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ARTICLE

Economic and Human Loss Empirical Models for Earthquakes in the Mediterranean Region, with Particular Focus on Algeria

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Abstract In this study, loss estimation models were developed for reasonably accurate assessment of economic and human losses from seismic events in the Mediterranean region, based on damage assessment at an urban scale. Data were compiled from existing worldwide databases, and completed with earthquake information from regional studies. Economic data were converted to a single common currency unit (2015 USD value) and the wealth of the areas affected by 65 earthquakes of the region from 1900 to 2015 was assessed. Reduced-form models were used to determine economic and human losses, with earthquake magnitude and intensity as hazard-related variables, and gross domestic product of the affected area and the affected population as exposure-related variables. Damage to buildings was also used as a hazard-related variable to predict economic and human losses. Finally, site-specific regression models were proposed for economic and human losses due to earthquakes in the Mediterranean region, and more specifically, in Algeria. We show that by introducing the damage variable into the models, prediction error can be reduced, and that accuracy of loss model estimation is site dependent and requires regional data on earthquake losses to improve. A case study for Constantine, Algeria shows the improvements needed for increased accuracy.

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1 Introduction

Modeling the economic consequences of natural hazard-induced disasters has gained importance in recent years. In the Mediterranean region, earthquakes are one of the most critical natural hazards, and they can cause considerable economic and social losses. Coupled with the vulnerability of buildings and high social and economic exposure, earthquakes are a regular and serious threat to communities, particularly in Greece, Italy, Turkey, Morocco, and Algeria.

Between 1900 and 2015, the Mediterranean region experienced thousands of damaging earthquakes, some of which were major disasters, such as the earthquakes of Messina, Italy, in 1908 (Barbano et al. 2005), Chios-Cesme, Greece, in 1949 (Altinok et al. 2005), Agadir, Morocco, in 1960 (El Alami et al. 2004), El-Asnam, Algeria, in 1980 (Bertero and Shah 1983), Izmit, Turkey, in 1999 (Barka 1999), and more recently, Boumerdes, Algeria, in 2003 (Laouami et al. 2006). These six damaging earthquakes resulted in over 150,000 deaths and caused direct losses of more than USD 26.5 billion.

Magnitude and distance are the two key parameters that control the impact of an earthquake in an urbanized area. From 1900 to 2015, even moderate earthquakes (for example, the Agadir, Morocco, M 5.7 earthquake in 1960) have caused considerable economic loss and numerous fatalities, due to the vulnerability of traditional building stock. Although the number of potentially damaging earthquakes per year has neither increased nor decreased in recent decades, the vulnerability and exposure of communities have changed. According to the World Health Organization (WHO 2016), the urban population will continue to grow by approximately 1.5–1.6% per year from 2015 to 2030. As a result, about 2.8 million causalities due to earthquakes can be expected worldwide by 2100 (Holzer and Savage 2013). Because of the long return periods of the largest and most severe consequence earthquakes, and because few urban areas have yet to suffer such major events in their current configuration, Jackson (2006) noted that the greatest earthquake disasters appear to lie in the future.

The benefits of natural hazard mitigation programs have been fully recognized (Benson and Twigg 2004; Whitehead and Rose 2009), and earthquake loss models can provide relevant information for decision makers and policymakers (Guéguen et al. 2016). Moreover, the benefits of rapid and effective economic and human loss estimation modeling can be of utmost importance in the immediate aftermath of earthquake disasters (Erdik et al. 2011; Jaiswal and Wald 2013). Developing relevant earthquake loss models is challenging, because most economic and human loss models are based on post-earthquake interpretations, and the empirical relationships are derived from field observations that include substantial uncertainties (Brookshire et al. 1997). Before developing our earthquake loss models, the key questions that had to be addressed were: (1) how to represent the losses from the wealth of the region via a macroeconomic indicator; (2) how to express the economic losses by a homogeneous monetary value over the period of the earthquakes; (3) how to express the magnitude of the seismic hazard; and (4) which functional form of the loss model needed to be used?

There are various models in the literature for rapid assessment of earthquake losses based on economic and human predictors, such as gross domestic product (GDP) and population (Chen et al. 1997; Cha 1998; Chen et al. 2001; Dunbar et al. 2002; Heatwole and Rose 2013). Most of the models are reduced-form models, which consider only one or two parameters. Using a theoretical model, Schumacher and Strobl (2011) showed that economic loss (per capita) due to disasters increases with the size and density of the population in the affected area, and that GDP per capita and its squared value can show statistical significance for loss models. Chen et al. (1997) proposed a model for losses as a function of the occurrence probability of the intensity and a vulnerability function derived empirically by correlating reported losses from past earthquakes with the GDP of the affected area. Using only 29 earthquakes, Cha (1998) developed a log–log relationship between economic losses and GDP for each intensity. Heatwole and Rose (2013) proposed a specific reduced-form model based on U.S. earthquakes that considered a linear regression model of predictor variables to predict losses. Their study examined the population of the affected area, the magnitude of the earthquake, and the total economic losses adjusted to 2011 values using the Consumer Price Index. Jaiswal et al. (2011) published a worldwide model to predict economic impacts for any earthquake. They examined earthquakes that occurred between 1980 and 2007 in 119 countries through a combination of seismic intensity, spatial distribution of the population, and total GDP, as scaled using an exposure correction factor—ratio of wealth per capita to GDP per capita. The wealth estimate per capita was adjusted to the year 2000 value using values derived from the World Bank website.[1]

Based on the observation that economic and social losses are generally related to physical damage caused to buildings (D'Ayala et al. 1997; Bommer et al. 2002; Coburn and Spence 2002; So and Spence 2013), models require a detailed inventory of buildings. Several such models have been developed to forecast socioeconomic losses; for example, the U.S. Federal Emergency Management Agency (FEMA) methodology (HAZUS) for the estimation of potential losses from disasters (FEMA 2016), and the Norwegian Seismic Array (NORSAR) methodology of seismic loss estimation (SELENA) that uses a logic tree approach (Molina et al. 2010). For these models, economic losses and casualties were computed based on building vulnerability and damage for a given seismic hazard. The requirement for a detailed building inventory can be a major drawback for extending loss models to specific areas because of the sheer number of different buildings and the complications involved in accurately assessing their seismic resistance (Guéguen 2013). But recent studies have shown the efficiency of data mining-based vulnerability assessment methods on a large scale that use elementary building characteristics, such as the number of floors and the roof shape. These structural features can easily be assessed by remote sensing or are contained in national databases (Riedel et al. 2014, 2015).

There are relatively few studies on human casualties in the literature. Samardjieva and Oike (1992), Samardjieva and Badal (2002), and Badal et al. (2005) analyzed and tested a model to estimate the (log value of the) number of casualties as a function of the magnitude and population density for earthquakes worldwide. Nichols and Beavers (2003) established a simple equation between fatalities and magnitude for U.S. earthquakes. Jaiswal and Wald (2010) developed a specific empirical model for estimation of earthquake fatalities based on the shaking intensity and the number of people exposed to earthquakes recorded between 1973 and 2007. Post-earthquake observations consistently show that there is strong correlation between

[1] http://www.worldbank.org.

fatalities and damage to buildings. After the Armenian earthquake in 1988, Armenian et al. (1997) reported that being inside a building at the time of the earthquake was the most efficient predictor for fatality, which was related to the damage grade. Coburn and Spence (2002) developed an empirical fatality model that considers the European Macro Scale damage grade (EMS98) as a predictor variable (that is, D4 for extensive damage and D5 for total collapse).

A consensus emerges with regard to the importance of building damage as a contributing factor for losses and the need to consider regional models based on regional earthquake data. Since it appears that losses are directly related to the amount of damage, construction quality will be a key factor, which requires limiting the model to a specific region wherein the structural design is comparable. Moreover, in our dataset, many moderate earthquakes—for example, the 1960 Agadir earthquake—caused significant economic and human losses associated with severe building damage. Consequently, earthquake characteristics—for example, magnitude, intensity—alone are not sufficient to derive earthquake loss models. Moreover, to help earthquake crisis management and the prediction of the recovery period, the number of people who lost their homes is another key piece of information.

The main objective of this study is to consider damage as a hazard-related parameter and to show improvement in the accuracy of loss estimation obtained in empirical models by using this parameter instead of intensity and/or magnitude alone as hazard-related parameters. We developed empirical models for economic losses and human losses (home loss, injuries, fatalities) from earthquakes as applied to the Mediterranean region through the compilation of data from different databases and countries. Particular attention has been paid to Algeria—a high exposure, seismic-prone region—to show the benefit of reducing uncertainties by considering regional events for loss models. Several models and exposure variables were also tested (population, GDP). In the following section, we present the data on seismological features (magnitude, location) and economic, social, and physical consequences. When the regression models are developed, the results and their interpretations are discussed. Finally, these models are applied to a case study of Constantine, Algeria using data from a large-scale vulnerability assessment that was carried out previously using data mining-based methods.

2 Mediterranean Earthquakes and Losses Data

To develop a seismic loss model for a specific region with any degree of reliability, historical data of earthquake impact must be carefully considered and compiled in a comprehensive way. This involves the review of existing earthquake catalogs, engineering damage reports, and databases of losses reported after earthquakes, among other sources. The objective of the present study was not to offer a comparative analysis of data quality, and the selection of the data sources here was based on their international use and dissemination, or considered as being authoritative at the national scale. For this study, hundreds of reports and publications were consulted, but only a few reports that described losses in detail were ultimately used.

The region considered is the Mediterranean region (Fig. 1), which includes several earthquake-prone countries and is exposed to both strong (for example, Italy, Algeria, Greece) and moderate (for example, France, Morocco, Libya) seismic hazard. The data are drawn from the period of 1900–2015, and are for earthquakes for which detailed loss reports were available. Following a scientific approach, only accessible, public documents were considered, and these are referenced to allow the traceability of the information used.

The characteristics of the earthquakes are given in Tables 1 and 2. Magnitude and intensity (the Mercalli modified intensity) are from the U.S. Geological Survey earthquake search catalog[2] for earthquakes after 1980, and from public reports or peer-reviewed articles for others. As an example, Benouar (1994) completed a database of the strongest Algerian earthquakes for the 1900–1980 period, the Algerian Technical Office (Azzouz 2002; Azzouz and Rebzani 2005) provided information on specific earthquakes, and on behalf of the French ministry in charge of natural disaster management, Payany (1983) provided information on the damaging earthquakes that occurred in France in 1909. The final dataset consisted of 65 earthquakes that occurred between 1908 and 2014, with maximal epicentral intensities $\geq$ VI (Table 1), and located in nine countries: Algeria (24), Italy (12), Greece (11), Turkey (11), Morocco (2), Spain (2), France, Libya, and Egypt (1 each). Figure 2a shows the distribution of the earthquakes per country. This study does not include all the damaging earthquakes in the Mediterranean region over this period, mainly because either no data or only data from largely uncertain sources were available for some in terms of economic and human losses.

The Earthquake Engineering Research Institute (EERI) reports (EERI 1986, 1992, 1995, 1998, 1999, 2004, 2012) provided a lot of post-earthquake descriptions that were collected in the field soon after the events, and these were used to complete the seismological information in our study. In terms of damage and economic and human losses, the EERI reports are often limited to information available immediately after the event. Several months, or even years,

[2] https://earthquake.usgs.gov/earthquakes/search/.

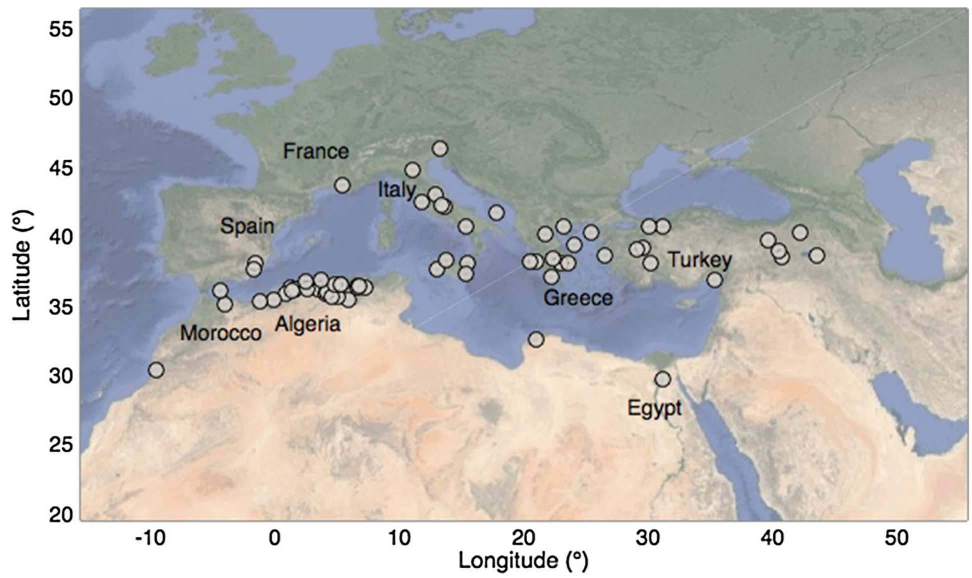

Fig. 1 The 65 earthquakes (circles) in the Mediterranean region considered in this study, during the period 1900–2015

can pass after an earthquake before this information can be considered to be comprehensive, and definitive missing information on total socioeconomic losses is never updated in these reports. Additional official databases were therefore examined to gather the missing information for this study: the International Disaster Database EM-DAT (Guha-Sapir et al. 2016), the Damaging Earthquakes Database CATDAT (Daniell et al. 2011; CATDAT 2016), and the Significant Earthquake Database of the National Geophysical Datacenter (NGDC 2016). In these databases, no information was available on the reliability and accuracy of the data that they contained, related to, for instance, the exposed populations, economic losses, and fatalities, as these databases consisted only of compilations of reports.

The EM-DAT database was created in 1998 and is maintained by the Centre for Research on the Epidemiology of Disasters in Brussels, Belgium. This database contains comprehensive data related to the occurrence and effects of over 18,000 natural disasters throughout the world, from 1900 until the present day. The EM-DAT data were cross-checked with other sources of information, such as UN agencies, nongovernmental organizations, and reinsurance companies. The NGDC database that was developed by the National Center for Environmental Information is similar to EM-DAT. It contains data on over 5700 destructive earthquakes from 2150 B.C. to the present, including information related to socioeconomic losses. CATDAT was created in 2010, and it contains over 20,000 sources of information that provide data on losses from over 12,000 historical damaging earthquakes (Daniell et al. 2011). In the present study, we considered information from CATDAT for earthquakes that occurred between 2011 and 2014. Finally, additional sources of information, such as public and official reports and peer-reviewed articles completed the loss databases used in this study (Table 2). Figure 2b–d shows the distribution of the earthquakes considered in the present study for each data source, in terms of economic losses (Fig. 2b), home loss (Fig. 2c), and number of damaged buildings (Fig. 2d).

The earthquakes were mainly located in the most seismically active countries of the Mediterranean region (Italy, Greece, Turkey, and Algeria), which represent 90% of the dataset. As particular attention was given to the Algerian region in the present study, 37% of the selected earthquakes were in Algeria. This proportion is not representative of the seismicity rate over this period, but is due to the information that was available to the authors. As shown in Fig. 2, more than 60% of the data for socioeconomic losses was drawn from the EM-DAT (Guha-Sapir et al. 2016) and NGDC (2016) databases. Because our objective was to construct the most comprehensive and traceable dataset possible, the data sources were cross-referenced according to their international audience or dissemination and validation at the international level, and references for the preferred source of information for earthquake occurrence were included in Tables 1 and 2.

3 Method

Based on data from the Mediterranean earthquake and loss database developed for this study, and using regression analysis between economic and human losses and hazard and exposure factors, empirical loss models for earthquakes in the Mediterranean region are developed in this study and their accuracy is examined. These models are then applied in a case study of Algeria for earthquake loss prediction. As a first step to develop empirical seismic loss

Table 1 Mediterranean earthquakes from 1900 to 2015 compiled in the database, with the Algerian earthquakes listed separately at the end

ID location	Date	Country	Lat (°)	Long (°)	*M*	*MMI*	*H*	*I*	*F*	References
1 Messina	28.12.1908	Italy	38.08	15.41	7.2	XI	10,000	–	85,925	RMS (2008), Barbano et al. (2005) and Baratta (1910)
2 Lambesc	11.06.1909	France	43.70	5.40	6.2	IX	–	250	46	Payany (1983)
3 Avezzano	13.01.1915	Italy	42.18	13.59	6.7	XI	13,000	–	29,978	NGDC (2016) and Storchak et al. (2013)
4 Chios	23.07.1949	Greece	38.71	26.45	6.5	IX	–	435	7	Altinok et al. (2005) and NGDC (2016)
5 Lixouri	12.08.1953	Greece	38.18	20.94	6.8	X	10,000	2412	476	NGDC (2016) and Guha-Sapir et al. (2016)
6 Agadir	29.02.1960	Morocco	30.45	− 9.62	5.7	X	20,000	25,000	12,000	NGDC (2016) and Guha-Sapir et al. (2016)
7 Barce	21.02.1963	Libya	32.66	20.99	5.6	IX	8500	375	300	NGDC (2016)
8 North. Sporades	09.03.1965	Greece	39.40	24.00	6.3	VIII	–	253	38	NGDC (2016)
9 Belice	15.01.1968	Italy	37.70	13.03	6.4	X	–	563	216	NGDC (2016)
10 Gediz	28.03.1970	Turkey	39.17	29.55	7.4	VIII	80,000	1200	1086	NGDC (2016) and Mitchell (1976)
11 Tuscania	06.02.1971	Italy	42.50	11.80	5.0	VIII	5000	150	24	NGDC (2016)
12 Lice	06.09.1975	Turkey	38.52	40.77	6.7	IX	100,000	4500	2386	NGDC (2016) and Yanev (1975)
13 Friuli	06.05.1976	Italy	46.38	13.27	6.5	X	157,000	2400	978	NGDC (2016) and US Geological Survey (2016)
14 Salonica	20.06.1978	Greece	40.74	23.23	6.2	VIII	–	100	50	NGDC (2016) and Psycharis (1978)
15 Irpinia	23.11.1980	Italy	40.79	15.31	6.9	X	235,000	7700	4689	NGDC (2016)
16 Athens	24.02.1981	Greece	38.16	22.98	6.6	VIII	100,000	400	22	NGDC (2016) and Berz and Hettler (1981)
17 Erzurum	30.10.1983	Turkey	40.33	42.18	6.6	VIII	25,000	1142	1330	NGDC (2016) and Erdik (1984)
18 Kalamata	13.09.1986	Greece	37.07	22.18	5.9	X	–	300	20	NGDC (2016)
19 Carlentini	13.12.1990	Italy	37.29	15.40	5.6	VII	2500	200	19	NGDC (2016) and Psycharis (1978)
20 Erzincan	13.03.1992	Turkey	39.73	39.65	6.6	VIII	36,000	3850	653	NGDC (2016) and Turkish Red Crescent Society (2006)
21 Cairo	12.10.1992	Egypt	29.73	31.16	5.8	VIII	50,000	9900	557	NGDC (2016) and EERI (1992)
22 Dinar	01.10.1995	Turkey	38.08	30.14	6.4	VIII	–	240	96	NGDC (2016) and Turkish Red Crescent Society (2006)
23 Kozani	13.05.1995	Greece	40.15	21.71	6.6	VIII	–	25	0	NGDC (2016) and Hatzfeld et al. (1997)
24 Egion	15.06.1995	Greece	38.44	22.31	6.5	VII	–	60	26	EERI (1995) and NGDC (2016)
25 U.-Marche	26.09.1997	Italy	43.05	12.84	5.7	X	–	100	14	NGDC (2016)
26 Adana	27.06.1998	Turkey	36.90	35.33	6.3	VIII	–	1041	145	EERI (1998), NGDC (2016) and Turkish Red Crescent Society (2006)
27 Duzce	12.11.1999	Turkey	40.80	31.22	7.1	IX	–	4948	845	NGDC (2016) and Turkish Red Crescent Society (2006)
28 Mula	02.02.1999	Spain	38.06	− 1.54	4.8	VII	3500	327	9	NGDC (2016) and CATDAT (2016)
29 Kocaeli	17.08.1999	Turkey	40.77	30.00	7.6	X	600,000	43,953	17,127	NGDC (2016) and Turkish Red Crescent Society (2006)
30 Athens	07.09.1999	Greece	38.12	23.60	6.0	IX	25,000	1600	143	EERI (1999) and NGDC (2016)
31 Molise	31.10.2002	Italy	41.74	17.85	5.7	VI	2295	100	30	NGDC (2016) and Protezione Civile (2002)
32 Palermo	06.09.2002	Italy	38.34	13.73	5.9	VI	–	20	2	NGDC (2016)
33 Bingol	01.05.2003	Turkey	39.01	40.46	6.4	IX	–	520	176	NGDC (2016) and Turkish Red Crescent Society (2006)

Table 1 continued

ID location	Date	Country	Lat (°)	Long (°)	*M*	*MMI*	*H*	*I*	*F*	References
34 Al Hoceima	24.02.2004	Morocco	35.18	− 3.98	6.4	IX	15,600	926	629	EERI (2004), Akoglu et al. (2006), NGDC (2016) and Cherkaoui (2004)
35 L'Aquila	06.04.2009	Italy	42.33	13.33	6.3	VIII	30,000	1500	306	NGDC (2016)
36 Simav	19.05.2011	Turkey	39.15	29.10	5.8	VIII	10,000	94	3	NGDC (2016)
37 Lorca	11.05.2011	Spain	37.70	− 1.67	5.1	VII	–	300	9	Martínez-Díaz et al. (2012) and NGDC (2016)
38 Van	23.10.2011	Turkey	38.69	43.50	7.1	VIII	125,400	2608	644	NGDC (2016), Daniell et al. (2011) and CATDAT (2016)
39 Medolla	29.05.2012	Italy	44.82	11.07	5.8	VIII	14,000	350	17	NGDC (2016)
40 Kefalonia	26.01.2014	Greece	38.21	20.45	6.1	VIII	–	6	0	NGDC (2016)
41 Aegean Sea	24.05.2014	Greece	40.29	25.39	6.9	VIII	–	266	3	NGDC (2016)
42 Constantine	04.08.1908	Algeria	36.41	6.61	5.2	VIII	–		12	Benouar (1994)
43 Aumale	24.06.1910	Algeria	36.23	3.44	6.6	VIII	–	–	81	Benouar (1994)
44 Bordj hassan	25.08.1922	Algeria	36.40	1.20	5.4	VIII	–	–	4	Benouar (1994)
45 Mac-Mahon	16.03.1924	Algeria	35.42	5.90	5.3	VIII	–	–	4	Benouar (1994)
46 Chlef	24.08.1928	Algeria	35.90	0.90	5.4	VIII	–	–	4	Benouar (1994)
47 Carnot	07.09.1934	Algeria	36.20	1.60	5.1	VII	–	11	0	Benouar (1994)
48 Guelma	10.02.1937	Algeria	36.40	7.20	5.2	VIII	28	16	2	Benouar (1994)
49 Mansoura	16.04.1943	Algeria	35.90	4.00	5.3	VIII	900	11	9	Benouar (1994)
50 Mont Hodna	12.02.1946	Algeria	35.70	5.00	5.5	VIII	7500	118	277	Benouar (1994)
51 Constantine	06.08.1947	Algeria	36.31	− 6.68	5.0	VIII	–	8	3	Benouar (1994)
52 Kheratta	17.02.1949	Algeria	36.52	5.24	4.7	VII	350	16	2	Benouar (1994)
53 Chlef	09.09.1954	Algeria	36.27	1.59	6.7	X	60,000	5000	1243	Benouar (1994), NGDC (2016) and Ayadi and Bezzeghoud (2015)
54 Bou Medfaa	07.11.1959	Algeria	36.26	2.60	5.3	VIII	500	2	0	Benouar (1994) and NGDC (2016)
55 M'sila	21.02.1960	Algeria	36.04	4.17	5.0	VIII	4900	129	47	Benouar (1994)
56 M'sila	01.01.1965	Algeria	35.71	4.49	5.4	VIII	25,000	25	5	Benouar (1994)
57 Bordj	24.11.1973	Algeria	36.14	− 4.41	5.1	VII	14,922	43	4	Benouar (1994) and NGDC (2016)
58 Chlef	10.10.1980	Algeria	36.14	1.41	7.1	X	400,000	8369	2633	Bertero and Shah (1983), Benouar (1994), NGDC (2016) and Ayadi and Bezzeghoud (2015)
59 Constantine	27.10.1985	Algeria	36.46	6.76	5.8	VIII	–	300	10	Benouar (1994) and NGDC (2016)
60 Dj.Chenoua	29.10.1989	Algeria	36.79	2.45	5.7	VIII	50,000	700	35	Benouar (1994) and NGDC (2016)
61 Mascara	18.08.1994	Algeria	35.52	− 0.11	5.9	VII	10,000	295	172	NGDC (2016), Ayadi et al. (2002) and Ayadi and Bezzeghoud (2015)
62 Ain	22.12.1999	Algeria	35.32	− 1.28	5.6	VII	25,000	174	26	NGDC (2016), Ayadi and Bezzeghoud (2015) and Yelles-Chaouche et al. (2004)
63 Beni-Ourtilane	10.11.2000	Algeria	36.61	4.77	5.7	VII	–	50	2	Ayadi and Bezzeghoud (2015)
64 Boumerdes	21.05.2003	Algeria	36.88	3.69	6.8	X	182,000	11,450	2278	NGDC (2016), Ayadi and Bezzeghoud (2015), AFPS (2003) and JAEE (2004)
65 Laalam	20.03.2006	Algeria	36.62	5.33	5.2	VII	–	68	4	NGDC (2016) and Ayadi and Bezzeghoud (2015)

The ID (first column) is used to reference earthquakes in other tables

Lat latitude, *Long* longitude, *M* magnitude, *MMI* Mercalli modified intensity, *H* homeless, *I* injuries, *F* fatalities

Table 2 Population and damage for the Mediterranean for the 1900–2015 earthquakes compiled in the database, with the Algerian earthquakes listed separately at the end

ID	POP_{Tot}	*POP.unit*	*D4 + D5*	L_{EQ} (million)	*GDP* (million)	*GDP.Unit*	$L_{\$2015}$	References
1	35,899,000	150,000	110,000	$116	82,140	343,212,902	2,853,877,661	Guha-Sapir et al. (2016), CATDAT (2016), Baratta (1910) and NGDC (2016)
2	41,109,000	15,000	2648	15.5 FO	130,180	47,500,547	66,530,937	Payany (1983)
3	37,982,000	120,000	6000	$60	106,730	337,201,832	1,408,021,782	NGDC (2016)
4	7,475,335	47,715	6035	$25	14,680	93,702,269	248,967,437	Altinok et al. (2005) and NGDC (2016)
5	7,779,457	74,400	27,773	$100	18,053	172,653,864	887,704,119	NGDC (2016)
6	12,328,534	50,000	3650	$120	2037	8,262,134	960,879,729	Strauss (1974) and Guha-Sapir et al. (2016)
7	1,499,000	30,000	2000	$5	1000	20,013,342	38,728,267	Minami (1965), Guha-Sapir et al. (2016) and NGDC (2016)
8	8,534,252	30,253	1101	$8	7601	26,943,304	227,611,563	Rothe (1969), Guha-Sapir et al. (2016) and NGDC (2016)
9	52,802,703	55,563	20,000	$320	87,940	92,537,122	2,179,466,667	Guha-Sapir et al. (2016) and NGDC (2016)
10	34,772,031	128,061	9528	$55.6	17,087	62,929,516	339,642,917	Mitchell (1976) and NGDC (2016)
11	53,891,946	13,900	1718	$41	124,300	32,059,892	239,943,135	NGDC (2016)
12	39,185,637	160,000	5518	$17	44,640	182,270,457	30,838,643	Yanev (1975) and NGDC (2016)
13	55,539,118	500,000	43,000	$3600	224,100	2,017,496,929	14,995,803,163	Goretti and Di Pasquale (2002) and Guha-Sapir et al. (2016)
14	9,388,188	600,100	3245	$250	44,433	2,840,203,383	908,807,515	Guha-Sapir et al. (2016) and NGDC (2016)
15	56,336,446	4,641,620	120,000	$20,000	475,900	39,209,909,656	57,528,398,058	Guha-Sapir et al. (2016), Goretti and Di Pasquale (2002), Ferrer et al. (2004) and NGDC (2016)
16	9,704,947	80,400	8000	$900	52,539	435,259,230	2,117,247,569	Guha-Sapir et al. (2016) and NGDC (2016)
17	47,072,603	834,137	3241	$100	61,677	1,092,939,025	59,492,219	Guha-Sapir et al. (2016), Aysan (1984) and Erdik (1984)
18	9,945,576	45,300	1825	$745	56,587	257,743,666	1,611,110,082	EERI (1986) and Guha-Sapir et al. (2016)
19	57,007,577	10,000	1500	$500	1,178,000	206,639,198	906,721,500	NYT (1990) and Guha-Sapir et al. (2016)
20	55,811,134	348,850	8057	$750	159,095	994,430,443	675,743,407	NGDC (2016) and Guha-Sapir et al. (2016)
21	58,922,018	12,000,000	9350	$1200	41,855	8,524,249,797	3,378,717,035	EERI (1992), Guha-Sapir et al. (2016) and NGDC (2016)
22	58,522,320	35,000	5100	$205.8	169,486	101,363,146	388,807,415	NGDC (2016) and EERI (1998)
23	10,641,169	86,471	12,000	$450	137,383	1,116,391,580	699,853,346	NGDC (2016) and Guha-Sapir et al. (2016)
24	10,641,169	13,900	4301	$660	137,383	179,456,064	1,026,451,575	Guha-Sapir et al. (2016) and NGDC (2016)
25	57,044,614	112,412	27,000	$4520.49	1,240,000	2,443,541,471	6,675,594,880	Guha-Sapir et al. (2016) and Goretti and Di Pasquale (2002)
26	61,344,874	1,589,600	1700	$550	269,287	6,977,906,160	1,454,092,025	Guha-Sapir et al. (2016) and NGDC (2016)
27	62,295,617	714,668	26,704	$1000	249,751	2,865,198,627	1,422,671,068	Turkish Red Crescent Society (2006) and Guha-Sapir et al. (2016)
28	40,392,585	60,109	161	$60.109	633,194	942,268,591	85,515,335	Ferrer et al. (2004)
29	62,295,617	1,358,953	20,000	$20,000	249,751	5,448,225,197	22,762,737,095	Aydan et al. (2000) and Guha-Sapir et al. (2016)

Table 2 continued

ID	POP_{Tot}	*POP.unit*	$D4+D5$	L_{EQ} (million)	*GDP* (million)	*GDP.Unit*	$L_{\$2015}$	References
30	10,910,741	115,139	53,000	$4200	142,998	1,509,028,919	4,268,013,205	NGDC (2016) and Guha-Sapir et al. (2016)
31	57,655,677	330,900	300	$796	1,267,000	18,659,930,045	395,247,916	Protezione Civile (2002), EERI (2003) and NGDC (2016)
32	57,655,677	30,402	400	$500	1,267,000	668,107,905	658,746,526	NGDC (2016)
33	66,060,121	68,900	718	$290.52	303,005	316,031,288	374,229,233	NGDC (2016), Turkish Red Crescent Society (2006) and Guha-Sapir et al. (2016)
34	30,093,109	239,235	2539	$400	56,948	452,727,354	501,888,830	NGDC (2016) and Guha-Sapir et al. (2016)
35	59,467,196	56,000	15,000	$2500	2,186,000	2,058,546,699	2,761,959,476	NGDC (2016) and Guha-Sapir et al. (2016)
36	73,517,002	41,000	2208	$244	774,754	432,075,864	257,101,472	Daniell et al. (2011), CATDAT (2016) and Guha-Sapir et al. (2016)
37	46,708,366	150,000	1164	$332.5	774,754	2,488,058,135	1,264,433,469	Guha-Sapir et al. (2016) and Valcárcel et al. (2012)
38	73,517,002	291,000	28,650	$1500	744,800	2,948,118,042	1,580,541,836	Daniell et al. (2011), CATDAT (2016) and Guha-Sapir et al. (2016) and NGDC (2016)
39	59,737,717	1,000,000	16,900	$1433.2	2,075,200	34,738,522,063	1,479,536,766	Daniell et al. (2011) and CATDAT (2016)
40	11,000,777	35,800	1700	$178	237,592	773,200,323	178,211,281	CATDAT (2016) and NGDC (2016)
41	11,000,777	75,002	300	$450	237,592	1,619,876,276	450,534,139	KOERI (2014), Guha-Sapir et al. (2016) and NGDC (2016)
42	4,850,000	–	–	0.4 FA	450	–	1,716,927	Benouar (1994)
43	5,200,000	50,000		$1	470	451,923	24,129,270	Benouar (1994) and NGDC (2016)
44	5,450,000	–	50	–	–	–	–	Benouar (1994)
45	5,500,000	–	–	–	–	–	–	Benouar (1994)
46	5,650,000	603	100	0.4 FA	473	50,467	272,202	Benouar (1994)
47	6,170,000	800	100	–	–	–	–	Benouar (1994)
48	6,700,000	13,000	–	5 FA	–	–	3,170,176	Benouar (1994)
49	7,700,000	4000	250	–	–	–	–	Benouar (1994)
50	7,750,000	51,000	1000	$13.5[a]	3,520	23,163,870	60,773,589	Ayadi and Bezzeghoud (2015) and NGDC (2016)
51	7,850,000	10,000	50	$3[a]	3480	4,433,121	26,571,412	Benouar (1994) and NGDC (2016)
52	8,730,000	4603	50	300 FA	1,180	622,267	18,334,846	Benouar (1994)
53	9,609,507	129,250	20,000	$6	1689	22,716,079	52,866,245	Ayadi and Bezzeghoud (2015) and NGDC (2016)
54	10,848,971	915	100	300 FA	2,000	168,750	5,457,943	Benouar (1994)
55	11,124,892	10,000	600	500 FA	2037	1,831,208	8,778,887	Benouar (1994)
56	12,626,953	49,350	3145	$2	3,136	12,257,621	15,048,698	Benouar (1994) and NGDC (2016)
57	15,804,428	–	2000	–	8715	–	–	Benouar (1994) and Maouche et al. (2008)
58	19,337,723	930,317	60,000	$5200	42,345	2,037,186,718	14,957,383,495	Benouar (1994), Guha-Sapir et al. (2016), Azzouz (2002) and NGDC (2016)
59	22,565,908	20,000	–	$1	57,938	–	2,202,760	Benouar (1994) and NGDC (2016)
60	25,257,671	150,000	8000	$5	55,631	330,383,787	9,557,137	Benouar (1994) and NGDC (2016)
61	28,362,015	30,000	2806	$128	42,543	44,999,553	204,711,039	Azzouz and Rebzani (2005) and World Bank (1994)
62	30,766,551	30,731	2708	$112.84	48,640	48,584,622	160,534,203	CGS (2000) and World Bank (2000)

Table 2 continued

ID	POP_{Tot}	*POP.unit*	*D4* + *D5*	L_{EQ} (million)	*GDP* (million)	*GDP.Unit*	$L_{\$2015}$	References
63	31,183,658	956	3000	$24	54,790	1,679,308	33,033,728	Ayadi and Bezzeghoud (2015)
64	32,394,886	210,261	30,000	$5000	67,864	440,474,167	6,440,679,348	Maouche et al. (2008), Guha-Sapir et al. (2016) and NGDC (2016)
65	33,749,328	1000	40	$4.25	117,027	343,212,902	4,996,638	Ayadi and Bezzeghoud (2015) and estimated

POP_{Tot} total population on the day of the earthquake, *POP.Unit* the affected population, *D4* + *D5* damaged buildings, L_{EQ} economic losses for the day of the earthquake, *GDP* gross domestic product for the day of the earthquake, *GDP.Unit* GDP of the affected area, $L_{\$2015}$ adjusted losses to USD in 2015, *FA Ancien franc* currency, *FO Franc Or*

[a]From the National Geophysical Datacenter, losses are classified by range of losses, and for these earthquakes the mean values of the ranges were considered

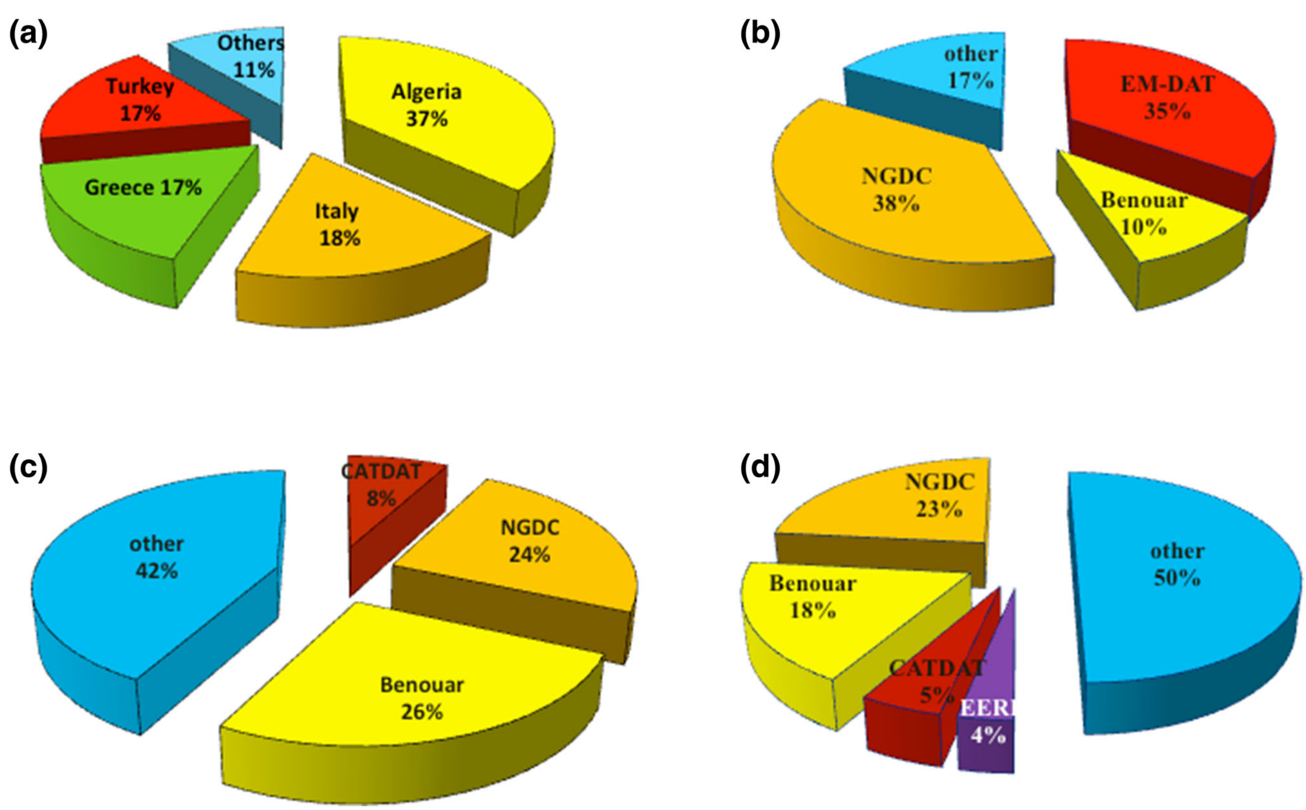

Fig. 2 Distribution of the earthquakes included in the present study: **a** by country in the Mediterranean region; **b–d** by associated socioeconomic losses used and data source, for economic losses (**b**), home loss (**c**), and number of damaged buildings (**d**)

models from the predictor variables available in the study database, the regression model forms proposed by Cha (1998) for GDP and seismic intensities, Heatwole and Rose (2013) for magnitude, population, and GDP, and Samardjieva and Badal (2002) for population and magnitude are adopted in this study.

Economic losses (*L*) are considered as a key dependent variable of the regression models. Daniell et al. (2010) reported that economic losses not adjusted to current USD values are a significant difficulty when compiling earthquake data from different epochs. To compare the consequences of earthquakes in a comprehensive manner, the actual economic losses were adjusted and normalized to a common and unique value (Daniell et al. 2011)—the 2015 USD currency. Nevertheless, for many countries around the Mediterranean (for example, France, Algeria, and Italy), this value was only available from the national census agencies after 1950, and GDP data before 1950 was

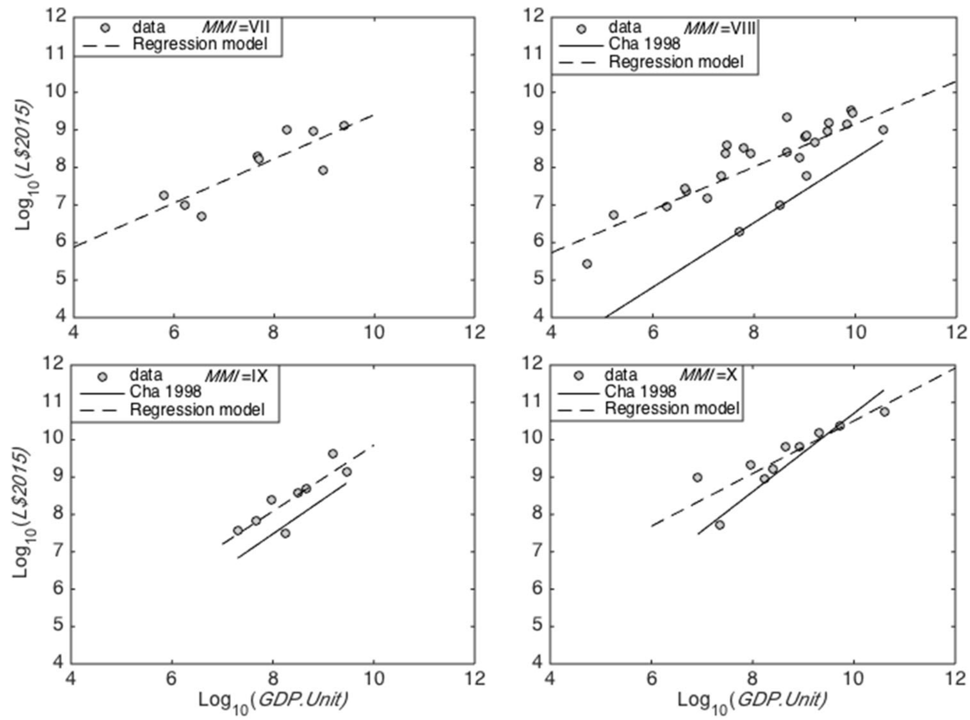

Fig. 3 Economic damage adjusted to 2015 USD value ($L_{\$2015}$) versus *GDP.Unit* with the regression models for the seismic intensities VII–X of the Mediterranean earthquakes examined in this study, compared with the Cha (1998) empirical model results

Table 3 Regression of the economic losses adjusted to 2015 USD value ($L_{\$2015}$) considering *GDP.Unit* as the exposure-related variable for seismic intensities between VII and X (Eq. 3)

Seismic intensity	$\text{Log}_{10}(L_{\$2015})$ regression	RMSE	Adjusted R^2	R^2	Observation
VII	$0.53G + 4.02$	0.55	0.57	0.62	9
VIII	$0.59G + 3.40$	0.55	0.71	0.72	24
IX	$0.88G + 1.03$	0.43	0.68	0.72	8
X	$0.69G + 3.51$	0.39	0.74	0.76	13

G: $\log_{10}(GDP.Unit)$

provided by Maddison (2006). Inflation was allowed for, with the use of the Consumer Price Index inflation calculator from the Bureau of Labor Statistics, U.S. Department of Labor[3] to update the economic loss value adjusted from the year of the earthquake (L_{EQ}) to the present-day value ($L_{\$2015}$). For the Algerian earthquakes and the single French earthquake of Lambesc (1909), L_{EQ} was given in currencies that no longer exist. Here, the French Institute of Statistics and Economic Studies converter[4] was used to convert L_{EQ} into current currency in Euros on the date of the earthquake, which was then adjusted to the $L_{\$2015}$ (Table 2).

Home loss (*H*), injury (*I*), and fatality (*F*) are used as dependent variables of the regression models for human (social) losses, and their statistics came directly from the EM-DAT and NGDC databases for most of the earthquakes considered in the present study, or from referenced reports (Table 1).

Earthquake intensity and magnitude and building damage are selected as hazard variables. Damage (*D*) is usually reported as the total number of buildings that suffer damage. The present study determined the total number of buildings based on those having suffered heavy to strong damage, as classified by the damage grades D4 and D5 (Table 2), according to the EMS98 damage scale.

Population affected by the earthquakes (*POP.Unit*) is considered an important exposure variable, and these data came either from direct reports or other references (Table 2):

$$POP.Unit = POP_{Tot}\frac{A_{Aff}}{A_{Tot}} \tag{1}$$

where A_{Aff} is the size of the affected area, A_{Tot} is the surface area, and POP_{Tot} is the population of the country, on the date of the earthquake. POP_{Tot} was provided by the

[3] http://www.bls.gov/data/inflation_calculator.htm.

[4] http://www.insee.fr/fr/service/reviser/calcul-pouvoir-achat.asp.

Table 4 Regression of the economic losses adjusted to 2015 USD value ($L_{\$2015}$) considering *POP.Unit* as the exposure-related variable for seismic intensities between VII and X

Seismic Intensity	$Log_{10}(L_{\$2015})$ regression	RMSE	Adjusted R^2	R^2	Observation
VII	$0.79P + 4.90$	0.64	0.43	0.50	9
VIII	$0.76P + 4.53$	0.73	0.49	0.51	24
IX	$0.77P + 4.60$	0.69	0.17	0.29	8
X	$0.94P + 4.52$	0.55	0.51	0.55	13

P: $\log_{10}(POP.Unit)$

Table 5 Regression of the economic losses adjusted to 2015 USD value ($L_{\$2015}$) considering magnitude (M) as the hazard-related variable and *GDP.Unit* or *POP.Unit* as the exposure-related variable, and the coefficients of the regression models (Eq. 4)

Predictor variables				RMSE	Adjusted R^2	Observation
Type	Name	Coefficient	Value			
$Log_{10}(L_{\$2015})$		c	− 0.00	0.60	0.65	57
Exposure	$Log_{10}(GDP.Unit)$	b	0.54			
Hazard	$Log_{10}(M)$	a	5.18			
$Log_{10}(L_{\$2015})$		c	0.92	0.70	0.53	57
Exposure	$Log_{10}(POP.Unit)$	b	0.65			
Hazard	$Log_{10}(M)$	a	5.72			

Population City database,[5] taking into account the population growth rate. A_{Aff} was obtained either from references or through estimation from seismic intensity maps.

GDP per capita on the date of the earthquake (GDP_{PC}), as another key exposure variable, is scaled by the population (*POP.Unit*), and GDP of the affected area (*GDP.Unit*) is then estimated by multiplying GDP_{PC} by *POP.Unit*, as follows and is presented in Table 2:

$$GDP.Unit = \frac{\text{GDP}}{POP_{Tot}} \times POP.Unit = GDP_{PC} \times POP.Unit \quad (2)$$

The GDP values adjusted to the USD 2015 values were obtained from the World Bank website.[6] For Algeria before 1960, this information was provided by Clerc (1975).

Because of the lack of information, earthquake-induced losses were not distinguished between those directly caused by the earthquake and those due to tsunamis and/or fires that accompanied the Messina earthquake in 1908. Indeed, Bird and Bommer (2004) reported a small contribution of secondary events to the total losses (except for mega-earthquakes, such as Indonesia 2004 and Japan 2011, which were not in the present study).

[5] http://population.city/country.

[6] http://data.worldbank.org/indicator/.

4 Results

Empirical relationships between loss variables and hazard and exposure factors are presented in this section. The accuracy of the relationships derived from the database information is estimated using the standard error (RMSE), the coefficient of determination (R^2), and the adjusted R^2.

4.1 Economic Losses ($L_{\$2015}$) Versus GDP and Intensity

The linear regression model proposed by Cha (1998) that considers the GDP of the country on the date of the earthquake, is as follows:

$$\log_{10} L_{EQ} = a(MMI) + b(MMI).\log_{10}(GDP) + \varepsilon \quad (3)$$

where $\log_{10}$ indicates the decimal logarithmic function, $a(MMI)$ and $b(MMI)$ are the regression coefficients that depend on seismic intensity, ε is the RMSE, and L_{EQ} and GDP are given in million USD.

In the Cha (1998) study, 29 earthquakes worldwide over the 1980–1995 period, of seismic intensities VIII, IX, and X were considered when deriving a loss empirical model. Figure 3 shows the $\log_{10}$ values of the losses in USD adjusted to the 2015 value ($L_{\$2015}$) versus the *GDP.Unit* predictor variable of the selected Mediterranean earthquakes and according to seismic intensities given in Table 1 and exposure-related variable in Table 2. Only 54

Table 6 Regression of the economic losses adjusted to 2015 USD value ($L_{\$2015}$) considering intensity (*MMI*) as the hazard-related variable and *GDP.Unit* or *POP.Unit* as the exposure-related variable, and the coefficients of the regression models (Eq. 4)

Predictor variables				RMSE	Adjusted R^2	Observation
Type	Name	Coefficient	Value			
$\text{Log}_{10}(L_{\$2015})$		*c*	− 1.16	0.56	0.70	57
Exposure	$\text{Log}_{10}(GDP.Unit)$	*b*	0.61			
Hazard	$\text{Log}_{10}(MMI)$	*a*	5.09			
$\text{Log}_{10}(L_{\$2015})$		*c*	1.93	0.72	0.51	57
Exposure	$\text{Log}_{10}(POP.Unit)$	*b*	0.75			
Hazard	$\text{Log}_{10}(MMI)$	*a*	3.25			

observations with VI < *MMI* < XI and with $L_{\$2015}$ and *GDP.Unit* information available are considered. Compared with Cha (1998), the linear regression models are different for seismic intensities (*MMI*) of VIII to X, which confirms the differences between the worldwide and regional models, and the need to derive a loss-prediction model for any specific area using the appropriate data (Heatwole and Rose 2013). For moderate seismic-prone regions, loss-prediction models for weak seismic intensity (VII) are also relevant, as shown by the moderate earthquake-induced losses referenced in the present dataset (Tables 1, 2).

Table 3 summarizes the results of the regression models for intensities VII–X using Eq. 3. Considering R^2, the model fits are relatively good, at 0.62–0.76, and is as good as for the models provided by Cha (1998). Regression for losses was also performed considering the exposed population as a predictor variable and using the same regression model form as Eq. 3. Table 4 gives the results of the regression models. As expected and reported by most previous studies, *POP.Unit* is not as relevant as *GDP.Unit* for the economic loss models. In this case, the fits of the R^2-based models fall around 0.5, which is notably lower than the values obtained by considering *GDP.Unit*.

4.2 Economic Losses ($L_{\$2015}$) Versus Earthquake Magnitude, GDP, and Affected Population

Heatwole and Rose (2013) used the magnitude of U.S. earthquakes as a hazard-related predictor variable for loss prediction, and considered the population of the affected area and *GDP* as exposure-related variables. Assuming a non-normal distribution of the variables, they considered a natural-log model using a conventional form, as follows:

$$\log(L_{\$2015}) = a\log(X1) + b\log(X2) + c + \varepsilon, \tag{4}$$

where log indicates the natural log; *a*, *b*, and *c* are the regression coefficients; ε is the *RMSE*; *X*1 is the hazard-related variable—magnitude or intensity; and *X*2 is the exposure-related variable—*GDP.Unit* or *POP.Unit*. The sparse nature of the data and the minimum number of predictor variables means that these variables are not normally distributed and are considered logged variables.

Table 5 summarizes the regression model coefficients following the original presentation by Heatwole and Rose (2013) using *POP.Unit* and *GDP.Unit* to predict the $L_{\$2015}$ losses. Only 57 observations with VI < *MMI* < XI and with $L_{\$2015}$ and *GDP.Unit* and *POP.Unit* information available are considered. As Heatwole and Rose (2013) reported, the regression fit coefficient (adjusted R^2) is higher for *GDP.Unit* (0.653) than for *POP.Unit* (0.527), because *GDP.Unit* is a macroeconomic variable that represents the wealth of the affected region, whereas the population is not. Compared with using the regression forms of Cha (1998) (Tables 3, 4), the same results are observed, which confirms the relevance of *GDP* rather than population for prediction of economic damage. For *GDP.Unit*, the coefficient of the regression fit (adjusted R^2) is of the same order of magnitude (0.610 versus 0.653) as for the regional U.S. earthquake-based model (Heatwole and Rose 2013), which also confirms the advantage of using regional earthquake loss databases. However, the magnitude characterizes the actual earthquake and does not take into account any seismic wave attenuation with distance, whereas the macroseismic intensity does. It is therefore reasonable to assume that intensity is a more relevant hazard-related predictor than magnitude. Table 6 gives the economic loss predictions with intensity as the hazard-related predictor variable, in the same manner as the formulation by Cha (1998). The fit model parameters (R^2, adjusted R^2) are higher with intensity than with magnitude, with values comparable to those from Eq. 3 considering *GDP.Unit* (Table 3), and R^2 close to 0.7. This result shows that intensity is a better hazard-related predictor variable for relevant loss assessment.

4.3 Human Losses Considering Building Damage

Extensive studies have been carried out using building damage as a predictor variable for loss assessment (D'Ayala et al. 1997; Bommer et al. 2002; Goretti and Di

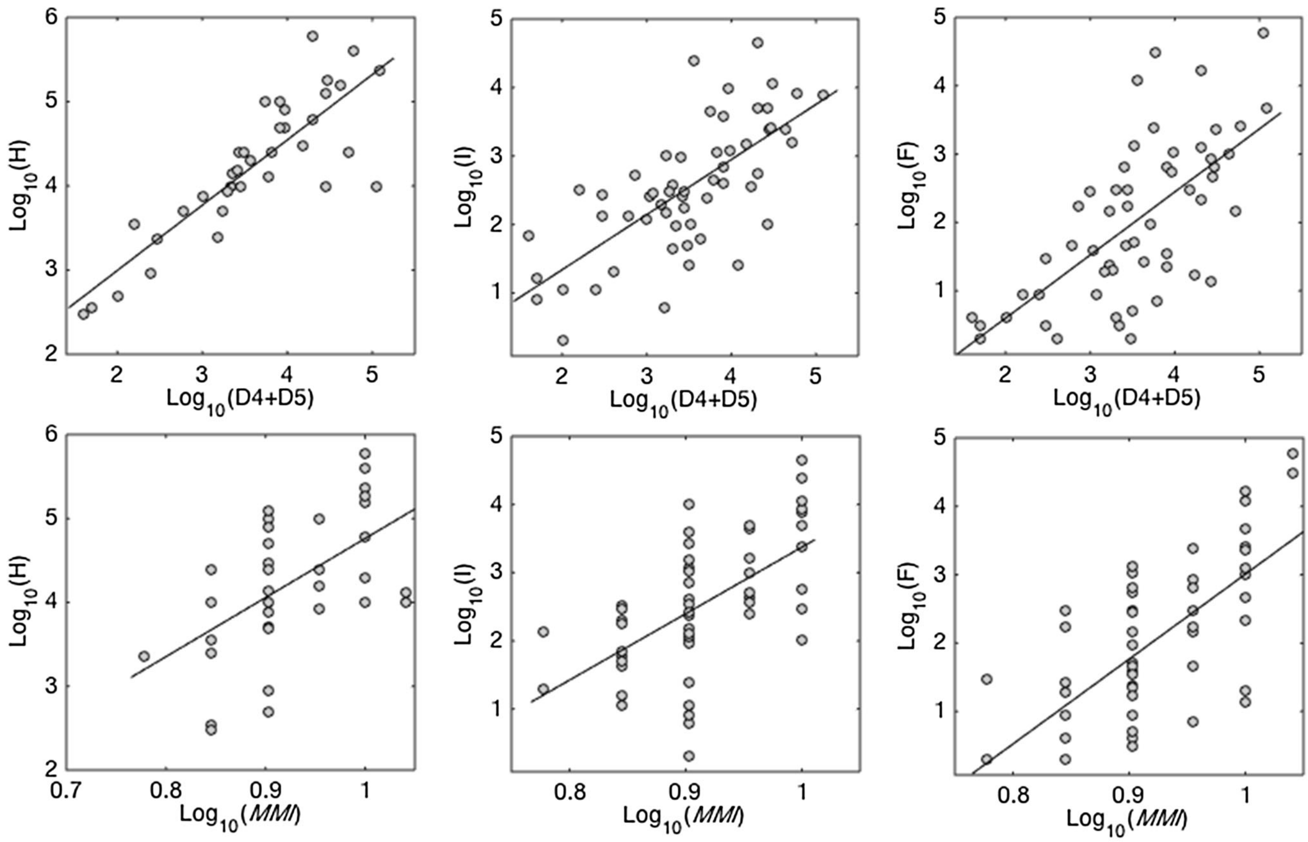

Fig. 4 Human losses (home loss, injuries, fatalities) versus damage (**a**) and intensity (**b**) as hazard-related predictor variables. The black lines correspond to the best-fit regression models

Pasquale 2002; Kappos et al. 2006; So and Spence 2013; FEMA 2016), on the premise that damage to structures produces direct and indirect economic losses and fatalities. Damage can indeed be considered as a proxy of intensity, as macroseismic surveys completed after earthquakes are mainly derived from the observed damage for the strongest shaking (> VII). The amount of damage also affects the costs related to reconstruction and business interruption because of loss of use of damaged buildings.

In the present study, extensive data allowed the development and testing of regression models, with the loss estimation based on reduced forms, like those proposed by Heatwole and Rose (2013), but considered on a $\log_{10}$ scale. The human loss variables are the number of homeless and injured people, and the fatalities, while considering the affected population (*POP.Unit*) as an exposure-related variable. The hazard-related predictor variables are seismic intensity and number of damaged buildings classified as $D4 + D5$, according to EMS98. In our dataset, the quality of the data is relatively heterogeneous, with some references indicating the numbers of casualties with accuracy to the unit, while others indicating rounded quantities, and thus introducing uncertainty into the regression models. The primary objective of the present study was also to develop prediction models for the Mediterranean region, with special focus on Algeria, and here the Algerian earthquakes are defined separately from the total dataset in each analysis.

Figure 4 shows as an example the distribution of human losses versus damage (Fig. 4a) and intensity (Fig. 4b) for all of the earthquakes. Exposed population is not considered here.

Table 7 summarizes all of the analysis results related to the regression fits, with RMSE and adjusted R^2. Table 7 and Fig. 4 show that for injuries (I) and fatalities (F), the models show low fits compared to those for home loss (H). Considering the whole dataset of earthquakes and intensities as the predictor variables (Fig. 4b, Table 7), low-fit models were derived, with adjusted R^2 of 0.23, 0.34, and 0.42 for the H, I, and F human loss variables, respectively. These values were significantly improved to become 0.72, 0.49, and 0.44, respectively when the damage was used as the predictor variable (Fig. 4a, Table 7). These models show the lowest RMSE values, which confirm the relevance of damage as a predictor of casualties. Furthermore, a reduced-form model that considered simultaneously intensity and damage was tested (Table 7), and the fits did not improve significantly (0.73, 0.53, and 0.54,

Table 7 Regression of the home loss (*H*), injuries (*I*), and fatalities (*F*) variables as human loss parameters using damage (*D*4 + *D*5), intensity (*MMI*), and population affected (*POP.Unit*) as the predictor variables for the earthquakes included in the Mediterranean database and for the Algerian earthquakes

Variables	Regression model	RMSE	Adjusted R^2	R^2	Observation
All earthquakes: intensity (*MMI*)					
Home loss	$H = 7.36\ MMI - 2.63$	0.81	0.23	0.25	38
Injuries	$I = 9.88\ MMI - 6.52$	0.78	0.34	0.35	58
Fatalities	$F = 12.80\ MMI - 9.85$	0.89	0.42	0.43	61
All earthquakes: Damage (*D*)					
Home loss	$H = 0.78\ D + 1.45$	0.44	0.72	0.72	36
Injuries	$I = 0.81\ D - 0.27$	0.69	0.48	0.49	56
Fatalities	$F = 0.92\ D - 1.25$	0.88	0.43	0.44	55
Algerian earthquakes: Intensity (*MMI*)					
Home loss	$H = 12.22\ MMI - 7.14$	0.78	0.43	0.48	13
Injuries	$I = 11.57\ MMI - 8.44$	0.83	0.28	0.33	17
Fatalities	$F = 13.64\ MMI - 10.91$	0.83	0.37	0.40	16
Algerian earthquakes: Damage (*D*)					
Home loss	$H = 0.98\ D + 1.94$	0.16	0.98	0.98	13
Injuries	$I = 0.91\ D - 0.75$	0.59	0.71	0.72	17
Fatalities	$F = 0.85\ D - 1.09$	0.77	0.54	0.57	16
All earthquakes: Damage (*D*) + Intensity (*MMI*)					
Home loss	$H = 0.84\ D - 1.26\ MMI + 2.39$	0.44	0.71	0.73	36
Injuries	$I = 0.62\ D + 4.34\ MMI - 3.60$	0.67	0.52	0.53	55
Fatalities	$F = 0.56\ D + 7.71\ MMI - 7.07$	0.80	0.53	0.54	55
All earthquakes: Damage (*D*) + Population (*P*)					
Home loss	$H = 0.55\ D + 0.32\ P + 0.67$	0.39	0.77	0.78	36
Injuries	$I = 0.49\ D + 0.45\ P - 1.38$	0.62	0.58	0.60	55
Fatalities	$F = 0.67\ D + 0.39\ P - 2.20$	0.84	0.48	0.49	55
Algerian earthquakes: Damage (*D*) + Intensity (*MMI*)					
Home loss	$H = 1.02\ D - 1.03\ MMI + 1.64$	0.16	0.98	0.98	13
Injuries	$I = 0.75\ D + 4.64\ MMI - 4.43$	0.57	0.73	0.76	17
Fatalities	$F = 0.60\ D + 7.54\ MMI - 7.07$	0.71	0.61	0.66	16
Algerian earthquakes: Damage (*D*) + Population (*P*)					
Home loss	$H = 0.77\ D + 0.25\ P + 0.40$	0.15	0.98	0.98	13
Injuries	$I = 0.63\ D + 0.39\ P - 1.50$	0.56	0.75	0.78	16
Fatalities	$F = 0.40\ D + 0.64\ P - 2.35$	0.66	0.67	0.71	15

H $\log_{10}$(Home loss), *I* $\log_{10}$(Injuries), *F* $\log_{10}$(Fatalities), *D* $\log_{10}$(*D*4 + *D*5), *P* $\log_{10}$(*POP.Unit*), *MMI* $\log_{10}$(*MMI*)

respectively). Despite the significant relevance of damage as a hazard-related variable, the fits remained low, which resulted in imprecise assessment when using these models. However, when considering the Algerian earthquakes only (Table 7), the fits are considerably improved, reaching 0.98, 0.72, and 0.57, respectively, although this is based on a small amount of data and is not sufficiently representative statistically. This does suggest that regional data-based models that integrate urban features (regional typology, building design, and quality of construction) can improve loss prediction models that consider building damage, which is not the case for the reduced-form regression model that considers intensity and the Algerian earthquakes only (Table 7; with adjusted R^2 of 0.43, 0.28, and 0.37, respectively).

The relevance of building damage as a predictor variable is also confirmed for economic losses. Table 8 gives the economic losses adjusted to 2015 USD value ($L_{\$2015}$) considering *GDP.Unit* and damage as the exposure-related and hazard-related variables of the reduced-form model. Compared with the fits given in Table 6, which consider intensity as the hazard-related variable, the adjusted R^2

Table 8 Regression of the economic loss adjusted to 2015 USD value ($L_{\$2015}$) considering *GDP.Unit* and damage ($D4 + D5$) as the exposure-related and hazard-related variables, respectively, and all of the earthquakes having these information (56 from Tables 1, 2)

$\text{Log}_{10}(L_{\$2015})$ regression model	RMSE	Adjusted R^2	R^2	Observation
$0.47\ D + 0.46\ G + 3.07$	0.55	0.71	0.72	56

D $\log_{10}(D4 + D5)$, *G* $\log_{10}(GDP.Unit)$

increases to 0.72 (from 0.70) and the RMSE decreases a little to 0.55 (compared with 0.56).

As human losses depend on the exposed population, as suggested by Samardjieva and Badal (2002) for a worldwide model, here a Mediterranean model was also derived that considered the exposed population (*POP.Unit*) and damage. Table 7 presents the results of the regression, with significant improvements to the fits given previously in Table 7, whereby R^2 reached 0.77, 0.58, and 0.48, for *H*, *I*, and *F*, respectively. These values were further improved when only the Algerian earthquakes were considered (Table 7), with values of 0.98, 0.75, and 0.67, respectively, which is also the case when damage is used instead of intensity (Table 7).

The relevance of damaged buildings in models of economic and human losses is confirmed by this analysis as well as the evident needs to consider exposed population for human losses. Combining damage as hazard-related variable and GDP or exposed population as exposure-related variables improve the accuracy of the prediction. Nevertheless, damage prediction is more challenging than intensity or magnitude for real-time predictions and especially for regions with no available building inventory or large-scale vulnerability models. New, rapid methods for large-scale damage estimation are becoming more readily available. These practices are based on statistical analysis or data mining of urban data derived from satellite remote sensing (Saito and Spence 2011) or national census databases (Pittore and Wieland 2013; Riedel et al. 2014, 2015; Guettiche et al. 2017).

5 The Constantine (Algeria) Case

In this section, the loss models developed in this study are applied to the city of Constantine, Algeria. We considered the Constantine environment to be suitable for testing the empirical relationships derived in the previous section, without having as an objective a full and extended seismic-risk analysis that includes a site-specific hazard assessment. Constantine is the third largest city in Algeria in terms of population and economic activities. It is located in Algeria's most seismically active region (acceleration, 0.129 g in the Algerian Seismic Hazard Map), and it has suffered several earthquakes in the past (Benouar 1994), including the strongest felt historical earthquake in 1985 of intensity VIII. Guettiche et al. (2017) performed a seismic vulnerability analysis of this area based on methods developed by Riedel et al. (2014) and Riedel et al. (2015), which were validated by comparing classical in situ engineering survey results. The elementary information provided by remote sensing and the national census (for example, period of construction, number of stories) was used to assess seismic vulnerability. We used the EMS98 damage matrix for intensities VII–X to compute seismic damage ($D4 + D5$) for each intensity. Our study is not focused primarily on the Constantine loss assessment for a realistic earthquake scenario, but more as a case study to provide insights on the uncertainties of the loss model related to the database. Only the damage-related scenarios given in Guettiche et al. (2017) were considered for testing the loss models for intensities VII–X.

The population of Constantine in 2008 was around 1 million, according to the National Office of Statistics.[7] The area considered in the present study is highly populated and is characterized by dense neighborhoods composed of old residential buildings. In terms of the urban surface area affected by the scenario earthquake defined by Guettiche et al. (2017), there is an exposed population (*POP.Unit*) of 100,000 inhabitants. The GDP per capita of Algeria is USD 4152.77[8] and for the area considered, *GDP.Unit* can be defined as follows:

$$\begin{aligned} GDP.Unit &= POP.Unit \times USD4152.77 \\ &= USD415,277,000 \end{aligned} \tag{5}$$

The reduced-form models defined in Table 6 for the economic losses and Table 7 for the human losses (home loss, injuries, fatalities) were applied to the area considered for Constantine. Table 9 summarizes the result for the seismic intensities of VII–X. It provides information related to building damage and economic and/or human impact, which are also key elements in performance-based, earthquake-engineering approaches. In Constantine the total number of damaged buildings was between 195 (VII) and 1654 (X), which produced mean loss indicators for home loss, injured persons (injuries), and fatalities of 6067, 157, and 91, respectively, and economic losses of about USD 200 million.

7 http://www.ons.dz/.

8 http://www.tradingeconomics.com/algeria/gdp-per-capita.

Table 9 Home loss, injuries, fatalities, and economic losses ($L_{\$2015}$) computed in Constantine for macroseismic intensities VII–X using $D4 + D5$ as a hazard-related variable and *POP.Unit* or *GDP.Unit* as exposure-related variable, respectively

	Regression model	Intensity	$D4 + D5$	*POP.Unit*	Variables		
					Min	Mean	Max
Home loss	$D4 + D5$	VII	195	100,000 (Algerian)	1834	2590	3659
	POP.Unit	VIII	589		4925	6067	8570
	(Table 7)	IX	1133		7108	10,041	14,183
		X	1654		9512	13,436	18,979
Injured persons (injuries)	$D4 + D5$	VII	195	100,000 (Algerian)	22	78	283
	POP.Unit	VIII	589		43	157	569
	(Table 7)	IX	1133		65	236	859
		X	1654		83	300	1091
Fatalities	$D4 + D5$	VII	195	100,000 (Algerian)	13	58	267
	POP.Unit	VIII	589		20	91	415
	(Table 7)	IX	1133		26	118	539
		X	1654		30	137	627
Economic losses ($L_{\$2015}$) $	$D4 + D5$	VII	195	415,277,000 (all)	36,370,702	129,048,122	457,880,018
	GDP.Unit	VIII	589		61,149,035	216,964,966	769,820,749
	(Table 8)	IX	1133		83,161,723	295,068,930	1,046,944,070
		X	1654		99,345,251	352,490,252	1,250,682,610

Data sources for $D4 + D5$ were from Guettiche et al. (2017)

It is worth noting that the uncertainty here is relatively high, which results from the uncertainties related to the information in the database. However, decision makers are not directly concerned with magnitude, building damage, or intensity, but rather pay attention to performance indices for loss and injuries to occupants, or the homeless people that need to be sheltered in the event of a seismic disaster. Compared with previous studies, this integration of building damage as a hazard-related parameter improves the prediction, and should thus be incorporated into the analysis of earthquake losses. Furthermore, data collection after earthquakes should be improved.

6 Conclusions

This study provided a compilation of data and empirical models to estimate the economic and human impacts of earthquakes in the Mediterranean region. Earthquakes are complex and rare events, and post-earthquake information has to be carefully scrutinized before regression models can be developed. But there is the need to define performance metrics that are relevant for decision makers and seismic risk mitigation. Generally speaking, these metrics relate to the risks of casualties for anticipation of the short-term responses to an emergency, such as home loss and personal injuries, and anticipation of economic losses and fatalities for the long-term recovery processes. In this study, data related to 65 earthquakes in the Mediterranean region were compiled in a comprehensive database, with particular attention paid to Algeria. Reduced-form models were then derived, based on hazard-related and exposure-related variables. Because building damage is a key indicator related to losses, we have demonstrated that the integration of such information into regional models improves the loss assessment by reducing the computed regression errors R^2. These parameters require extensive analysis of the area considered in terms of building vulnerability, but new data sources such as remote sensing and national census information, when coupled with data mining algorithms, promise to provide new perspectives for cost-effective and relevant ways to determine seismic damage to buildings.

Vulnerability of buildings is an essential element, since damage seems to be the critical element to define the hazard-related parameters. Riedel et al. (2014, 2015), and Guettiche et al. (2017) have shown that large scale-based methods for vulnerability assessment can provide relevant forecasting of damage ($D4 + D5$) for a given seismic intensity. These methods are based on information that describes the general characteristics of the regional typology of structures and their particular attributes, such as those that might be obtained by satellite imagery. In this way, loss models can be improved everywhere by integrating the spatial variability of local vulnerability in the concerned regions. Efforts to study additional predictor variables, such as population mobility during the day (exposure-related) and physical characterization of the hazard that use ground-motion parameters, are necessary in further research.

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