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A NEW TSUNAMI RISK SCALE FOR WARNING SYSTEMS - APPLICATION TO THE BAY OF ALGIERS IN ALGERIA, WEST MEDITERRANEAN SEA

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ABSTRACT

The city of Algiers and the surrounding coastal areas in northern Algeria are vulnerable to earthquakes which range from moderate to severe. In 2006, using several possible earthquake scenarios for the Western Mediterranean, the Japan International Cooperation Agency and the Algerian National Seismic Engineering Research Center predicted that heavy damage could occur in the Algiers region. Algerian Civil Defense authorities are particularly concerned by the threat of near-field earthquakes, associated slides and rock falls, as well as for tsunamis that can be generated. The present study proposes a new tsunami risk scale that provides information about the exposed communities and infrastructure, which can be used for regional tsunami alerts and warnings. Furthermore, it evaluates the vulnerability along the Bay of Algiers from tsunamigenic earthquakes. The JMA seismic intensity scale (Shindo scale) and the corresponding seismic peak ground accelerations are used in the evaluation. The results of tsunami modeling studies and of earthquake vulnerability assessment described by the present study, emphasize the significance of public education and preparedness in efforts to mitigate loss of life and damage to property.

Keywords: *vulnerability, earthquakes, tsunami, risk, Bay of Algiers, Algeria*

1. INTRODUCTION

Algiers is the capital of Algeria and its primary harbor. A 2009 report states that the city has a population of more than 3 million inhabitants (source: www.ons.dz). Situated at the limit between the Africa and European convergent tectonic plates, the seismic risk is high for this region and the tsunami hazard has been evaluated and well documented from the XIVth century to present day (Roger et al., 2008, 2011; Ambraseys and Vogt, 1988; Amir et al, 2012). By the XIVth century, the defenses of the city of Algiers were totally related to the defense of the naval forces and consequently to the consolidation and development of fortified structures within the harbor (Belhamissi, 2009). The harbor was further consolidated with walls, in order to protect ships from bad weather conditions (Diego de Haëdo, 2004). Today, the harbor is saturated because of high maritime traffic (freight and human transportation to/from Europe).

The severity of a disaster's impact along coastal Algerian cities is strongly related to: (1) urban planning; (2) the density of the population; and (3) the implementation and efficiency of prevention/education policies. The Algiers region is located in the central part of the country and extends over an area of 2730 km^2. The Bay of Algiers covers a distance of about 30 km from East to West. If a tsunami is generated in the region, immediate measures must be taken to rapidly evacuate people of coastal areas to higher ground. The challenge is mostly related in finding vertical evacuation infrastructures that are built in accordance to seismic safety rules, in designating roads for evacuation and in establishing shelters where people can be protected from maximum tsunami inundation. Specific problems which must be addressed, include traffic issues, potentially collapsed bridges, blocked roads and alternate evacuation routes.

In 2006, the Japan International Cooperation Agency and the CGS published a report that revealed the potential damage from a list of earthquake scenarios. Six active faults were identified in the Algiers region (JICA and CGS, 2006). In particular, the report noted that an earthquake with a magnitude of M_W 6.8 along the offshore fault of Kheireddine could inflict most of the structural damage in the central and western part of the Bay of Algiers. Furthermore, the report postulated that 22 bridges would collapse or suffer destruction and that the harbor would be highly affected. In that context, for a tsunami triggered by an earthquake along this fault, the key issue is to determine the vulnerability of coastal sites and to educate people living in such areas, to quickly evacuate to higher elevation immediately when they feel the ground shaking. Unfortunately, the western and central parts of Algiers Bay are the most vulnerable areas where numerous slums spread in recent years (Figure 1). During a tsunami disaster, people living in such areas have the highest level of risk and are likely to be greatly affected – thus needing protection. A 2009 report (Hoffman, 2009) stated: *"Vulnerable populations, also called "special needs" populations or "at risk" populations, are those that are particularly "at risk of poor physical, psychological or social health" after a disaster. They have additional needs before, during and after an incident in functional areas, including but not limited to maintaining independence, communication, transportation, supervision and medical care.*" Additionally, the report defined the categories of population potentially vulnerable during disasters to "*individuals with physical and mental disabilities, elderly persons, pregnant women, children, prisoners, economically disadvantaged minorities, undocumented workers and those with language barriers*".

Figure 1. Slum at the entrance of El Oued El Hamiz, Bordj El Bahri, Algiers bay, Algeria.

In view of the above-described vulnerabilities, the purpose of the present study is to develop a risk scale in the framework of a tsunami warning program. Thus, a disaster risk assessment method for Algiers Bay is specifically developed, based on the combined impact of earthquakes and of generated tsunamis that would affect the coast. A first attempt is to determine a vulnerability index, as developed and described in an earlier publication (Amir et al., 2012). Subsequently, additional consideration is given to vulnerability from seismic ground shaking, to the regional geology and to materials used for construction. By combining the tsunami risk to the seismic vulnerability, an attempt is made by this study to identify potentially weak vertical infrastructures and to quantify the population's exposure to the risk. Finally, tsunami parameters are estimated from a tsunami modelling study.

2. VULNERABILITY AND RISK SCALE

Assessment of risk from potential earthquakes and tsunamis is critical for populated coastal areas. The reports from the JICA and CGS (2006) support the premise that potential tsunami damage complicates planning and warning policies. With the growing of coastal infrastructure in vulnerable seismic areas, difficulties arise regarding the application of seismic safety rules and construction codes because of the high ground liquefaction potential. Furthermore, tsunami preparedness must include the previously stated objectives of rapid evacuation of people soon as the ground begins to shake and the designation of direct routes to safe shelters. Such policies are difficult to implement.

2.1 Tsunamigenic Earthquake Vulnerability Scale (TEV scale):

The first step in evaluating the vulnerability from a tsunamigenic earthquake is to establish a risk scale, based on realistic parameters that illustrate broad aspects of what can cause damage. In European countries and in North Africa, the seismic intensity scale being used for macro seismic studies, is that known as EMS-98 or MSK. However, materials used for construction are not specified and not considered. Hence, it is difficult to assess either the seismic or the tsunami energy that may have destroyed infrastructure or fortifications in past centuries.

The second parameter that is not considered, relates to local geology. Specific geological conditions could induce ground liquefaction or alternatively could attenuate seismic ground shaking.

In the present study work, we used the Shindo scale of the Japanese Meteorological Agency (Epstein, 2011) to develop a “tsunamigenic earthquake vulnerability” (TEV) scale. This scale helps consider additional parameters necessary to evaluate the potential damage from a tsunamigenic earthquake and to provide warning systems with vulnerability details of which communities are at risk.

Tsunami warning systems are commonly based on a severity scale of four degrees, ranging from low degree to high. This scale includes a fifth degree with no tsunami potential at all. From the description of the earthquakes damage, structural materials and geology, the TEV scale is derived from the Shindo scale to highlight indicators of vulnerability for urban or rural regions. Hence, corresponding ranges for peak ground accelerations recorded immediately after the first shock can then be correlated to potential damages and, consequently, help establish the communities and population at risk. The TEV scale is divided into 5 degrees (see Table 1 in Appendix).

2.2 Tsunami Vulnerability Indicators and Tsunami Risk Scale

Tsunami vulnerability is strongly related to an earthquake’s generation of near field tsunamis. In this section, we identify indicators that provide a ranking for tsunami vulnerability. The tsunami risk results from a combination of the hazard and the vulnerability. The physical parameters for the hazard include the initial wave height, the velocity/energy phase and the final coastal inundation and run-up heights.

The effects of tsunamis relative to damage from earthquakes were studied for northern Algeria (Amir et al., 2012). The index of vulnerability was estimated from the ratio of Tsunami Intensity (Papadopoulos and Imamura Scale) (12 degrees) (Papadopoulos and Imamura, 2001) relative to the Earthquake Seismic Intensity from the EMS-98 Scale (12 degrees). However, only water height, damage and estimated seismic intensity from reports and the literature were considered. Criteria such as construction materials, substrata and limited flooding, were not examined accurately to assess a rigorous vulnerability and to assign a risk scale. Only reported damage from past events helped determine that the vulnerability for earthquakes is higher than that for tsunamis.

In this work, we examined and correlated indicators from the Tsunami Intensity Scale of Papadopoulos and Imamura (2001) with the Shindo Scale. These indicators include impact of the tsunami on people, vessels, wooden structures, masonry buildings and reinforced concrete structures. Tsunami deposits, wave height and limited flooding are correlated as well in this scale. These represent valuable data that is needed for proper risk assessment. The present tsunami vulnerability study considers the indicators relative to the TEV, in addition to the classical tsunami vulnerability parameters (see Table 2 in the Appendix).

3. APPLICATION TO THE ALGIERS BAY

GPS coordinates of 18 points of interests (one for each coastal district) were measured along the shoreline of the Algiers Wilaya. These points either correspond to vulnerable places (slums, entrance of seismically vulnerable bridges) or to potential locations for population evacuation (funfair, gardens, etc).

3.1 Indicators of Vulnerability for the Algiers Region

As stated, urban population within the Algiers region is more than 3 million. Various civilizations from successive periods of colonialism and cultural dominations across centuries, have built structures and monuments that corresponded to materials and cultural architectures of their own. Many infrastructure facilities (hospitals, apartments, government buildings) were built prior 1962. At that time, seismic safety standard rules and seismic engineering codes were not yet well studied. It is only after the El Asnam Earthquake (October 1980, Ms= 7,3) that regulations began to be implemented.

Moreover, *"most of bridges in Algiers are reinforced concrete, composed of prefabricated and prestressed beams or steel beams supported by multiple columns piles. A large number of bridges have been built after 1980 without any seismic design."* (Lazzali and Farsi, 2009). In 2012, Lazzali and Farsi conducted a survey to match the buildings, infrastructure and private houses with seismic vulnerability classes. They used five vulnerability classes decreasing from A to E, deduced from the EMS-98 scale. Accordingly, classes A to C correspond to adobe houses, brick buildings and reinforced concrete structures with no earthquake resistant design. Classes D and E represent structures with earthquake resistant design (reinforced concrete, reinforced or confined masonry) (Lazzali and Farsi, 2012). The density of dwellings for the Algiers region is presented in a 2004 report (Belazougui et al., 2004). Which structures represent safe shelters for evacuation in case of a tsunami emergency is a very important policy decision. For example, most of the buildings in the center of Algiers are masonry buildings constructed prior to 1962, thus may not be safe.

The present study used this assessment of seismic vulnerability for the Algiers region and added the risk exposure based on the estimated population density (from Cheurfi, 2011) to provide full details of earthquake and tsunami vulnerability indicators for the eighteen coastal districts of Algiers (see Table 3 in Appendix).

3.3 Earthquakes Scenario and Tsunami Modelling for the Algiers Region

The Algerian coast has a high level of seismic vulnerability although tsunami damages have also been reported, observed and simulated. Mapping potential tsunami coastal inundations for vulnerable points is crucial in establishing evacuation policies and methodology for warning.

Identified active faults inland and offshore (JICA and CGS, 2006, 2007; Domzig et al., 2006) have the potential to trigger tsunamigenic earthquakes with magnitudes higher than 6.5 (Figure 2). Tsunami travel times for scenarios of offshore Algeria earthquake (M=7.5, off Algiers and Oran) were simulated in a previous paper (Amir and Cisternas, 2010; Amir et al. 2012) using the SWAN code, which solves the shallow water wave equations within a finite difference scheme (Mader, 2004). Whatever the scenario for near field tsunami along the Algerian coast (1,200 km in length), the travel times are in the same range of order. Tsunami waves reach the Algerian coast in less than 5 minutes and the Balearic Islands and the Spanish coast about 15 to 20 minutes later. As for the French and Italian coasts, tsunami waves can be expected about 20 minutes to 30 minutes later (Alasset et al., 2006). Inundating waves at the shoreline can be simulated with the code Geoclaw (George and Leveque, 2006). This finite element package includes the Rieman solver for flooding critical issues onto dry land.

In the present work, earthquake scenarios related to the active Kheireddine, the Chenoua and the Zemmouri thrust faults were reconsidered for mapping coastal tsunami inundation. For all these faults, tests were conducted for earthquakes having strikes ranging between 40˚N to 70˚N. For the Kheireddine and the Zemmouri faults, the dips vary between 30˚ to 60˚ in the SE direction. The Tsunami Hazard parameters necessary to assess the tsunami risk include the initial height of the tsunami waves at the source and their arrival times and terminal velocities for the eighteen districts along the shoreline of the Algiers region. The topographic data being used for the calculations is from the ETOPO-1mn database (NGDC/NOAA, http://www.ngdc.noaa.gov) (Amante and Eakins, 2009).

The results show that the time delay is extremely short, mostly for the western part of the Algiers coast (from D1 to D8), but the heights of the estimated inundating waves are higher. The height of the inundating waves varies as well from D1 to D18. In fact, regardless of what is used as scenario (for earthquakes along the Zemmouri or Kheirddine faults), the impact of the tsunami wave velocity for vulnerable points is crucial. The estimated range of the tsunami runups is less than 2 meters in height. But the tsunami wave velocity varies according to the geomorphology of the coast (Figure 2).

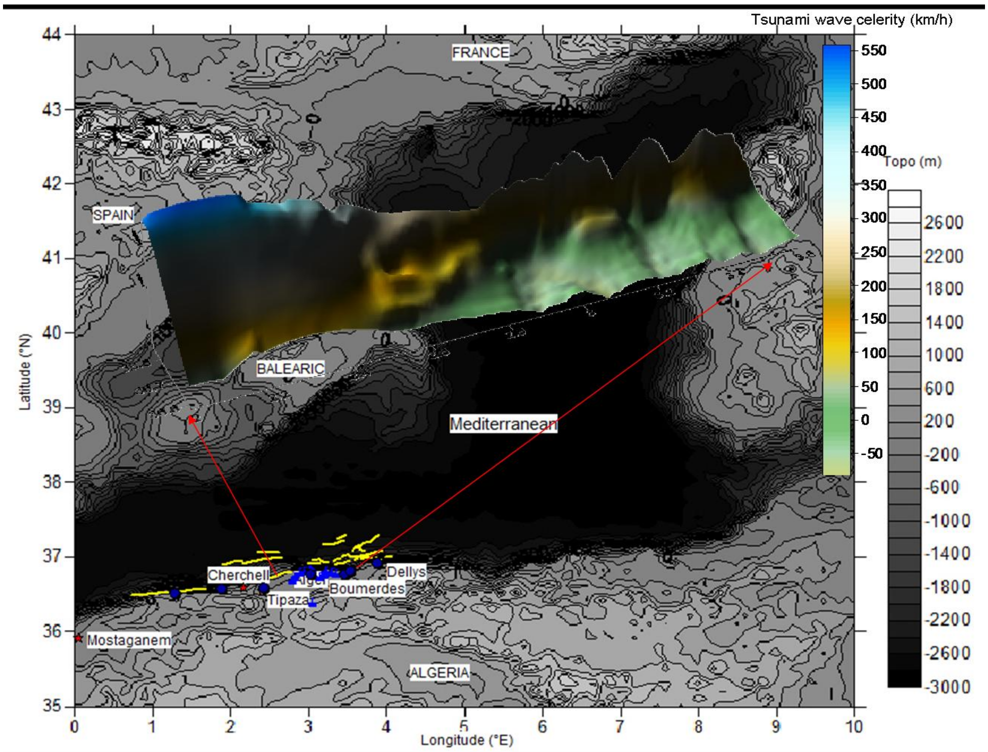

Figure 2: Tsunami Hazard Parameters for the Algiers Coast. The yellow lines represent the offshore faults (compiled after Mauffret et al., 1997, Domzig et al., 2006). The blue circles represent documented historical tsunamis from the NGDC-NOAA database. The blue flags represent the 18 points of interest measured along the coast.

These elements are very important in deciding where to place educational warning signs along coastal areas. The impact of tsunami waves traveling at 20 km/h on the boats of local fishermen is not the same as the impact of tsunami waves traveling at 50 km/h for the same elements (Figure 3).

Figure 3: Fishing boats of a vulnerable group.

4. TSUNAMI RISK ASSESSMENT FOR THE ALGIERS REGION

The tsunami risk is evaluated from the tsunami hazard parameters and the estimated TEV. From the peak ground accelerations (PGA) values, parameters such as the ground slope failures or structural damage can be "predicted", based on the Shindo scale and the tsunamigenic earthquake vulnerability.

The results integrate flooding due to potential liquefaction in the marshy lands or nearby rivers or the tsunami flooding. PGA values are from the JICA and CGS study (2006). Figure 4 represents the TEV and the Tsunami Risk (TR) estimated for the Heir Eddie EQ scenario (Mw= 7). The Tsunami Risk is evaluated for the 18 points of interest along the coastal area of Algiers. The results reflect either places of vulnerability or places for evacuation of people or are related to structures (informal or formal dwellings).

The Tsunami Risk is mostly low to moderate, except for the locations characterized as PI7, PI13 and PI14. For these three points of interest, the tsunami can be damaging. The soil is vulnerable to earthquake liquefaction and the dwellings are "informal" and located at the shoreline. Hence, the potential flooding due to a combination of earthquake impact, triggered turbidity currents and the tsunami waves coming from the Kheir Eddine offshore epicentral area, may have an importance for a group which is already considered vulnerable from the definition of Hoffman (2009). On the other hand, even if the tsunami hazard is higher in the older part of the city (Algiers Center, Bologhine, Belouizdad), crucial issues in estimating the tsunami risk include: (1) the potential collapse of buildings due to their prior state of degradation, (2) the density of the dwellings, 3) traffic, and 4) the number of people exposed to earthquake vulnerability.

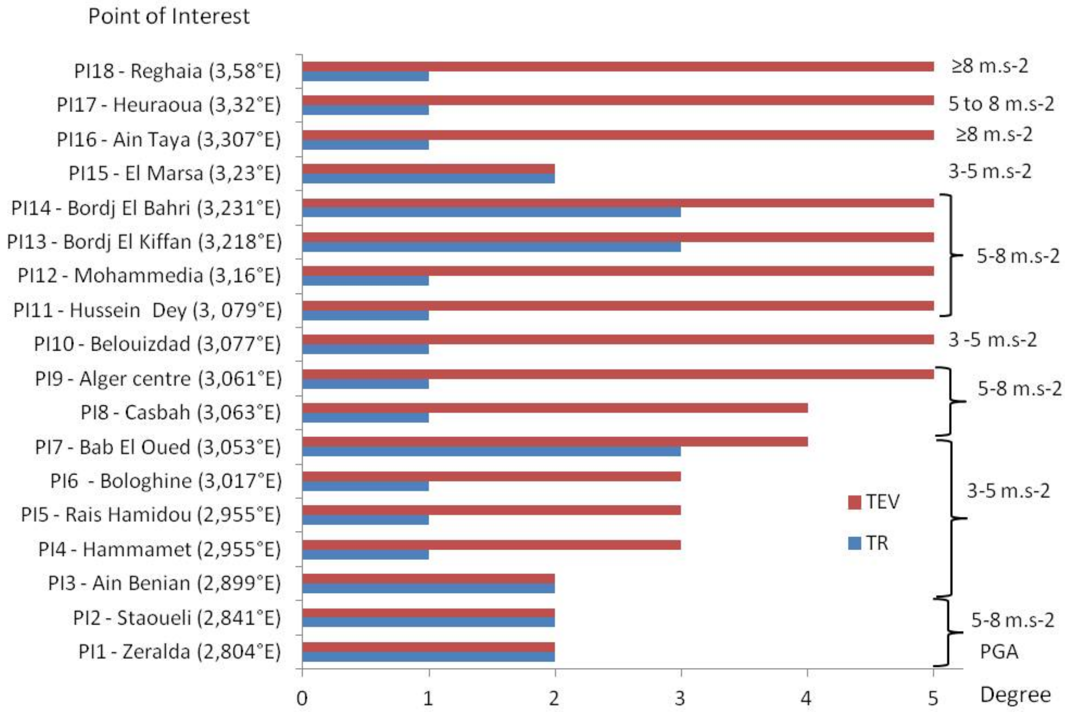

Figure 4. Tsunamigenic Earthquake Vulnerability (TEV) and Tsunami Risk estimated for the 18 Points of Interest in the Algiers Wilaya. Peak Ground Accceleration (PGA) values from JICA and CGS (2006) are reported.

5. DISCUSSIONS AND CONCLUSIONS

The city of Algiers is built amphitheatrically. The wealthier members of society reside at the higher levels of the city while the poorer people live at the lower level (slums of Bordj El Kiffan and Bordj El Bahri). More and more buildings are constructed with no control for seismic regulations or right distances between the shoreline and the private homes.

On the other hand, seawalls of 3 m in height exist in the harbor of Algiers and in the district of Ain Benian. The beaches at Ain Benian are located behind the seawall that only protects the harbor. The configurations of beaches differ along the Algiers coast. Along the Bay of Algiers, the beaches are urban. People who swim there belong to the "vulnerable group" (Figures 6, 7 and 8).

Figure 6. View of the district of Ain Benian (Harbor El Djemila, seawall height = 3m).

Figure 7. People walking along the path next the sea wall (2 – 3 m), eastern Algiers, road in the direction of Bologhine district.

Figure 8. Sea Wall (2 - 3 m) in front of the Popular Beach of Bab el Oued

Most of the structures in the Algiers region date back to periods of colonialism. In the older part of the city (Bologhine, Alger Centre, Bab El Oued, Belouizdad), the walls are already vulnerable because of the degree of degradation. The rehabilitation of older buildings is extremely difficult to attain. According to a 2008 UNEP report: *"The use of specific systems of knowledge and practices developed and accumulated over generations within a particular group and region reflects many experiences and problems solving"*.

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Appendix – Tables

Table 1: Tsunamigenic Earthquake Vulnerability Scale (TEV scale); LP: Liquefaction Potential; RS: Rock Slide; F: Flooding; CV: Class Vulnerability; AS: Available Space to evacuate.

Rank	Indicators of Vulnerability						Shindo Scale	PGA (m/s^2)
	Physical			Buildings		Population Exposure		
	LP	RS	F	CV	AS			
1: Very Unlikely							1(1) to 2(2) / 0.5-2.4	0.008 to 0.08
2: Unlikely							3 (3) / 2.5-3.4	0.08 to 0.25
3: Possible							4 (4) / 3.5-4.4	0.25 to 0.8
4: Likely							5-lower to 5-upper/ 4.5-5.4	0.8 to 2.5
5: Very Likely							6-lower to 7 (7) / 5.5 and up	≥ 2.5

Table 2: The Tsunami Risk Scale

Score	Vulnerability		Shindo Scale	Papadopoulos-Imamoura Tsunami Intensity Scale
	Physical	Structural & Population		
0: No Risk			1(1) to 2(2) / 0.5-2.4	1 (I)
1: low			3 (3) / 2.5-3.4	2 (II) – 4 (IV)
2: moderate			4 (4) / 3.5-4.4	5 (V) – 7 (VII)
3: destructive			5-lower to 5-upper/ 4.5-5.4	8 (VIII) – 9 (IX)
4: catastrophic			6-lower to 7 (7) / 5.5 and up	10 (X) – 12 (XII)

Table 3: Tsunami vulnerability indicators in Algiers; (a) SC (classification of sites from the Algerian seismic code RPA99-2003): S1 (rocky site); S2 (firm site); S3 (soft site); S4 (very soft site) s; (a) SC for classification of sites (Algerian seismic code RPA99-version 2003): S1 (rocky site); S2 (firm site); S3 (soft site); S4 (very soft site)

District	VC (Lazzali et Farsi, 2012)	Exposed area & population (www.ons.dz; Cheurfi, 2011)		Geology (compiled after the Cheragas and Algiers Geological Map-scale : 1/50 000)	Site Classification SC (a)
		Pop (1998)	Area (km^2)		
Zeralda (D1)	B	18183	31,46	Beaches, dunes (recent & consolidated), shaly sand, shale & clays, sandy & shaly-sand facies	S3; S4
Staoueli (D2)	C	35241	22,23	beaches, dunes (recent & consolidated), gneiss, marshy & lacustrine deposits, shaly sand, coquina, pudding stone & marine sandstones	S3; S4
Ain Benian (D3)	B	50756	13.26	Beaches, dunes (recent & consolidated), coquina, pudding stone & marine sandstones.	S3; S4
Hammamet (D4)	B	19651	8.6	Beaches, consolidated dunes, shaly sand, shales and clays, sandy & shaly-sand facies	S3; S4
Rais Hamidou (D5)	B	21518	4.94	Beaches, schist (lens of limestone), gneiss	S1
Bologhine (D6)	A	43283	2.76	Beaches, schist (lens of limestone), gneiss	S1

Bab El Oued (D7)	B	87557	1.2	Beaches, schist (lens of limestone), alluviums; shaly sand.	S1; S2
Casbah (D8)	A	50453	9000 m2	Schist (lens of limestone).	S1;
Alger centre (D9)	B	96329	3.70	Mica schists, shaly sand, schists (lens of limestones)	S1; S2; S3
Belouizdad (D10)	A	91482 (2002)	2.16	Beaches, shaly sands, limestone; lutetian limestone with bivalvia.	S1; S2; S3
Hussein Dey (D11)	B	49921	49	beaches, dunes (recent & consolidated); shaly sand	S3; S4
Mohammadia (D12)	C	42079	7.9	Beaches, dunes (recent & consolidated); shaly sand; marine deposits with small quartz pebbles and red sands, pudding stone & coarse sandstones; ancient alluviums.	S3;S4
Bordj El Kiffan (D13)	B	143000 (2009)	21.7	Beaches, dunes (recent & consolidated); shaly sand; marshy and lacustrine deposits; marine deposits with small quartz pebbles and red sands, pudding stone & coarse sandstones;	S3; S4
Bordj El Bahri (D14)	B	27905	7.5	Beaches, dunes (recent & consolidated); shaly sand; marshy and lacustrine deposits; coquina; pudding stone and marine sandstone; marine	S3; S4

				deposits with small quartz pebbles and red sands, pudding stone & coarse sandstones;	
El Marsa (D15)	B	8783	3.9	Shists, schists (lens of limestones), gneiss, shaly sand, sandstone facies	S1,S2,S3,S4
Aïn Taya (D16)	B	28430	9.55	beaches, shaly sand, marine deposits with small quartz pebbles and red sands, pudding stone & coarse sandstones;	S3; S4
Heuraoua (D17)	B	18121	13	Alluviums, marchy & lacustrines deposits, consolidated dunes, shaly sands	S4
Reghaia (D18)	B	62474	26.3	Alluviums, marshy & lacustrines deposits, consolidated dunes.	S4