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Potential Seismic Damage Assessment of Residential Buildings in Imzouren City (Northern Morocco)

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Abstract: The main purpose of this study is to assess seismic risk and present earthquake loss scenarios for the city of Imzouren, in northern Morocco. An empirical approach was chosen to assess the seismic vulnerability of the existing buildings, using the Vulnerability Index Method (RISK-UE), and considering two earthquake scenarios (deterministic and probabilistic). Special concern was given to the seismic vulnerability in Imzouren since the 2004 earthquake (24 February, mw = 6.4) that struck the region and caused substantial damage. A site investigation was conducted in the city targeting more than 3000 residential buildings, which had been closely examined and catalogued to assess their seismic vulnerability. The results of the seismic risk assessment in the city are represented through damage to the buildings, harm to the population and economic loss. Generally, the results obtained from the deterministic approach are in agreement with the damage caused by the 2004 earthquake.

Keywords: earthquakes scenarios; vulnerability index; seismic risk; Imzouren

1. Introduction

There are numerous uncertainties in the process of obtaining earthquake loss scenarios which are mainly related to either the seismic source or the building inventory [1]. Several methods have provided credible results while taking into account these uncertainties, such as performance-based methods and reliability-based design approaches [2–4]. Concerning the source location, earthquake scenarios can rarely be associated with certainty to the rupture of well-identified faults, since in the past, numerous destructive earthquakes occurred on blind faults or on offshore faults. In case the source location is uncertain, a probabilistic scenario may arguably be preferable to a deterministic one [5]. Still, if the site location is near a seismic source, first order rupture effects on ground motion are expected, which are difficult to assess in probabilistic hazards analysis. The second obstacle is the difficulty of categorizing the built environment into well-defined typologies and construction periods. Sometimes, renovations and post-earthquake reinforcements get in the way of properly characterizing the structural nature of the buildings, and thus properly estimating their seismic vulnerability on a large scale [1].

In case of this study, numerous challenges including the aforementioned problems are present in Imzouren. The city is located in the Al Hoceima region, which is the most seismically active zone in

Morocco [6–8]. In ten years period, the region was struck by two destructive earthquakes; the first one in 26 May 1994 of magnitude 5.9 mw and the second and strongest one in 24 February 2004 of magnitude 6.4 mw [9]. Both were shallow earthquakes (depth < 15 km), but they didn't cause a surface rupture of a clear tectonic origin even though the observed cracks in the region back in 2004 were interpreted as such [10]. The identification of the responsible faults for these earthquakes was very problematic; especially since the assumed location of the epicenter had evolved over time [7,11–18]. Imzouren suffered the greatest damage in the aftermath of the 2004 earthquake that struck the region, while Al Hoceima experienced significantly less damage, even though the two cities are equally distant from the seismic source. Many believe that the damage difference is due to the bad design of the structures and the position of Imzouren in a soil field [9,18,19], which amplified the ground shaking.

Regarding the buildings, they are mostly reinforced concrete moment frame structures with masonry infill walls, mainly because the city was founded in the second half of the 20th century. One of the main problems that the built environment suffers from is a lack of supervision during the construction period of the buildings. In fact, many owners live abroad (Europe) and have their dwellings constructed without inspection and without any respect to the seismic standard in the region. Additionally, since many earthquakes have struck the city in the recent past (1994, 2004), there have been reconstructions and reinforcements of the damaged and affected buildings, which makes the estimation of the seismic vulnerability difficult.

Imzouren (35°09′ N, 3°52′ W) is located in the province of Al Hoceima on the northern coast of Morocco. Almost as important as Al Hoceima, Imzouren has different structural characteristics. It stretches along 3 km of the left margin of the Oued Nekkor and occupies part of the recent alluvial plain and oldest terraces formed by conglomerates and sandstones of the Pliocene age [19]. The 2004 population census for the province of Al Hoceima reported that Imzouren counts 26,474 inhabitants, 5147 residential buildings and an average of 5 inhabitants per dwelling [20]. As recently as the 1990s, constructive measures (BAEL 91 and PS92) [21,22] were introduced to protect buildings in the Rif region; the national seismic standard R.P.S. 2000 [23] came afterwards to set the essential seismic codes in the country [24]. According to the current Moroccan seismic code, the acceleration has a value of 0.18 g for an exceedance probability of 10% in a return period of 50 years [25].

The flow chart in Figure 1 shows an overview of the methodology applied in this paper. Seismic hazard assessment was evaluated in terms of macroseismic intensity, where probabilistic and deterministic scenarios were carried out. Site effects have also been considered in this study since Imzouren is formed on soft sediment, and were given incremental values added to the macroseismic intensity for both scenarios. The seismic vulnerability of the built environment was evaluated in terms of a Vulnerability Index Method (VIM) adapted and applied to the regional building characteristics. The seismic risk is represented by direct damage to the buildings, damage to population and economic loss. Ideally, earthquake loss models should include all possible induced phenomena from earthquakes: landslides, liquefaction, surface fault rupture, and tsunamis. However, strong ground motion is often the only hazard considered in loss assessment methods. It is commonly an acceptable approach because as the size of the loss model increases, the relative influence of the secondary hazards such as liquefaction and landslides decreases [26]. Harm to the population is defined in terms of casualties and people needing to be relocated (homeless), while economic loss is calculated based on reconstruction costs. All of these aspects are directly related to the direct damage on buildings.

The vast amount of building inventory data made the use of a Geographical Information System necessary for this study. Furthermore, the GIS-generated damage distribution maps also have the advantage of being easily understood and used by city planners and risk managers.

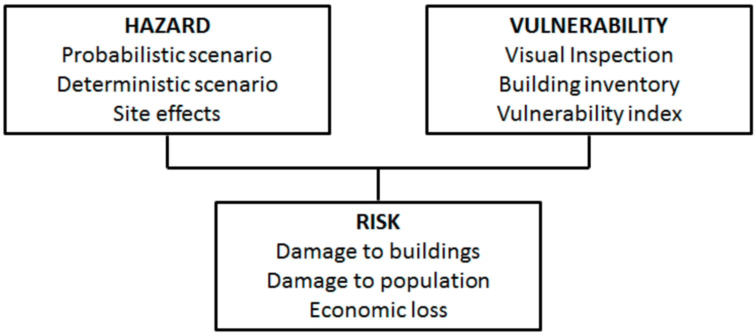


Figure 1. Flow chart of the adopted methodology for the seismic risk assessment in Imzouren.

2. Seismic Intensity and Earthquake Scenarios

2.1. Earthquake Scenarios

Two main scenarios were considered for this study. A deterministic scenario may be the better approach for a city in a seismic zone; however, we have also considered a probabilistic scenario to compare the differences between the two damage loss scenarios. Given the small size of Imzouren, the macroseismic intensity is considered to be constant all over the city.

The deterministic scenario is based on a reference event, which represents the closest earthquake to the target site that caused the greatest damage. In this case, we assume this event to be similar to the earthquake that struck the region of Al Hoceima in 24 February 2004 [9]. The earthquake took place at an epicentral distance of 12 km from the city and was estimated at a depth between 6 and 10 km. The damage caused was catastrophic; 629 dead, 966 injured and 15,600 homeless people [17]. The estimated intensity in the city of Imzouren was in the range of IX-X degree of MSK scale [27]. The same reference event was considered beforehand in the study of seismic risk in Al Hoceima [24] since the two cities are relatively close to each other.

The seismic hazard for the probabilistic scenario was addressed by the Risk Management Solutions Inc. in 2012 [28]. According to the results, the city of Imzouren was assigned an intensity of VIII in MSK scale [29] and a peak ground acceleration equivalent to 0.303 g for a return period of 475 years. According to the national seismic standard R.P.S. 2000, Version 2011 [25], the seismic acceleration for a return period of 475 years is equal to 0.18 g, which is significantly lower than the one estimated by the RMSI report [28].

2.2. Site Effects

The surface ground motion may be strongly amplified if the geological conditions are unfavorable; whether it's topography or surface failure or sedimentary basins. These geological specificities can strongly influence the nature and severity of shaking at a given site. For this study, site effects were estimated based on a seismic microzonation conducted in the city [30]. An iso-frequency map was elaborated using the Nakamura method H/V (Figure 2), which consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of ambient noise vibrations. The obtained spatial distribution map of iso-frequency values shows the existence of homogeneous zones that correlate well with the lithology of this area [30]. Three zones were considered: zone 1 with frequencies ranging from 0.93 Hz to 1.57 Hz (deposits of conglomerates, sandstone, coastal glaze loam and silt), zone 2 with frequencies between 1.57 Hz and 1.88 Hz (conglomerates, sandstones and silt trays and gray silt of the plain of Oued Nekor) and zone 3 with frequencies between 1.88 Hz and 4.90 Hz (schist bedrock, shale formations and rock).

Geotechnical characterization of the area around the town was carried out to define site effects in terms of intensity values, based on the spatial distribution map of soil frequencies (Figure 2). The intensity has been incremented by frequency margins and the used increments were decided based on expert opinion. The introduction of soil effects in terms of intensity was also recommended in the

RISK-UE project [31]. In zones 1 and 2, increments of 1 and 0.5 were applied respectively, while no intensity increments were considered for zone 3. The intensity map for the city of Imzouren, including the soil effects, is shown in Figure 3a,b according to both scenarios. As can be seen, the seismic intensity according to the deterministic scenario is significantly higher than the one estimated by the probabilistic scenario.

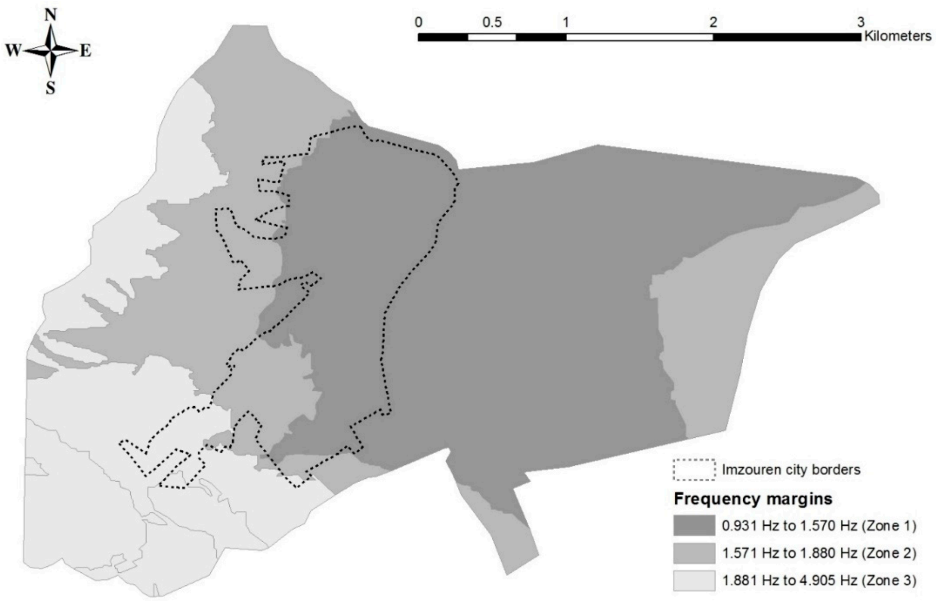


Figure 2. Spatial distribution of frequencies and identification of homogeneous areas in the town of Imzouren [30].

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

Figure 3. Intensity map for the city of Imzouren including soil effects according to (**a**) the deterministic scenario and (**b**) the probabilistic scenario.

3. Description and Classification of Imzouren Building Inventory

Imzouren is a new city where residential buildings are mostly low-rise reinforced concrete moment frame structures. According to the 2004 census [20] the modern Moroccan house is the predominant type, constituting 94% of total dwellings (Table 1). It is a city where the money from emigration to Europe was recently invested in multiple buildings of 3, 4 or 5 floors [19], and this is indicated in the results of the same census, where more than 30% of the dwellings are either vacant or seasonal

(Table 2). Most of the buildings have simple geometrical shapes with small construction areas ranging from 100 m^2 to 150 m^2 (Figure 4).

Table 1. Types of housing in the city of Imzouren [20].

Housing Types	Number	%
Villa	9	0.2
Apartment	4	0.1
Traditional Moroccan house	74	1.4
Modern Moroccan house	4834	93.9
Slum	20	0.4
Rural dwelling	23	0.4
Others	183	3.6

Table 2. Housing occupation in the city of Imzouren [20].

Housing Occupation	Number	%
Total dwellings	7471	100
Occupied dwellings	5122	68.6
Vacant dwellings	1492	20
secondary or seasonal dwellings	857	11.5

Figure 4. Modern Moroccan houses in the city of Imzouren.

For the purposes of this study, the city was subdivided into multiple sections representing 11 districts (Table 3). Each section is represented by a number of studied buildings that characterize the structural nature and the geometry of the residential buildings in the area. The investigation targeted buildings in the whole city, where geometrical features were inspected; from number of floors to irregularities and maintenance. A total of 3077 residential buildings spread throughout the city were the object of this study (Figure 5), which represents approximately 60% of the total number of residential buildings. It is also of interest to comment on the number of reinforcements and reconstructions that has been seen throughout the investigation, especially in the southern part of the city, where the damage caused by the 2004 earthquake was more important (Figure 5). However, the reinforcements aren't applied in the most efficient way; it mostly consists of additional steel bars to the first floor columns.

Table 3. Adopted code level for the existing buildings in Imzouren.

Construction Period	Before 1960	1960–1994	After 1994
Code level	Low code	Medium code	High code

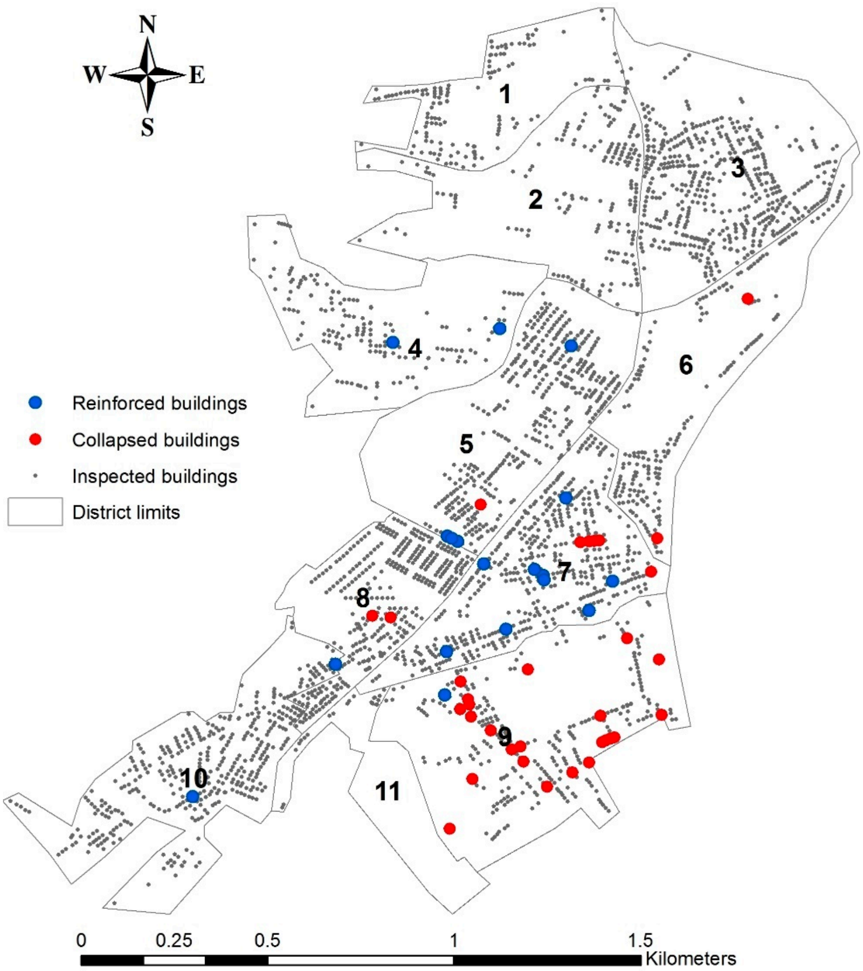


Figure 5. District limits and studied buildings in the city of Imzouren.

During the investigation, several obstacles were encountered, which will inevitably induce uncertainties in the results. Among the problems encountered, there were poor construction procedures, usually due to the lack of supervision and control on site, especially the linking of structural elements and the quality of construction materials, which can be very difficult to trace during the visual inspection. Also, the buildings share structural and architectural similarities, which is why it has proved difficult to characterize them individually. The code level was introduced in order to assess the seismic vulnerability of buildings more efficiently.

Three code levels were defined for residential buildings in Imzouren (Table 3), depending on the construction period; before 1960, between 1960 and 1994 and after 1994. The 2 events (1960, 1994) are very important in the seismic history of Morocco, given the fact that they represent a substantial change in construction habits, especially in the region of Al Hoceima [24]:

- The 1960 event: Agadir was struck by one of the most destructive earthquakes in the 20th century [32] on 29 February 1960, causing more than 12,000 fatalities. A first seismic standard resulted from the studies and investigations in site, named "Agadir Standard". Without a proper seismic code, the Moroccan construction has been greatly affected by this standard.
- The 1994 event: A violent earthquake ($M_w = 6.0$) struck the region of Al Hoceima, causing casualties and extensive damage [28,33]. Constructive measures have been taken post-earthquake to protect and reinforce buildings in the Rif region, based on the PS92 [22] and BAEL 91 [21]. These decisions were applied after 1994 in Al Hoceima, Imzouren and surrounding towns and, subsequently, contributed to developing the first national seismic code known as R.P.S. 2000 [23].

The distribution of the existing buildings according to number of stories and code level is shown in Figure 6, where most low-code constructions are only one or two-story buildings.

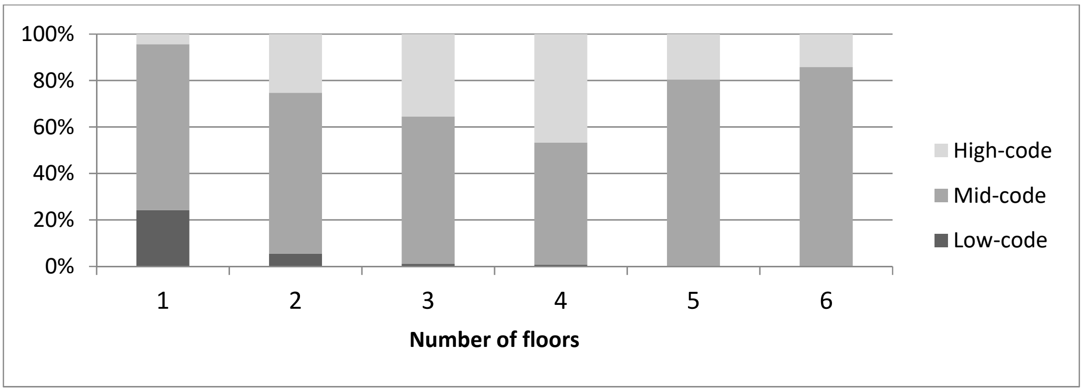


Figure 6. Distribution of the existing buildings according to number of stories and code level.

4. Seismic Vulnerability using the Vulnerability Index Method

The "Vulnerability Index Method" [34,35] has been widely used in Italy during the last decades. This method is considered "indirect" because the relationship between the seismic action and the seismic response is established by a "vulnerability index". The method uses a field survey form to gather information about the parameters of the buildings that might influence their vulnerability. The data on registered earthquakes is used to calibrate and adjust the vulnerability functions to link the vulnerability index (VI) to the main damage factor (d) for a specific seismic intensity or PGA.

RISK-UE (An Advanced Approach to Earthquake Risk Scenarios with Application to Different European Towns) was an important research project funded by the European Commission. Seven cities (Barcelona, Bitola, Bucharest, Catania, Nice, Sofia and Thessaloniki) were involved in this project, whose main objective was to develop a general methodology for assessing seismic risk in European cities [36–39]. The Vulnerability Index Method was chosen as one of the vulnerability assessment procedures that have been successfully developed and applied to all the cities mentioned above.

The main advantage of the "Vulnerability Index" methods is that they can determine the vulnerability characteristics of each building, rather than defining the vulnerability based only on the typology. However, the method requires expert judgment since the coefficients and weights applied in calculating the vulnerability index have a degree of uncertainty that is not taken into account. In addition, the calculation of the vulnerability index for a large building stock would be very time consuming, if such data is not already available [40].

The Vulnerability Index Method applied in the RISK-UE project was used for the purposes of this study. This method provides a typological classification system [41], to group structures with the same seismic performance V_I^{class} and then adds the Vm_j behavior modifiers specific to each building, to calculate a total vulnerability index $V_I^{building}$ for each building, using the following Equation [37]:

$$V_I^{building} = V_I^{class} + \Delta M_R + \sum_{j=1}^{n} Vm_j \quad (1)$$

where ΔM_R is a regional modifier which takes into account the characteristics of the region or the building period. The total vulnerability index $V_I^{building}$ takes values ranging from 0 (least vulnerable building) to 1 (most vulnerable building).

The method was adapted to the Moroccan features of the buildings [24] and applied to the studied buildings in Imzouren. The results show that the vulnerability index takes values ranging from 0.2 to 0.86, with an average value of 0.38 (Figure 7). The city has a low vulnerability, as can be seen from Table 4. The mean vulnerability indices for the different districts have values ranging between

0.31 and 0.44. This could be related to the reconstructions and reinforcements of the buildings that are accounted for since the 2004 earthquake. However, the existence of a minority of buildings can't be overlooked (7.5% of the total number of the studied structures) having a vulnerability index greater than 0.5 (Figure 7) and can be exposed to the collapse in case of an earthquake. The results correlate well with the 2004 census, where 4.7% of the households are below the relative poverty line and 7.6% are below the vulnerability threshold [20].

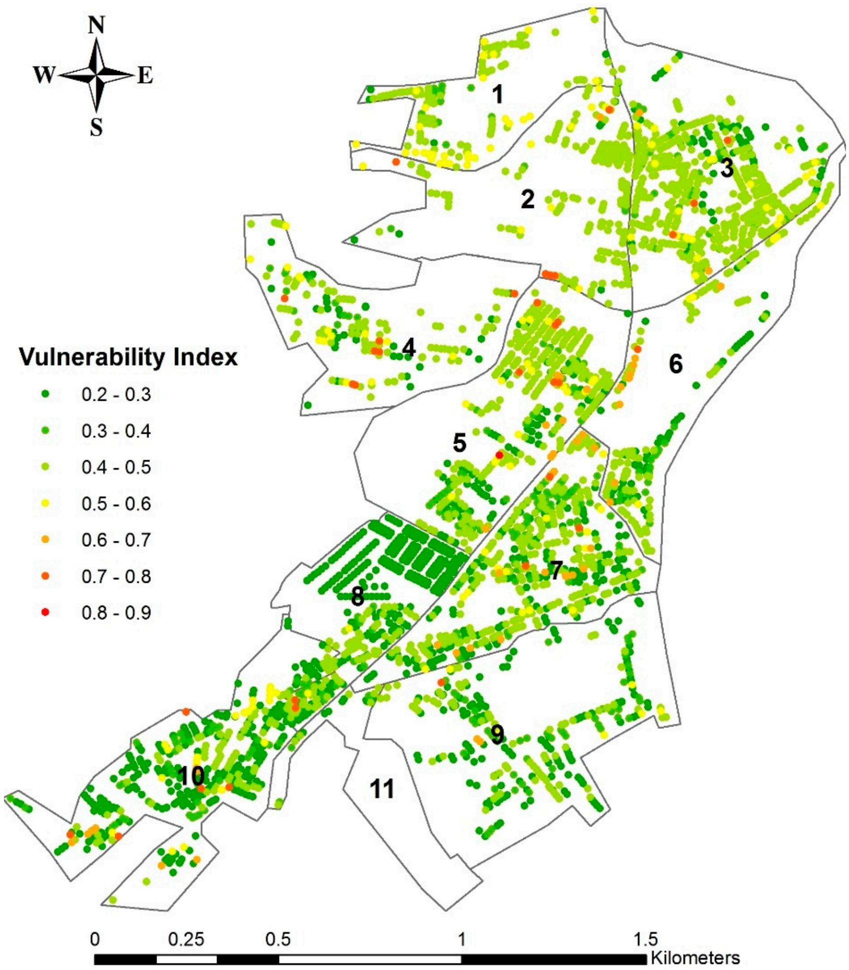


Figure 7. Vulnerability index values for the existing buildings in Imzouren.

Table 4. Mean Vulnerability Indices (MVI) for the Districts of Imzouren.

Label	District Name	Number of Inspected Buildings	MVI
1	Laazib	131	0.44
2	Iboujiren	185	0.44
3	Zaouia	530	0.42
4	Ait Moussa et Amar	155	0.41
5	Quartier Commercial	396	0.41
6	Ait M'hand Ou Yahya	182	0.40
7	Quartier Masjid	478	0.38
8	Souk	339	0.31
9	Tanaouia 1	267	0.33
10	Hay Rabia	392	0.32
11	Tanaouia 2	22	0.32

The VIM introduces five non-null damage states; Slight, Moderate, Substantial to Heavy, Very Heavy and Destruction [42]. The mean damage grade μ_D is introduced to characterize the likely damage to the building, for a given vulnerability (V_I) and a macroseismic intensity (I) according to the following Equation:

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25V_I - 13.1}{\phi}\right)\right] \quad (2)$$

where ϕ is the ductility index, which is assessed taking into account the typology of the building and its geometrical and material characteristics [43]. For residential buildings, it has a value of 2.3 [36]. The distribution of the mean damage grade for the different building codes is shown in Figure 8. It is in fact the most important factor in the seismic vulnerability assessment in the city, since all existing residential buildings have the same structural build (reinforced concrete moment frame structures) and the same height (low to mid rise).

A weighted average index of damage DS_m can be calculated using the following Equation [37]:

$$DS_m = \sum_{k=0}^{5} kP[DS_k] \quad (3)$$

where k represents the state of damage taking values from 0 to 5 and $P[DS_k]$ represents the corresponding probabilities of occurrence of the damage state k. The damage distribution is calculated using the beta distribution [37].

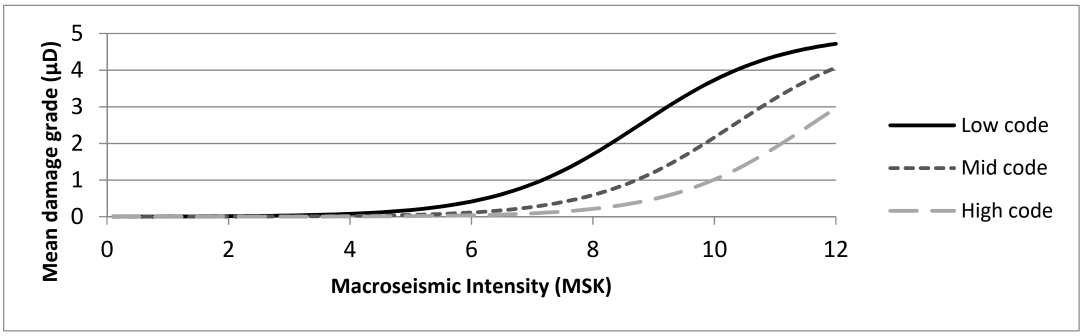


Figure 8. Mean damage grade for the considered building codes.

5. Seismic Risk and Loss Scenarios

The data gathered on the seismic vulnerability of the buildings was combined with the macroseismic intensity of the region, including site effects. The results are shown below according to a deterministic and a probabilistic scenario.

5.1. Direct Damage

The mean damage grade for each district can be seen in Figure 9 for both the deterministic and probabilistic hazard scenarios. The distribution of damage follows the same pattern as the site effects (Figure 3); the damage is more significant in the eastern part of the city where site effects are more present. The damage grade values range between 0.58 to 4.59 for the deterministic scenario and 0.17 to 3.77 for the probabilistic scenario, with mean values of 2.08 and 0.89 respectively. This corresponds to a moderate damage for the deterministic scenario and a slight damage for the probabilistic scenario. It is also important to note that the number of structures with a Very Heavy mean damage grade (partial collapse) is considerable for the deterministic scenario (73 structures).

Figures 10 and 11 display the distribution of damage in the different districts in the city according to the deterministic and probabilistic hazard scenarios. Similar to the mean damage factor (Figure 9), the damage distribution difference between the considered scenarios is significant, since the considered intensities affecting both scenarios are quite different (IX-X for the deterministic scenario and VIII for the probabilistic scenario).

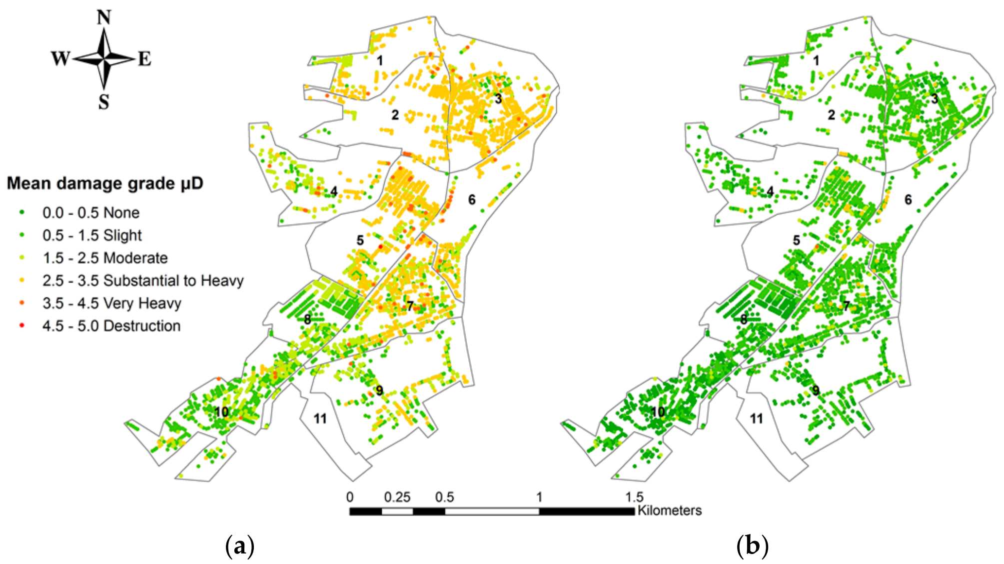


Figure 9. Mean damage grade for the residential buildings of Imzouren according to (**a**) the deterministic scenario and (**b**) the probabilistic scenario.

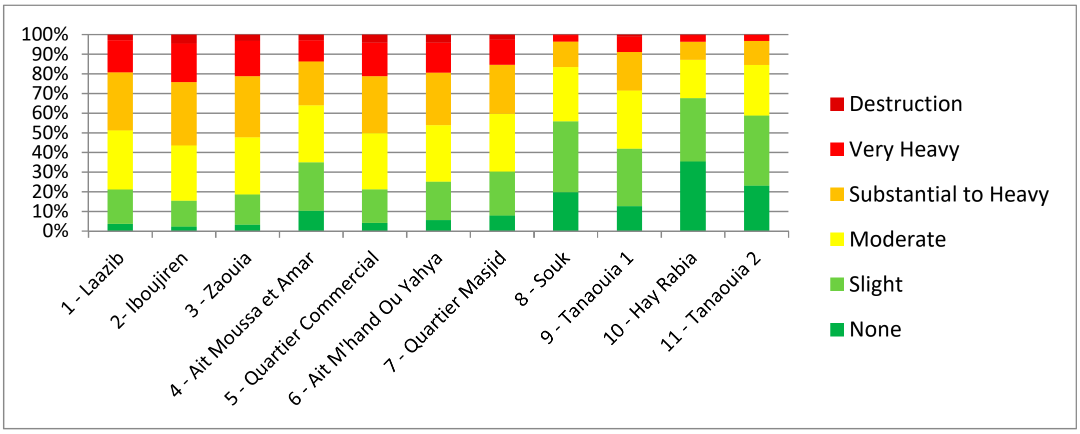


Figure 10. Damage distribution by districts according to the deterministic hazard scenario.

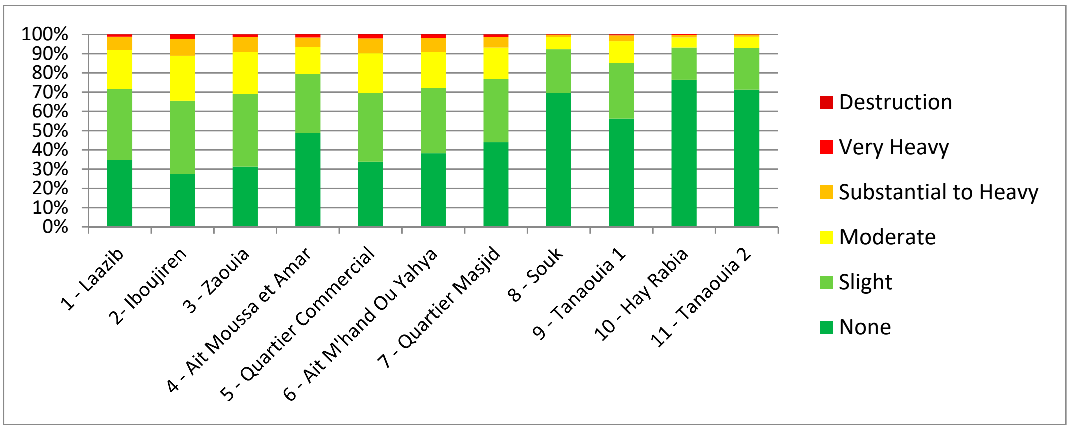


Figure 11. Damage distribution by districts according to the probabilistic hazard scenario.

5.2. Harm to Population

Harm to the population is estimated considering the number of casualties and homeless. First, to evaluate the number of fatalities and injured, the casualty model given by Coburn and Spence (2002) is used [32]:

$$K_S = C \cdot [M1 \cdot M2 \cdot M3 \cdot (M4 + M5 \cdot (1 - M4))] \quad (4)$$

The parameter K_S represents the number of casualties, C is the number of collapsed buildings, obtained by the number of buildings multiplied by the collapse probability. $M1$ is the number of inhabitants per building, according to the [20], an average of five persons per household are estimated for the city. $M2$ is the occupancy at time of the earthquake and a value of 75% for residential buildings is assumed for this case. $M3$ is the percentage of occupants trapped by collapse. Since Imzouren is a case of residential low-rise buildings, a percentage of 50% is assumed. $M4$ is the estimated injury distribution at collapse and the parameter depends on the building typology. Multiple cases are considered for the $M4$ parameter (Table 5): light injuries not necessitating hospitalization, injuries requiring hospital treatment, life-threatening cases needing immediate medical attention and dead or unsaveable cases. $M5$ is the percentage of trapped survivors in collapsed buildings that subsequently die, assumed to be equal to 90%. Table 5 shows the adopted values of $M2$–$M5$ parameters.

Table 5. The assumed values for the M2–M5 parameters [32].

Typology	M2 (%)	M3 (%)	M4 (%)				M5 (%)
			Light Injuries	Injuries Requiring Hospitalization	Life-Threatening Cases	Fatalities	
Values for reinforced concrete buildings	75	50	10	40	10	40	90

The results of casualties are carried out only for the deterministic scenario, where the case of collapsed buildings is possible (Figures 10 and 11). Table 6 shows the total injuries and fatalities for each district in the city of Imzouren. The estimated number of casualties is 580 and the number of fatalities is estimated at 147, which is strongly correlated with the estimated number of collapses that is equal to 84 for the deterministic scenario.

Table 6. Number of casualties for the deterministic scenario for each district in Imzouren.

Label	District Name	Light Injuries	Injuries Requiring Hospitalization	Life-Threatening Cases	Fatalities
1	Laazib	12	13	12	13
2	Iboujiren	36	37	36	37
3	Zaouia	31	32	31	32
4	Ait Moussa et Amar	7	7	7	7
5	Quartier Commercial	26	27	26	27
6	Ait M'hand Ou Yahya	15	16	15	16
7	Quartier Masjid	10	10	10	10
8	Souk	1	1	1	1
9	Tanaouia 1	5	5	5	5
10	Hay Rabia	0	0	0	0
11	Tanaouia 2	0	0	0	0
	Total	143	147	143	147

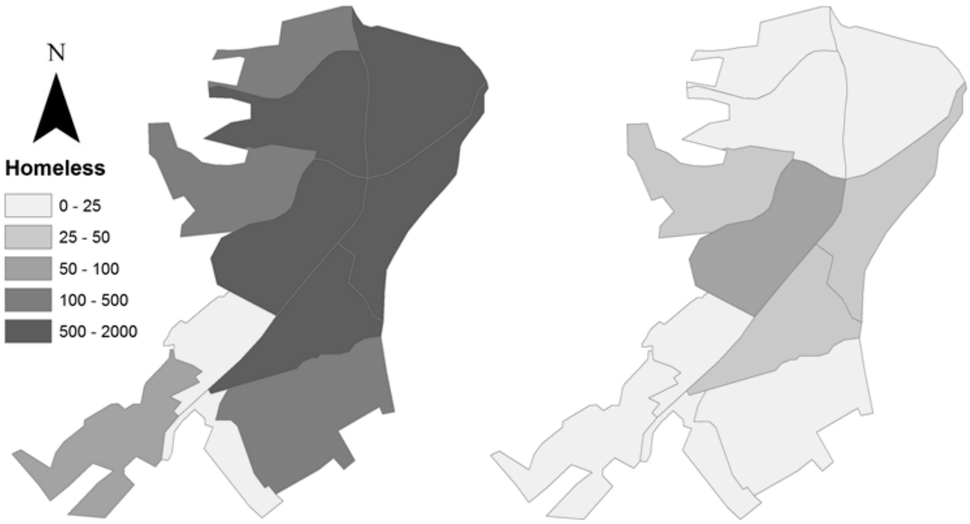
Harm to population was afterwards estimated in terms of the number of homeless people. The number of persons to be relocated because of uninhabitable buildings is also an important parameter in disaster management. The methodology that was applied is based on HAZUS 1999 [44] and considers that 100% of partially or completely destroyed buildings and 90% of the buildings with Heavy damage are considered uninhabitable.

The total number of residential units uninhabitable because of structural damage is calculated by the following Equation:

$$\begin{aligned} \%MF &= 0.9 \times \%H_{MF} + 1.0 \times \%VH_{MF} + 1.0 \times \%D_{MF} \\ UNU_{SD} &= U_{MF} \times \%MF \end{aligned} \quad (5)$$

where U_{MF} is the total number of multi-family residential units, $\%H_{MF}$, $\%VH_{MF}$ and $\%D_{MF}$ are the probabilities corresponding to Substantial to Heavy damage, Very Heavy damage and collapse states respectively.

The estimated number of homeless people according to both deterministic and probabilistic scenarios is shown in Figure 12. The total number of homeless people estimated in both scenarios is 6404 and 221 respectively. The big difference between the two results is due to the fact that the damage exceeded the "Substantial to Heavy" limit in the deterministic scenario.



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

Figure 12. Number of homeless people for each district according to (**a**) the deterministic scenario and (**b**) the probabilistic scenario.

5.3. Economic Cost

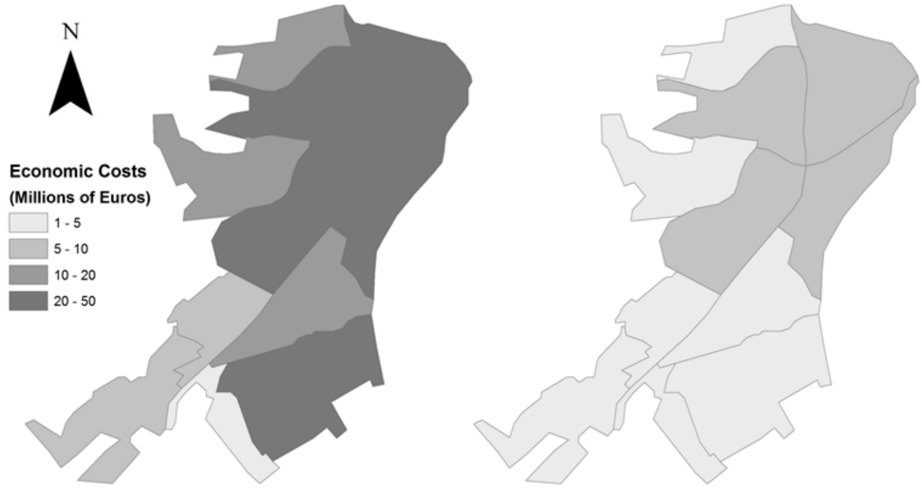
Economic losses are considered as the present costs of reconstructing the damaged buildings. This value is estimated by the cost of reconstruction of reinforced concrete buildings without including the cost of land. Absolute economic cost S_{Cost} in millions of euros is given by the following equation [44]:

$$S_{Cost} = \sum_{k=2}^{5} CS(k) = V_C \sum_{K=2}^{5} \sum_{J=1}^{Ne} [Area(j) \cdot P_s(k,j) \cdot RC(k,j)] \quad (6)$$

where S_{Cost} is the sum of repair costs $CS(k)$ due to the damage state k; V_C is the cost per unit area. A constant value of V_C is assumed for all types of buildings [24]; Area is the building area; $P_s(k,j)$ is the probability for the construction j to be in the state of damage k and $RC(k,j)$ is the value of compensation due to the degree of damage k to the building j and is given as a percentage of the reconstruction cost per square meter. The used cost estimation doesn't take into account other factors such as finance charges, resale and residual values, or repair costs, all considered in the LCCA method for a single building or a building system [45]. However, given the objectives of the study and the scale of work, the economic estimate is considered satisfactory.

Figure 13 shows the economic losses in millions of euros for each section of the city, caused by the deterministic and probabilistic hazard scenarios. The total economic cost of the city is 197 Million

Euros in the case of the deterministic scenario, and 48.4 million euros in the case of the probabilistic scenario. The losses according to the deterministic scenario represent 43% of the estimated losses of the 2004 earthquake, taking into account the overtime dollar value and the exchange rates [46], which is fairly accurate given the statements in the technical reports of the overall damage distribution in the region of Al Hoceima [9,20,47].



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

Figure 13. Distribution of economic cost according to (**a**) the deterministic scenario and (**b**) the probabilistic scenario.

6. Discussion

The results show that most buildings have a low vulnerability index, which can be linked to the improved quality of construction materials and construction practices since the 2004 earthquake. In addition, an increasing number of reinforcements and reconstructions have been identified throughout the city since the 2004 event. However, this fact doesn't exclude 7.5% of the buildings having important vulnerability indices, which is mainly related to the failure to comply to seismic construction regulations.

The results also show that direct damage in the city is moderate for the deterministic scenario, and light for the probabilistic scenario. The damage difference between the two considered scenarios is rather important, since the considered intensities affected to both scenarios are quite different. The results show similarities with the conducted surveys of the reference earthquake. According to damage surveys of the 2004 earthquake, buildings belonging to the same vulnerability class (B and C from EMS 98) show different results, some stood in good condition while others (around 30) completely collapsed [19,47]. All the reports believe the damage is related to the site effects and construction defects.

The estimated number of casualties is significant in case of the deterministic scenario, while inexistent for the probabilistic scenario. A total number of 84 Collapses, 580 casualties and 147 fatalities are estimated in the worst-case scenario. According to NatCatSERVICE, the overall losses due to the 2004 earthquake in the region of Al Hoceima is estimated around 400 million dollars [46]. The economic losses in the city of Imzouren according to the deterministic scenario are about 197 million euros and represent 43% of the estimated overall losses of the 2004 earthquake, taking into account the overtime dollar value and the exchange rates, which is a good estimate.

During the investigation, it was rather difficult to distinguish buildings by their characteristics since they have the same structural build and the same appearance. However, the existing dwellings were mainly categorized by their code level, in other words, whether the buildings respect new and old seismic construction standards or not. Additionally, this study doesn't take into account the poor construction practices that are not apparent on buildings (e.g., quality of construction materials, column-beam connections) which frequently occur when there is lack of supervision.

Based on the estimated states of damage according to both deterministic and probabilistic scenarios in the city of Imzouren, it is important to consider risk mitigation actions, which may include:

- Control of the mechanical characteristics of the existing buildings suspects of construction defects;
- Planning a seismic microzonation of the city using Vs_{30};
- Updating the seismic standard in the region of Al Hoceima, by adding response spectra for the cities and fragility curves for the typical structures;
- Increasing the level of preparedness of disaster and rising societal awareness of seismic risk.

7. Conclusions

Seismic risk in the city of Imzouren was assessed with an empirical approach based on site investigations and vulnerability index scoring. The evaluation of the seismic hazard and seismic vulnerability allowed a proper estimation of damage based on two seismic hazard scenarios; a deterministic scenario and a probabilistic one. The seismic hazard was defined in terms of macroseismic intensity including site effects.

A building inventory of 3077 residential buildings was collected for the purposes of this study. The inspection results indicate that all buildings are reinforced concrete moment frame constructions with masonry infill walls. The seismic vulnerability of the buildings was performed using the Vulnerability Index Method applied in the RISK-UE project. The results show that most buildings have a low vulnerability index. However, this fact doesn't exclude 7.5% of the buildings having important vulnerability indices. In terms of seismic risk results, direct damage in the city is considered to be moderate for the deterministic scenario, and light for the probabilistic scenario. The same difference in scenarios is observed for the harm to the population and economic costs, since these aspects are tightly linked to direct damage.

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