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EARTHQUAKE HAZARD SCENARIO AND SEISMIC MICRO-ZONING ASSESMENT IN MÁLAGA PROVINCE OF SPAIN

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Abstract

Spain is considered as a land of moderate seismic activity compared to other Mediterranean countries. Seismic activity is more intense in the south and eastern part of Spain. Málaga province is situated in the southern part of Spain and located near the boundary between the African and Eurasian plates. Málaga has experienced strong and frequent earthquakes in past, caused severe damages. To measure the effect of earthquake 'peak ground acceleration (PGA)' has commonly been used by the scientists. Here, in this study the seismic zone map of Málaga province has been created depending on available PGA data (return period of 475 years). The obtained seismic micro-zoning is important for assessing hazard prediction and urban regional planning in the earthquake prone areas of Málaga. The result shows the existence of spatial variation of vulnerability of earthquake in the province, which increases from west to east of Málaga.

Keywords: *Earthquake susceptibility, peak ground acceleration, seismic zone, Málaga province*

1. INTRODUCTION

An earthquake is rapid vibrations of earth's surface resulting from the sudden release of energy from the earth's asthenosphere. According to plate tectonic theory the plate i.e. the segmented crust of the earth is constantly moving in various directions with different velocity. This movement can create stress which is being considered as main root cause of earthquake. Earthquake can be smaller or larger. Similarly, it is a natural phenomenon, but sometimes human activities can also lead to its magnitude. Earthquakes can last from a few seconds to several minutes. It occurs suddenly and it can happen at any time and at any place of its susceptive area. Earthquake can occur on land or under the sea floor. Strong earthquake can damage buildings, roads, bridges and even change the direction of river within a few minutes. Many people also loss their lives due to the earthquake damage. Seismic risk assessment is very complex phenomenon because of direct or indirect, immediate, or long-lasting effects of the earth surface (De Pascale et al, 2015). Normally plate margins seem to be earthquake prone region.

The southern part of Spain is located at the boundary between Eurasian plate and African plate. Since the Cretaceous African plate is moving towards the Eurasian Plate (Di Bucci et al, 2010). This is a convergent plate boundary where two plates are colliding. When two plates collide, one plate diving beneath the other and into Earth's mantle. The boundary which marks the collision between two plates along with downward movement is known as subduction zone. In this case, the African plate is diving below the Eurasian plate. So, in southern region, earthquakes are more frequent than other parts of Spain.

Here the two plates collide very slowly, 2 to 5 mm/year in the NW-SE to WNW-ESE directions (source: Solares, 2016; Actualización de mapas de peligrosidad sísmica de España, 2012). When two plates collide, initially a fault is being created. The fault releases sudden energy that accumulates along the margin surrounding and finally earthquake occurs. Earthquakes happen only on that time, when fault builds up highest tensions (Parsons, 2008) and crossed the threshold limit of the surround rocks. There are two major right-lateral strike-slip fault systems in the study area; a) Maro-Nerja fault (NW – SE) and b) Yusuf fault (WNW – ESE), and those are presently active in the Alboran sea region, located near Málaga province (Alvarez-Marrón, 1999; Fernández-Ibáñez et al, 2007). The intensity of earthquake is near to moderate in Málaga province, but large earthquakes also occurred in this region (Casado et al, 2001; Grácia et al, 2006). The Granada-Málaga-West of Alboran zone has the vast majority of superficial earthquakes with epicenters (h) less than 50 km, but a large number of earthquakes have also been generated at intermediate depths of 50-200 km (Solares, 2016).

Several kinds of maps are used to analyze the earthquake hazard; like- intensity map, acceleration map etc. Intensity map represents isolines of the expected intensities for a certain return period. Acceleration is defined as changes of velocity per unit time. During the time of earthquake when the ground is shaking, it also experiences acceleration. Acceleration map shows the probability that the expected PGA will be exceeded for a certain return period by the isolines. PGA is the largest increase in velocity recorded by a particular station during an earthquake. It is the most commonly used ground motion parameter to estimate seismic hazard in a region. The purpose of this article is to classify Málaga province in micro seismic zones depending on PGA value and identify the vulnerable zones. Results of the study could potentially be used for risk analysis and to build earthquake resistance structure in Málaga province.

2. STUDY AREA

Málaga is located in southern Spain, under autonomous community of Andalucia (Fig. 1). It is situated on northern side of the Mediterranean Sea. It is surrounded by the Cadiz province to the west, Sevilla and Cordoba provinces to the north, the Alhama Mountains separate Málaga from Granada to the east and Mediterranean Sea to the south. The province contains 103 municipalities and the capital of the province is Málaga. Geographically Málaga Province is situated between 36°3′N - 37°29′N and 3°76′W - 5°65′W longitude.

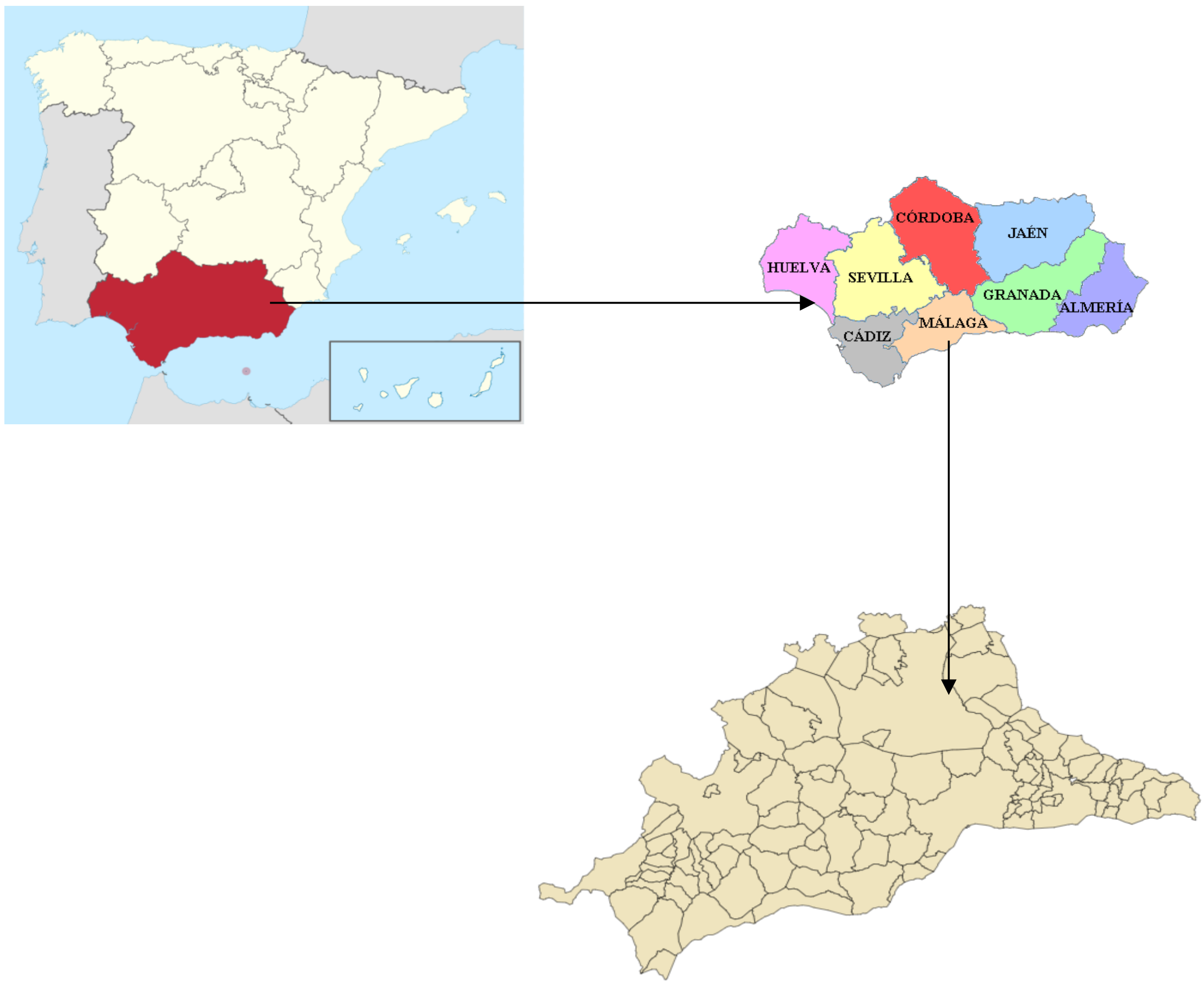

Figure 1. Location map of Málaga province

The province of Málaga has over 160 kilometres of coastline, which falls under famous Costa del Sol (Coast of Sun). The most of beaches in both the eastern and the western part of the province are sandy and sunny. Many municipalities are situated above 500 meter height. The Mountains in Málaga are steep and rocky with peaks of around 500 meters. The highest peak of Málaga province is La Maroma at a height of 2,066 meter. It is located in the Natural Park of the Sierras Tejeda, Almijara and Alharma. Guadalhorce River is the main river of the province of Málaga, both in terms of its length and the size of its catchment area. Other rivers of the province are Guadalmedina, Guadiaro, Genal, Rio Grande, Chillar, Rio Velez, Hozgarganta etc. The climate of the province is Mediterranean type. Málaga enjoys an average of more than 320 sunny days in each year. Warmest months are July and August and sometimes temperature reaches over 40°C. The winter is rainy and sometimes minimum temperature falls near to 0°C.

The population of Málaga is 1,594,808 (2011) (Intituto de Estadística y Cartografía de Andalucía) and population density is 218.20/ sq. km (2011). The female population is more than male population. Male: female ratio of Málaga province is 1000:1025 in 2011. Málaga province has a high literacy rate. The average literacy rate is 96.50% in 2001. In the past, Málaga's economy was based on various industries such as agriculture and textiles and it was even reported to be one of the richest provinces in the 19th Century. At present, the most important sector of economy in Málaga province is tourism. Other important economic sectors are construction, agriculture and technology services.

3. OBJECTIVES

It is essential to have at least one seismic hazard map of a region that can determine the possibility of occurrence of earthquake damage. The map is also capable of generating the spatial identity regarding the personal injury and property damage.

Thus the main objective of this study is to prepare a seismic micro-zonation map of the Málaga province depending on PGA values (return period of 475 years) that will help to identify areas at susceptibility of earthquake. This map will help to estimate the probability of the earthquake generated hazard for each municipality of Málaga and to take remedial measures to minimize elements at risks and to avoid losses occurring due to earthquakes.

Also another objective is to analyze the history of earthquake in Málaga province that involves the identification and description of the devastating earthquakes along with the trends of recent earthquake in the study area. Earthquake catalog is considered to be very useful for seismicity analysis and evaluation of earthquake risk.

In Spain, earthquakes are concentrated mainly in the southern region (including Málaga province). Here the causes of earthquake in Málaga province have also been discussed.

4. MATERIAL AND METHODS

There have been several methods to determine and analyze hazards of earthquake; Ex. by analyzing seismic zone and earthquake hazard micro-zonation (depending on spectral amplification or peak ground acceleration value), adopting Neo-Deterministic Seismic Hazard Analysis (N-DSHA) method, and as well as using Remote Sensing (Sari et al, 2017).

This work is based on municipality wise secondary data. To know the history of earthquake in the province, a lot of literature surveys have been conducted. The hazard map of Spain has been collected from Instituto Geográfico Nacional (IGN). To characterize seismic action, specifically three types of data have been utilized:

1. History of past earthquakes: To estimate the seismic hazard values in any region, past earthquake data with a magnitude scale is essential (Vipin et al, 2009). The seismic catalogue of IGN is the source of history of earthquake (1581 – 2006) data for Málaga province. A catalogue for intensity ≥V or magnitude ≥ 4 has been considered to generate a broad idea of the seismic activity of the province.
2. Recent earthquakes: Data of all earthquakes that have epicenters in Málaga province over past twelve years are highlighted.
3. PGA values: PGA is widely adopted parameter in seismic hazard assessments. Several authors (Makropoulos et al, 1985; Irwansyah et al, 2013; Abdalla et al, 2004) have used this parameter to identify the seismic zone. The 'Actualización de mapas de peligrosidad sísmica de España 2012' is the main source of PGA data for a seismic hazard study in Málaga province. Based on PGA value, Málaga province has been classified into five different vulnerable zones.

5. DISCUSSION

5.1 Scenario of Earthquake in Spain

Probably first seismic hazard map of Spain was made by the Gómez-Guillamón (1957) and divided the Iberian Peninsula (includes the countries of Andorra, Portugal, Spain and the British Crown colony of Gibraltar and small part of France) into 17 areas assigning each a maximum seismic degree and frequency (Actualización de mapas de peligrosidad sísmica de España, 2012). Spain is considered to be a country of moderate to low seismic activity with relatively low seismic hazard in world's perspective (Gaspar-Escribano et al, 2008). Seismic fault activity rate in Spain is of moderate type (including the historic period) (Gaspar-Escribano et al, 2010). The seismic activity is more intense in south-east area, as displayed in the map of seismicity of the National Geographic Institute (Fig. 2). The highest acceleration (> 0.20) is concentrated in two regions of south-east area of Spain. Málaga, Granada, Murcia and Alicante are the four provinces which are located in these high intensity regions. The lowest values are recorded in the whole Avila province and in parts of Palencia, Burgos, Zamora, Valladolid, Segovia, Salamanca, Guadalajara, Madrid, Toledo, Caceres, Badajoz and Ciudad Real provinces. Hazard map shows the acceleration to a return period of 475 years, which corresponds to a probability of 10% at 50 years. Generally, a destructive earthquake is recorded in every 70 years in Spain (Sanchez, 1986).

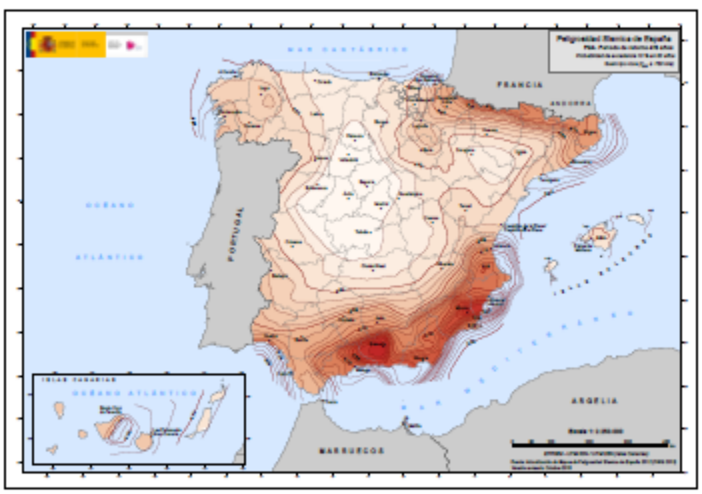

Figure 2. Seismic hazard map of Spain in PGA values for a return period 475 years according to the Updating seismic hazard maps of Spain 2012 (CNIG 2013). Revised version: October 2015.

Source: Instituto Geográfico Nacional

Table no. 1 shows some significant earthquakes in the country. The last moderate earthquake happened on 11th May, 2011 in Lorca, situated in south-eastern part of the country. More than 300 people were injured and around 462 million Euros economic loss were reported due to this earthquake (Monsó et al, 2018).

Table 1. List of some significant earthquakes in Spain (Since 1700)

Date	Latitude	Longitude	Epicenter	Magnitude
23/03/1748	39.0333	-0.6333	Estubeny (Valencia)	6.2
01/11/1755	36.5000	-10.0000	SW. Cabo San Vicente	8.5
13/01/1804	36.0833	-3.5833	Sea of Alboran	6.7
25/08/1804	36.7667	-2.8333	Dalias (Almeria)	6.4
27/10/1806	37.2333	-3.7333	Pinos Puente (Granada)	5.3
20/03/1829	38.0833	-0.6833	Torrevieja (Alicante)	6.6
25/12/1884	37.0000	-3.9833	Arenas del Rey (Granada)	6.5
29/03/1954	37.0000	-3.6000	Dúrcal (Granada)	7.0
19/04/1956	37.1833	-3.6833	Albolote (Granada)	5.0
28/02/1969	35.9833	-10.8167	SW. Cabo San Vicente	7.8
11/05/2011	37.7000	-1.6833	Lorca (Murcia)	5.1

Source: Instituto Geográfico Nacional. "Terremotos más importantes (En España)" (in Spanish). Retrieved 2018-03-12.

5.2 Scenario of Earthquake in Andalucia

According to the report of Instituto Geológico y Minero de España, (survey year: 1987 – 2001) Andalucia is the most vulnerable area of Spain (Análisis del impacto de los riesgos geológicos en España, 2004) due to earthquake in terms of economic loss. Andalucia has higher seismic activity amongst different regions of Spain (Benito et al, 2008), although in a global context the seismic activity of Andalucia lies between low to moderate.

Most of the earthquakes occurred in Andalucia at shallow depth ($h < 40$ km), a significant number with at intermediate depth ($40 < h < 150$ km) and only a very few earthquakes occurred in deep depth (around 630 km) (Buforn et al, 1995). This region is closer to where the Eurasian and African plates are met. So earthquakes are more frequent than the other parts of Spain. Seismic epicenters are concentrated in eastern Andalusia of Granada, Málaga and Almeria provinces (Agencia Andaluza de la Energía) (Fig. 3[B] and 4).

The intensity of earthquake is moderate, occasionally reach or surpass 6 in Richter scale. Highest PGA value has been found in Granada province of Spain. Cullar Vega, La Malaha and Las Gabias municipalities have highest PGA value (0.24) in Granada. The probability of recurrence of earthquake is more in east of Málaga province, all Granada and west of Almeria.

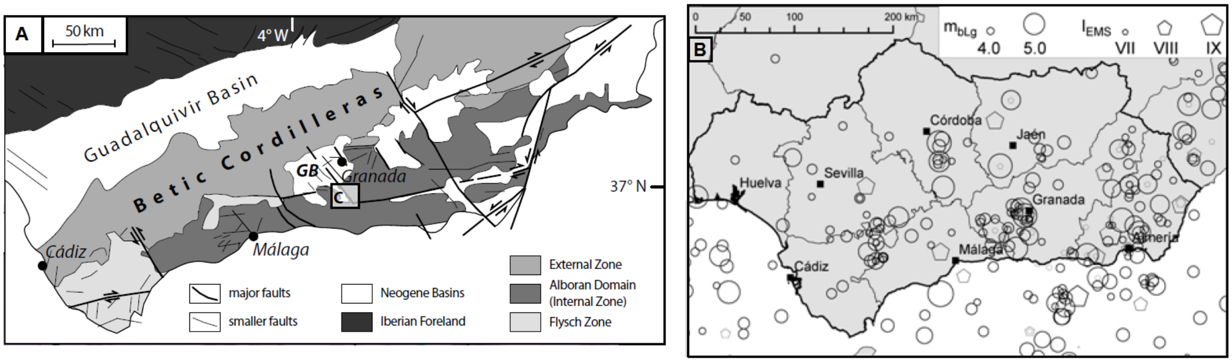

Figure 3. [A] Geo-tectonic environment of the study area and [B] Location of major earthquakes.
Source: Hürtgen et al. 2013, Benito et al. 2008

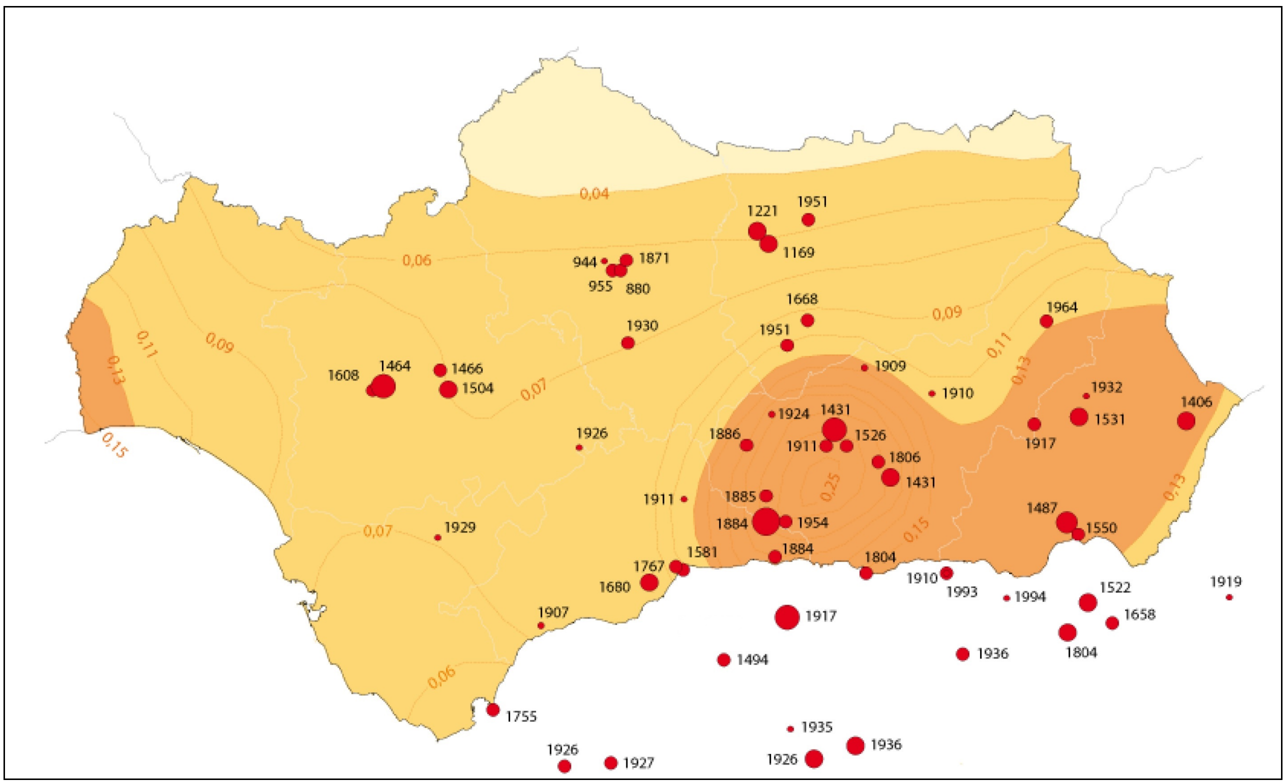

Figure 4. Spatial distribution of large earthquakes in Andalucia from 880 to 1994.
Source: Plan de actuación local ante riesgo sísmico en Benalmádena, 2012

5.3 Scenario of Earthquake in Málaga Province

5.3.1 Historical earthquakes

Málaga province has suffered earthquakes greater than or equal to maximum intensity VIII (epicenter within Málaga province) in 1494 and 1680. Earthquakes were generally occurred in the southern region of the Málaga province. The earthquake of January 26, 1494, caused significant damages in whole Málaga province. It was felt from Granada and Sevilla, around 200 km away from Málaga city (Goded et al, 2008). Most of the houses of Málaga city were destroyed. City walls and towers of the city were also badly damaged. On 9th October, 1680, a catastrophic earthquake attacked Málaga. This is the most devastating earthquake listed in the study area. This earthquake was felt in all Andalusia. It was even felt in Madrid Toledo and Valladolid (Peláez et al, 2011). The tremor was felt in Málaga city at 7:15 in the morning. The epicenter of the earthquake was in Alhaurin el Grande. In Málaga, 20% houses were destroyed and 30% houses were uninhabitable (IGN). After the earthquake many cracks were observed in ground and variations happened in flow of springs (Millán, 2006).

Earthquake of Arenas del Rey (Granada) in 1884, also caused significance damages in the province. Arenas del Rey is a city located near the border of Málaga and Granada province. The earthquake almost completely destroyed some villages of Periana municipality. Vélez-Málaga municipality was also badly affected. One kilometer away from the town of Vélez-Málaga, water came out through the surface cracks, dragging sands from the subsoil and produced a layer of eight meters depth of water (Sánchez, 2011). The history of earthquake catalogue of Spain published by IGN has been divided into three periods by Gaspar-Escribano et al, (2010) depending to the type of information contained. The first period is historic (upto 1923), second period is pre-instrumental (1924 – 1962) and third period is instrumental (from 1963 to present). History of earthquake in the province is shown in the following table (Table 2).

Table 2. Earthquake history in Málaga province with intensity V and above (1581 – 1962) and magnitude 4.0 and above (1963 – 2006) and epicenter within Málaga province.

Sl. No.	Date	Epicenter (Latitude)	Epicenter (Longitude)	Intensity	Magnitude	Epicenter
1	18/06/1581	36.7167	-4.4167	VII		Málaga
2	09/10/1680	36.8000	-4.6000	VIII-IX		NW of Málaga
3	29/08/1722	36.7167	-4.4167	VI		Málaga
4	16/07/1767	36.8000	-4.4000	VI		N. Málaga
5	30/10/1852	36.7000	-4.4000	V		Málaga
6	18/01/1858	37.1833	-4.4500	V - VI		Villanueva de Algaidas
7	12/03/1860	36.7500	-4.4167	V - VI		Málaga
8	26/01/1885	36.6167	-5.3333	IV - V		Cortes de la Frontera
9	17/11/1885	36.7833	-4.1000	IV - V		Vélez-Málaga
10	07/05/1888	36.7667	-4.0333	IV - V		Algarrobo
11	18/03/1890	36.9000	-4.1167	V - VI		Alcaucín
12	20/02/1894	36.7500	-3.8833	V		Nerja
13	20/08/1895	36.6667	-4.7500	IV - V		Málaga
14	11/09/1895	36.7833	-4.1000	IV - V		Vélez-Málaga

15	20/12/1896	36.5167	-5.3167	V		Gaucín
16	28/01/1897	37.0167	-4.5500	V		Antequera
17	11/08/1907	36.6000	-5.2667	VI		Benadalid
18	22/01/1909	36.7000	-4.2000	V		Málaga
19	28/01/1909	36.7500	-4.3000	VI		Totalán
20	15/04/1909	36.7167	-4.3167	V		El Palo
21	22/01/1911	37.0000	-4.6000	V		Antequera
22	29/06/1916	36.6167	-5.3500	V		Cortes Frontera
23	15/08/1926	37.0500	-4.7667	VI		Bobadilla
24	18/08/1926	37.0500	-4.7667	V		Bobadilla
25	03/05/1936	36.7333	-5.2500	V		Montejaque
26	05/05/1936	36.7333	-5.2500	VI		Montejaque
27	05/10/1937	36.9333	-4.1833	V		Periana
28	19/08/1939	36.8667	-4.0333	V		Sedella
29	30/09/1944	36.8333	-3.9500	VI		Cómpeta
30	01/07/1954	37.0500	-4.8667	V		Campillos
31	23/12/1964	36.9717	-4.4783		4.0	SE Antequera
32	13/02/1968	36.4800	-4.5650		4.3	SE Fuengirola,
33	04/03/1970	36.7167	-5.2500		4.0	W Ronda
34	13/06/1974	36.8750	-4.1217		4.1	NE Viñuela
35	24/08/1976	36.7967	-4.6200		5.4	SW Almogía
36	03/05/1977	36.7650	-4.4750		4.2	NW Málaga
37	05/02/1979	36.7983	-4.1017		4.0	N Vélez-Málaga
38	22/12/1979	37.0633	-4.3400		4.0	N Villanueva del Trabuco
39	21/01/1981	36.8550	-4.7100		4.0	N Alora
40	25/01/1981	36.9350	-4.9350		4.4	SW Teba
41	13/05/1986	36.5967	-4.4833		4.3	SE Torremolinos
42	02/05/1990	36.5317	-4.5217		4.2	SE Benalmádena
43	17/03/1995	36.8250	-4.3383		4.0	NW Totalán

44	03/07/2002	36.8033	-4.1626		4.2	NW Benamocarra
45	21/11/2002	36.5335	-4.4438		4.3	SE Torremolinos
46	28/07/2004	36.5248	-5.1538		4.3	SE Jubrique
47	11/03/2006	36.9296	-4.9323		4.4	S Teba
48	04/11/2006	36.7046	-4.3817		4.2	SE Málaga

Source: Instituto Geográfico Nacional (IGN)

5.3.2 Recent Earthquakes (last 12 years)

A full list of earthquakes (over magnitude 2) occurred in Málaga province in last 12 years has been catered in Table 3. Except the mega earthquakes rocked in past, every year many minor earthquakes have been registered in Málaga. Some of these earthquakes originated in Mediterranean Sea. Coastal Mediterranean zone of Málaga province has triggered with more earthquakes in comparison with the inner part of the province. The intensity of these earthquakes is normally lies between 2 to 5. Very few of those are exceeding 4 in Richter scale. Some earthquakes even have not been felt by people and some of those have been experienced by few persons only. These earthquakes are only detected by the seismograph. In most of the cases, no notable destructions have been found these tremors.

Table 3. Last 12 years earthquake in Málaga province (Epicenter within Málaga province or within 30 km from the sea coast)

Date	Epicenter	Location	Magnitude	Depth
17/06/2018	7 km from Villanueva del Tapia	Land	3.6	10 km
26/04/2018	8 km from Cortes de la Frontera	Land	3.9	10 km
09/02/2015	22 km from Fuengirola	Sea	3.8	89 km
09/07/2014	7 km from Canillas de Albaida	Land	4.2	62 km
29/12/2013	6 km from Velez-Málaga	Land	4.2	68 km
27/11/2013	5 km from Manilva	Land	3.5	1 km
18/10/2008	3 km from Periana	Land	2.9	57 km
24/09/2008	6 km from Fuengirola	Land	2.5	66 km
17/09/2008	2 km from Almogia	Land	2.9	39 km
21/07/2008	13 km from Fuengirola	Sea	2.6	46 km
24/05/2008	7 km from Fuengirola	Sea	2.7	75 km
17/05/2008	2 km from Archidona	Land	2.7	5km
09/05/2008	7 km from Fuengirola	Sea	2.7	73
06/04/2008	2 km from Valdes (under Moclinejo municipality)	Land	2.5	50 km

03/04/2008	24 km from Fuengirola	Sea	3.0	91 km
20/03/2008	6 km from Genalguacil	Land	2.7	38 km
01/03/2008	10 km from Fuengirola	Land	2.6	60 km
27/02/2008	2 km from Iznate	Land	2.5	57 km
14/02/2008	2 km from Torremolinos	Land	3.1	69 km
20/11/2007	21 km from Fuengirola	Sea	3.6	69 km
18/11/2007	8 km from Canete la Real	Land	2.8	10 km
18/11/2007	2 km from Canete la Real	Land	2.4	0 km
12/11/2007	29 km from Fuengirola	Sea	2.5	88 km
11/11/2007	2 km from Mijas	Land	3.0	62 km
06/11/2007	5 km from Competa	Land	3.2	50 km
04/11/2007	3 km from Torremolinos	Sea	2.5	79 km
15/10/2007	3 km from Casares	Land	2.2	10 km
10/09/2007	13 km from Marbella	Land	3.4	54 km
09/09/2007	1 km from Fuengirola	Land	2.5	72 km
05/09/2007	3 km from Alhaurín de la Torre	Land	2.9	57 km
10/08/2007	6 km from Casabermeja	Land	3.9	65 km
20/07/2007	5 km from Torremolinos	Sea	2.6	83 km
19/07/2007	19 km from Marbella	Sea	3.0	54
28/06/2007	12 km from Torremolinos	Sea	3.6	84
26/05/2007	6 km from Villanueva del Trabuco	Land	2.7	4 km
09/05/2007	1 km from Vinuela	Land	2.6	47 km
08/04/2007	8 km from Ardales	Land	2.5	11 km
22/02/2007	4 km from Colmenar	Land	2.8	31 km
20/02/2007	6 km from Genalguacil	Land	2.4	5 km
12/02/2007	11 km from Fuengirola	Sea	3.0	82
03/01/2007	14 km from Torremolinos	Sea	2.7	87

Source: https://www.earthquaketrack.com/es-51-málaga/recent

The province of Málaga is included in the Betic Systems. It is located in the western part of Betic Cordillera. The Betic System is a geological feature belongs to a larger orogeny. An event at convergent plate margins is termed as orogeny. Here Eurasian plate and African plate are colliding with each other and causes an orogeny event. Betic Cordillera is the most seismically and tectonically active region within the Iberian Peninsula (Insua-Arévalo et al, 2012). It is divided into two parts; internal zone and external zone (Fig. 3[A]). Internal zone is considered to be more vulnerable for earthquakes. History of earthquake shows that epicenter of two most devastating earthquakes (1494 and 1680) were situated in the internal zone of Betic Cordillera. Past earthquakes and as well as recent earthquakes have been mostly concentrated in the eastern part of the province due to the presence of Sierra Tejeda fault, Ventas de Zafarraya fault and also in the southern part of the province (Marbella-Mijas-Fuengirola-Torremonilos-Málaga region) mainly due to the presence of active tectonics. Sierra de las Nieves fault, La Robla fault, Los Alamillos fault, Acebuchal fault, El Carrascal fault, Campanillas fault and Guadalmedina fault are active tectonics in southern region (Insua-Arévalo et al, 2012).

5.3.3 Seismic microzonation of Málaga province

PGA corresponds to the maximum horizontal acceleration of a rigid soil or rock and PGA data of municipalities of Málaga have been obtained from 'Actualización de mapas de peligrosidad sísmica de España 2012'. All municipalities of Málaga province have been categorized into five different vulnerable zones and shown in Table 4.

Table 4. Classification of PGA values

Category	PGA (in gals)	Name of the Municipalities	Total Number of Municipalities
Very Low	0.11 - 0.132	Algatocín, Benahavís, Benalauría, Benarrabá, Casares, Estepona, Faraján, Gaucín, Genalguacil, Igualeja, Jubrique, Júzcar, Manilva, Pujerra	14
Low	0.133 - 0.155	Alhaurín el Grande, Almargen, Álora, Alozaina, Alpandeire, Ardales, Arriate, Atajate, Benadalid, Benalmádena, Benaoján, Burgo (El), Cañete la Real, Carratraca, Cartajima, Casarabonela, Coín, Cortes de la Frontera, Cuevas del Becerro, Fuengirola, Guaro, Istán, Jimera de Líbar, Marbella, Mijas, Monda, Montecorto, Montejaque, Ojén, Parauta, Pizarra, Ronda, Serrato, Teba, Tolox, Yunquera	36
Medium	0.156 - 0.178	Alameda, Alhaurín de la Torre, Almogía, Campillos, Cártama, Cuevas Bajas, Cuevas de San Marcos, Fuente de Piedra, Málaga (capital), Rincón de la Victoria, Sierra de Yeguas, Torremolinos, Totalán, Valle de Abdalajís	14
High	0.179 - 0.201	Algarrobo, Almáchar, Antequera, Arenas, Benamargosa, Benamocarra, Borge (El), Casabermeja, Colmenar, Comares, Cútar, Frigiliana, Humilladero, Iznate, Macharaviaya, Moclinejo, Mollina, Nerja, Sayalonga, Torrox, Vélez-Málaga, Villanueva de Algaidas, Villanueva de la Concepción	23
Very High	0.202 - 0.224	Alcaucín, Alfarnate, Alfarnatejo, Árchez, Archidona, Canillas de Aceituno, Canillas de Albaida, Cómpeta, Periana, Riogordo, Salares, Sedella, Villanueva de Rosario, Villanueva del Tapia, Villanueva del Trabuco, Vinuela	16

Municipality wise seismic zone map of Málaga province has been displayed in Fig.5. Higher PGA value indicates the highest risk region within the province. The map shows that more than 50% municipalities of Málaga province positioned between 'Medium' to 'Very High' risk zones. Whereas, 15.53% municipalities of the province are under 'Very High' risk prone zone. PGA value is highest (0.22) in the municipalities of Alcaucín, Alfarnate, Alfarnatejo, Canillas de Aceituno and Periana. All these five municipalities are situated in the eastern part of the province and except Alfarnatejo other four municipalities have shared border with Granada Province. Lowest PGA value (0.11) found in Manilva municipality which is located in the western border of the Province.

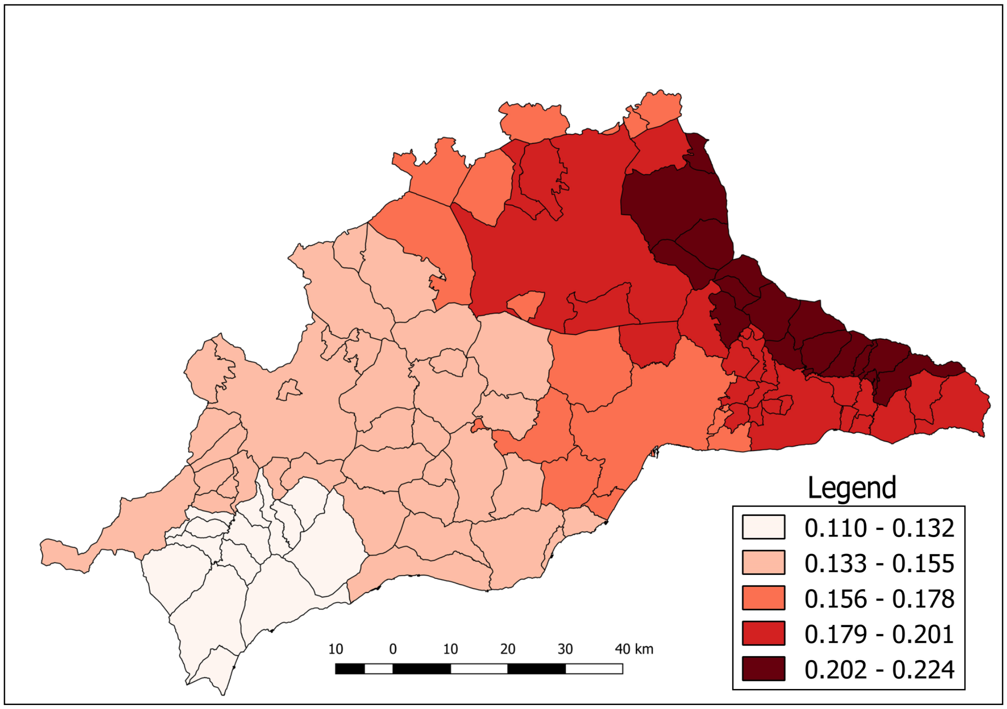

Figure 5. Seismic zone map of Málaga province.

Least vulnerable blocks are located in the western part, whereas very high vulnerable blocks are located in the eastern part of the province. It is important to notice that vulnerability of the province gradually increases from west to east. Eastern region of the province is more vulnerable because of presence of faults. North of Sierra Tejeda fault is situated in the border region with Granada province. This fault is active and probably responsible for the 1884 earthquake (Sanz de Galdeano et al, 2012). Other important faults are Alcaucín and Sedella (both are probably active) and are also responsible for vulnerability of this region.

6. CONCLUSION

Like other natural hazards, prediction of earthquake is not possible. Scientists are trying many different ways of predicting earthquakes. But, it is near to impossible to predict, where and when the next earthquake will occur. It is not possible to stop earthquake but the vulnerability can be reduced through various management procedures. In this respect, the attempt towards the assessment of susceptibility of this extreme event is more applicable. Everyone who takes appropriate earthquake safety precautions can minimize damages and injuries. Most of the buildings in Málaga province were constructed before 20th century. It is essential to improve the design of the old buildings and strengthening the old houses to incorporate the latest advances in seismic and structural engineering. Improvement of the building elements that resist the forces generated by seismic waves, reconstruction of weak structures in highly seismic zones, land use control and public awareness will significantly reduce the impact of earthquake. Damage of earthquake is inversely proportional to the resistant power of the infrastructure.

Earthquake resistance structures are able to protect the buildings. It decreases the probability of damage and so the loss of life could be minimized. The thematic maps on the various parameters of earthquake (i.e. historic earthquake maps, major damaged maps, vulnerable maps, map on safe zone, map regarding fast aids facilities, road network of shortest path, rescue and relief maps etc.) should be displayed in the public places. Kiosk regarding the micro-zoning of this disaster must be opened in the crowded areas. These types of information will be more useful for the tourists and outsiders. As Málaga is fully occupied by urban settlement, the micro-zoning of earthquake hazards should be prepared at utmost priority.

This work shows the regions of past earthquakes. This data representation helps to recognize date, epicenter coordinates, magnitude or intensity, depth, fault and the direction of slips of past earthquakes. The peak ground acceleration map will be helpful to identify the earthquake vulnerable zones and the map can be used for land-use planning including building infrastructure, earthquake mitigation, emergency response, and minimizing the environmental damages.

To reduce the risk of earthquake several 'Seismic Alert Network Stations' have been constructed in Spain. In Málaga province, this station is situated in Mijas and is responsible for sensing the ground motion, determining time and collecting data. The objectives of seismic alert network stations is to detect the initiation of an earthquake at earliest possible time by estimating the ground motion before shaking starts which can reduce damage and casualties during an earthquake. Ground rupturing is also one of the important footprints of earthquake. Detail study on ground rupturing and its associated phenomenon is the scope of the future work. The Instituto Geográfico Nacional, through the National Seismic Network (Red Sísmica Nacional), is also trying to frame a project that will be able to establish an alert procedure for tsunamis in the Atlantic and Mediterranean coastal regions.

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