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Vulnerability of Existing RC Building with Seismic Damage Scenarios: Case of Educational Buildings in Mostaganem City

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Abstract: The present work aims to assess the large-scale seismic vulnerability of a set of 55 reinforced concrete educational establishments of different typologies (approximately 516 constructions) located within the urban perimeter of the city of Mostaganem. Among them, 328 buildings were constructed in accordance with the Algerian seismic regulation (built after 1980), while 188 constructions were built without a seismic design code (built before < 1980). This classification corresponds to the application/creation of this regulation following a major earthquake in Chlef (El Asnam) in 1980. Using the RISK-UE lm1 method, the vulnerability index was assessed based on a visual inspection for each building using an on-site inventory form to determine the general sources of seismic vulnerability. This strategy allows the prioritization of constructions according to their typologies, considering the structural system of the building and modifying factors, such as code level, maintenance condition, number of floors, plan and elevation irregularities, soil morphology, etc. The application of this methodology generated several seismic scenarios expressing the probable damage to the constructions, and the following results were suggested: The first two seismic scenarios have no damage corresponding to intensities I = 5; 6. The third scenario is characterized by low to negligible damage corresponding to intensity I = 7. Moderate damage was observed for the fourth seismic scenario (I = 8), while the fifth scenario generated by seismic intensity I = 9 presents moderate to heavy damage. The sixth scenario, with intensity I = 10, exhibits a relatively heavy damage balance. Starting from intensity I = 11, the damage becomes heavy to very heavy for the seventh scenario. Finally, the eighth scenario describes total destruction of the constructions. The results obtained from the application of this methodology on the educational buildings have been integrated into a Geographic Information System (GIS) environment to better understand the seismic behavior of the structures and to estimate the magnitude of seismic risk. This facilitates simulation and enables efforts to be made to take concrete preventive measures to strengthen existing educational buildings, thus reducing the negative impact of future earthquakes.

Keywords: seismic scenarios; vulnerability; RISK-UE; damage; RC buildings; intensity; GIS

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1. Introduction

The current buildings worldwide are in constant danger due to recent violent earthquakes. For example, Turkey and Syria have experienced several significant seismic aftershocks, including a magnitude 7.8 earthquake that resulted in over 53,000 deaths, 110,000 injuries and the collapse or risk of collapse of more than 84,000 buildings [1,2]. This necessitates a thorough analysis of the seismic performance of numerous existing structures in order to mitigate the seismic risk [3]. In this regard, the study of seismic scenarios allows decision-makers to adequately estimate the probable damage to structures designed using previous versions of seismic regulations or without seismic codes, as well

as those constructed according to new seismic codes [4]. Therefore, the calculated damages by simulating seismic scenarios using the RISK-UE method are based on the definition of the general sources of seismic vulnerability of constructions [5].

The seismic vulnerability of buildings can be defined based on their intrinsic capacity to withstand damage due to an earthquake of a certain intensity [6]. These properties are directly linked to the conceptual characteristics of the buildings (building typology, geometry, quality of materials, maintenance condition, code compliance, etc.), which constitute structural factors that exacerbate vulnerability independent of seismic action [7].

Various methods have been implemented to assess the seismic vulnerability of buildings on a large scale in countries with active seismicity. The emergence of these methods began in the 1970s in Japan and the United States [8], as well as the Gruppo Nazionale per Difesa dai Terremoti in Italy [9]; GNDT, 1993 [10]; Cherubini et al., 1999 [11]), which was developed in the 1980s in the Euro-Mediterranean region. These approaches have been applied in several countries worldwide with numerous adaptations and modifications (ATC13, 1985) [12]; IRC, 1993 [13]; FEMA154, 2002 [14]; Giovinazzi and Lagomarsino, 2004 [15]; Calvi et al., 2006 [16]; NZSEE, 2006 [17]; Guéguen et al., 2007 [18]). Algeria is part of the Euro-Mediterranean seismic zone, and for this purpose, we have adopted the RISK-UE LM1 approach (Lagomarsino and Giovinazzi, 2004) [15] as the methodology for this article.

Mostaganem is one of the most important cities in Northwestern Algeria and has experienced different periods of urbanization: antiquity, Arab-Turkish, colonial and post-independence [19]. This indicates that the urban fabric of the city contains different building typologies. The purpose of this article is to present the results of a large-scale preliminary study aimed at assessing the seismic vulnerability and expected damage (seismic scenario study) of 45 reinforced concrete (RC) educational facilities corresponding to 516 buildings located within the urban perimeter of Mostaganem. This study is carried out in two stages: (1) Field investigations were conducted for the school buildings through visual inspections to identify the general sources of seismic vulnerability for the 516 existing RC school buildings [20]. For each building, a diagnostic record was created containing information about the building typology, technical design, topographic conditions, construction type, age of the building, number of floors, number of basements, history of building damage and repairs, expansion works, etc. [21]. (2) Estimation of the average damage index for each construction using a semi-empirical relationship that correlates data from the seismic hazard with the estimated seismic vulnerability analysis. This study is based on the RISK-UE method and results in eight seismic scenarios expressing the probable damage to buildings according to the European Macroseismic Scale EMS-98 [22].

In order to preserve the educational infrastructure in the city of Mostaganem, this study aims to assess the seismic risk by estimating the seismic vulnerability of reinforced concrete buildings. In this context, several advantages related to the RISK-UE method are significant in terms of the expected functional damages, which should undoubtedly concern the local authorities and necessitate rehabilitation and strengthening works for the school buildings [5]. The results obtained using this methodology form a database describing the probable damages to school buildings, which are presented and integrated using a GIS environment.

2. Inventory of the Educational System in Algeria

To ensure the success of the country's economic and social development plans, it is crucial to invest in education, particularly in terms of human resources. This has been a concern for the Algerian government since independence, as they have prioritized the development of the educational system [23]. Due to the rapid population growth in Algeria after independence, significant investments in the educational system and the development of teaching staff have led to a substantial expansion of the educational infrastructure. As a result, the Algerian government has been working to address the delays in various educational programs by providing new infrastructure for this educational system [24].

Analysis of Table 1 reveals that school buildings designed based on various seismic codes are distributed across four seismic periods, which are presented below.

2.1. Buildings Designed before the El-Asnam Earthquake on 10 October 1980 (Date < 1980)

This phase of spatial occupation reflects a military character [25] and did not have seismic regulations in place. Practically all constructions were dimensioned according to various regulations, such as the Antisismic AS 55 and the Parasismic PS 69 [26–28]. This period's educational infrastructure includes 9034 primary schools, 873 middle schools, 208 high schools and 32 university centers. Most of these constructions, with different typologies, are in a deteriorated state due to aging and poor maintenance, representing 30% of the educational system [5].

2.2. Buildings Designed with the RPA 81V83; RPA 81V88 (1980 < Date < 1999)

On 10 October 1980, Algeria experienced a major earthquake in El-Asnam, in the Chlef province (Ms = 7.3; MMI = X), which resulted in over 3000 deaths, 8369 injuries, 20,000 destroyed buildings and more than 480,000 homeless individuals [29]. In response, Algeria implemented the seismic regulation RPA (81V83) [30] Subsequent seismic events, such as the one in Constantine in October 1985 [31–33], led to the modification of these regulations, resulting in RPA (88) [34]. Following these seismic events, the Algerian Center for Seismic Engineering (CGS) established the first seismic microzonation update in 1988 [35]. Educational institutions designed according to these different seismic updates are as follows: 6473 primary schools, 2351 middle schools, 975 high schools and 27 university centers. This period is characterized by the use of self-supporting frames in Zone III, and some construction provisions were adopted.

2.3. Buildings Designed with RPA 99 (1999 < Date < 2003)

Previous revisions of the RPA were found to be insufficient in meeting the conceptual and technical requirements of school buildings, following the occurrence of the Temouchent earthquake in 1999 with an intensity of I(EMS98) = VIII [36]. This led to the creation of RPA 99 [37], which introduced significant seismic actions. Consequently, the educational infrastructure developed between the Temouchent and Boumerdes earthquakes includes 1207 primary schools, 426 middle schools, 147 high schools and 3 university centers. This period is characterized by the emergence of self-supporting reinforced concrete frame structures.

2.4. Buildings Designed with RPA 99V2003 (Date < 2003)

The fourth revision took place following the Boumerdes earthquake on 21 May 2003, with an intensity of I(EMS98) = VII [38]. Based on the new seismic zones identified through microzonation studies conducted by the Center for Seismic Engineering (CGS) [35] in 2003, the RPA was updated to ensure that buildings meet the new seismic requirements following the recommendations of the new RPA 99V2003 [39]. The educational infrastructure after the Boumerdes earthquake consists of 2594 primary schools, 1980 middle schools, 1158 high schools and 54 universities. It addressed the educational needs resulting from the population growth after the Boumerdes earthquake [23].

Table 1. Evolution of Algeria's school buildings from 1962 to 2020 (NOS (2020) [23]; RPA (81V83) [30]; RPA (88) [34]; RPA (99) [37]; RPA (99V2003) [39]).

Years	Primary School	Middle School	Secondary School	Universities	Total	Codes Application	Years	Primary School	Middle School	Secondary School	Universities	Total	Codes Application
1962–1963	2263	364	39	8	2674	No seismic building codes	1991–1992	13,461	2433	845	54	16,793	Seismic building code: RPA 1980
1963–1964	--	379	--	8	387		1992–1993	13,970	2541	883	55	17,449	
1964–1965	4065	418	--	10	4493		1993–1994	14,734	2651	912	55	18,352	
1965–1966	4255	--	--	11	4266		1994–1995	14,836	2778	968	56	18,638	
1966–1967	4266	427	59	12	4764		1995–1996	15,186	2921	1033	57	19,197	
1967–1968	4581	454	63	12	5110		1996–1997	15,426	3038	1100	58	19,622	
1968–1969	5073	478	63	13	5627		1997–1998	15,199	3145	1132	58	19,534	
1969–1970	5263	502	67	15	5847		1998–1999	15,507	3224	1183	59	19,973	
1970–1971	6467	519	72	20	7078		12/22/1999: Ain Temouchent Earthquake, Intensity (EMS 98) = VII						
1971–1972	6507	530	71	22	7130		1999–2000	15,729	3315	1218	59	20,321	Seismic building code: RPA 1999
1972–1973	6990	540	86	23	7639		2000–2001	16,186	3414	1259	60	20,919	
1973–1974	7376	545	93	23	8037		2001–2002	16,482	3526	1289	62	21,359	
1974–1975	7794	569	114	25	8502		2002–2003	16,714	3650	1330	62	21,756	
1975–1976	7798	584	120	26	8528		5/21/2003: Boumerdes Earthquake, Intensity (EMS 98) = IX						
1976–1977	8182	665	142	27	9016								
1977–1978	8380	788	175	30	9373		2003–2004	16,899	3740	1 381	62	22,082	Updating of the Algerian earthquake regulation: RPA99/V2003
1978–1979	8652	812	181	32	9677		2004–2005	17,041	3 844	1 423	64	22,372	
1979–1980	9034	873	208	32	10,147		2005–2006	17,163	3 947	1 473	66	22,649	
10/10/1980: El-Asnam major earthquake, Intensity (EMS 98) = X							2006–2007	17,357	4 104	1 538	67	23,066	
							2007–2008	17,429	4 272	1 591	68	23,360	
							2008–2009	17,552	4 579	1 658	72	23,861	
1980–1981	9263	932	230	33	10,458	Seismic building code: RPA1980	2009–2010	17,680	4 784	1 745	80	24,289	
1981–1982	9399	1036	246	34	10,715		2010–2011	17,790	4 901	1 813	86	24,590	
1982–1983	9864	1181	272	34	11,351		2011–2012	17 853	5 007	1 870	95	24,825	
1983–1984	10,266	1267	319	37	11,889		2012–2013	17,994	5 086	1 956	98	25,134	
1984–1985	10,588	1388	353	40	12,369		2013–2014	18,248	5 185	2 065	99	25,597	
1985–1986	11,144	1561	415	42	13,162		2014–2015	18,333	5 239	2147	105	25,824	
1986–1987	11,427	1747	481	49	13,704		2015–2016	18,588	5 339	2251	110	26,288	
1987–1988	11,843	1929	550	50	14,372		2016–2017	18,770	5 419	2355	111	26,655	
1988–1989	12,240	2108	705	51	15,104		2017–2018	18,856	5455	2392	115	26,818	
1989–1990	12,694	2248	758	52	15,752		2018–2019	19,037	5512	2433	116	27,098	
1990–1991	13,135	2339	812	53	16,339		2019–2020	19,308	5630	2488	116	27,542	

3. Damage to the Educational System Due to Various Earthquakes

The Algerian educational system has suffered significant damage due to destructive earthquakes, including El-Asnam 1980, Chenoua-Tipaza 1989, Beni Chougrane-Mascara 1994, Ain Temouchent 1999 and Boumerdes-Alger 2003 [40]. Among them, the Boumerdes earthquake caused fatal damage to the education sector compared to other earthquakes. As a result, 1304 educational establishments experienced no or minor damage, 753 buildings suffered moderate damage, and 103 school centers were destroyed. These results (Figure 1) led to typical damage such as staircase collapse, joint destruction, damage to short columns, masonry damage, appearance of plastic hinges in columns and pancake collapse due to weak columns, solid beams and heavy roofs (reinforced concrete slabs).

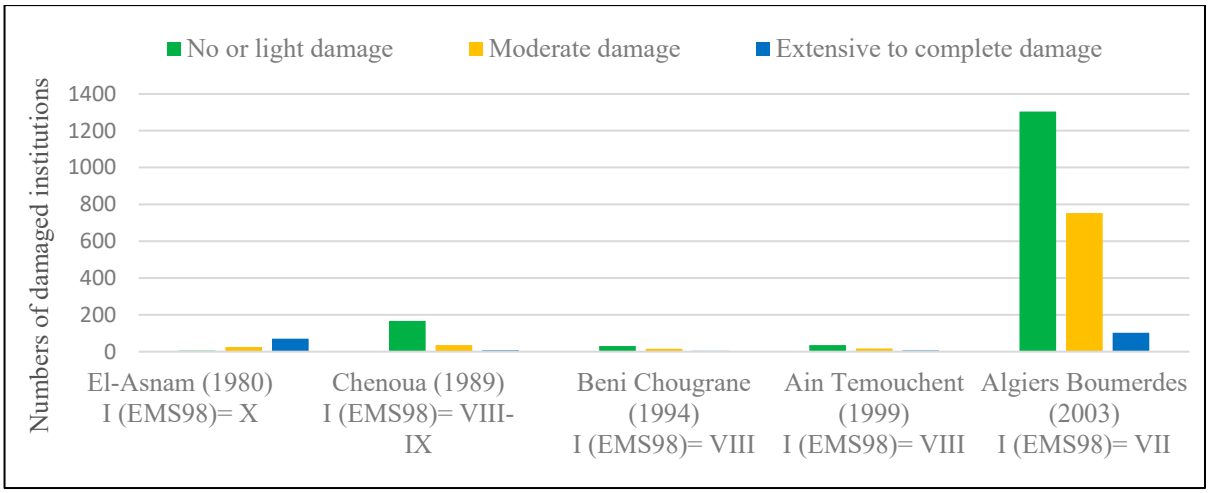


Figure 1. Damage assessment of reinforced concrete school buildings caused by recent devastating earthquakes [41].

Structural changes have exacerbated the seismic vulnerability of many reinforced concrete school buildings, as evidenced by the earthquakes mentioned in Figure 1, which can be considered the main causes of the destruction of these school buildings.

The Boumerdes earthquake caused severe damage, forcing the Algerian government to allocate a significant budget for the rehabilitation/reconstruction of the educational infrastructure. This led to the refurbishment of over 422 establishments at a cost of DZD 38.06 million and the reconstruction of more than 122 buildings costing DZD 31.59 million (Table 2). These human and material losses have prompted the authorities to implement methods for assessing vulnerability and seismic scenarios in order to mitigate the seismic risk.

Table 2. Costs of reconstruction and rehabilitation of educational buildings after the Boumerdes earthquake in 2003 [40].

Category of School		Number		Cost (DZD Millions)	
		Rebuilt	Rehabilitated	Rebuilt	Rehabilitated
Algiers Province	Primary School	3	122	75	585
	Middle School	3	76	180	760
	High School	3	40	450	570
Boumerdes Province	Primary School	97	131	225	160
	Lower Secondary School	9	35	540	700
	Upper Secondary School	7	18	1050	270
Total		122	422	2520	3045
				31.59 (USD millions)	38.06 (USD millions)

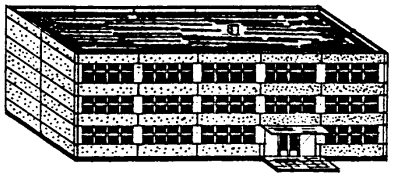
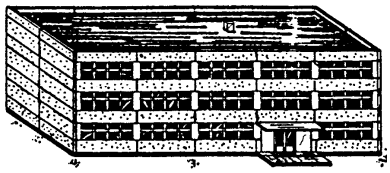
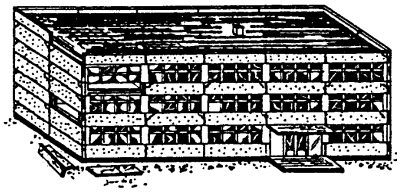
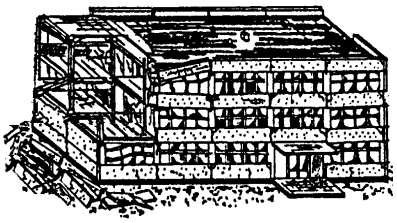
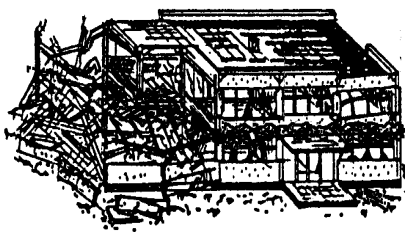
Classification of Damages Using the RISK-UE Method According to EMS-98

The typology of buildings defines their seismic behavior under a given seismic action intensity and is grouped into five conventional damage degrees defined by the European Macroseismic Scale EMS-98, ranging from D0 to D5. Table 3 presents the classification of damages for reinforced concrete buildings according to the EMS-98 scale using the RISK-UE LM1 methodology [22].

Mapping of damages requires a conventional color coding associated with the EMS-98 damage degrees as follows:

D0: light green (no structural damage)
D1: brown (negligible to slight damage)
D2: yellow (slight damage for structural, moderate damage for non-structural)
D3: dark yellow (moderate damage for structural, heavy damage for non-structural)
D4: purple (heavy damage for structural, very heavy damage for non-structural)
D5: red (very heavy damage leading to structural collapse, total or near-total damage)

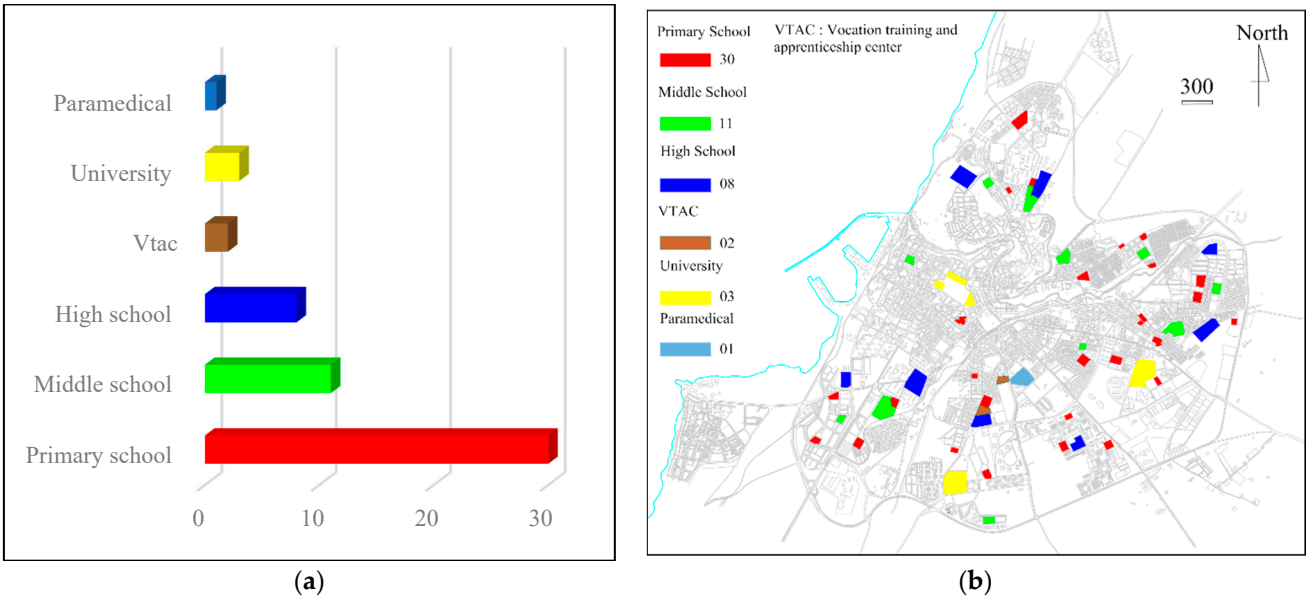
Table 3. EMS 98 classification of damage to buildings of reinforced concrete.

Classification of Damage to Buildings of Reinforced Concrete	
	**Grade 1**: Negligible to slight damage (No structural damage, slight non-structural damage) Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2**: Moderate damage (Slight structural damage, moderate non-structural damage) Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3**: Substantial to heavy damage (Moderate structural damage, heavy non-structural damage) Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4**: Very heavy damage (Heavy structural damage, very heavy non-structural damage) Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5**: Destruction (Very heavy structural damage) Collapse of ground floor or parts (e.g., wings) of buildings.

4. Study Area

Our study area is located within the urban perimeter of the city of Mostaganem and consists of two distinct urban areas. One area comprises the historical core, which includes historical buildings, while the other area represents the city's expansion after independence. This study area covers a surface area of 20 km^2 and extends with an average radius of 2.50 km (Figure 2).

The current research focuses on 55 reinforced concrete educational establishments out of a total of 516 buildings located in the urban fabric of Mostaganem. This area includes buildings of various uses, including 30 primary schools, 11 middle schools, 8 high schools, 3 universities, 2 vocational training centers and 1 paramedical center.



(**a**) (**b**)

Figure 2. Spatial distributions/uses of educational buildings. (**a**) Localization of reinforced concrete (RC) existing buildings in the study area; (**b**) Categories of existing RC school buildings.

The distribution by category of buildings in the study area is illustrated in Figure 2, where the percentage of primary schools is high compared to other categories. The identified buildings cover the entire urban area of the city of Mostaganem. Consequently, a database has been derived from this spatial distribution, catering to the educational needs in the province of Mostaganem.

5. RISK-UE lm1 Approach

This methodology was developed by the partner institutions of the RISK-UE project [42] as part of Work Package 4, which focuses on the assessment of vulnerability of existing buildings. The goal of this project was to analyze seismic risk at the city scale and develop a methodology for risk assessment.

The RISK-UE lm1 method, also known as the macroseismic approach (level 1), is based on the evaluation of a vulnerability index for a given building. This index considers the building's construction typology and various factors that can affect its behavior [43]. Using this index, vulnerability curves can be defined based on the macroseismic intensity according to EMS-98 (European Macroseismic Scale), which allows for the assessment of the distribution of damage probabilities on the building. This approach involves identifying different states of deterioration of the building and assessing the probability of a structure being in different damage states at a given level of seismic ground motion [44,45].

Based on the EMS-98 [22] European Macroseismic Scale, building vulnerability is categorized into six levels from A to F, with A being the highest and F the lowest [46]. This classification groups together different types of buildings characterized by similar seismic

behavior. Each construction class is associated with a relationship between the excitation (seismic intensity) and the response (damage incurred).

6. Results and Discussion

6.1. Estimation of Vulnerability Index

Based on visual assessment, the vulnerability index is calculated by considering 11 modifying factors of the studied buildings [15,44]: (1) material type, (2) code level, (3) maintenance condition, (4) number of floors, (5) plan irregularity, (6) elevation irregularity, (7) short columns, (8) arched windows, (9) inadequate seismic joints, (10) foundations, (11) soil morphology. The sum of the modifying factors listed in Table 4 will be added to the base vulnerability index V to determine the overall vulnerability index V (Equation (1)), which is then normalized between 0 for buildings with high seismic resistance and 1 for the most vulnerable ones.

Two main factors are essential for evaluating damage to existing structures within the RISK-UE method (seismic scenario study):

1. Building vulnerability is assessed by general factors independent of seismic epicentral distance. These factors consider intrinsic characteristics of the buildings, such as their designs, typologies, ages, maintenance, etc.

2. Seismic intensity: The effects of seismic epicentral distance in a region are directly related to the seismic hazard data. However, the effects of epicentral distance on existing buildings are considered negligible since the city of Mostaganem has been classified as a region of moderate seismic activity according to RPA99V2003 [39]. Nevertheless, it is possible to consider the effects of epicentral distance by converting seismic intensity into terms of magnitude, acceleration spectrum, etc., and the epicentral distance [47]. This correlation requires a historical-statistical study of known earthquakes in the Western region of Algeria to establish a correlation that links building damage with seismic hazard expressed in terms of epicentral distance.

$$\overline{V_I} = V_I^* + \Delta V_R + \Delta V_m \quad (1)$$

where the vulnerability index V_I^* is related to the building class, ΔV_R is a factor used to account for the characteristics of specific typologies at the regional scale. It is considered null for this research, ΔV_m are modifiers that show the influence of different parameters of the typology on the seismic behavior of the building (Table 5).

Based on visual assessment, four vulnerability typologies were evaluated for the reinforced concrete buildings in the study area (RC3.1, RC3.2, RC4 and RC5), with RC3.1 being clearly dominant: RC3.1 (93.60). The resulting vulnerability of the constructions (Table 4) can now be assessed and mapped using the RISK-UE approach.

The RISK-UE approach is used to account for the influence of aging on the characteristics and performance of buildings over time. Table 5 classifies buildings based on their construction dates and associates them with appropriate seismic codes. This approach considers potential variations in strength and structural behavior that can result from reinforcement corrosion, a deterioration process commonly observed in reinforced concrete structures. Table 5 also emphasizes the importance of maintaining the structural components of buildings to combat reinforcement corrosion and to ensure the durability and strength of the buildings in the long term.

Table 4. RC buildings typology according to RISK-UE [21].

RISK-UE Type		Description	Number	(%)	∑ (%)
RC Buildings	RC3.1	Regularly infilled walls	483	93.60	100
	RC3.2	Irregular frames	14	2.71	
	RC4	RC dual systems (RC frame and wall)	4	0.78	
	RC5	Precast concrete tilt-up walls	15	2.91	
Total			516	100.00	

For a single building, the overall vulnerability index can now be obtained by summing up all the scores of modifying factors.

$$\Delta V_m = \sum V_m \quad (2)$$

Table 5. Values of the V_m factors for reinforced concrete (R.C) buildings.

Vulnerability Factors		Earthquake Resistant Design (ERD) Level		
		Pre or Low Code	**Medium Code**	**High Code**
Code Level		+0.16	0	−0.16
Bad Maintenance		+0.04	+0.02	0
Number of floors	Low (1 or 2)	−0.04	-0.04	−0.04
	Medium (3, 4 or 5)	0	0	0
	High (6 or more)	+0.08	+0.06	+0.04
Plan Irregularity	Shape	+0.04	+0.02	0
	Torsion	+0.02	+0.01	0
Vertical Irregularity		+0.04	+0.02	0
Short-column		+0.02	+0.01	0
Bow windows		+0.04	+0.02	0
Aggregate buildings (Insufficient aseismic joint)		+0.04	0	0
Foundation	Beams	-0.04	0	0
	Connected Beans	0	0	0
	Isolated Footing	+0.04	0	0
Soil Morphology	Slope	+0.02	+0.02	+0.02
	Cliff	+0.04	+0.04	+0.04

Furthermore, surveys conducted in the study area in accordance with the requirements of the RISK-UE approach (Milutinovic and Trendafiloski 2003) [46] affect 52.13% of buildings with a vulnerability index of 0.30 < VI < 0.54 to vulnerability class D, 16.09% of buildings belonging to vulnerability class C (0.46 < VI < 0.70), and 40.70% of constructions are assigned to vulnerability class B (0.46 < VI < 0.70). Figure 3 shows the spatial distribution of the vulnerability index for pre-diagnosed educational buildings.

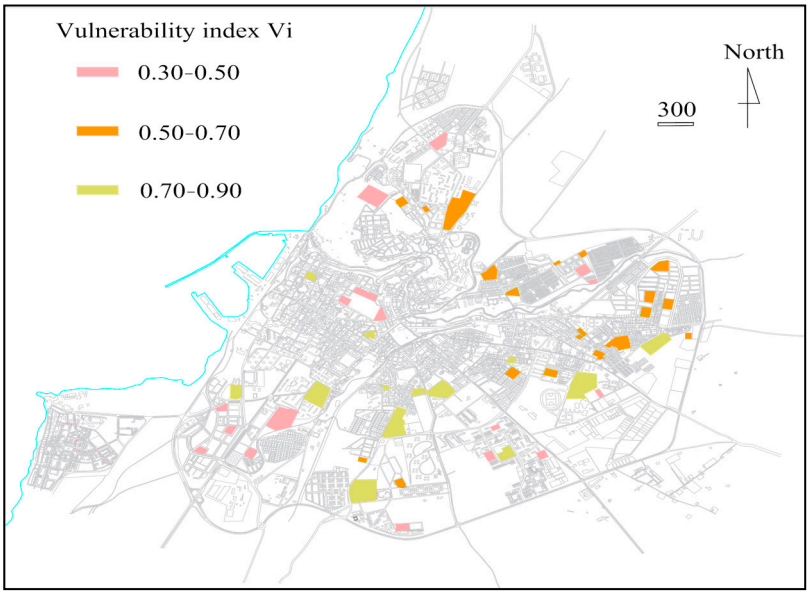


Figure 3. Spatial distribution of the vulnerability index using the RISK-UE method.

When diagnosing buildings to identify general sources of seismic vulnerability, various criteria need to be defined, such as the age of the buildings, the structural system, the basic materials, the foundations, etc. However, assessing the vulnerability of buildings

can face limitations and challenges. Among these are the absence of records describing the construction methods and histories of buildings constructed during the colonial period. Additionally, there may be a lack of detailed execution plans (architecture and civil engineering plans) providing information about the type of infrastructure, the age of the building, the arrangement of bracing elements, etc. This lack of information has compelled us to explore alternative and complementary means and methods to accurately estimate the seismic vulnerability of buildings. It has been necessary to resort to simplified models, indirect indicators of vulnerability and comparative studies with similar buildings to extrapolate results. Despite these challenges, it is important to continue research efforts and data collection to better assess the seismic vulnerability of buildings. This will enable appropriate measures to be taken to strengthen existing buildings and to develop construction standards that are more resilient to earthquakes.

6.2. Estimation of Average Damage to Educational Buildings

The related average damages, μ_D, are then estimated based on the macroseismic intensity I according to the EMS-98 scale and the vulnerability index V (Equation (3)). μ_D ranges from 1 to 5 according to the EMS-98 scale in five classes [21].

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 6.25V_I - 13.1}{2.3}\right)\right] \quad (3)$$

The fragility curves shown in Figure 4 are generated by Equation (3)by correlating seismic hazard data (seismic intensity I) with those obtained from seismic vulnerability analysis (V). The pre-diagnosed buildings are classified based on the occurrence date of the first Algerian seismic code RPA 80 in 1980, following the major earthquake of El Asnam with an intensity (EMS-98) = X. Some curves of mean damages are more or less parallel due to the similarity of a certain vulnerability class according to the degree of seismic intensity (I = V to XII) to the next vulnerability class.

The RISK-UE methodology was chosen as the most appropriate to meet the specific needs of the study, due to significant divergences observed in the beta distribution, as mentioned by Sandi (1995) [47], during the detailed evaluation of the buildings. Overestimations were observed in significant damages of several buildings with relatively low values of the average damage slope. The simplicity of the beta distribution allows for the identification of a convergence of damage levels towards a mean and unique factor. The beta distribution offers several advantages, such as the ability to concisely represent different degrees of damage and provide an estimation of their probability.

6.3. Seismic Scenario Study

The RISK-UE method is based on the estimation of a vulnerability index for structures, which is directly related to the identification of typology VI and modifying factors of behavior Vm (such as plan irregularity, maintenance condition, etc.) [15]. However, from this index, the distribution of building damage probabilities is estimated by establishing vulnerability curves that express the rate of average damage, and then fragility curves [22], which are established based on the macroseismic intensity I of EMS-98 and the VI index. The subsequent use of a beta distribution of damages allows for the conversion from damage rates to EMS-98 damage degrees required to establish fragility curves. Fragility curves are defined for a given EMS-98 damage degree Dk. They allow, based on the macroseismic intensity, to reach or exceed this degree Dk [21].

The beta distribution is an appropriate probability distribution for modeling discrete degrees of damage. It can be used in conjunction with the Damage Probability Matrix (DPM). The statistical application of the beta distribution has been successful in analyzing data generated by the Irpinia earthquake in 1980 in Italy [48]. This earthquake shares similarities with the Chlef earthquake in Algeria, which occurred in the same year. The simplicity of the beta distribution allows for the identification of a convergence of damage levels towards a mean and unique factor. The beta distribution offers several advantages,

including the ability to concisely represent different degrees of damage and provide an estimation of their probability. This facilitates decision-making regarding the prioritization of in-depth studies and the strengthening of existing buildings. Furthermore, the beta distribution allows for the integration of a measure of uncertainty in the obtained vulnerability index, considering the margin of error and providing nuanced results.

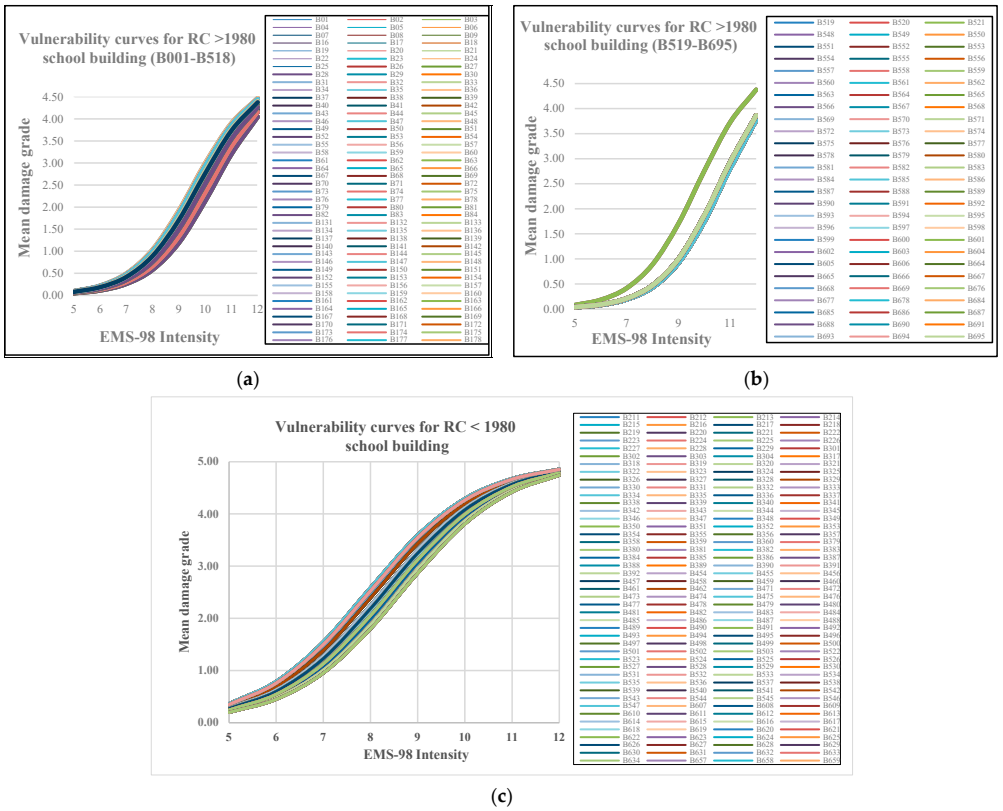


Figure 4. Mean damage grade estimation of school building. (**a**) μ_D index for RC > 1980 (B001–B518); (**b**) μ_D index for RC > 1980 (B519–B695); (**c**) μ_D index for RC < 1980.

In summary, the beta distribution is an effective statistical method for analyzing levels of damage. It is widely used in the field of seismic research and provides important information for assessing risks and making informed decisions regarding structural strengthening.

Seismic scenarios should be calculated using the beta distribution for each vulnerability class. This damage distribution function is defined as follows (basic equation of the beta distribution).

The damage distribution is calculated using a beta distribution.

Probability density:

$$P_\beta(x) = \frac{\Gamma(t)}{\Gamma(t)\Gamma(t-q)} \frac{(x-a)^{q-1}(b-x)}{(b-a)^{t-1}} \; a \le x \le b \tag{4}$$

Cumulative distribution function:

$$P_\beta(x) = \int_a^x p_\beta(\varepsilon) d(\varepsilon) \tag{5}$$

where: the beta distribution is parameterized by a, b, t and q, and x represents the continuous random variable ranging between a and b. Γ is the gamma function.

With the parameters:

$$a = 0, b = 6, t = 8$$

$$q = t\left(0.007\ {\mu_D}^3 - 0.052{\mu_D}^2 + 0.28\mu_D\right) \quad (6)$$

Discrete probabilities:

The probability p_k associated with each damage degree k is expressed in the following form:

$$p_k = P_\beta(k+1) - P_\beta(k) \quad (7)$$

Fragility curve:

The fragility curve, which defines the probability of reaching or exceeding a damage level k, is directly obtained from the cumulative distribution function.

$$p(D \geq D_k) = 1 - P_k(k) \quad (8)$$

This RISK-UE method generates eight seismic scenarios expressing the probable damage to each structure based on intensities ranging from V to XII. These results are presented in Tables 6 and 7, which show the classification of the study area's buildings according to damage degrees (D_k) based on the intensity of the corresponding seismic scenario.

The present study stands out from previous research by employing a qualitative and statistical approach based on the RISK-UE method to assess the seismic performance of existing structures. The beta distribution was used as a statistical tool to establish fragility curves and specific seismic scenarios for each type of construction. This chosen qualitative and statistical approach enables us to consider the variability of structural parameters, resulting in a more precise and realistic evaluation of the seismic performance of existing structures. Consequently, a better understanding of the risks associated with each type of construction is obtained to help the development of appropriate strengthening actions.

6.3.1. Seismic Scenarios for RC < 1980

Analyzing Table 6 for RC structures built before 1980 reveals several seismic scenarios. For IEMS-98 = 5 and 6, all buildings are classified as D0, indicating no damage in this probable seismic scenario. No damage or degradation was observed in the structures of the study area. The intensity effect of IEMS-98 = 7 resulted in a seismic scenario characterized by negligible or slight damage, with all constructions classified as D1. The seismic scenario associated with seismic intensity IEMS-98 = 8 expresses probable damage reaching D2 (73.40%) and D3 (26.60%). The damage observed in this scenario is slight for structural damage and moderate for non-structural damage. For seismic intensity IEMS-98 = 9, the expected damage is heavy for structural and very heavy for non-structural, with 37.23% of buildings classified as D3 and 62.77% as D4. The scenario corresponding to intensity IEMS-98 = 10 presents probable damage that is very heavy, including structural collapse, total or near-total, with a damage distribution of 26.79% for D4 and 70.21% for D5. The other two scenarios with intensities IEMS-98 = 10 and 11 show the total destruction of all school buildings.

Table 6. Seismic scenarios according to EMS-98 intensities (RC < 1980).

Intensity	D0%	D1%	D2%	D3%	D4%	D5%
I = 5	100.00					
I = 6	100.00					
I = 7		100.00				
I = 8			73.40	26.60		
I = 9				37.23	62.77	
I = 10					29.79	70.21
I = 11						100.00
I = 12						100.00

6.3.2. Seismic Scenarios for RC > 1980

The analysis of damage related to reinforced concrete structures with educational purposes leads to the identification of several seismic scenarios. Table 7 provides information on the damage to reinforced concrete buildings constructed after 1980. For the first scenario, corresponding to IEMS-98 = 5, 6 and 7, no probable damage to the structures was reported, and all structures are classified as D0. Minor to slight damage is predicted for seismic intensity IEMS-98 = 8, with 85.67% of the buildings classified as D0 and 14.33% as D1. The seismic scenario generated by seismic intensity IEMS-98 = 9 reveals probable damage reaching D1 (72.87%) and D2 (27.13%). The expected damage for this scenario is minor to slight. For seismic intensity IEMS-98 = 10, moderate damage is predicted for structural elements and heavy damage for non-structural elements, with 34.15% of buildings classified as D2 and 65.85% as D3. The scenario evaluated by seismic intensity IEMS-98 = 11 predicts heavy damage for structural elements and very heavy damage for non-structural elements, with a distribution of 27.74% for D3 and 72.26% for D4. The final scenario, corresponding to intensity IEMS-98 = 12, is characterized by total building collapse, with 23.78% of structures classified as D4 and 76.22% as D5.

Table 7. Seismic scenarios according to EMS-98 intensities (RC > 1980).

Intensity	D0%	D1%	D2%	D3%	D4%	D5%
I = 5	100.00					
I = 6	100.00					
I = 7	100.00					
I = 8	85.67	14.33				
I = 9		72.87	27.13			
I = 10			34.15	65.85		
I = 11				27.74	72.26	
I = 12					23.78	76.22

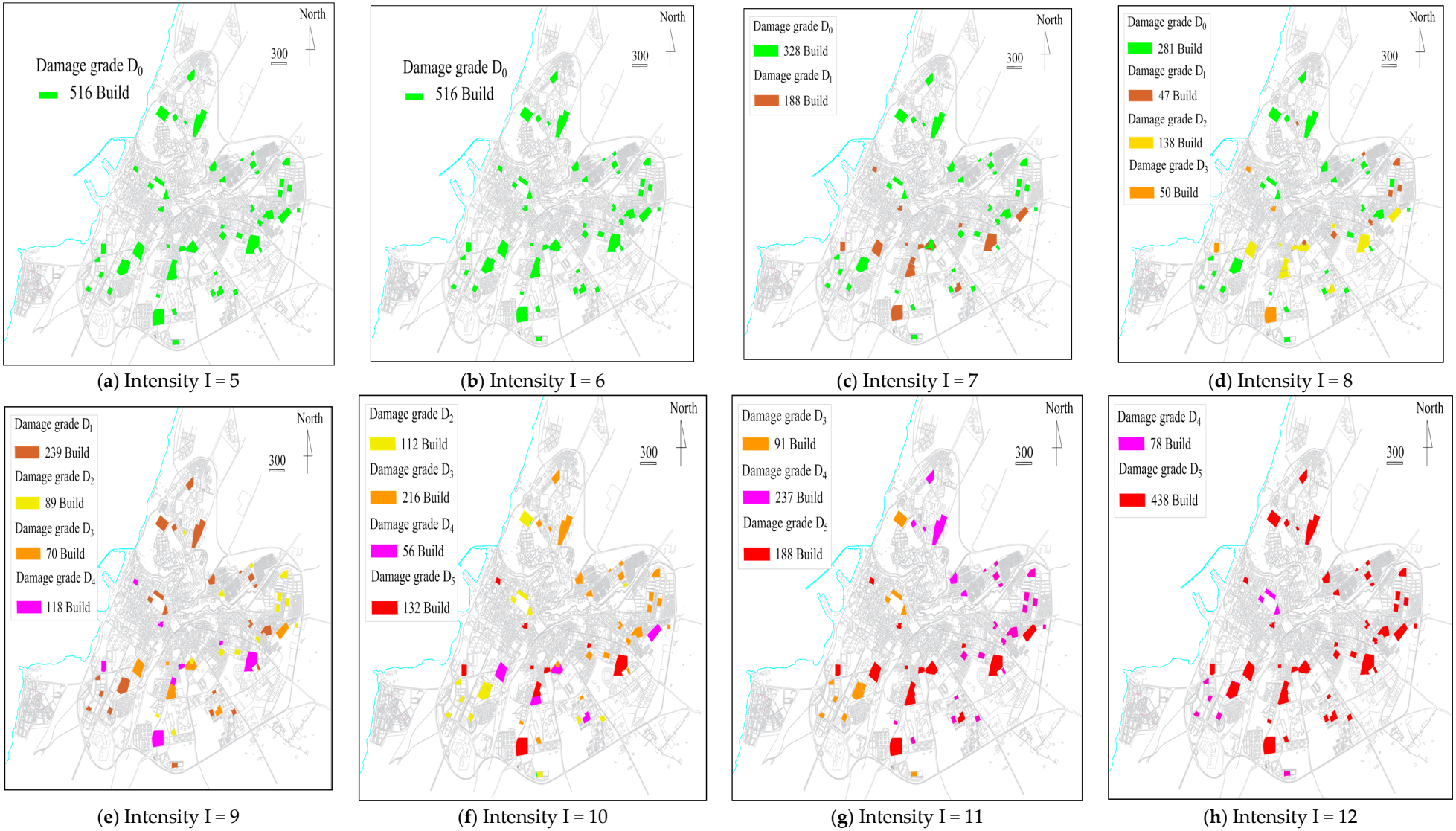
6.4. Spatial Distribution of Damages

A Geographic Information System (GIS) is implemented to visualize the different seismic scenarios, where the results obtained and generated by the RISK-UE method offer a spatial process. The number of pre-diagnosed buildings must exceed 100 to achieve statistical significance. Figure 5 presents the various states of deterioration/damage of buildings according to seismic intensities for each scenario.

In particular, the first seismic scenario corresponding to intensities 5 and 6, presented in Figure 5a,b, shows negligible damages to all buildings in the study area. This level of damage is associated with the D0 damage category. Figure 5c,d shows an increase in the damage level, where, as a result of seismic intensity IEMS-98 = 7, some buildings (188) experience minor damages (D1). The level of damage increases in Figure 5e, with expected damages corresponding to intensity IEMS-98 = 8, resulting in overall D2 damage to the buildings. Subsequently, the building damages escalate in Figure 5f, with expected heavy damages for this scenario at intensity IEMS-98 = 9, corresponding to D4 level damage. Figure 5f,g demonstrates severe damage and partial/total destruction of the buildings for intensities IEMS-98 = 10, 11 and 12, where all buildings exhibit similar damages at D4 and D5 levels.

The main lesson extracted from the Geographic Information System, as shown in Figure 6, is the absolute variation in estimated damages across different intensities for all educational facilities.

The damage level is low for I = 5, 6, moderate for I = 7, 8, heavy damage for I = 9 and complete destruction or ruin of structures for intensities I = 10, 11, 12.



(**a**) Intensity I = 5 (**b**) Intensity I = 6 (**c**) Intensity I = 7 (**d**) Intensity I = 8

(**e**) Intensity I = 9 (**f**) Intensity I = 10 (**g**) Intensity I = 11 (**h**) Intensity I = 12

Figure 5. Mapping of damages using the RISK-UE method for seismic intensities: 5, 6, 7, 8, 9, 10, 11 and 12.

The results obtained, as illustrated in Figure 6, can also be used to compare the probable process of this current research with the actual damage incurred from various known earthquakes in different similar regions in Algeria. This process provides a database available to local authorities to safeguard the educational infrastructure during future major earthquakes.

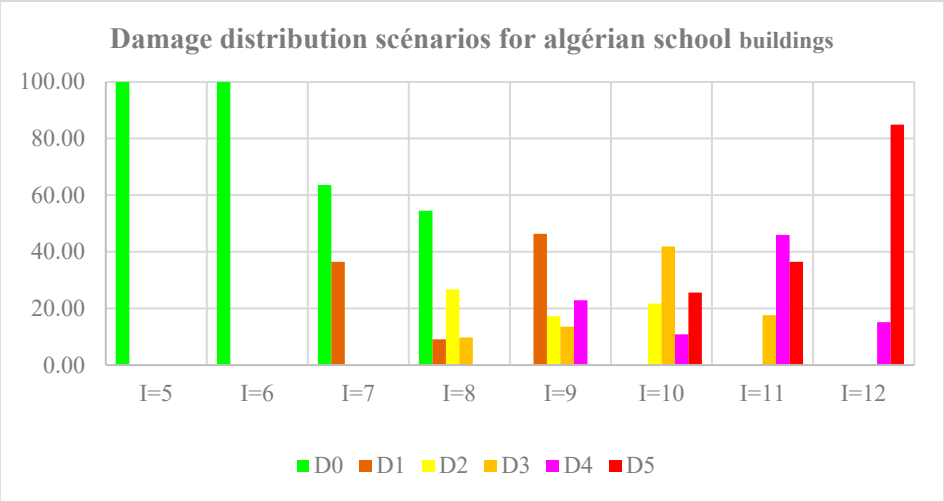


Figure 6. Synthesis of global damage scenarios for different EMS-98 intensity.

7. Conclusions

The study of seismic scenarios presented in this work provides reliable insights into the seismic behavior of RC educational buildings evaluated through the RISK-UE method. The developed database in this study allows for the prioritization of intrinsic building characteristics and general sources identifying vulnerability. The generation of seismic scenarios for each building requires the correlation of data from seismic hazard (intensity) with vulnerability analysis. A GIS environment was derived from this process to assess the different states of expected deterioration for a set of 516 reinforced concrete educational buildings. The research can be divided into three distinct steps: (1) Evaluation of seismic vulnerability of pre-diagnosed buildings through on-site investigation missions to determine general sources defining the seismic vulnerability of RC school buildings. (2) The average damage index was determined by correlating the previously evaluated vulnerability index with seismic intensity according to EMS-98, showing a very satisfactory agreement for reinforced concrete buildings. (3) Based on these results, a series of processes and analyses were performed using the RISK-UE method to determine scenarios for different seismic damages, which were classified based on the regulation seismic code implementation in 1980 following the El Asnam earthquake.

The application of this method resulted in eight seismic scenarios expressing the probable damages to structures, with the following findings: the first scenario corresponding to intensity I = 5, 6 and 7, all buildings were classified as D0 (negligible damage). The second scenario, at seismic intensity I = 8, the buildings experienced slight damage. For the third scenario (I = 9), expected damages were low to moderate (D1). The fourth scenario corresponds to I = 10, where observed damages ranged from moderate to heavy (D3). The fifth scenario (I = 11, 12) is marked by structural collapse, with scenario I = 11 showing very heavy damage (total destruction), where all buildings are classified as D4 and D5.

It is important to note that the accuracy of the reported results can be improved by considering site-specific impacts. However, it is anticipated that this would not have a significant impact on the distribution of damages caused by the ground conditions in the study area. The assessment of average building damages resolved by seismic intensity resulted in vulnerability curves for each building type. These criteria could be considered for other applications in regions with similar characteristics. The next step

involves estimating economic losses, repair costs, as well as the probability of loss of life and homelessness. Furthermore, this information can assist in supporting planning strategies and classifying interventions and/or seismic retrofit works.

At this stage, it is crucial to focus the research on how school buildings vulnerability should be reduced to protect students under future earthquakes.

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