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ALGERIA'S VULNERABILITY TO TSUNAMIS FROM NEAR-FIELD SEISMIC SOURCES

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ABSTRACT

Evaluation of the effects of tsunami damage relative to earthquake damage may help to identify critical coastal zone structures and exposed populations for near field tsunami risk. In this work, we propose to define the ratio between tsunami intensity and earthquake intensity as a measure of near field tsunami vulnerability for coastal communities. This parameter is estimated for 13 tsunami events reported in North Algeria from the 14th century to present. Although the results show that there are no tsunamis that are unusually large for the size of the earthquake that generated them, coastal communities remain at risk from these periodic hazards.

We also use tsunami modelling and published information to estimate maximum inundation in Northern Algeria. Then, we generate a flooding map, which reveals the communities, buildings and infrastructure that are exposed to the tsunami hazard. This map shows that the majority of the people in Algiers and Oran live above 5 meters in elevation, and are hence not exposed to the hazard. Despite this, the coastline remains vulnerable to tsunami as earthquakes can damage poorly constructed buildings and other infrastructure, weakening it prior to the arrival of the tsunami. To increase resilience in the coastal zone, tsunami and earthquake awareness, education and preparedness must become a priority in the context of regional early warning programs.

1. INTRODUCTION

In the southwest Mediterranean, the convergence between Eurasia and Africa plates (< 1 cm/yr) results in earthquakes that reach magnitude up to 7.5. Northern Algeria is located at the boundary between the two tectonic plates. This region is subjected to moderate to large earthquakes (Fig. 1).

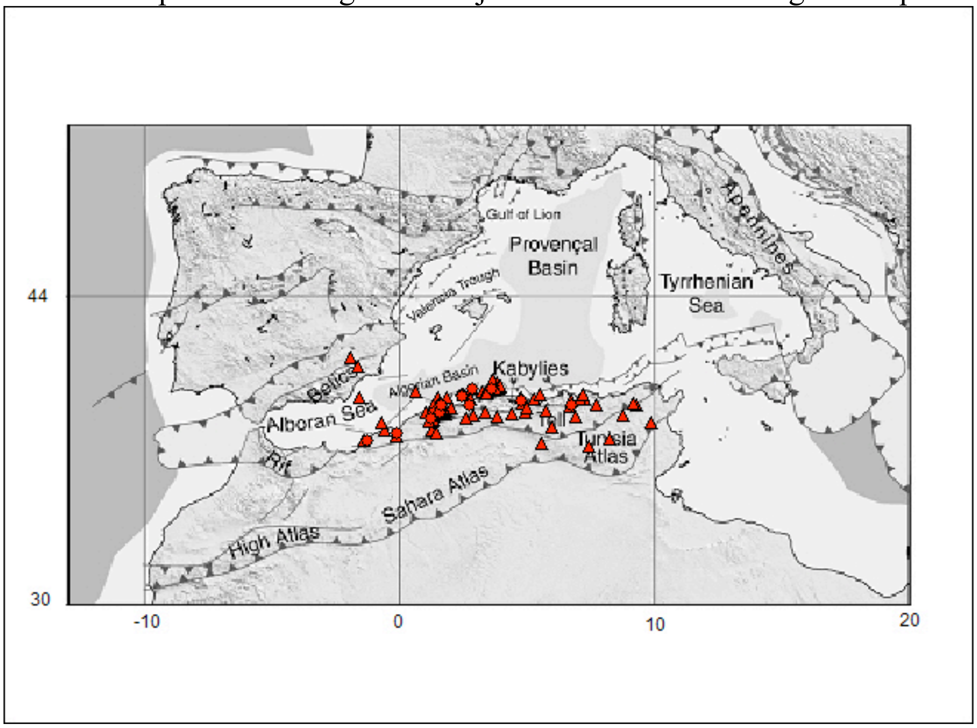


Fig. 1: Seismicity of Northern Algeria and Tectonic sketch of the West Mediterranean (modified from Mauffret, 2007). Earthquakes data are from the USGS-NEIC database (from 1980 to present). Red circles represent magnitude above 5.5 and red stars represent magnitude between 4.5 and 5.5.

Tsunami events have also been reported in historical documents. The first reported tsunami dates from the 14th century in Algiers (Ambraseys and Vogt 1988). The most recent tsunami was triggered in 2003 after a magnitude Mw 6.8 earthquake offshore of Boumerdes, 40 km east of Algiers (NEIC-USGS) (death toll: 2300) (Alasset et al., 2006). Advance and retreat of the sea were also observed in the coastal village of Dellys (50 km east of Algiers) (see pictures in Fig. 2– Anonymous).

Since the Sumatra-Andaman tsunami of December 2004 (death toll: 250000), the UNESCO - IOC (International Oceanographic Commission) has been working on a Tsunami Warning Program for the Mediterranean Sea. The Mediterranean is narrow and the disaster vulnerability (earthquake and tsunami) differs considerably from one country to the next. The rapid pace of urbanism in coastal cities that face near field tsunamis raises a question about the efficiency of a tsunami warning system and the consequences of possible false alarms.

The rapid growth of coastal infrastructure, individual houses and other features associated with urbanism and economic development raises the issue of tsunami and earthquake preparedness related to socio-economic challenges and vulnerability of urban centers to natural hazards. The Algerian

Mediterranean coast extends by 1200 km from the east to the west. The number of the total inhabitant of the country is 35 million. As of 2010, more than 60% of the Algerian population was considered as urban. Indeed, the urban population increased by 114% from 1960 to 2008 (Univ. of Sherbrooke, data from the World Bank, http://perspective.usherbrooke.ca). Expansion of the coastal city of Algiers (capital of Algeria) has increased every year and the agglomeration limits and the demography evolve in such a way that today, the number of inhabitants living in Algiers is more than 4 million (source: Algerian National Statistic Organism, 2010). With 1.8 million of inhabitants, Oran (Western part of coastal Algeria) is considered as the second largest urban agglomeration in the country.

Fig. 2: Pictures of the 2003 tsunami waves in Dellys (50 km east of Algiers) after a 6.8 magnitude earthquake in Zemmouri (40 km east of Algiers) (Pictures from Anonymous)

Because of the possibility of having destructive earthquakes, and induced tsunamis, this work is aimed at contributing to the development of a tsunami warning system policy for Northern Algeria. In this paper, we first review potential tsunami sources for the central and the western part of Northern Algeria from published information. Then, we present the tools and the methods we use to quantify and qualify the potential flooding limits from exposure to the near field tsunami hazard for the coastal Communities of Algiers and Oran. Finally, we discuss on the disaster risk policy in Northern Algeria in the context of the development of the Mediterranean Tsunami Warning System.

2. SEISMICITY, TSUNAMI SOURCES AND TSUNAMI OCCURRENCE IN ALGIERS AND ORAN REGIONS (NORTH ALGERIA)

Algeria is located at the boundary between the African and the Eurasian tectonic plates. Seismicity is shallow (5 to 20 km in depth) and concentrated in the northern part of the country. It is related to the Tell Atlas fold belt and associated active reverse faulting (Meghraoui, 1988; Aoudia et al., 2000). Seismicity is moderate to large and earthquakes magnitude reach 7 to 7.5. Those are mostly associated with thrust faulting mechanisms (Bezzeghoud et al., 1995, Deverchere et al., 2005).

The compressive motion between Africa and Eurasia has led to the formation of Quaternary faulted folds structures. In the central part of Algeria, the Sahel Anticline is related to the Sahel Blind Fault and in the western part of the country, the Murdjajo anticline is also associated with reverse faulting (Fig. 3) (Harbi et al., 2007, Bouhadad, 2001). Those geological structures are oriented NE – SW with strikes varying from 40 to 70°N. Offshore geophysical surveys conducted along the Algerian margin revealed numerous thrust faults dipping to the southeast direction (Domzig et al., 2006; Mauffret, 2007). Further, numerous canyons and headwall scarps were also identified and mapped offshore the Algerian margin by Dan et al. (2009).

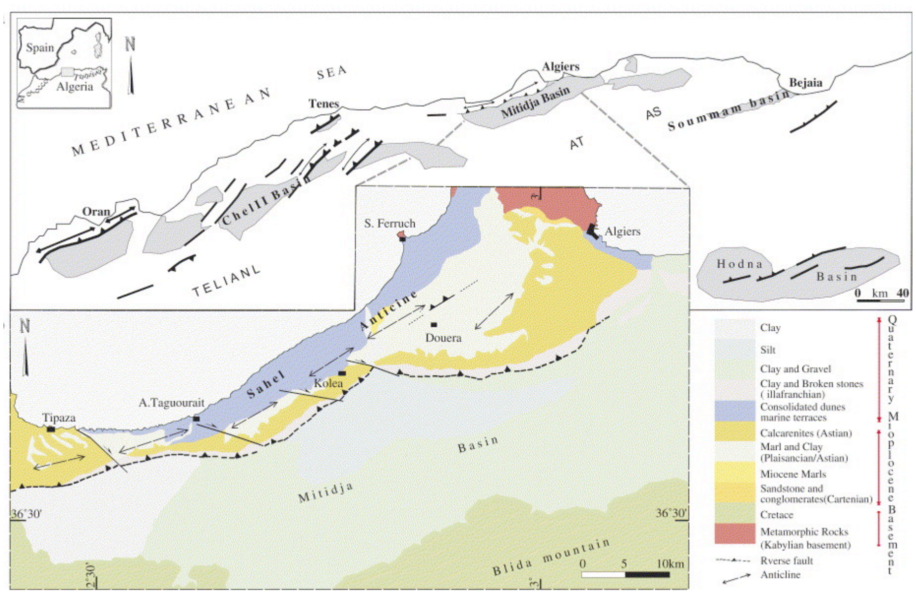


Fig. 3: The Sahel and the Murdjajo structures near Algiers and Oran (From Harbi et al., 2007).

2.1 The Central Algeria (Algiers Region)

The first reported earthquake that hit Algiers occurred on 3 January 1365. This earthquake destroyed the city (Io=X, EMS-98). The earthquake triggered a tsunami that flooded the lower part of the city of Algiers (Ambraseys and Vogt, 1988). In 1716, the Mitidja region was hit by another devastating earthquake (Io= IX-X, EMS scale) (death toll: 20,000 people). The city of Algiers was seriously impacted and the town of Blida was nearly destroyed (Ambraseys and Vogt, 1988). Landslides triggered by the event were also reported by Ambraseys and Vogt (1988). Harbi et al. (2007) also report the description of a tsunami event in 1773 in Algiers.

In September 1954, the Orleansville earthquake (M=6.7) generated turbidity currents. As explained by Heezen and Ewing (1955) "Breaks in submarine cables following the 1954 earthquake are believed to have been caused by the motion of a mass of sediments detached from the continental slope by the shock and transformed into a strong turbidity current which swept out across the Balearic abyssal plain, rather than directly by earthquake movements".

The 1980 El Asnam (Ms=7.2) seismic event was disastrous (2600 deaths). The earthquake focal mechanism indicates reverse faulting (Cisternas et al., 1982). Again, the breaking of phone cables is attributed to turbidity currents generated by the strong seismic shock (Robrini, 1985).

The 1989 Chenoua-Tipaza earthquake (M_s=5.9, USGS) also highlighted the existence of a blind thrust fault system (Meghraoui, 1990). The epicentre was located offshore and noted to have induced a disturbance in the sea. Meghraoui (1990) reported landslides observed on the coast road and on the southern side of the Mount Chenoua. A sea wave was observed by sailors and the sea dropped by more than a meter in Tipaza harbour (Meghraoui, 1990).

The most recent tsunami was triggered by a magnitude Mw 6.8 earthquake offshore of Zemmouri, 50 km east of Algiers (Alasset et al., 2006). Disturbance of the sea is reported for the Algerian coast and run ups of 1 to 2 meters in height were recorded on the Balearic tide gauges.

2.2 The Western Algeria (the Oranie Region)

In Western Algeria, the Oranie region is also a seismogenic area with destructive earthquakes reported in historical and recent documents. In 1790, the city of Oran was severely affected by an earthquake of intensity X (MSK intensity scale) (Marinas Lopez and Salord, 1990; Bouhadad, 2001; Bouhadad and Laouami, 2002). This earthquake was felt elsewhere in North Africa and Spain as well, and a tsunami was triggered (Marinas Lopez and Salord, 1990).

The Murdjajo fold-faults are considered as potential tectonically active structures prone to cause devastating earthquakes and tsunamis (Bouhadad, 2001). Mauffret (2007) pointed out the Arzew escarpment may result from a NE-SW left lateral fault with a reverse component. We suggest it also could have played a role during the 1790 Alboran tsunami (Amir and Cisternas, 2010). Since 1790, a seismic gap has been observed in the region with no event with magnitude larger than 5.5 (Ayadi et al., 2002).

3. MATERIAL AND METHODS

3.1 Mapping the Tsunami Flooding Hazard from modelling and published information

3.1.1 Tsunami Modelling

Tsunami models for earthquakes with moment magnitude of 7.5 are computed at the entrance of Algiers and Oran harbours. Those models are considered as a worst-case scenario.

Tsunami generation and propagation are calculated from the non-linear shallow water code SWAN (Mader, 2004). This program solves the 2D non-linear Eulerian equations within a finite difference scheme. The Mediterranean topography was obtained from the NOAA ETOPO two minute and one minute grids for the Algiers and the Oranie - Alboran case studies respectively (Amante and Eakins, 2009) (source: http://www.ngdc.noaa.gov). The two-minute grid was from 0 to 10 E and 35 N to 44 N. The one-minute grid was from 6 W to 2 E and 34 N to 42 N. For both tests, the time step calculation is 5 minutes.

The tsunami sources were computed from the Okada equations (Okada, 1992). The earthquake source parameters and the co-seismic rupture geometry were deduced from the seismic moment and the conventional seismological relationships of Kanamori (1975) and Wells and Coppersmith (1994). Table 1 lists the tsunami source input parameters for sea bottom calculation offshore for Algiers and Oran.

Table 1: Tsunami source input parameters for sea bottom calculation in Algiers and Oran.

	Algiers	Oran
Magnitude Mw	7.5	7.5
Epicenter coordinates (°)	3.1E, 36.8N	0.58W, 35.76N
Focal depth (km)	07	05
Strike and Dip (°)	55N, 40SE	65N, 45SE
Length * Width (fault plane) (km)	73.3*29.2	73.3 * 29.2
Slip (m)	3.45	3.45

3.1.2 Map Flooding for the Algiers and the Oran Bays.

The study of historical earthquakes and tsunamis is critical in order to evaluate the flooding hazard along the coast. In this work, potential tsunami flooding is estimated from numerical modelling tasks and published information (articles, photographs, public database).

Geo-browsers are useful tools that help common users and authorities to visualise, analyse and combine geo hazard information with coastal geography and urbanism as well. Using the path features from the Google Earth program, we created KML and KMZ files to represent inundation limits.

3.2 Preliminary Vulnerability Assessment:

Vulnerability to tsunamis and earthquakes can be defined as the impact of a catastrophic event in terms of damage (houses and infrastructures destroyed, casualties, and homeless people). Near-field tsunami regions are exposed to a combination of earthquakes and tsunami damage. To assess the vulnerability to near field tsunamis, this preliminary study focuses on the ratio of tsunami to earthquake intensity (TI / EI).

Damage from earthquakes (buildings, infrastructures and people) is identified using macroseismic intensities. In particular, the EMS intensity scale involves 12 grades that describe the effects of vulnerability to earthquakes.

Several scales have been defined to quantify tsunamis. Papadopoulos and Imamura (2001) proposed a new 12-grade intensity scale. This scale can be considered as an analog to the seismic intensity scale. Consequently, it helps to compare the damage of a near-field tsunami relative to the damage generated by earthquakes.

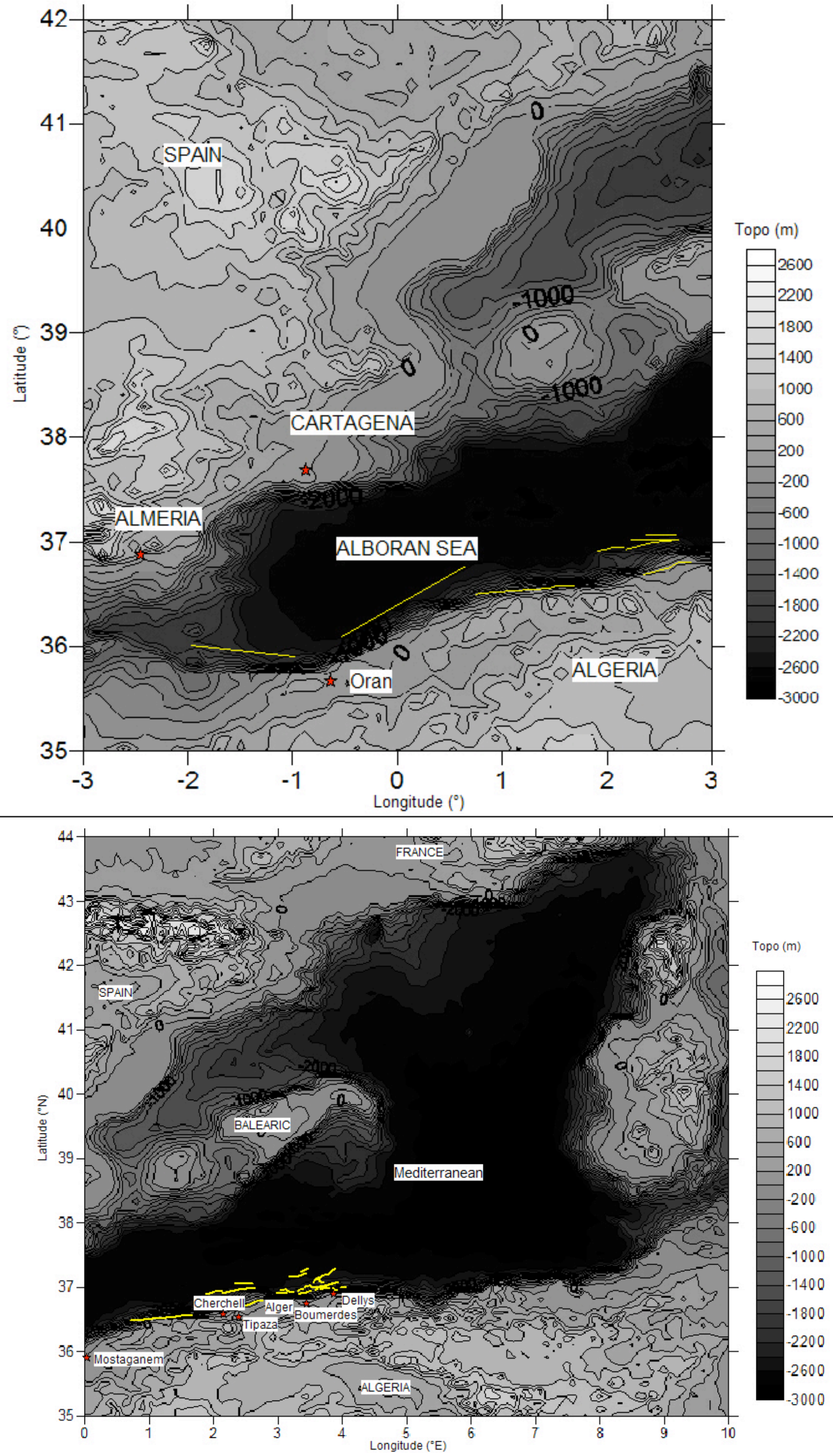
Scientists classically quantify the tsunami intensity from the Imamura or the Soloviev Intensity scale. In this study, we use available data from the NOAA-NGDC database (source: http://www.ngdc.noaa.gov). Here, the Soloviev and Go (1974) tsunami intensity values are converted into the Papadopoulos – Imamura (2001) intensities. Then, the vulnerability index is calculated from the ratio TI / EI.

4. RESULTS

4.1 Tsunami models for Algiers and Oran region

Near field tsunamis triggered in Northern Algeria produce water waves that reach the coast in less than 5 minutes. Figure 4 illustrates the topography and the offshore tectonic context for Western and North Central Algeria.

Figures 5a and 5b shows an earthquake located at 3.1E, 36.8N, e.g. nearby harbour of Algiers (distance to the shoreline is less than 05 km) which generate tsunami waves that are soon trapped in the Bay of Algiers for more than 15 minutes.



(a)

(b)

Fig. 4: Bathymetry (ETOPO database) for (a) North Western and (b) Central Algeria. Selected Offshore faults (yellow lines) are from (Domzig et al., 2006; Dan et al; 2009; Mauffret, 2007).

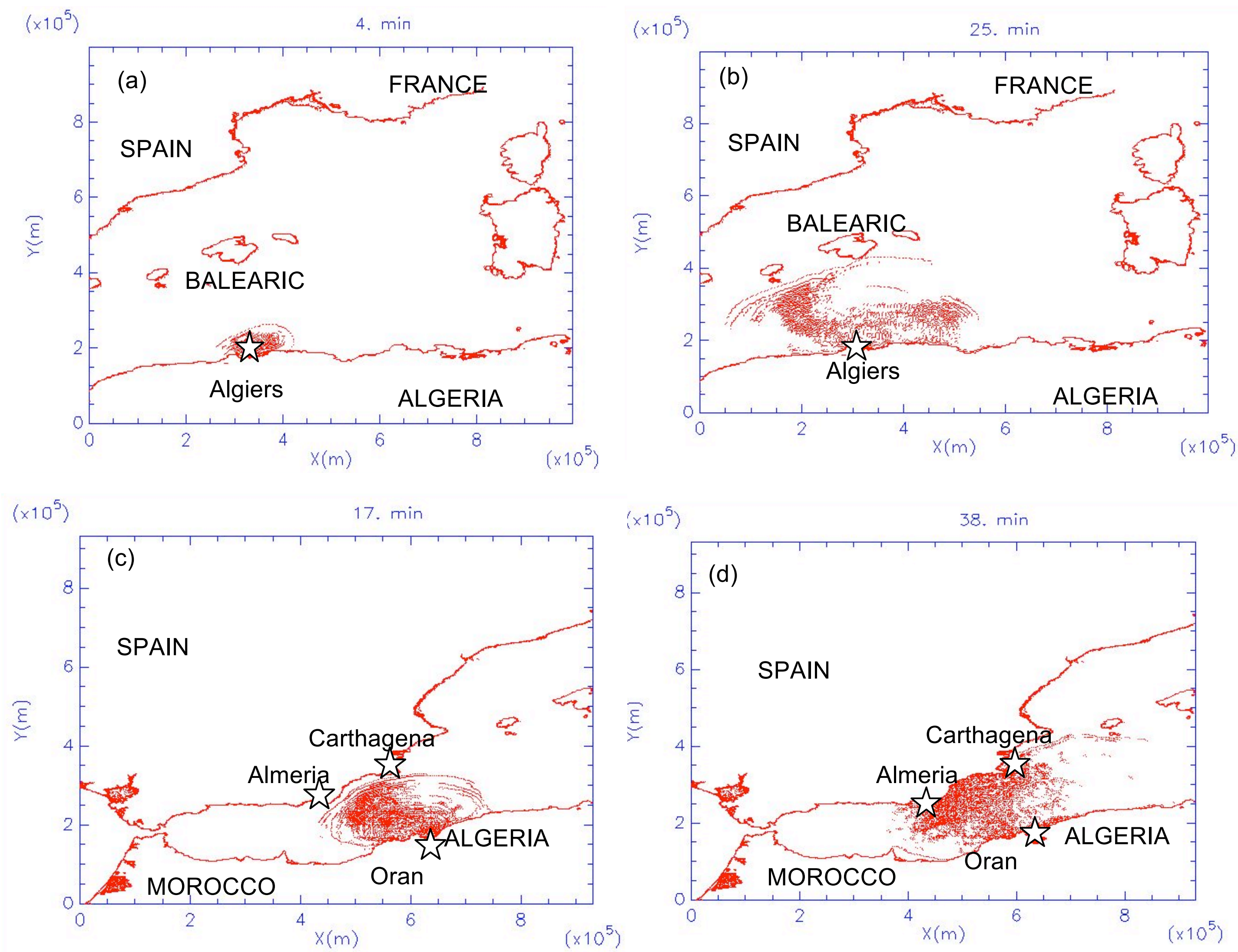


Fig. 5: Tsunami wave propagation for (a & b) Algiers and (c & d) Oran-Alboran study cases. The times are 4 and 25 min for Algiers and 17 and 38 min for Oran. The grid size is 2 min for Algiers and 1 min for Oran-Alboran.

The choice of this epicentre corresponds to the hypothetical earthquake location for the 1365 Algiers event (Ambraseys and Vogt, 1988; internal publication of the CRAAG). Likewise a seismogenic source located at 35.76N, 0.58W (distance to the shoreline less than 03 km), in the entrance of Oran harbour (Figures 5c and 5d) is used. This epicentre was adjusted according to published information on the 1790 Oran event (Bouhadad, 2001; Bouhadad and Laouami, 2002) and the description of tsunami waves observed in Oran, Carthagena and Almeria and reported by Marinas and Salord (1990). Hence, advance and retreat of the sea can be observed along the Algerian coast for a period of 15 minutes. For the Algiers case study, the maximum wave heights computed in Algiers are no greater than 2 meters in Algiers (Figure 6a). For Oran, water wave heights are less than 3 meters (Figure 6c). In both cases, sources located in Northern Algeria results in tsunami waves that reach the Spanish and French coasts in less than 20 minutes.

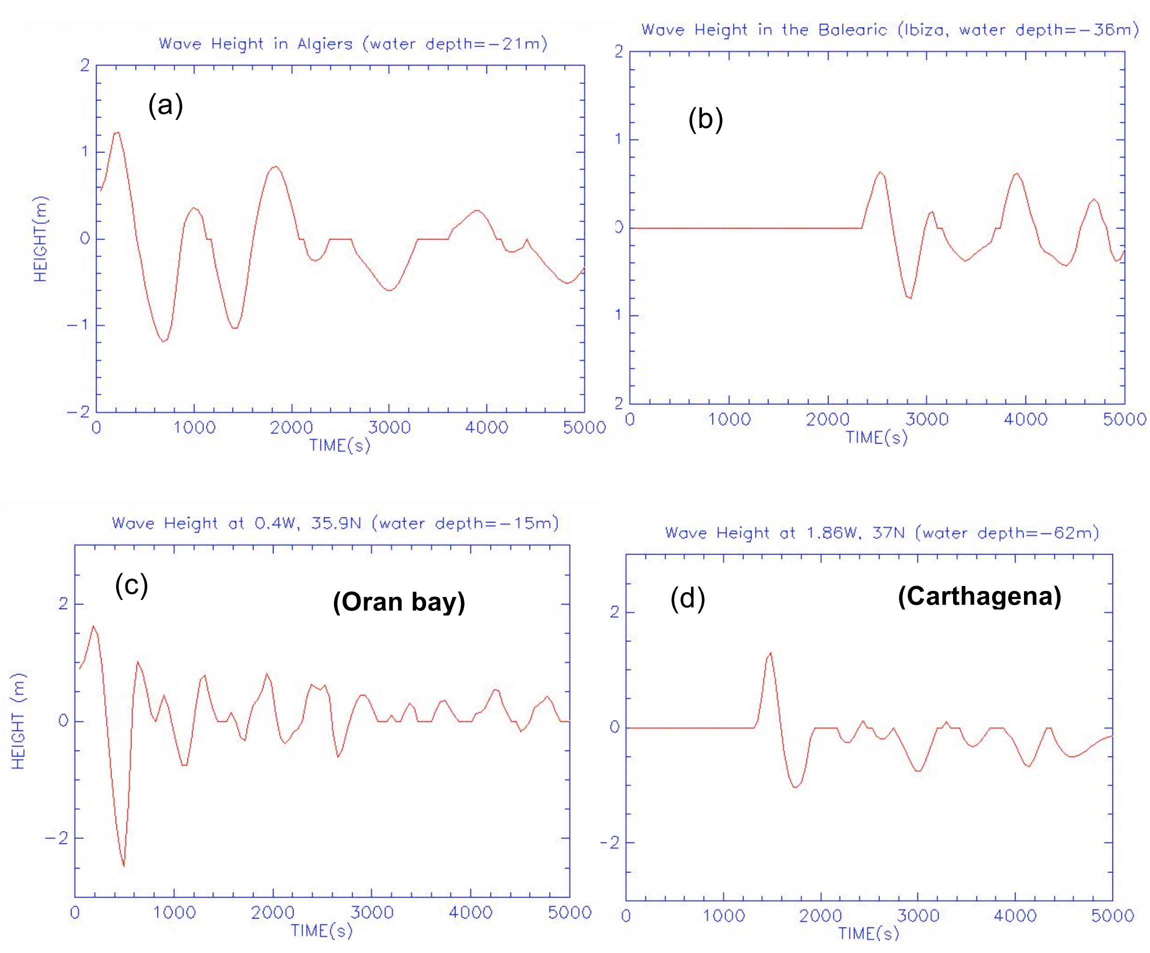


Fig. 6: Wave profiles computed with the SWAN code for (a & b) Algiers and (c & d) Oran – Alboran study cases.

4.2 Flood hazard map for Algiers and Oran urban coastal cities and Tsunami vulnerability in Northern Algeria

Modelling results showed maximum tsunami waves heights range from 0.5 to 3 meters. In 2009, Maouche et al. found tsunami evidence (boulders) from field investigations west and east of Algiers. They estimated those boulders could be associated with waves up to 5 meters in height. Studying the 1856 Jijel tsunamis (East of Algeria) from a compilation of historical documents, Roger and Hebert (2008) and Yelles et al. (2009) reported the flooding of the coast in Jijel and Bejaia after the destructive earthquake. Tsunami waves of 2-3 meters in height in Jijel and 5 meters in Bejaia are mentioned in historical documents. As a result, a maximum potential inundation height of 5 meters is reported on the flooding hazard map (Fig. 7 & 8).

Fig. 7: Flooding map for Algiers region (with Google earth). The red contour line is 5 meters in elevation. Credit for Pictures: L. Amir

Fig. 8: Flooding map for Oran region (Google Earth); the contour line is 5 meters in elevation (in red) – Photographs showing the Oran harbor and the Oran city are downloaded from Google Earth

Figure 9 presents the vulnerability index calculated for 13 tsunami events recorded for tsunami sources in Northern Algeria from the 14th century to present day. Results show that the ratio TI (Tsunami Intensity) / EI (Earthquake Intensity) is lower than 1. As a result, tsunami damage is minor relative to the corresponding earthquake damage.

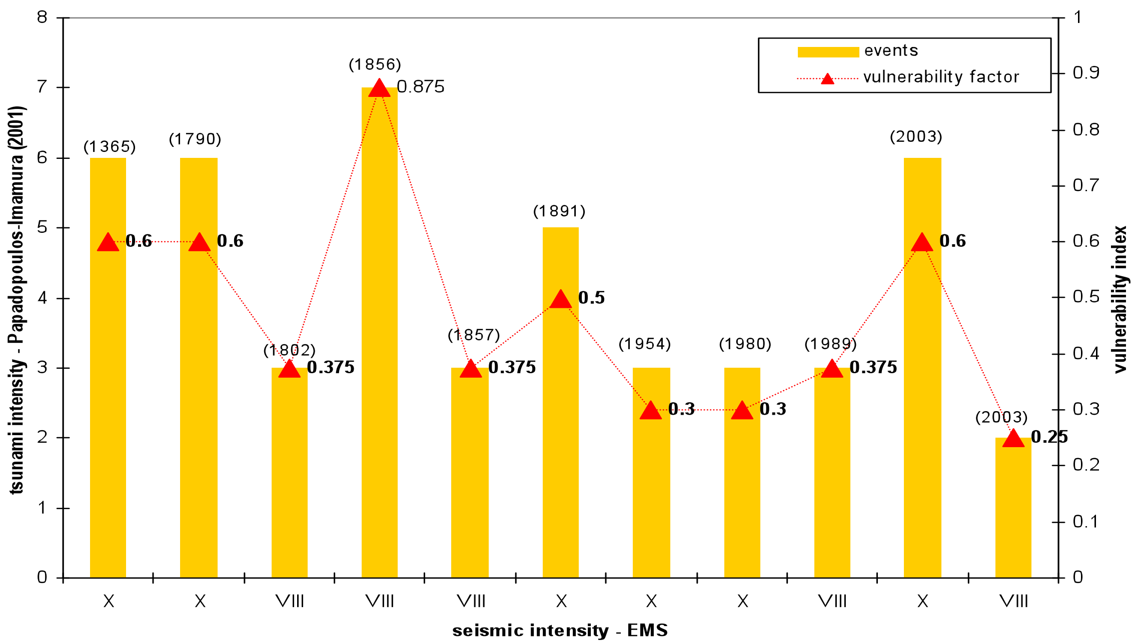


Fig. 9: Vulnerability index for Northern Algeria. (Year of the tsunami event between the brackets).

The inhabitants of Algiers and Oran mostly live in areas above 5 meters elevation. However, rapid urban growth raises the issues of (1) new coastal infrastructure and (2) commercial/residential buildings where the ground floor is dedicated to commercial activities. Nevertheless, the distance between the shoreline and safe places during a tsunami event is not respected. As a result in event of a tsunamigenic earthquake with a magnitude greater than 6, the lack of tsunami education and preparedness could result in panic reactions from the inhabitants.

5. DISCUSSION

5.1 Tsunami inundation limits from the modelling approach

In this work, computed values for tsunami flood hazard mapping are deduced from simulations using the shallow water SWAN code (Mader, 2004). Although the offshore wave heights calculated are less than 3 meters in height, near shore bathymetry and topography often amplifies wave heights, therefore tsunami risk should be considered for the northern part of the country. The effects of the friction and bottom slope angle were not considered in the present modelling. Limits of Tsunami inundation modelling from the SWAN code are discussed in Mader (2004).

The development and evaluation of a realistic friction model is an important remaining tsunami flooding problem. The tsunami wave period and amplitude, bottom slope angle and friction are parameters that affect the assessment of tsunami coastal inundation. Discrepancies between run-ups calculated from the Eulerian and the Navier-Stokes equations are also pointed out by Mader (2004). Numerical simulations need to be refined by using a higher resolution bathymetric grid and considering a slide component associated with the earthquake event.

6.2 Disaster preparedness in Northern Algeria

The timing between the earthquake occurrence along the fault and the first waves that reach the Algerian coast is less than 5 minutes. Fortunately, the tsunami vulnerability index shows that earthquakes in Algeria do not produce unusually large tsunamis. Regardless, coastal city urbanism, traffic, coastal erosion, and bay morphology all raise challenges that vulnerable populations have to face and necessitate improvements in disaster preparedness (construction, creation and location of evacuation routes, coastal infrastructure and effective emergency management policies). Early warning, education, and preparedness programs for earthquake and tsunami in near field tsunami regions marked by rapid urban growth helps reduce vulnerability and increase resilience.

One of the main issues for tsunami preparedness relates to earthquake-resistant coastal infrastructure and individual coastal buildings and residences. The question is what to do when a devastating earthquake occurs, site effects are such that buildings are damaged or collapse, and tsunami waves reach the coast so that people have to evacuate to higher elevations. The present study shows that a flooding hazard exists, but thanks to the topographic features of Algiers and Oran, most inhabitants live in sites above 5 meters. Consequently, the problem focuses on coastal urban growth and tsunami and earthquake preparedness, and mitigation zoning measures for threatened inhabited coastal areas.

Disaster preparedness, prevention and education are the object of a series of laws adopted by the Algerian national parliament on the 25th of December 2004, the day before the Asian tsunami disaster (law n°04-20, *source*: Ministry of the Territory Management). The content of these laws is concerned with emergency planning (ORSEC plans, the requirement for insurance for natural disasters; rules to reduce vulnerability, alert systems, education and information to be integrated within schools…).
Nevertheless, the application of the procedures is still a challenge. Working on a project related to a Housing Earthquake Safety Initiative for a group of countries (Algeria, Indonesia, Nepal and Peru), the UNCRD (United Nations Centre for Regional Development) pointed to socio-economic problems in implementing disaster management in Algeria.

Although building codes exist since the 1954 Orleansville earthquake (1981: RPA/99; 2003: RPA/99 version 2003), 60% of the total buildings are not built to these codes (EERI, 2003). After the disaster resulting from the 2003 Mw 6.8 earthquake in Boumerdes, a building survey from the ERI (Earthquake Research Institute) revealed 42% to 59% of the individual homes were built without a legal permit (EERI, 2003).

In that context, only public information explaining tsunamis, their origin and occurrence, the range and probable limits of flooding, and vulnerability can help to create an effective warning tsunami program for near field tsunamis in Algeria.

6. CONCLUSIONS

Destructive earthquakes and tsunamis events have occurred and been reported in North Algeria in the past and up to the present day. The Sahel Anticline System (nearby of Algiers, central part of Algeria) and the Murdjajo Anticline system (Oran, west of Algeria) are associated with reverse faulting. Both geological structures have the potential to generate a disaster (earthquake and associated tsunami) along the Algerian coast.

Hence, the implementation of local tsunami warning centers for near field tsunamis regions could help to minimize loss of life and damage for urbanised coastal cities. However, an education and information campaign could reduce tsunami vulnerability and increase resilience.

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