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ELABORATION OF THE GEOTECHNICAL MAP OF AIN TEMOUCHENT-CITY (ALGERIA)

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Abstract: The region of Ain-Témouchent is a seismic zone; its land is predominately agricultural and shows complex structures, with many problems linked to the development of urbanized areas; these problems are directly or indirectly related to the geotechnical conditions of soil.
The purpose of the present research is to build a database from the different measurements carried out in the region, and to conduct tests in places where information is not available in order to consider the entire perimeter of the study area.
Once the database is completed, an analysis of all the data will be carried out using a numerical tool in order to establish the geotechnical map of the city. This map will certainly allow all decision-makers and designers to have clear and precise information when proposing or designing new structures.
The geotechnical mapping of Ain-Temouchent soils based on 178 observations divided these soils into ten groups. Eight of them according to the Unified Soil Classification System (USCS): CH (High plasticity clay), CL (Low plasticity clay), MH (High plasticity silt), ML (Low plasticity silt), SC (clayey sand), SM (Silty sand), GM (Silty gravel with sand), OH (organic soil of high plasticity). The other two groups are rocky soils: basalts (hard volcanic rock with high resistance), and limestone turf (sedimentary rock).

Keywords: Thematic map; Geotechnical map; Thiessen polygons; Ain Temouchent.

1. Introduction

After the earthquake of magnitude 5.8 on the Richter scale of the year 1999, which destroyed much of the ancient town, Ain-Témouchent experienced a great urban development, marked by the birth of the new neighborhood of Akid Othmane, in the northern part of the town. The construction project, which was financed by the World Bank, was intended to accommodate the victims of the earthquake disaster. Ten years later, a second neighborhood emerged in the south-eastern part of the town, with the university center, Dr. Benzerdjeb Hospital, civil protection unit, several housing programs of different types and public facilities programs already completed or still in progress.

Following this huge expansion of the Town in building construction, hydraulics and public works, several hydraulic drillings, geotechnical works, reconnaissance campaigns, identification of subsoil profiles and thematic maps were realized.

Unfortunately, this enormous amount of recorded documentation poses a major challenge with regard to its storage and management, and consequently remains difficult to access because it is not adequately archived by design offices and other companies.

To remedy this problem, it was decided to develop a digital geotechnical map, which is very important and indispensable, in order to make the needed data available to decision-makers and managers and help them to better manage natural resources, and also to better understand land use planning, urban and construction techniques.

It is worth noting that the computer tool is today of paramount importance as it offers considerable and effective help in geotechnical mapping, with its triple aspect of:

- Data bank for information storage,

- Processing and statistics,
- Automatic mapping [1].

2. Presentation of the study area

2.1 Geographical situation and morphology

The Town of Ain-Temouchent, capital of the Wilaya (Province) of Ain-Temouchent, is located in northwestern Algeria, about 500 km to the west of the capital Algiers.

The area concerned by this study includes the old Town and the two new urban centers named the north pos and the southeast pos II, with a total area of 11.66 square kilometers and a perimeter of 15.30 kilometers, as shown in Figure 1. This area is limited by the projected coordinates X = 667 000 to 672 000 m and Y = 3 905 800 to 3 910 000 m (WGS 84 / UTM Zone 30 North projection).

The morphology of the area under study is between the altitudes of +200 m north and +300 m south of the town.

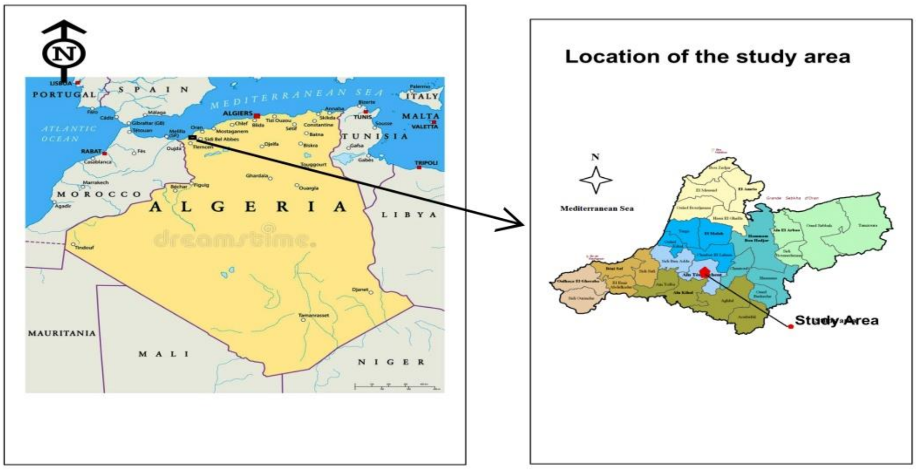

Fig.1- Geographical location of the study area[2]

2.2 Geological context

The geological structure of Ain Témouchent is composed of basaltic-type volcanic formations and volcanic ash that owe their appearance to the Pliocene and Quaternary eruptions. These formations cover the entire south-eastern and southern part of the region going as far as the sectors of Chaabat El Leham, Béni Saf and Ain Tolba.

According to the explorations and geological sketches carried out between 1964 and 1971 by [3] and reported on the map of Ain-Temouchent (sheet N° 209, to scale 1 / 50 000), the geology of the region is characterized by:

- Continental to brackish Miocene detritus formations,
- Basalt formations or cast stone basalts as well as pyroclastic products from volcanic events,
- Quaternary formations consisting of low Wadi terraces (sandy-clay soils).
- Limestone formations.
- Recent undifferentiated deposits, moderately sandy soils marked by the presence of dark mud [3] (Figure 2).

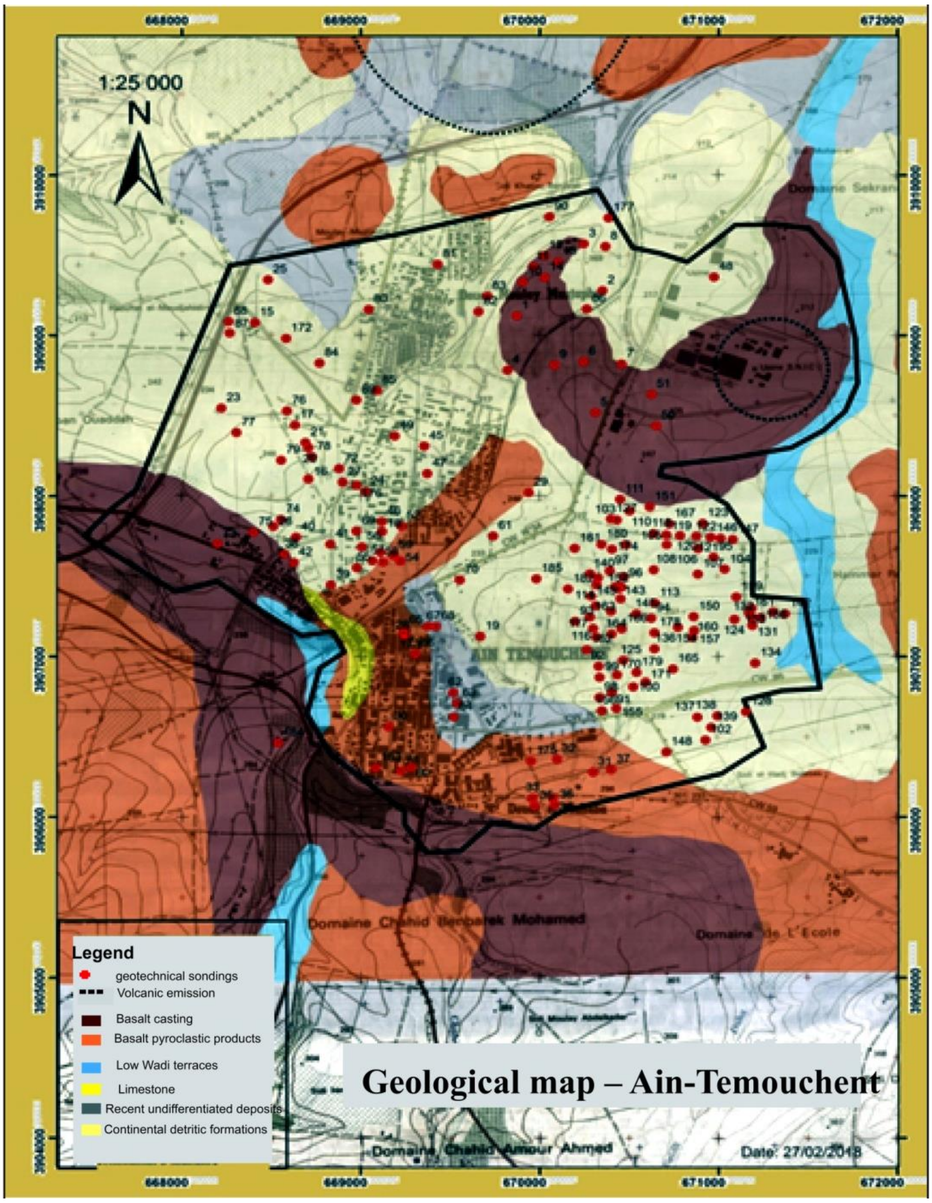

Fig. 2 - Geological map – Ain-Temouchent [3]

2.3 Hydrogeology and climatology of the study area

The area under study is crossed by several rivers among which the most important are Oued Souf El Tel and Oued Sennane, which take their source in the mountains of Tessala in the South, as well as other tributaries "Chaâbats" before they join the river of Oued El Maleh. In addition, research conducted by [4] allowed confirming the presence of rock aquifers in the volcanic massif.

From the climatological point of view, the region of Ain-Temouchent has a Mediterranean climate with a relatively cold and rainy winter and hot and dry summer; the average annual rainfall was 320 mm/year for the period extending from 2000 to 2011 [5, 6] and the average temperature was 18.9 °C for the period ranging from 1994 to 2010 [7] .

3. Materials and methods

The present research study was based on the analyses of the regional and local geological contexts, geomorphological contexts and hydrogeological contexts, based on the available cartography, and on the various water well drillings completed throughout the Town of Ain-Temouchent. The analyses were conducted in the National Laboratory for Housing and Construction (LNHC - *Laboratoire National de l'Habitat* & de la *Construction*) in Algeria.

The data used to establish the geotechnical map were obtained from:

Particle size analysis, according to standards NF P 94-056 [8] and NF P 94-057[9].

Determination of Atterberg limits, according to standard NF P 94-051 [10].

The variables measured were the liquid limit ω_l and the plastic limit ω_p determined on soil samples that can pass through a 0.40 mm sieve. These variables were used to calculate the plasticity index I_p, using the expression: $I_p = \omega_l - \omega_p$.

The average depth prospected is 10 meters.

The geotechnical classification used in this article is that of the Central Laboratory of Roads and Bridges (LCPC) and Unified Soil Classification System (USCS); another classification that is also used is the Road Earthworks Guide (GTR - Road Works Guide) and Standard NF P 11-300 [11] for rock materials.

The maps were developed using the Software ArcGis 10-2. The geotechnical map was developed from the Thiessen polygons and completed with the help of spatial analysis tools (fusion of contiguous polygons having the same geotechnical class).

The nature of clays contained in the soils under study was determined using the Casagrande abacus which uses the compression index C_c to deduce the nature of clay mineral present in soil. This index was measured in the Laboratory using the standard oedometer test, based on Standard XP P 94-090-1 [12]. The slope map, watercourses and watersheds of the Town were realized using the Digital Terrain Model (DTM).

The data used are based on the information from the geotechnical soundings that are located in the perimeter of the study area; they are clearly illustrated on the map in Figure 3.

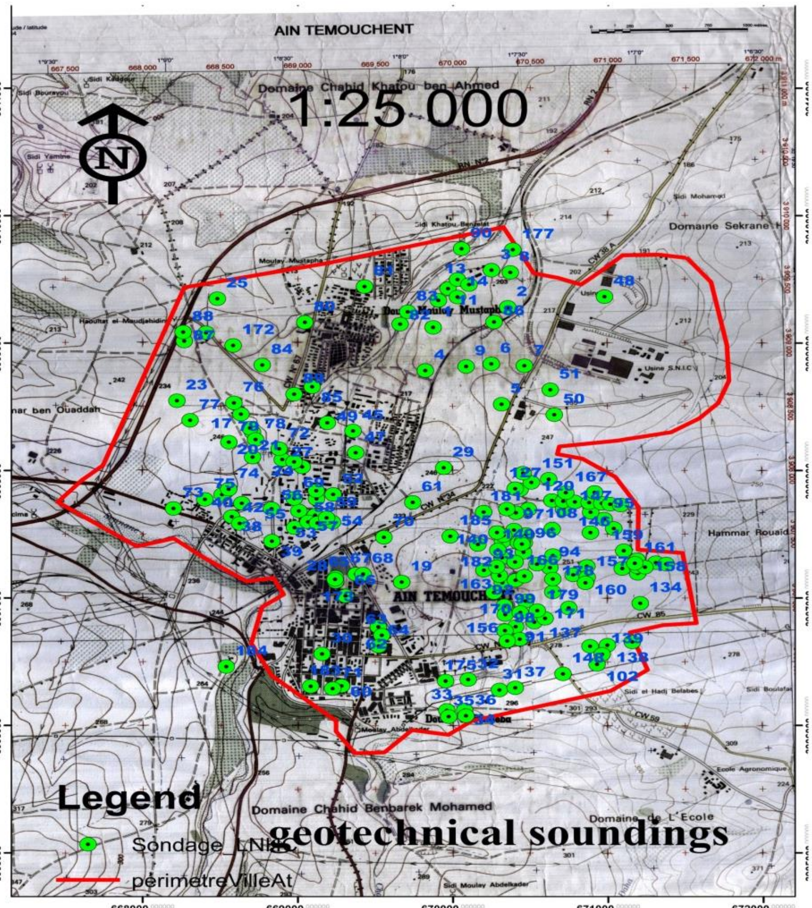

Fig. 3 - Location of geotechnical soundings

4. Results and discussions

4.1 The slope map

The major part of the study area belongs to the plain of Ain-Temouchent which is characterized by gentle to moderate slopes, slightly inclined from south to north, with a percentage of 1% to 15% (zone in green and yellow colors on the map). Locally, the slope gradients sometimes exceed 30% to 63% (zone in red color). These slope gradients are between two banks; i.e. on the left bank, there is Wadi Sennane and on the right bank Wadi Souf Ettel, where the relief is more imposing (Figure 4).

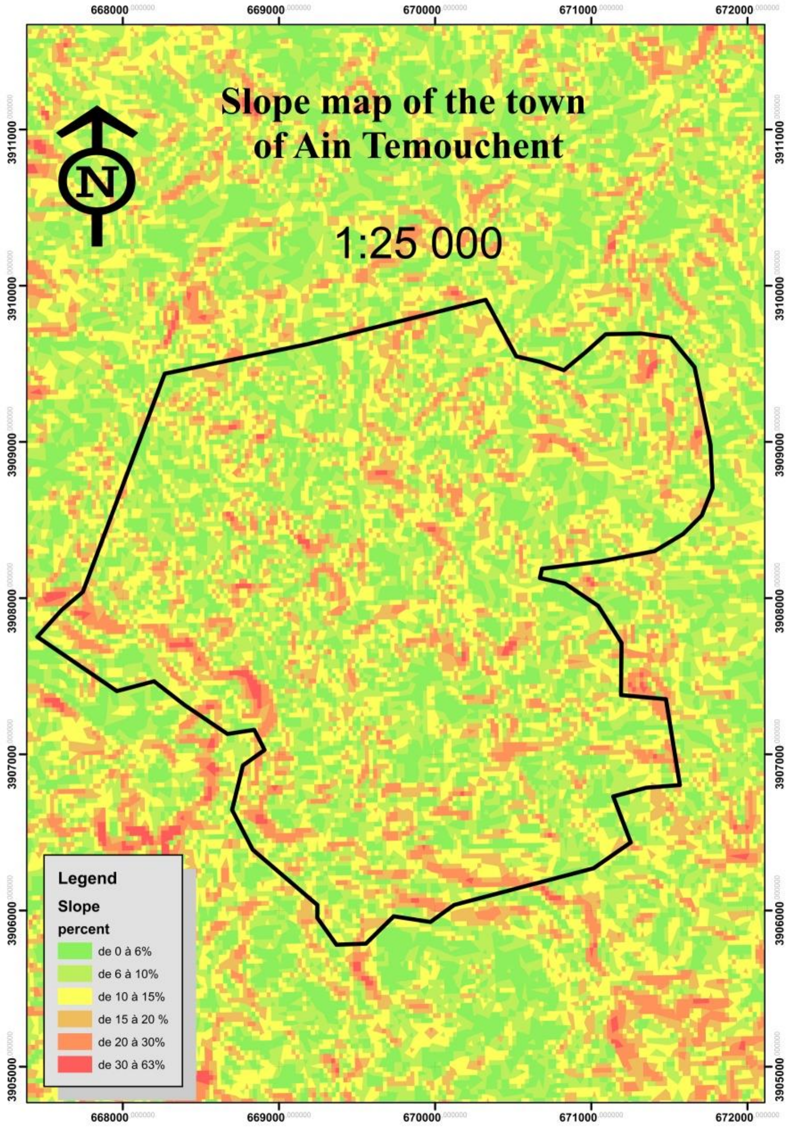

Fig. 4 - Slope map.

4.2 The hydrogeological map

The hydrogeological map shown in Figure 5 was established using the Digital Terrain Model (DTM) of the study area along with the ArcMap Spatial Analyst extension.

On this map, the two Wadis, namely Wadi Sennane on the left and Wadi Souf Ettel on the right are clearly illustrated. One can easily observe that the study area is spread over three sub-watersheds of Wadi El Maleh watershed.

Note also the presence of the so-called Ain-Temouchent Wadi, which passes through the center of the Town and heads to the northeast, a large part of which contains filling materials. Upwelling was observed in buildings constructed near that river, particularly in the basements of the F*orest Management Direction building*, the Public Library and the buildings of "BARAKA" District, approximately of the railway station of the Town of Ain-Temouchent.

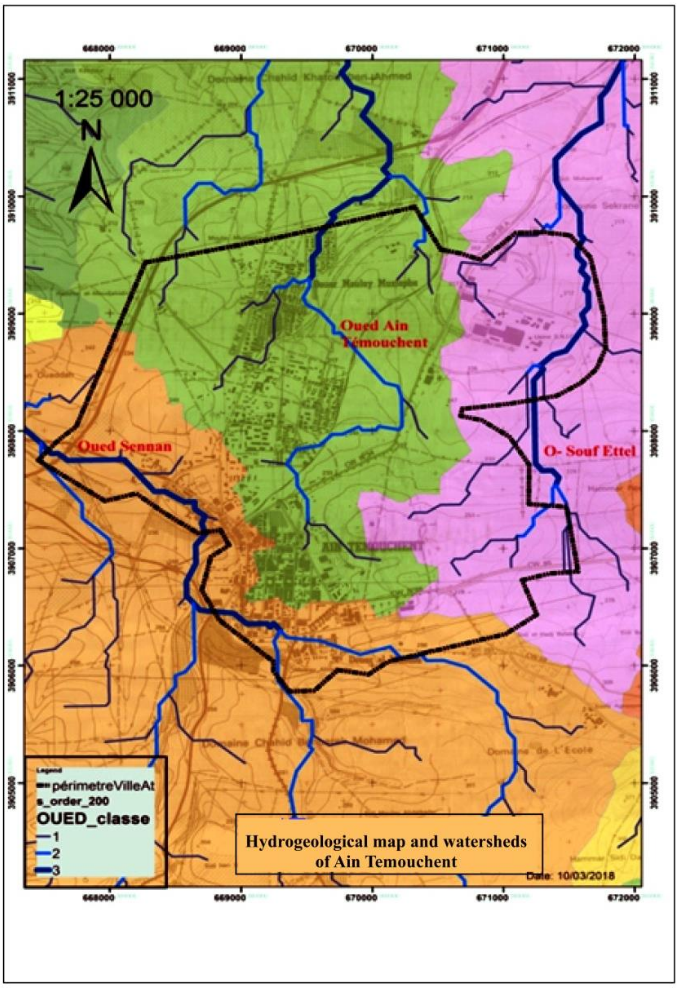

Fig. 5 - Hydrogeological map and watershed.

4.3 Map of allowable soil stress in the study area

The map in Figure 6 was derived from the 178 information points [13] using the Inverse Distance Weight (IDW) interpolation method under the ArcMap Geostatistical Analyst extension [14].

The allowable soil stress was estimated from cone penetrometer tests carried out by means of the dynamic penetrometer made by the Swedish company *BORRO. This penetrometer* has the following characteristics [13]:

Weight of hammer M = 63.50 Kg.

Weight of rod P = 6.28 Kg.

Fall height H = 50 cm.

Tip cross-section A = 15.90 cm^2.

The dynamic resistance Rd is given by the so-called Dutch formula:

$$\mathrm{Rd} = \frac{\mathrm{H.M}^2}{\mathrm{A.e.(M+P)}} \quad [15]$$

Where e is the average penetration (cm) per stroke.

Furthermore, the allowable stress is given by $qadm = \frac{Rd}{K}$, where K is the safety factor that depends on the nature of soil being penetrated.

On the other hand, [18] recommended taking the value k = 20 for the evaluation of the allowable stress. And his value is supposed to be between 15 and 20 [16].

The particular interest for the map of allowable soil stress is to determine the distribution of the bearing capacity of soil in the study area. The results shown in Table 1 indicate that most of the area under study is characterized by a soil lift greater than 1.30 bars for 90% of the total area.

Table 1

Soil bearing capacity of the study area

qadm (bars)	1.00 - 1.20	1.21 - 1.30	1.31 - 1.50	1.51 - 2.00	2.00 - 3.00	Total
Surface (Km^2)	0.15	1.07	2.66	6.83	0.95	11.66
Percent (%)	1.29	9.18	22.81	58.57	8.15	100

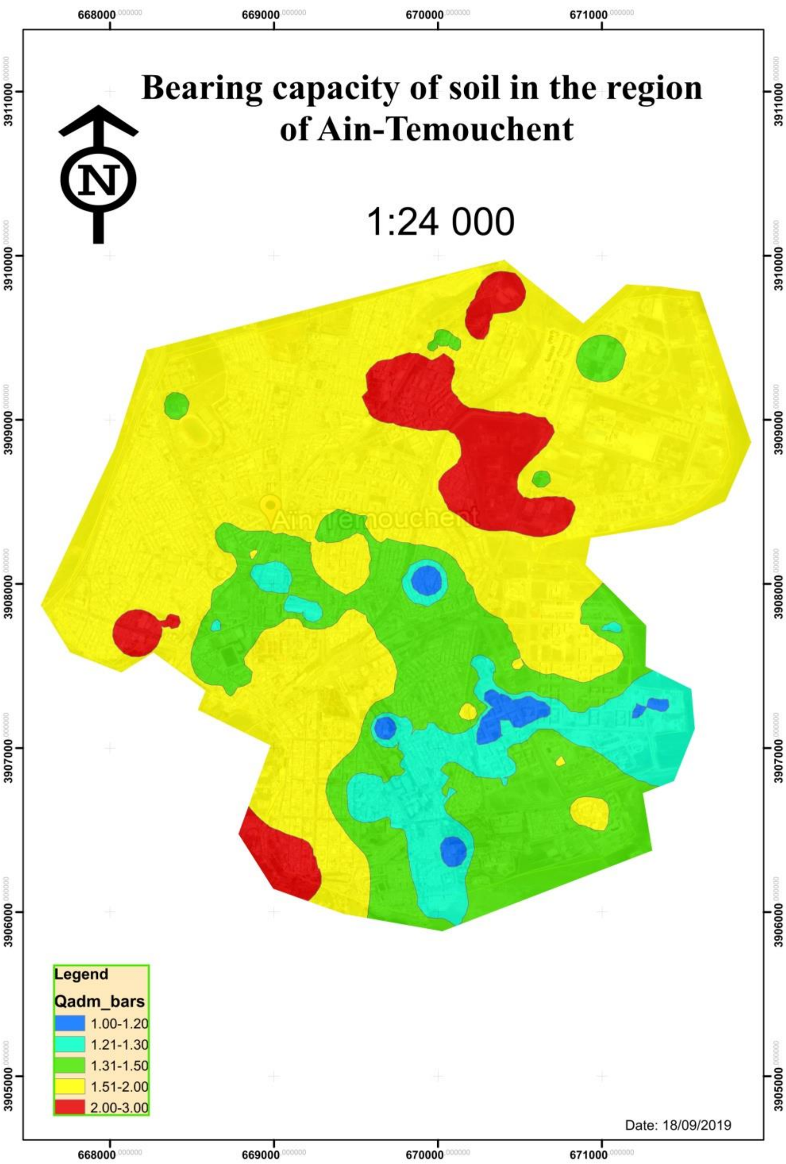

Fig. 6 – Bearing capacity of soil in the region of Ain-Temouchent

4.4 Geotechnical map of the study area

The classifications used in this article have highlighted the following soil groups:

Class CH soils (High plasticity clay) (Table 2) consist of 17% sand, 83% fine particles under 0.08mm, with an average liquid limit of 53.50%, average plasticity index of 30%, average compression index of 0.192, and average allowable stress of 1.20 bars. It is a wet, saturated, very plastic, *compacted expansive soil*.

Table 2

Geotechnical characteristics of class CH soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ωl (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
14.2 - 15.4	18.5 -19.1	24. - 30	50 - 57	19 – 28	29 – 31	1.18 - 1.92	0.166 -0.218
C_g	Φ (°)	C (bar)	q_{adm} (bar)	Soil compaction and compressibility			
0.026-0.053	19 - 22	0.13 - 0.43	1.20	*Compacted expansive soil*			

Soils of class CL (Low plasticity clay) (Table 3) consist of 10% sand, 90% fine particles under 0.08 mm, with an average liquid limit of 41%, average plasticity index of 18%, average compression index of 0.020, and average allowable stress of 1.10 bars. It is a saturated, little swelling in depth soil.

Table 3

Geotechnical characteristics of class CL soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
13.8 - 15.1	17.4 -18.2	15 - 32	39 - 43	22 - 24	17 – 19	1.47	0.010-0.031
C_g	Φ (°)	C (bar)	q_{adm} (bar)	Soil compaction and compressibility			
0.0010-0.0017	9-20	0.71-1.20	1.00-1.20	Low swelling soil			

Clay soils of classes CH and CL cover the major part of the study area; they mask the oldest terrains as described on the geological map (continental to brackish Miocene detritus formations). These soils are clearly visible over a large part of the Town of Ain-Temouchent.

Soils of class MH (High plasticity silt) (Table 4) consist of 4% sand, 96% fine particles under 0.08 mm, with an average liquid limit of 72.03%, average plasticity index of 53.40%, average compression index of 0.202, and average allowable stress of 1.30 bars. This is a saturated, moist, very plastic, compacting and swelling, with a soil ratio $e < 1$.

Table 4

Geotechnical characteristics of class MH soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
14.6	18.8	28.60	72.03	18.63	53.4	1.29	0.202
C_g	ϕ (°)	C (bar)	q_{adm} (bar)	Soil compaction and compressibility			
0.042	17.93	0.44	1.30	*Compacted expansive soil*			

Soils of class ML (Low plasticity silt) (Table 5) consist of 19% sand, 81% fine particles under 0.08 mm, with an average liquid limit of 54.65%, average plasticity index of 22.24%, average compression index of 0.109, average allowable stress of 1.40 bars. It is a moist, not very plastic, compressible and moderately swelling soil.

The silty soils of classes MH and ML are particularly found in the neighborhood of *Hai Zitoune* (Archives Center, Religious Affairs Division, and Cultural Complex) and in the neighborhood of *Hay Moulay Mustapha* (Ben Babouche Middle School).

Table 5

Geotechnical characteristics of class ML soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
12.7	17.7	39.40	54.65	32.41	22.24	2.01	0.109
C_g	Φ (°)	C(bar)	q_{adm} (bar)	Soil compaction and compressibility			
0.012	42.05	0.90	1.40	*Compacted expansive soil*			

Soils of class SC (Clayey sand) (Table 6) consist of 40% sand, 30% silt particles, 30% fine particles, with an average liquid limit of 51.24%, average plasticity index of 26.50%, average compression index of 0.136, average allowable stress of 1.15 bars. These are average-quality fine soils; they are also *compact and expansive*. They are mainly encountered in the south, near the Hospital *Doctor Benzerdjeb*, as well as in the northern part, next to the Bus Station.

Table 6

Geotechnical characteristics of class SC soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
14.0-16.2	17.0-18.6	14.81-21.42	49.99-52.50	23.81-25.67	26.18-26.83	1.65-2.12	0.076-0.196
C_g	Φ (°)	C (bar)	q_{adm} (bar)	Soil compaction and compressibility			
0.012 -0.017	42.60	0.47	1.00-1.30	*Compacted expansive soil*			

Soils of class SM (Silty sand) (Table 7) consist of 35% sand, 45% silt particles, 20% fine particles, with an average liquid limit of 50.84%, average plasticity index of 25.73%, average compression index of 0.172, and average allowable stress of 1.30 bars. These are little to highly plastic, over-consolidated, low swelling and low compacted soils. They are found in the center of the Town (Saida Khadija Mosque, Public Garden) and in the southern part, in the neighborhood of *Douar El Mahiba.*

Table 7

Geotechnical characteristics of class SM soils

γ_d (KN/m^3)	γ_h (KN/m^3)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
11.9 - 12.6	16.5 -16.8	30.2 - 33.2	44.43 -57.26	21.53 -28.70	22.90 -28.56	1.87-2.00	0.139 -0.206
C_g	ϕ(°)	C(bar)	q_{adm}(bar)	Soil compaction and compressibility			
0.020 -0.035	24.48	0.69	1.30	Soil with low compaction and low swelling			

Class GM soils (Silty gravel with sand) (Table 8) consist of 29% gravel, 36% sand, 35% fine particles (silt - clay), with an average liquid limit of 28%, average plasticity index of 12%, average allowable stress of 2.48 bars. These are practically stable soils. This type of soil is located only in the northeastern part of the town, on the way to *Chaâbats El Leham*, next to the industrial zone and National Road *RN 101*.

Table 8

Geotechnical characteristics of class GM soils

γ_d (KN/m³)	γ_h (KN/m³)	ω (%)	ω_l (%)	ω_p (%)	I_p (%)	σ_c (bar)	C_c
			28	16	12	/	/
C_g	ϕ (°)	C (bar)	q_{adm} (bar)	Soil compaction and compressibility			
/	28-32	0.19-0.31	2.41-2.55	Soil with negligible compaction			

Mud of class OH (Organic soil of hight plasticity) is black in color; it contains more than 93% fine particles (sand, silt, clay and organic colloids) under 0.20 mm, with a plasticity index of 30.34% and a degree of saturation of 89%. It is located in the center of the town, in the neighborhood of *Abid Djellou*, in the northern small woods, next to the National Road *RN 2* and *Gallant* farm, adjoining the railway station.

Basalt rocks (Table 9) have an average density of 24.70 KN/m³ and an average uniaxial compressive strength of 63 MPa; the average propagation speed of ultrasonic waves through this rock is 4923 m/s. According to the recommendations of the French Tunneling and Underground Space Association (AFTES) - Description of rocky massifs used in the study of stability - Tunnels and Underground Structures, Supplement No. 117, 223 p (1993), these basalt rocks belong to class R2 (high strength) [17].

This rocky massif is located in the northern part, in the center of the Town (National Insurance Fund), in the neighborhood of *Sidi Said* (Court of Justice) and in the south-west part of the Town (Islamic Cultural Center).

Table 9

Characteristics of basalt rocks

γ (KN/m³)	R_c (Mpa)	V (m/s)
23.3 - 26.1	59 – 67	4774 – 5071

The limestone turf layers (Table 10) are generally beige to whitish, sometimes sandy or clayey, with calcareous nodules and a thickness between 1.50 m and 8.00 m; they have a dry density equal to 14.3 KN/m³, water content of 24.90% and a degree of saturation of 76%. They are found in the neighborhood of *Hai Zitoune* (Wilaya Headquarters, APW Headquarters, and Health Center) and in the neighborhood of *Hai Moulay Mustapha* (AADL villas, semi-olympic swimming pool, Security Department of the Wilaya).

Table 10

Characteristics of limestone turf

γ_d (KN/m³)	γ_h KN/m³)	ω (%)	S_r (%)
14.30	17.86	24.90	76

The spatial distribution of each of the geotechnical classes is illustrated on the map of Figure 7.

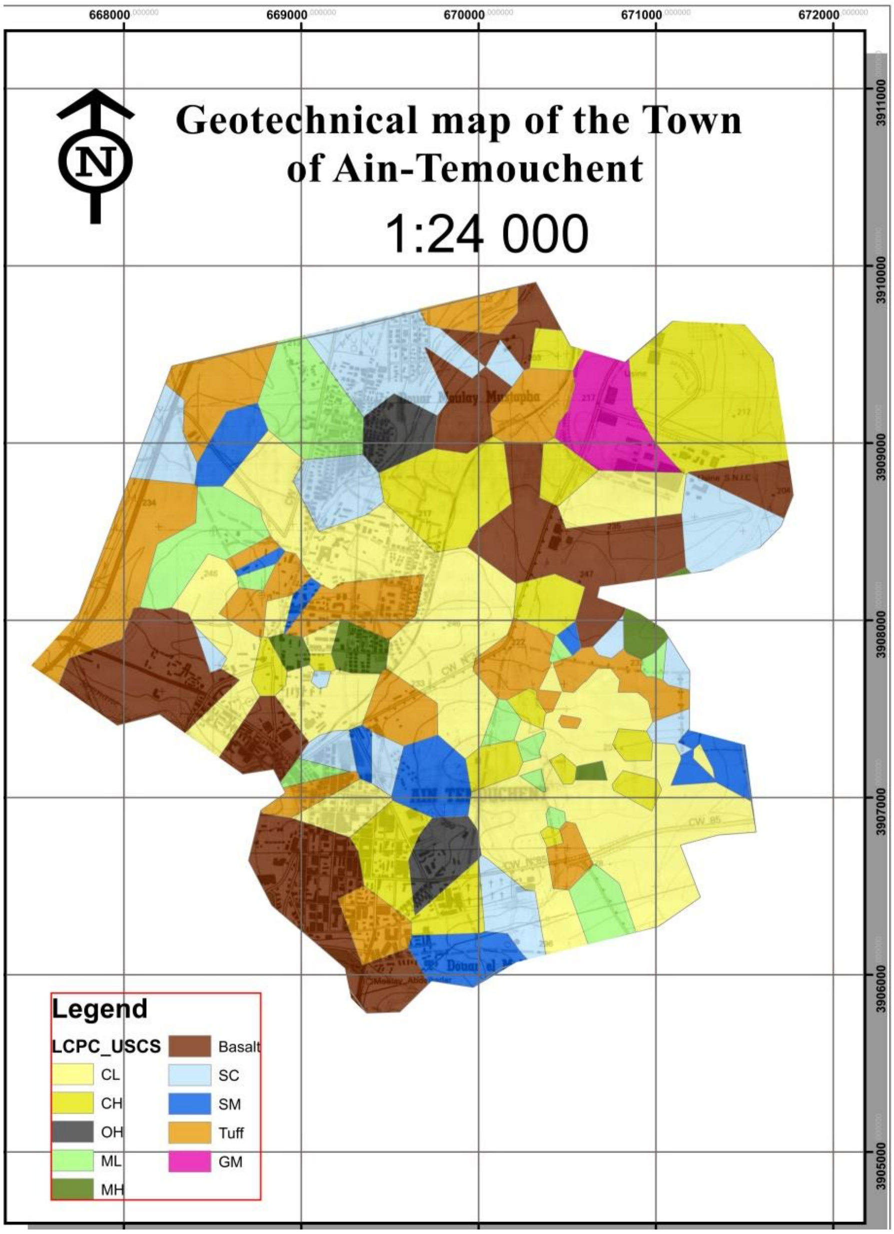

Fig.7 - Geotechnical map of the Town of Ain-Temouchent

5. Conclusion

From the geotechnical point of view, the soils of the Town of Ain-Temouchent are distributed over 10 different classes; eight (08) of them according to the LCPC-USCS classification, namely class CH (High plasticity clay), CL (Low plasticity clay), MH (High plasticity silt), ML (Low plasticity silt), SC (clayey sand), SM (Silty sand), GM (Silty gravel with sand), OH (organic soil of high plasticity). The other two classes are rocky soils: basalts (hard volcanic rock with high resistance), and limestone turf (sedimentary rock).

The compressibility index C_c shows that theses soils contain kaolinite clays [18].

The rocky soils (basalts and limestone turf) as well as soils of classes GM and SM are practically stable and provide a good support for the foundations of the different structures. Soils of classes SC, ML, MH, CL and CH are also good bases for foundations, but are vulnerable to erosion, compaction and swelling.

Class CH and CL soils form impermeable aquifer substrates. These sites can be used to set Up technical landfill sites. They are also valuable clay deposits for the manufacture of building materials (bricks and ceramics). Soils of class OH, which are in the form of layers of thickness varying between 8.00 m and 12.00 m, rest on a layer of fine to very fine sand. These soils are unfavorable subsoils for construction foundations and are very vulnerable to liquefaction.

The geotechnical map is a necessary but not sufficient document for geotechnical studies. Moreover, a detailed study of soils with an assessment of alteration degree of the different parts of the rocky massif is inevitable [19]. The knowledge of internal friction and cohesion angles, as well as the characteristics of soil density as a function of water content, is mandatory for the calculation of allowable stresses, because there are no universal rules for the design of foundations from the dynamic resistance R_d. Only an order of magnitude of the bearing capacity can be deduced based on correlations with other parameters deduced from *in situ* static *penetrometer* or *pressurmeter tests* [20].

Symbology:

C : Cohesion.
C_C : Coefficient of compression.
Cg : Coefficient of swelling.
E: Void index.
Ip: Plasticity index.
q_{adm}: Allowable pressure.
R_c : Compression resistance.
R_d: Dynamic resistance.
S_r : Degree of saturation.
V : Sound velocity.
W : Water content.
Wp : Plasticity limit.
Wl : Liquidity limit.
σ_c : Pre-consolidation pressure.
φ : Internal angle of friction.
γ : Unit weight.
γ_d : Dry unit weight.
γ_h : Wet unit weight.

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