Mapping of Induced Effects of an Earthquake in the Region of Algiers, Algeria Using the Geographical Information System GIS

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Abstract. Landslides, rock blocks falls, liquefaction, the appearance of the surface fault and flood present the principle geological-hazard in relationship with earthquakes which will be mapped in the region of Algiers. The determination of these areas passes through a qualitative and quantitative analysis based on a recognition of the soil conditions; geological, lithological, hydro-geological, topographic, morphological and geotechnical. The assessment and mapping of the degree of induced hazard allows individualizing homogeneous areas that can behave similarly during the earthquakes.

1. Introduction

Secondary geological hazard is defined as a movement due to the displacement of the ground or basement that occurs more or less brutally and which can be slow or fast. The main hazards that are likely to occur in the study area are; the landslide, blocks falling, liquefaction, soil compaction, faults appearance at surface and, the flood.

2. Presentation of the study area

The physical environment of the study area and the location of urban sites of the Algiers Department, of this study, are represented in figure 1.

It is bounded by geographical following UTM coordinates (coordinates corresponding to the kilometric grid UTM, zone 31): X between 500,000 and 525 000m and Y between 4 054 000 and 4 074 000m.
The induced effects of an earthquake may occur at the level of the region of Algiers are of two types (susceptibility to liquefaction of soils, susceptibility to ground movement).

3. Susceptibility to Liquefaction Potential
The potential for liquefaction is based on both predisposition and the opportunity of the liquefaction of a zone. Susceptibility to liquefaction is the relative probability that a ground deposit liquefies and collapses during a violent earthquake, it depends on conditions (geological, geotechnical and hydrogeological) characterizing the formations constituting the site. The opportunity to liquefaction is the probability that the soil deposit is a subject to a violent earthquake.

Susceptibility to liquefaction of soils is highly dependent on geological, hydrogeological and geotechnical conditions of the site, necessary for the occurrence of liquefaction. It is, mainly according to Youd and Perkins (1978) [2]: (i) Presence of water table close to the surface, (ii) presence of non-cohesive sand bodies Sediments (grain size), (iii) geology and geomorphology (ages and origin of soil), (iv) composition and texture (grain size and relative density).

3.1 mapping susceptibility to liquefaction
Mapping susceptibility to liquefaction of soils located in the study zone presents a qualitative mapping, based on the data characterizing the site (places of deposit, age and type of formations, water tables depth). These data are summarized in:

- Geotechnical Map and hydrogeological data (from figure 2) which shows the distribution of geological formations in place with water levels.
- The methodological guide of studies for the seismic microzoning (AFPS 1995; [3]); susceptibility to liquefaction of soils according to the place of filing and the influence of the depth of the water and the age of the deposit.
Figure 2. Card geotechnical and hydrogeological data of the study area CGS [1]

On the basis of these data, four (4) classes of susceptibility to liquefaction have been mapped in the study area (Figure 3); they are:

1. High susceptibility: Includes the areas on loose sandy soils, found in coastal areas, beaches and at rivers level with a water table depth below or equal to 3 m.
2. Moderate susceptibility: Includes the areas located on the loose sandy soil with an average depth of the water table between 3 m and 10 m. When lenses of loose sands are contained in clay soils with a shallow water table level, to check the predisposition to the liquefaction of the sandy layer.
3. Low susceptibility: Includes areas on sandy soils consolidated with a level of greater than 10 m water table
4. Zero susceptibility: Corresponds to the areas represented by the Rocky soils, clays, the marls and dense Sands with deep water (whatever the level of the water), they are not affected by the phenomenon of liquefaction.
Figure 3. Map of susceptibility to liquefaction of the study area [1]

4. Susceptibility to ground movement
Susceptibility to the area 'slope movements' requires a good knowledge of the phenomena of instabilities and their factors of predisposition.

The general objective of this part is to develop and validate an operational methodology for assessment and mapping of ground movement hazard in the region of Algiers by the use of digital modeling based on techniques of the system of Geographic Information (GIS). The strategy used for mapping susceptibility to ground movement in the study area is performed in stages five (05): (Bourenane, 2016) [4].

- Step 1: Collection and development of suitable and representative spatialized databases of the characteristics of the study zone;
- Step 2: inventory and map the land movements, to draw up a descriptive typology of the slope movements and the main factors of predisposition and triggers influencing the location of different 'movements of slope';
- Step 3: mapping of factors of susceptibility for the spatial occurrence of ground movement and their analysis. The main factors of predisposition are: The geology in place, the topography, the vegetation occupation of the ground, and the hydrographic network.
- Step 4: Evaluation and mapping of susceptibility to ground movement, using more of expert methods of probabilistic GIS models. The assessment reflects the spatial relationship between the movements of land and predisposition factors.
- Step 5: Statistics and an expert validation of the map of susceptibility to ground movement.

For the realization of this mapping of susceptibility to the movements of land, a database is being developed under the Geographic Information System (GIS). This table summarizes the main factors taken and combined for the realization of the map.
Table 1. Database for susceptibility analysis and sources of information

| Categories of data | Parameter               | Source                                                                 |
|--------------------|-------------------------|------------------------------------------------------------------------|
| Geomorphology      | 1 - Ground movement     | Data of movements of the ground, satellite images from Google Earth, field observations. |
| Topography         | 2 - Gradient slope      | Terrain with a resolution of 32 m (ASTER GMED Worldwide NASA Elevation data). |
| Geology            | 3 - Lithology           | Geological maps to 1/50 000e, carrots surveys, geotechnical studies, field observations. |
| Occupation of the ground | 4 - Land use     | Satellite images (Google Earth) to the 1/10 000e, field observations, topographical map. |
| Hydrology          | 5 - Hydrographic network | Map to 1/25 000th, field observations and satellite (Google Earth) images. |

The thematic layers have been integrated into a GIS for geo-referenced management, via the software Map info 11 and Surfer 11. The statistical processing of the data was carried out using the software Excel 2007 and XLStat 2011 trial version. Several maps have been drawn (Figure 4-8), their combinations give

Figure 4. Map of inventory of ground movement in the study area on Google Earth satellite images CGS [1]
Figure 5. Geologic map of the study area CGS [1]

Figure 6. Main topographical sets in the region of Algiers from the MNT CGS [1]

Figure 7. The distance to the hydrographic network card CGS [1]
4.1 Assessment of the susceptibility to mvt: méthode de rapport de fréquence ou de densité (frequency ratio method fr)

The FR method allows defining the spatial relationship between the distribution of the MVT and their susceptibility factors. The FR is the ratio between the percentage (%) of MVT in the class and the percentage (%) of the area of the class. The index of hazard (LHI) is calculated by a summation of each value from FR to each factor (Lee Min et al. 2001) [5]:

\[
LHI = Fr_1 + Fr_2 + Fr_3 + \ldots + Fr_n
\]

Where LHI is the hazard index of MVT, FR is the ratio of the frequency of each factor.

If Fr > 1, this means a strong correlation and Fr < 1 means a low correlation.

The main advantage of the FR method is that it is easy to apply, and the results are producible. It is one of the most used methods in evaluations of the risks of MVT.

| Factors                          | Classes                        | Indexed class | % of the area (has) | % of MVT (b) | Frequency (b/a) |
|----------------------------------|--------------------------------|---------------|--------------------|--------------|-----------------|
| (A) lithology                    | Current beaches                | 1             | 0.236              | 0            | 0               |
|                                  | Dunes current                  | 2             | 0.405              | 0            | 0               |
|                                  | Epots Marsh and Lake           | 3             | 8.541              | 0            | 0               |
|                                  | Current alluvium               | 4             | 9.25               | 33.33        | 3,603           |
|                                  | Silty alluvium                 | 5             | 52,734             | 25           | 0,474           |
|                                  | Consolidated dunes             | 6             | 5,435              | 0            | 0               |
|                                  | Limestone, sand Astien         | 7             | 4,253              | 20,833       | 4,898           |
|                                  | Marnes House cobbled - square  | 8             | 11,647             | 4.166        | 0,357           |
|                                  | Astien                          |               |                    |              |                 |
|                                  | Facies sandy or clayey sandstone Astien | 9     | 2,228              | 9,284        | 4,167           |
|                                  | Facies clay or clayey          | 10            | 0.168              | 0            | 0               |
|                                  | More or less clayey sands      | 11            | 11,174             | 16,666       | 0               |
old alluvium: 12 0,101 0 0
Marly or clayey 13 0,067 0 0
Sandstone facies 14 0,067 0 0
Clay facies 15 0,844 0 0
Pegmatite in the micaschistes 16 27,008 0 0
On sericite schists 17 0,202 0 0

| (B) slope (°) | 0-5 | 5-10 | 10-15 |
|---------------|-----|------|-------|
|               | 1   | 2    | 3     |
| 82,95         | 15,8| 1,181|
| 58,33         | 45,833 | 0,703|
| 0,703         | II.90 | 0     |

| (C) land use   | 1   | 2    | 3     |
|----------------|-----|------|-------|
| Bare soil      | 1   | 2    | 3     |
| 8,541          | 46,691 | 3,409 | 39,095 |
| 33,333         | 20,833 | 4,166 | 37,5 |
| 03.IX          | 0,446 | 1.222 | 0,959 |
| Urbanized areas| 2   | 3    | 4     |
| Soil natural (green area) | 3 | 2 | 2 |
| 3,409          | 4,166 | 4,625 |
| 4,166          | 4,166 | 4,166 |
| 0,881          | 0,9 | 0,919 |
| Forests and shrubs | 4 | 5 |
| 39,095         | 2,126 | 8,333 |
| 37,5           | 8,333 | 3,919 |
| 1.222          | 0.919 |       |
| Bare soil      | 5   |      |       |
| 2,126          |       |       |
| 8,333          |       |       |
| 3,919          |       |       |

| (D) Distance / hydrographic network (m) | 1   | 2    | 3     |
|----------------------------------------|-----|------|-------|
| 0-100                                  | 1   | 2    | 3     |
| 1 5,266 29,166 5,538                  | 4,861 25 5,142 |
| 80,384 41,666 0,518                    |       |       |
| 100 - 200                              | 2   |      |       |
| 4,861                                  |       |       |
| 25 5,142                               |       |       |
| 0,518                                  |       |       |
| 200 - 300                              | 3   |      |       |
| 4,726                                  |       |       |
| 4,166 0,881                            |       |       |
| 0,919                                  |       |       |
| 300 - 400                              | 4   |      |       |
| 4,625                                  |       |       |
| 4,166 0,919                            |       |       |
| > 400                                  | 5   |      |       |
| 80,384 41,666 0,518                    |       |       |

4.2. Validation and verification of results

The obtained results were verified using the two statistical rules (Bai, 2010; [6]), by comparing the percentage of susceptibility classes to the percentage of field movements (Figure 9).

![Figure 9. Comparison of the percentage of susceptibility and ground movement classes](image)
The resulting ground motion susceptibility map (Figure 10) shows the distribution of the susceptibility classes defined as follows:

1. Very low susceptibility is essentially characterized by zones with zero gradient of low slope varying from 0 to 5° and a soil occupied either by the buildings, by the cultivated lands or the forests. From the geological point of view, these zones are constituted by the Quaternary and Neogene formations.
2. The weak susceptibility is essentially characterized by gradient zones with a slope varying from 5 to 10° and a soil occupied either by the Buildings or by the cultivated land.
3. Moderate susceptibility is essentially characterized by zones with a moderate to high gradient varying from 5 to 10° and a soil occupied either by vegetation or by trees.
4. High susceptibility is essentially characterized by areas with a steep gradient greater than 15° and not covered by vegetation.

5. Conclusion
The main secondary geological hazards in the region of Algiers, in relation to the earthquakes, are the liquefaction of the soils and the ground movements. The interest of this study is to give an orientation of the future construction projects in order to take into account these hazards during the territory development while ensuring a maximum security of the people and the goods.
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