, Ecuador, macroseismic intensity, seismic hazard, seismicity, structural design

For citation
Cajamarca-Zuniga D., Kabantsev O., Marin C. Macroseismic intensity-based catalogue of earthquakes in Ecuador. Structural Mechanics of Engineering Constructions and Buildings. 2022;18(2):161–171. http://doi.org/10.22363/1815-5235-2022-18-2-161-171
История статьи
Поступила в редакцию: 21 ноября 2021 г.
Доработана: 12 февраля 2022 г.
Принята к публикации: 29 февраля 2022 г.

Для цитирования
Cajamarca-Zuniga D., Kabantsev O., Marin C. Macroseismic intensity-based catalogue of earthquakes in Ecuador // Structural Mechanics of Engineering Constructions and Buildings. 2022;18(2):161–171. http://doi.org/10.22363/1815-5235-2022-18-2-161-171

Аннотация. Каталоги магнитуд землетрясений и карты пиковых ускорений грунта (ПУГ, англ. PGA) для Республики Эквадор можно найти во многих исследовании, однако работы, посвященные характеристике эпицентральной макросейсмической интенсивности, связанной с землетрясениями, встречаются редко. В связи с тем, что макросейсмическая интенсивность позволяет классифицировать степень и тяжесть ущерба, нанесенного землетрясением зданиям и сооружениям, целями данного исследования стали: 1) составление каталога землетрясений в Эквадоре на основе макросейсмической интенсивности; 2) характеристика эпицентральной макросейсмической интенсивности, связанных с сейсмогенными источниками; 3) сравнение с Национальной картой сейсмической опасности. Впервые представлены каталог землетрясений с макросейсмической интенсивностью ≥VII и серия карт эпицентров землетрясений в соответстви с интенсивностью, глубиной очага, данными и магнитудой сейсмических событий в Эквадоре, основанных на изучении исторических и инструментальных записей с 1900 по 2021 г. Полученные данные показывают, что 95 % территории Эквадора имеют PGA > 0,1 g, что соответствует сейсмической интенсивности более VII, регионы с сейсмичностью >VIII (ag = 0,2 g) составляют 86 %, а 3,8 % территории Эквадора имеют очень высокую сейсмичность (>IX), где PGA превышает 0,5 g. Это свидетельствует о том, что нормативная Национальная карта сейсмической опасности Эквадора не учитывает опасность в основном на юго-востоке и в Центральных Андах Эквадор и требует актуализации.

Ключевые слова: землетрясение, Эквадор, макросейсмическая интенсивность, сейсмическая опасность, сейсмичность, сейсмостойкое проектирование

Introduction

The greatest earthquakes are known to occur at the tectonic plate interface of subduction zones. Ecuador is located at the northwest interface of the South American tectonic plate which the Nazca tectonic plate. This zone is part of the Rim of Fire, which is the world’s most seismically active region. In this region about 90% of all earthquakes and about 80% of the strongest earthquakes have occurred [1]. The Andes are one of the highest seismic activity regions in the world, accounting for around 20% of the Earth’s total released seismic energy [2]. About 90% of continental territory of Ecuador presents high seismic hazard. The subduction of the Nazca tectonic plate and the complex system of active geological faults generates mostly shallow earthquakes in Ecuador, where the 7th world’s largest earthquake was registered in 1906 (Mw = 8.8) [3; 4].

The definition of seismic hazard is fundamental to study the influence of the seismicity of a given region on earthquake-resistant structural design. In this work we present a catalogue of macroseismic events with intensities

Кахамарка-Сунига Давид, доцент департамента строительства, Католический университет города Кузники, Республика Эквадор, 010101, Кузники, Ave Las Americas & Humboldt; аспирант, Национальный исследовательский Московский государственный строительный университет, Российская Федерация, 129337, Москва, Ярославское шоссе, д. 26; ORCID: 0000-0001-8796-4635, Scopus ID: 57251506300, WoS ID: AAO-8887-2020, eLIBRARY SPIN-код: 6178-4383; cajamarca.zuniga@gmail.com

Кабанцев Олег Васильевич, доктор технических наук, профессор, Национальный исследовательский Московский государственный строительный университет, Российская Федерация, 129337, Москва, Ярославское шоссе, д. 26; ORCID: 0000-0001-9907-8470, Scopus ID: 15055871000, WoS ID: T-3937-2017, eLIBRARY SPIN-код: 2114-1185; ovk531@gmail.com

Марин Кристофер, инженер-строитель, магистр, Инженерный факультет, Католический университет города Куэнки, Республика Эквадор, 010101, Куэнка, Ave Las Americas & Humboldt; ORCID: 0000-0002-6601-032X; crmaring80@gmail.com

1 United States Geological Survey. 20 Largest Earthquakes in the World. USGS. Earthquake Hazards. Available from: https://www.usgs.gov/natural-hazards/earthquake-hazards/science/20-largest-earthquakes-world?qt-science_center_objects=0/qt-science_center_objects(accessed: 20.02.2020).
greater than VII based on the study of seismogenic sources of Ecuador and its relation with the epicentres of historical high intensity earthquakes in order to compile a catalogue and maps of epicentres of earthquakes by intensities, years, depth and magnitudes, and compare the seismic events with the normative National Seismic Hazard Map of Ecuador.

To compile this catalogue, we reviewed pre-instrumental and instrumental information from several local, regional, and global sources such as IG-EPN, CERESIS, EHB, ISS, ISC, CENTENNIAL, NEIC, GCMT, USGS, and from other scientific works.

Based on the compiled catalogue, we have developed some maps of earthquakes locations according to registered intensities. In this paper, we also present the maps of epicentres of earthquakes by their intensities, years, depth and magnitudes, as well as comparison of the seismic events with both the normative National Seismic Hazard Map of Ecuador and the latest map of seismic hazard developed by the Ecuadorian Institute of Geophysics of the National Polytechnical School issued in 2021.2

Geodynamics of Ecuador and seismogenic sources

It is established that in the Equatorial latitudes the subducting process of the Nazca plate beneath the South American tectonic plate (55–75 mm/year) is the main and most evident geodynamic process in the north-western region of South America and in the territory of Ecuador (Figure 1) [5–8].

![Figure 1. Tectonic setting, major faults and relative plate motions in Ecuador. Locations of the 1906 earthquake (Mw = 8.8, black star); from north to south the 1979, 1958, 2016, 1942, 1901, 1953 earthquakes (M ≥ 7.8, red circles)](image)

Source: edited after Gutscher et al., 1999 [7].

The segment of the Northern Andes where both thrust faulting and crustal shortening are observed coincides with the subduction zone of Carnegie Ridge. Along the subandean zone and the eastern cordillera of Ecuador, a large system of thrusts, as well as strike-slip and transpressive faults is located [9; 10]. Three main seismogenic sources affect the seismicity of Ecuador. The subduction of the oceanic Nazca plate beneath the continental South American plate is the major geodynamic process which controls the tectonic setting of this region and originates two other seismogenic sources: the subduction and collision of the Carnegie Ridge (CR), and the segmentation and “escape” of the North Andean Block (NAB) with an intricate strike-slip fault system [11]. The Ecuadorian Andes mainly defines a compression zone featured by reverse faults in the foothills essentially orthogonal to the plate convergence vectors and

2 Catalogue of earthquakes in Ecuador. Mapa digital interactivo de peligro sísmico para Ecuador. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN); 2021. Available from: https://www.igeponline.edu.ec/mapas/sismicidad/mapa-peligro-sismico (accessed: 23.09.2021).
slip faults as the Dolores-Guayaquil Megashear (DGM) [12; 13] and the Chingual-Cosanga-Pallatanga-Puná (CCPP) fault system [8; 14], which are segments of the Guayaquil-Caracas Continental Megashear (GCM).

The subduction of the Carnegie Ridge controls the locations of large earthquakes and the clusterisation of seismic activity along the northwest coastline of Ecuador, as well as the evolution of the foothill basins of Borbon and Manabi, the uplifting of both the coast region and the Pastaza-Napo region at the Amazon basin [15–17]. The schematic geological cross-section of the subduction process at the collision zone of Carnegie Ridge between latitudes 1°N-2°S suggested in [18] shows geological events related to this process (Figure 2).

![Figure 2. West-East cross-section of Ecuador at 1°11' S, showing geological events related to Carnegie Ridge subduction [18]](image)

In the collision zone of the Carnegie Ridge, the orientation of crustal faults changes from north-south to northeast-southwest along the subduction margin [15; 19]. The morphology of the Ecuadorian subandean zone and its strong tectonic activity can be attributed to a major geodynamic event, such as the subduction of Carnegie Ridge. The bulldozing effect associated to the subduction of the CR has contributed to uplift of the coastal ranges at rates of 0.30–0.50 mm/year for the Peninsula of Manta [20], and generates the northeastward displacement of the NAB along the Guayaquil-Caracas Continental Megashear [21].

To understand the geodynamic scheme of Ecuador, it is necessary to consider the movement of North Andean Block as a detaching “mini-plate” sliding through the northwest corner of South America on a large right-lateral strike-slip fault. This tectonic block is bordered on the north by the South Caribbean deformed belt, on the west by the Colombia-Ecuador trench and Panama Block, and on the east by the Guayaquil-Caracas Continental Megashear. As a result of this process the NAB is being ejected to the northeast following the front of the Eastern Cordillera along a transpressive system of faults [22–25]. According to recent studies [8; 23; 24; 26], the NAB is migrating relatively fast, just as the Nazca Plate is subducting to the east relative to the Amazonian Craton, the NAB is migrating to the north-east in relation to the South American plate at 6–10 mm/year. The Guayaquil Gulf opens at the southern junction between two fracture zones (the Colombia-Ecuador Trench and the GCM) that isolate the NAB [22]. The east Andean front fault zone starts east of the Gulf of Guayaquil as the dextral Pallatanga Fault [27–29]. Northern this fault continues as the Chingual-La...
Sofia Fault [5; 8; 27; 28]. The motion of the North Andean Block “produces a complex system of active faults that generate shallow-focus earthquakes on the eastern front of the Andes” [21; 26].

The Chingual-Cosanga-Pallatanga-Puna fault system (Figure 3) is the most developed fault system in the territory of Ecuador and defines the NAB eastern tectonic border in Ecuador, where several shallow earthquakes have been registered [27]. The CCPP fault system extends from Guayaquil Gulf in Ecuador to the eastern “Cordillera Real” on the border between Ecuador and Colombia [8], then continues into Colombia as the Algeciras Fault [24]. It should be noted that multiple large earthquakes have occurred in the north-south trending segments of the CCPP fault and in the Carnegie Ridge collision zone. The shear zone of CCPP accounts for high cortical seismic activity in the central-northern Andes Cordillera of Ecuador.

Results and discussion

The main seismogenic source in Ecuador is the subducting process of the Nazca tectonic plate beneath the South American continental plate. In the background of this process, is important to consider two factors: the influence of the Carnegie Ridge, which causes a “ploughing” effect (expression suggested by D. Cajamarca-Zuniga) on the shoreline and deep seismic activity in the Pastaza-Napo region at the Amazon basin, and the northward drift of North Andean block, which generates an intricate system of active strike-slip faults and generates shallow-focus earthquakes along the CCPP fault system.

The shoreline of Ecuador experienced large and great megathrust earthquakes along the northern flank of Carnegie Ridge collision zone: 1906 (Mw 8.8, intensity IX), 1942 (Mw 7.8, intensity IX), 1958 (Mw 7.7, intensity VII), 1979 (Mw 8.2, intensity VIII), 2016 (Mw 7.8, intensity IX) [3; 30].

The central-north Andean region of Ecuador shows high crustal activity and registers multiple large historical earthquakes along the NNE-trending zone of CCPP fault system. Earthquakes with epicentral macroseismic intensity ≥ VIII have occurred in 1541, 1557, 1575, 1587, 1645 (Mw 7, intensity IX), 1698 (Mw 7.7, intensity IX), 1755, 1757, 1797 (Mw 8.3, intensity XI), 1834, 1868 (Mw 7, intensity IX), 1923, 1926, 1938 (Mw 6.3, intensity VIII), 1949 (Mw 6.7, intensity X), 1996 (Mw 5.5, intensity VIII) [10; 31], mainly along NE-SW fault systems governed by the Guayaquil-Caracas Continental Megashear.

Figure 4. Location and years of earthquakes with macroseismic intensities ≥ VII from 1900 to 2021. Here we can see the major seismic intensity at the collision zone of the subducting Carnegie Ridge (CR), as well as along the CCPP fault system.

The sub-Andean zone at the Amazon basin shows an intermediate-depth seismicity in the Pastaza-Napo region and a high shallow-focus activity to the south, between the Macas and Quito-Napo fault systems: 1961 (Mw 6.6,
intensity VIII), 1971 (Mw 7.4, intensity VII), 1987 (Mw 6.4, intensity IX), 1995 (Mw 6.5, intensity VIII), 2019 (Mw 7.5, intensity VII)\(^3\) [32; 33].

In the Figure 4 we present a map developed in ArcMap software and show the epicentres and years of earthquakes with macroseismic intensities ≥ VII from 1900 to 2021, where we can see the major seismic intensity at the Carnegie Ridge collision zone, as well as along the CCPP fault system.

**Figure 6.** Locations and depth of earthquakes with intensities ≥ VII from 1900 to 2021

**Figure 7.** Location and years of earthquakes with intensities ≥III from 1900 to 2021 (a) and location, depth, intensity and magnitude of earthquakes with intensities ≥III from 1900 to 2021 (b)

\(^3\) United States Geological Survey. Earthquake catalog. USGS. Earthquake Hazards program. Available from: https://earthquake.usgs.gov/earthquakes/search/ (accessed: 30.07.2021); Catálogo Homogenizado 1587–2011. Sismicidad. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN). Available from: https://igepn.edu.ec/mapas/sismicidad/mapa-catalogo-homogenizado (accessed: 30.07.2021).
| Date, ddmmyyyyy | Time, UTC | Intensity, MMI | Magnitude, M | Scale | Depth, km | Location | Latitude, °S | Longitude, °W |
|----------------|-----------|---------------|--------------|-------|-----------|----------|--------------|---------------|
| 1929 03/01/1929 12:00:00 | VII 6.3 | Mw | 19 km SW of Quito. Ecuador | -0.40 | -78.40 | | | |
| 1911 09/06/1911 02:00:00 | 7.8 | Mw | 20 km SW of Popayán. Colombia | -0.59 | -77.85 | | | |
| 1900 05/06/1900 01:00:00 | VIII 6.7 | Mw | 33 km SW of Quito. Ecuador | -2.78 | -78.75 | | | |
| 1899 12/06/1899 16:30:00 | VII 6.6 | Mw | 9 km NW of Rioja. Peru | -1.08 | -77.87 | | | |
| 1897 09/06/1897 12:00:00 | VII 6.7 | Mw | 11 km NE of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1896 09/06/1896 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1895 09/06/1895 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1894 09/06/1894 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1893 09/06/1893 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1892 09/06/1892 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1891 09/06/1891 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1890 09/06/1890 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1889 09/06/1889 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1888 09/06/1888 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1887 09/06/1887 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1886 09/06/1886 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1885 09/06/1885 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1884 09/06/1884 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1883 09/06/1883 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1882 09/06/1882 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1881 09/06/1881 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1880 09/06/1880 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1879 09/06/1879 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1878 09/06/1878 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1877 09/06/1877 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1876 09/06/1876 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1875 09/06/1875 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1874 09/06/1874 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1873 09/06/1873 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1872 09/06/1872 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1871 09/06/1871 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1870 09/06/1870 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1869 09/06/1869 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1868 09/06/1868 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1867 09/06/1867 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1866 09/06/1866 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1865 09/06/1865 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1864 09/06/1864 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1863 09/06/1863 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1862 09/06/1862 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1861 09/06/1861 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
| 1860 09/06/1860 00:00:00 | VII 6.7 | Mw | 33 km NW of Babahoyo. Ecuador | -2.48 | -79.00 | | | |
The geodynamic and seismic activity in the territory of Ecuador suggest that the prolongation of the CR and the geological expression of its subduction beneath Ecuador requires about 400 km from the Colombia – Ecuador – Peru trench. In the Figure 5 we show the locations of depth earthquakes epicentres according to data from the IG-EPN earthquake catalogue. Also, we suppose that the eastern interface boundary of the Carnegie Ridge under the territory of Ecuador may be a triple junction of the Nazca tectonic plate with the Farallon plate and the Amazonian Craton, which probably controls the intermediate-depth seismicity in the Pastaza-Napo region at the Amazon basin.

Regarding the influence of earthquakes on buildings and structures, the only magnitude of an earthquake does not allow us to understand the level of damage to the structures, as it depends on other factors. For understanding the effects of an earthquake on buildings and structures, it is important to know and understand the macroseismic intensity of earthquakes. This concept enables us to categorise the extent and severity of earthquake-related damage to structures. Below we present information and maps related to earthquakes in Ecuador from 1900 to 2021 according to the intensity, focal depth and magnitude of each event. The proposed maps were developed in ArcMap software for geospatial data processing.

In the Figure 6 we show the epicentres and depth of earthquakes with intensities ≥VII from 1900 to 2021. The Figure 7, a presents a map of earthquake epicentres with intensities ≥III and the corresponding year of each event from the 1900 to 2021. In the Figure 7, b we present a map that shows the depth, intensities and magnitudes of earthquakes with intensities ≥III from 1900 to 2021.

In the Table we present a catalogue of earthquakes with macroseismic intensities ≥VII based on historical and instrumental records from 1900 to date5 [2; 5; 14; 31; 32].

We provide a comparison intensity-based map of earthquakes with both, the National Seismic Hazard Map of the Ecuadorian Building Standard NEC-SE-DS 2015 (Figure 8) and the latest (non-normative) probabilistic seismic hazard map issued by the Institute of Geophysics of the National Polytechnic School of Ecuador in 20216 (Figure 9).

---

4 Catalogue of earthquakes in Ecuador. Mapa digital interactivo de peligro sísmico para Ecuador. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN); 2021. Available from: https://www.igepn.edu.ec/mapas/sismicidad/mapa-peligro-sismico (23.09.2021).

5 United States Geological Survey. 20 Largest Earthquakes in the World. USGS. Earthquake Hazards. Available from: https://www.usgs.gov/natural-hazards/earthquake-hazards/science/20-largest-earthquakes-world?qt-science_center_objects=0qt-science_center_objects (accessed: 20.02.2020); Catálogo Homogenizado 1587–2011. Sismicidad. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN). Available from: https://igepn.edu.ec/mapas/sismicidad/mapa-catalogo-homogenizado (accessed: 30.07.2021); Catalogue of earthquakes in Ecuador. Mapa digital interactivo de peligro sísmico para Ecuador. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN); 2021. Available from: https://www.igepn.edu.ec/mapas/sismicidad/mapa-peligro-sismico (23.09.2021).

6 Catalogue of earthquakes in Ecuador. Mapa digital interactivo de peligro sísmico para Ecuador. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN); 2021. Available from: https://www.igepn.edu.ec/mapas/sismicidad/mapa-peligro-sismico (23.09.2021).
Based on the IG-EPN seismic hazard map for a return period of 475 years, we calculated the area of seismic regions and their respective percentages in relation to the continental surface of Ecuador, and prepared the map (Figure 10). The analysis of this map shows that 95% of the territory of Ecuador has a PGA > 0.1 g which corresponds to seismic intensities greater than VII [34–36], while regions with seismicity >VIII ($a_g = 0.2$ g) constitute 86%, and 3.8% of the territory of Ecuador has very high seismicity (>IX), where the peak seismic acceleration exceeds 0.5 g.

The analysis carried out in this research shows that the Normative Seismic Hazard Map of Ecuador underestimates the seismic hazard in the Central Andes and in the south-eastern region of the country. For instance, this paper shows that earthquakes up to X–XI intensity have been registered in the Central Andes of Ecuador, with an equivalent PGA above 0.5 g, while the Ecuadorian building standard (NEC-SE-DS 2015) specifies a PGA of 0.30–0.40 g for these zones.

**Conclusion**

Several scientific works present databases of magnitudes and maps of seismic activity in Ecuador; however, this paper is the first that provides a catalogue of earthquakes with macroseismic intensities greater than VII based on historical and instrumental records from 1900 to 2021. The studied events correspond to earthquakes of very strong and higher intensity levels, according to macroseismic scales MSK-64, MMI or EMS-98. Additionally, we have proposed a series of maps of earthquake epicentres according to intensity, focal depth and magnitudes that allow us to understand the actual effect of Ecuador’s seismic activity on buildings and structures. The availability of this information in addition to the seismic hazard is relevant to study the influence of the seismicity of Ecuador on buildings and structures.

The main seismogenic sources in Ecuador are linked to the subduction process of the Nazca plate beneath the South American Plate. However, in this process, the convergence of the Carnegie Ridge, on one hand causes a ploughing effect resulting in shallow-focus earthquakes on the shoreline and deep seismic activity in the Pastaza-Napo region at the Amazon basin, and, on the other hand, the oblique collision of CR generates the northward drift of the NAB, which produces high seismic activity and shallow-focus earthquakes along the Central and Northern Andes.

The shoreline of Ecuador experienced large and great megathrust earthquakes mainly along the northern flank of Carnegie Ridge collision zone. The central and north Andean region of Ecuador shows high crustal activity and registers large historical earthquakes along the CCP fault system. The sub-Andean zone at the Amazon basin shows an intermediate-depth seismicity in the Pastaza-Napo region and a high shallow-focus activity to the south, between the Macas and Quito-Napo fault systems.

---

7 *Catalogue of earthquakes in Ecuador. Mapa digital interactivo de peligro sísmico para Ecuador. Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN); 2021. Available from: https://www.igepon.edu.ec/mapas/sismicidad/mapa-peligro-sismico (23.09.2021).*
The National Seismic Hazard Map of Ecuador underestimate the seismic hazard, mainly in the south-east of Ecuador and in the Central Andes region related to CCPP fault system, where events with macroseismic intensities up to X–XI (PGA > 0.5 g) have been registered. The obtained results suggest that the normative seismic hazard map of Ecuador deserves an actualization.

References

1. About earthquakes. In: Coffman J.L. (ed.) Earthquake Information Bulletin (vol. 3). Rockville: United States National Earthquake Information Center; 1971.

2. Giesecke A., Gómez Capera A.A., Leschiutta I., Migliorini E., Rodriguez Valverde L. The CERESIS earthquake catalogue and database of the Andean Region: background, characteristics and examples of use. Annals of Geophysics. 2004;47(2–3):421–435. http://doi.org/10.4401/ag-3310

3. Collot J.Y., Sanclemente E., Nocquet J.M., Leprêtre A., Ribodetti A., Jarrin P., Chlieh M., Grandorge D., Charvis Ph. Subducted oceanic relief locks the shallow megathrust in central Ecuador. Journal of Geophysical Research: Solid Earth. 2017;122(5):3286–3305. http://doi.org/10.1002/2016JB013849

4. Mayorga E.F., Sánchez J.J. Modelling of Coulomb stress changes during the great (Mw = 8.8) 1906 Colombia-Ecuador earthquake. Journal of South American Earth Sciences. 2016;70:268–278. http://doi.org/10.1016/j.jsames.2016.05.009

5. Beauval C., Marieníre J., Yepes H., Audin L., Nocquet J.-M., Alvarado A., Baize S., Aguilar J., Sngauchio J.-C., Jamard H. A new seismic hazard model for Ecuador. Bulletin of the Seismological Society of America. 2018;108(3A):1443–1464. http://doi.org/10.1785/0120170259

6. Soto-Cordero L., Melzer A., Bergman E., Hoskins M., Stachnik J.C., Agurto-Detzel H., Alvarado A., Beck S., Charvis Ph., Font Y., Hayes G.P., Hernandez S., Lynner C., Leon-Rios S., Nocquet J-M., Regnier M., Rietbrock A., Rolandone F., Ruiz M. Structural control on megathrust rupture and slip behavior: insights from the 2016 Mw 7.8 Pedernales Ecuador earthquake. Journal of Geophysical Research: Solid Earth. 2020;125(2). http://doi.org/10.1029/2019JB018001

7. Gutscher M.A., Malavieille J., Lallemand S., Collot J.Y. Tectonic segmentation of the North Andean margin: impact of the Carnegie Ridge collision. Earth and Planetary Science Letters. 1999;168(3–4):255–270. http://doi.org/10.1016/S0012-821X(99)00060-6

8. Alvarado A., Audin L., Nocquet J.M., Jiaillard E., Mothes P., Jarrin P., Segovia M., Rolandone F., Cisneros D. Partitioning of oblique convergence in the Northern Andes subduction zone: migration history and the present-day boundary of the North Andean Sliver in Ecuador. Tectonics. 2016;35(5):1048–1065. http://doi.org/10.1002/2016TC004117

9. Fiorini E., Tibaldi A. Quaternary tectonics in the central Interandean Valley, Ecuador: fault-propagation folds, transfer faults and the Cotopaxi Volcano. Global and Planetary Change. 2012;90–91:87–103. http://doi.org/10.1016/j.gloplacha.2011.06.002

10. Tibaldi A., Rovida A., Corazzato C. Late Quaternary kinematics, slip-rate and segmentation of a major Cordilleraperpendicular transcurrent fault: the Cayambe-Afifadores-Sibundoy system, NW South America. Journal of Structural Geology. 2007;29(4):664–80. http://doi.org/10.1016/j.jsg.2006.11.008

11. Witt C., Bourgeois J., Michaud F., Ordoñez M., Jimenez N., Sosson M. Development of the Gulf of Guayaquil (Ecuador) during the Quaternary as an effect of the North Andean block tectonic escape. Tectonics. 2006;25(3):1–22. http://doi.org/10.1029/2004TC001723

12. Baudino R., Herrmoza W. Subduction consequences along the Andean margin: thermal and topographic signature of an ancient ridge subduction in the Marañón Basin of Perú. Geologica Acta. 2012(4):287–306. http://doi.org/10.1344/GeologicaActa2014.12.4.2

13. Kellogg J.N., Vega V., Stailings T.C., Aiken C.L.V. Tectonic development of Panama, Costa Rica, and the Colombian Andes: constraints from Global Positioning System geodetic studies and gravity. Geologic and Tectonic Development of the Caribbean Plate Boundary in Southern Central America. 1995;295:75–90. http://doi.org/10.1130/SPE295-p75

14. Dimate C., Drake L., Yepez H., Ocola L., Rendon H., Granthul G., Giardini D. Seismic hazard assessment in the Northern Andes subduction zone (PILOTO project). Annali di Geofisica. 1999;42(6):1039–1055. http://doi.org/10.4401/ag-3787

15. Hoskins M.C., Meltzer A., Font Y., Agurto-Detzel H., Vaca S., Rolandone F., Nocquet J-M., Soto-Cordero L., Stachnik J.C., Beck S., Lynner C., Ruiz M., Alvarado A., Hernandez S., Charvis Ph., Regnier M., Leon-Rios S., Rietbrock A. Triggered crustal earthquake swarm across subduction segment boundary after the 2016 Pedernales, Ecuador megathrust earthquake. Earth and Planetary Science Letters. 2021;553:116620. http://doi.org/10.1016/j.epsl.2020.116620

16. Pedoja K. Les terrasses marines de la marge Nord Andine (Equateur et Nord Pérou): relations avec le contexte géodynamique. Paris: Pierre and Marie Curie University (Paris 6); 2003.

17. De Berc S.B., Soula J.C., Baeyens P., Souris M., Christophoul F., Rosero J. Geomorphic evidence of active deformation and uplift in a modern continental wedge-top – Foredeep transition: example of the eastern Ecuadorian Andes. Tectonophysics. 2005;399(1-4 SPEC. ISS.):351–80. http://doi.org/10.1016/j.tecto.2004.12.030

18. Michaud F., Witt C., Royer J.Y. Influence of the subduction of the Carnegie volcanic ridge on Ecuadorian geology: reality and fiction. Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision. 2009;204:217–228. http://doi.org/10.1130/2009.1204(10)
19. Manchuel K., Régnier M., Béthoux N., Font Y., Sallarès V., Díaz J., Yepes H. New insights on the inter-seismic active deformation along the North Ecuadorian-South Colombian (NESC) margin. Tectonics. 2011;30(4):1–25. http://doi.org/10.1029/2010TC002757

20. Pedroja K., Dumont J.F., Lamothe M., Ortlieb L., Collot J.Y., Ghaleb B., Auclair M., Alvarez V., Labrousse B. Plio-Quaternary uplift of the Manta Peninsula and La Plata Island and the subduction of the Carnegie Ridge, central coast of Ecuador. Journal of South American Earth Sciences. 2006;22(1–2):1–21. http://doi.org/10.1016/j.janes.2006.08.003

21. Staller A., Álvarez-Gómez J.A., Luna M.P., Béjar-Pizarro M., Gaspar-Escribano J.M., Martínez-Cuevas S. Crustal motion and deformation in Ecuador from cGNSS time series. Journal of South American Earth Sciences. 2018;86:94–109. http://doi.org/10.1016/j.janes.2018.05.014

22. Dumont J.F., Santana E., Vilema W., Pedroja K., Ordóñez M., Cruz M., Jiménez N., Zambrano I. Morphological and microtectonic analysis of Quaternary deformation from Puná and Santa Clara Islands, Gulf of Guayaquil, Ecuador (South America). Tectonophysics. 2005;399(1–4 SPEC. ISS.):331–350. http://doi.org/10.1016/j.tecto.2004.12.029

23. Egbue O., Kellogg J. Pleistocene to present North Andean “escape.” Tectonophysics. 2010;489(1–4):248–257. http://doi.org/10.1016/j.tecto.2010.04.021

24. Yepes H., Audin L., Alvarado A., Beauval C., Aguilar J., Font Y., Cotton F. A new view for the geodynamics of Ecuador: implication in seismogenic source definition and seismic hazard assessment. Tectonics. 2016;35(5):1249–1279. http://doi.org/10.1002/2015TC003941

25. Taboada A., Rivera L.A., Fuenzalida A., Cisternas A., Philip H., Bijwaard H., Olaya J., Rivera C. Geodynamics of the northern Andes: subductions and intracontinental deformation (Colombia). Tectonics. 2000;19(5):787–813.

26. Nocquet J.M., Villegas-Lanza J.C., Chlieh M., Mothes P.A., Rolando F., Jarrin P., Cisneros D., Alvarado A., Audin L., Bondoux F., Martin X., Font Y., Régnier M., Vallée M., Tran T., Beauval C., Maguiña Mendoza J.M., Martin X., Troncoso L., Taboada A., Luz E., Pérez H. Motion of continental slivers and creeping subduction in the northern Andes. Nature Geosciences. 2014;7(4):287–291. http://doi.org/10.1038/ngeo2099

27. Ego F., Sébrier M., Lavenu A., Yepes H., Egues A. Quaternary state of stress in the Northern Andes and the restraining bend model for the Ecuadorian Andes. Tectonophysics. 1996;259(1–3 SPEC. ISS.):101–116. http://doi.org/10.1016/0040-1951(95)00075-5

28. Taboada A., Rivera L.A., Fuenzalida A., Cisternas A., Philip H., Bijwaard H., Olaya J., Rivera C. Geodynamics of the northern Andes: subductions and intracontinental deformation (Colombia). Tectonics. 2000;19(5):787–813.

29. Winter T., Avouac J.-P., Lavenu A. Late Quaternary kinematics of the Pallatanga strike-slip fault (Central Ecuador) from topographic measurements of displaced morphological features. Geophysical Journal International. 1993;115(3):905–920. http://doi.org/10.1111/j.1365-246X.1993.tb01500.x

30. Salocchi A.C., Minarelli L., Lugli S., Amoroso S., Rollins K.M., Fontana D. Liquefaction source layer for sand blows induced by the 2016 megathrust earthquake (Mw 7.8) in Ecuador (Boca de Briceño). Journal of South American Earth Sciences. 2020;103(June):102737. http://doi.org/10.1016/j.jsames.2020.102737

31. Beauval C., Yepes H., Palacios P., Segovia M., Alvarado A., Font Y., Aguilar J., Troncoso L., Sandro Vaca S. An earthquake catalog for seismic hazard assessment in Ecuador. Bulletin of the Seismological Society of America. 2013;103(2 A):773–786. http://doi.org/10.1785/0120120270

32. Beauval C., Yepes H., Bakun W.H., Egred J., Alvarado A., Singsauch JC. Locations and magnitudes of historical earthquakes in the Sierra of Ecuador (1587–1996). Geophysical Journal International. 2010;181(3):1613–1633. http://doi.org/10.1111/j.1365-246X.2010.04569.x

33. Swenson J.L., Beck S.L. Historical 1942 Ecuador and 1942 Peru subduction earthquakes, and earthquake cycles along Colombia-Ecuador and Peru subduction segments. Pure and Applied Geophysics. 1996;146:67–101. http://doi.org/10.1007/bf00876670

34. Richter C.F. Elementary seismology (J. Gilluly, A.O. Woodford, eds.). San Francisco: W.H. Freeman and Company; 1958.

35. Richter C.F. Elementary seismology (J. Gilluly, A.O. Woodford, eds.). San Francisco: W.H. Freeman and Company; 1958.