USE OF GIS SYSTEMS TO ANALYZE SOIL COMPRESSIBILITY, SWELLING AND BEARING CAPACITY UNDER SUPERFICIAL FOUNDATIONS IN ALGIERS REGION, ALGERIA

Fatiha DEBICHE
PhD student, Civil Engineering Department, Ecole Nationale Polytechnique, Algiers, Algeria, e-mail: fatiha.debiche@g.enp.edu.dz

Ratiba MITICHE KETTAB
PhD, Professor, Civil Engineering Department, Ecole Nationale Polytechnique, Algiers, Algeria, e-mail: ratiba.kettab@g.enp.edu.dz

Mohammed Amin BENBOURAS
PhD student, Civil Engineering Department, University of Abbes Laghrour, Khenchla, Algeria, e-mail: mouhamed_amine.benbouras@g.enp.edu.dz

Bilal BENBELLIL
PhD student, Civil Engineering Department, Ecole Nationale Polytechnique, Algiers, Algeria, e-mail: bilal.benbellil@g.enp.edu.dz

Lynda DJERBAL
PhD, Habil., Faculty of Civil Engineering, University of Science and Technology Houari Boumediene, Algiers, Algeria, e-mail: ldjerbal@usthb.dz

Alexandru-Ionut PETRISOR
PhD, PhD, Habil., Associate Professor, Doctoral School of Urban Planning, "Ion Mincu" University of Architecture and Urban Planning, Bucharest, Romania, e-mail: alexandru.petrisor@uauim.ro

Abstract. Nowadays, information about geotechnical parameters and future stability of soil is highly demanded by geotechnical laboratories and companies. The use of geotechnical information systems integrated in a GIS offers a better manipulation of the geotechnical parameters of different sites for a general exploitation of storage, manipulation, management and analysis of geotechnical data. The aim of the current research is to present the results of studies developed to set up a geotechnical database for Algiers region using «Géo-Base» information system developed within the framework of this research and integrated in a GIS through a descriptive statistical analysis of mechanical and geophysical identification parameters of velocity measurements collected from 1200 survey profiles located on 80% of the surface of the region. The visualization of geotechnical maps of bearing, consolidation, settlement, swelling of soils at any depth of Algiers region are obtained by manipulating the system technology produced as part of this research. These results are very helpful to builders, planners, researchers and engineers in their future work; they will help them making better decisions and producing safer and more economical designs. Furthermore, this research allows establishing the first geotechnical map of Algiers region.

Key words: geotechnical information system, geographical information systems, geotechnical maps, consolidation, bearing capacity.

1. Introduction

In recent years, Algiers has witnessed a rapid urbanization, which can be explained as the process that involves the growth of the population of a nation living in cities (Boughedir, 2015). Urban expansion is a very important topic, which becomes a major problem facing the state (Petrişor, 2012; Hamma and Petrişor, 2018), not only in the management of sustainable development but also in the fields of remote sensing and geographic information systems (GIS). Today, planning and decision-making methods are used to make the engineering process easier and more cost-effective, with new development and advanced geospatial technologies (Arnous, 2013; Malczewski, 2006). A critical view of the classical geotechnical reconnaissance system is revealed, in which it allows progressively to conduct a general study to identify geotechnical parameters that characterize the sites, and to predict various potential risks, summarizing all the obtained results in a cost and detailed geotechnical report, which contains a very large and rich amount of information. Unfortunately, this wealth is either stored in a laboratory or in an archive center, with the difficulty of benefiting from it in the future. In this regard, the creation of a system that could provide the means to efficiently store, analyze and update this wealth, and then produce other forms of information such as maps and tables, could speed up the process of decision making and design. These types of systems will be useful for engineers and planners in the industry and spatial planning, considering their important scientific, technical and economic interest.

The management of geotechnical data of different sites is done through the consultation of the geotechnical reports of each construction project. In order to compile the mass of geotechnical information, which is very important and very expensive, geotechnical researchers were interested in the development of analysis tools: firstly by storing information from coring surveys, benefiting from the rapid development of information systems. All geotechnical and geophysical parameters have been subject to numerous works around the world (Debiche, 2003). A brief review of these works is given below.

- In 1976, the UNESCO commissioned a working group of the International Association of Engineering Geology (AIGI) to develop this aspect of cartography and draft a guide for the preparation of geotechnical maps (Kaniche *et al.*, 2000).
- In 1990, the "MODELISOL" database has been collected as a result of a project developed in 1988 at the Central School of Paris with subsidies from the Ministries and the Geological and Mining Research office (BRGM) (Favre *et al.*, 1990).
- In 2006, the Trièves database, which consisted of collecting and organizing existing geological, geotechnical, geodetic and geophysical data on a geographic information system, for the sake of presenting and referencing all

collected data (Petrişor, 2016) in a Geographic Information System (GIS), has been developed. For this purpose, the data set has been classified into thematic tables in order to be managed under GIS carrying out thematic analyses visualized in maps format (Kanungo *et al.*, 2012).

- In 2008, Geotechnical data from in-situ observations and geotechnical surveys was managed by GIS in Athens (Greece). The HelGeoRDaS (Hellenic Geotechnical Relational Database management system) was used to illustrate the distribution of engineering geological characteristics in GIS produced thematic maps and to create a geological map of Athens (Antoniou *et al.*, 2008).
- In 2010, the automatic mapping of soil classes on regional scale using a digital model of land or surface has been proposed. For this purpose, a database of direct or indirect measurements of mean shear wave velocities in the first 30 meters of soil was established for the metropolitan area. These data were then used to establish correlations between a morphometric parameter (slope, openness) and soil classes that will be soon regulated in France (soil classes of Euro code 8). In a second step, routines were developed to automatically perform a mapping of soil classes according to the estimated average velocity of the first 30 meters of soil (Vs, 30) (Kanungo et al., 2012).
- In 2016, Roulle *et al* collected a database of direct or indirect measurements of mean shear wave velocities in the first 30 meters of soil. A new geotechnical zoning map for the basement of Mexico Valley afterward was presented. Geostatistical techniques were also used to assess the spatial distribution of the clay lacustrine deposits' thickness in the area until called deep deposits. As a result, a contour map was used to update the current geotechnical one. A zoning map for Mexico Valley was proposed to include this new map in the Building Code for the Federal District (Juarez-Camarena *et al.*, 2016).
- In 2018, Lillouch *et al.*, (2018) proposed a method based on the exploitation of the geological formation of Bejaia region via the GIS. They classified areas of low to high seismicity by using a topographic map on the scale of the 1/25000, a geological map on the scale of the 1/50000 and geotechnical soil reports. Based on this method, a series of maps, which summarized soil parameters, have been carried out.
- Many others studies have successfully used the GIS technologies to analyze geotechnical and geological parameters: McBratney *et al.*, 2003; Chang and Park, 2004; Kunapo *et al.*, 2005; McCarthy and Graniero, 2006; Augusto *et al.*, 2010; Youssef *et al.*, 2011; Todo *et al.*, 2013; Eljamassi, 2013; Boştenaru Dan *et al.*, 2014; Papatheodoroua *et al.*, 2014; Sun and Kim, 2017; Razmyar and Eslami, 2017; Dodagoudar, 2018

In order to facilitate and optimize the geotechnical identification within the Algiers region, we have attempted to develop a Geotechnical Information System, which manages a geotechnical database of 1,200 surveys with 800 samples taken at different depths. The present work contributes to establishing geotechnical maps of bearings, settlements, swellings and consolidation of Algiers soils. This research constitutes premises to create the first geotechnical mapping of Algiers. The resulting maps can constitute a good tool assisting builders, planners, researchers and engineers in the future works of the capital Algiers.

2. Materials and basic characteristics

2.1. Studied area

2.1.1. Algiers geography

Algiers is situated on the Mediterranean Sea and in the north-central part of Algeria, on the latitude 36.4635° north, longitude 3.0331° to the east of Greenwich line (Benbouras *et al.*, 2017, 2018), characterized by wild and excellent maritime location. The city's population was estimated to be around 3,500,000 in 2011 (Ameraoui *et al., 2017*).

2.1.2. Algiers Geology

The lithological ensemble of the Algiers region can be reduced to two main units. The upper unit consists of the predominant quaternary sediments of a cohesive character. This layer contains a large amount of scree formed by a sedimentary filling. The next unit consists of clastic sediments of sandy to clayey type of great heterogeneity, grouped under the term molasses. The deepest unit in the region of Algiers is clay loams of low to medium consistency. The marls are largely impermeable and thus form along their surface. The level of continuous aquifer is situated in the sandy sediments of Molasses, which is partially characterized by good permeability (Derriche *et al.*, 2004; Harbi *et al.*, 2007). A representative profile of the geological formation is displayed in Fig. 1.

2.2. Soil consolidation

Soil consolidation is one of the most important phenomena in civil engineering (Ilieş, 2016). An intact sample is analyzed using the oedometric test to determine the soil consolidation properties, which are generally described using: the compressibility coefficient C_c, the swelling coefficient C_s and the coefficient of consolidation C_v (Benbouras *et al.*, 2018). These coefficients are used to predict how the settlement and swelling will be held. It is generally determined by means of the graphical analysis of the oedometric curves of void ratio as a function of the logarithm of effective stresses (e-log (σ)) (see Fig. 2) (Niemunis and Krieg, 1996; Kurnaz *et al.*, 2016). Table 1 indicates the evaluation scale of the swelling and compressibility depending on the swelling index (C_s) and the compressibility index (C_c) according to the French Design Standards.

2.3. Ultimate bearing capacity

In geotechnical engineering, the bearing capacity is defined as the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil, which should not produce shear failure in the soil. However, the ultimate bearing capacity is the theoretical maximum pressure which can be supported without failure. Studies provided a varied number of estimations for ultimate-bearing capacity, Nevertheless, the following formula, derived from laboratory tests (Meyerhof, 1951), remained the best one until today.

$$\sigma_{adm} = \gamma D + \frac{0,5.B.\gamma.N_{\gamma} + \gamma.D\left(N_q - 1\right) + C.N_C}{F}$$

where:

- $N_c; N_q; N\gamma$: are dimensionless parameters depending on the friction angle.
- B: foundation width.
- D: anchorage depth.
- F: Safety factor (generally F=3)
- σ_{adm} : Ultimate bearing capacity
- γ: Wet density of soil.

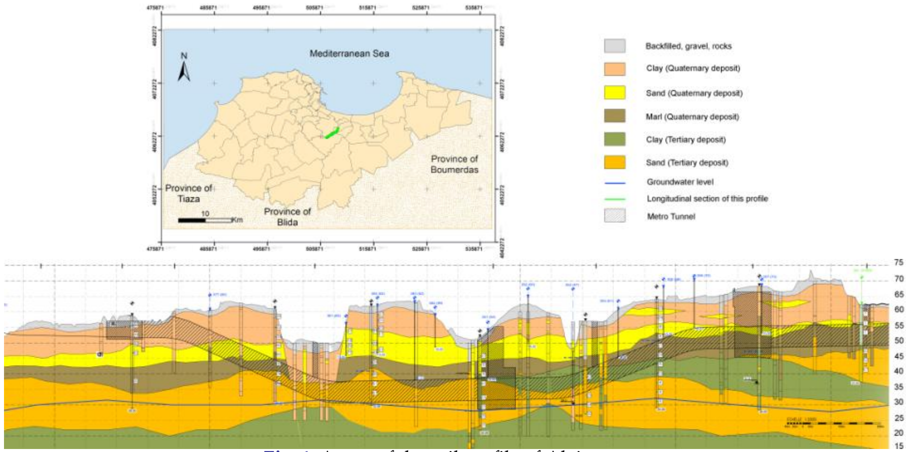

Fig. 1. A part of the soil profile of Algiers area.

Table 1. The evaluation scale of the swelling and compressibility factor (Costet et al., 1981; Jiang *et al.*, 2015).

Factor	*Parameter*	*Attribute*	*Relative value*
Swelling	Swelling index C_s	$C_s > 0.025$ $0.025 < C_s < 0.035$ $0.035 < C_s < 0.055$ $0.055 < C_s$	Low swelling Moderate swelling Swelling Strong swelling
Compressibility	Compressibility index C_c	$C_c > 0{,}035$ $0{,}035 < C_c < 0{,}05$ $0{,}05 < C_c < 0{,}1$ $0{,}1 < C_c < 0{,}2$ $0{,}2 < C_c < 0{,}3$ $0{,}3 < C_c < 0{,}5$ $0{,}5 < C_c$	Incompressible Very little compressible Little compressible Moderately compressible Quite strongly compressible Very compressible Extremely compressible

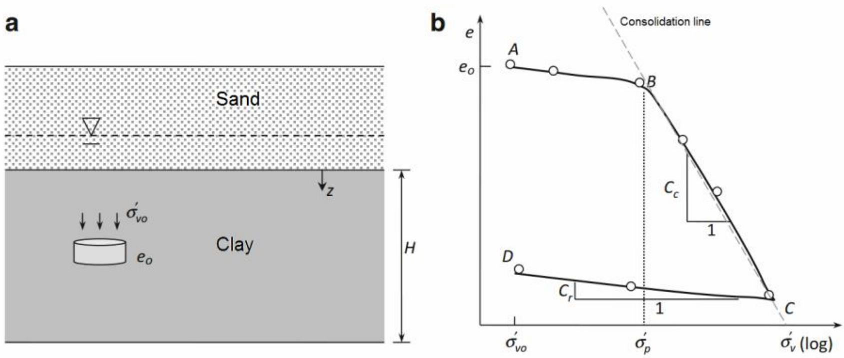

Fig. 2. Consolidation: (a) Soil profile, and (b) oedometric curves e (log (σ ')).

2.4. Geotechnical information system "Géo-Base"

Once the data was collected, the data processing (extraction, tabulation and sorting of the data) began. In order to take advantage of thousands of geotechnical, geophysical and geological data properly, while ensuring the easiest use of the database as a workable and easy to process tool by GIS, the geotechnical information system Géo-Base was successfully used in the current study. This system was created in 2003 as part of a Master thesis research at the National Polytechnic School of Algiers (Debiche, 2003). The conceptual model was developed using the Merise method, which proposes an information system design approach separating the study of the data from that of the treatment, gradually progressing by levels. Each level aims to provide a number of documents that allow the textual synthesis of a reflection process. The physical model of "Géo-Base" is developed using the visual basic language to generate the objects in the tables (Debiche, 2003). The visualization of the software is made possible using a simple and practical interface. Fig. 3 presents an example of the physical model window of "Géo-Base" which contains all information about Oedometer tests, such as Project no., sample no., device no., and all information and conditions of the test progress. For any additional information for the conceptual model such as tables, data dictionary, object relationship, object information, and physical model, readers are advised to consult directly the referred thesis (Debiche, 2003).

2.5. Research methodology and scheme

The research methodology is divided into three main steps summarized in Fig. 4, which take a form of flowchart, consisting of the following subheadings.

2.5.1. Data preparation

The geotechnical database used in the research is made from projects carried out since 2003, consisting of 150 geotechnical reports that gather:

- 1180 coring surveys from 10 to 100 meters deep.
- 878 oedometric tests
- 297 Casagrande box shear tests
- 878 identification tests (density, water content, saturation levels, plasticity and liquidity limits measurements)

The initial work consisted of synthesizing all the recognition campaigns and placing them on the geological map of the Algiers region, and finally of producing tables for all the geotechnical parameters for their input into the "Géo-Base" system. Fig. 5 shows the locations of the boreholes collected for the present study.

2.5.2. Data Export

From the information generated using the dictionary data, the Microsoft Access software has been used to create the tables. The next step of the methodology, as revealed in Fig. 4, is to store the parameters in the geotechnical information system "Géo-Base" which exports them in a relational database (for more information see Debiche, 2003). These steps were:

- Transformation of hardcopy data into digital versions
- Organization of the data in the Géo-Base system and export to GIS using ArcGIS software tools. The resulting data became easy to manipulate for the forthcoming steps.

Fig. 3. Physical model of Géo-Base "Oedometer test window".

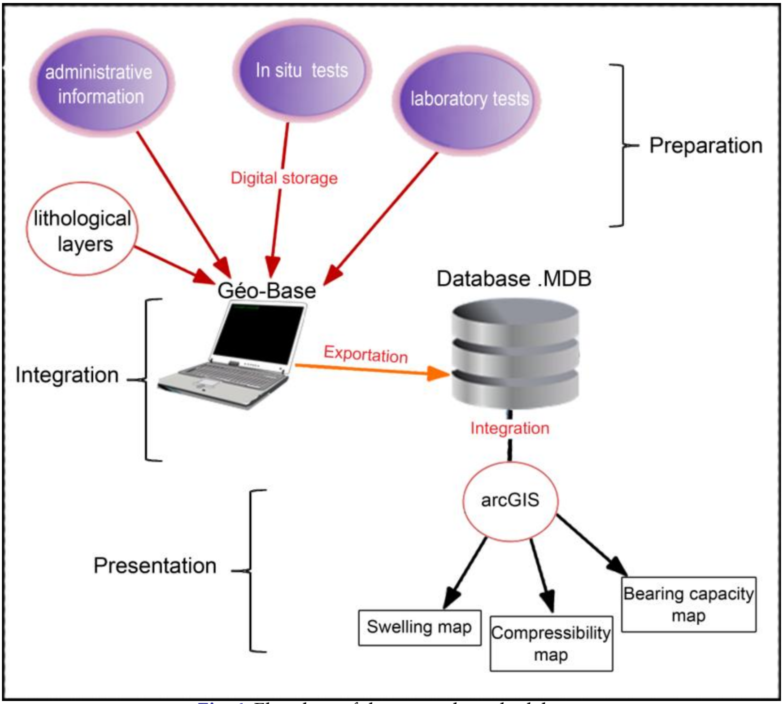

Fig. 4. Flowchart of the research methodology.

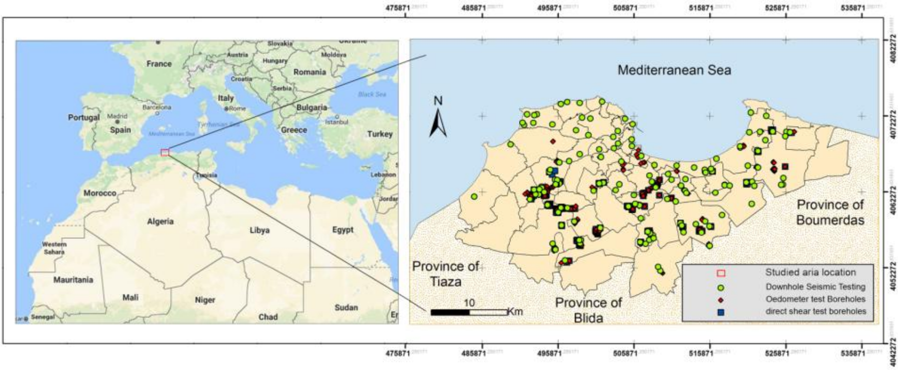

Fig. 5. Different geotechnical and geophysical boreholes location in Algiers area.

2.5.3. Presentation of geotechnical maps

The third phase of our work concerned the establishment of the following geotechnical maps by analyzing the geotechnical data integrated in GIS software:

- Bearing capacity
- Compressibility
- Swelling

3. Result and Discussion

3.1. Descriptive statistics

After the introduction of the geotechnical data of 150 projects in the "Géo-Base" information system, a descriptive statistical analysis was carried out on all the geotechnical parameters used for the computation of surface foundations, bearing, settlement and swelling. Table 2 shows the descriptive statistics of collected samples (mean, median, mode, standard deviation, variance, skewness, error of skewness, kurtosis, error of kurtosis, range, minimum and maximum values). The skewness values show that all variables are regularly distributed. Furthermore, the results show that the database comprises a wide range of data. Subsequently, this database can be successfully used in geotechnical identification maps. Algiers soil can be characterized as a dense soil with an average wet density of 2.007 according to the French norms XP 94-011 European norms. Moreover, the soil appears to be a moderately compressible soil with C_c equal to 0.167. Last but not least, in the classification based on swelling, according to the French norms XP 94-090-1, Algiers area could be classified as a swelling soil, with C_s equal to 0.046. This descriptive analysis was used in this research for the establishment of the geotechnical cartography of settlements, bearing and swelling .

3.2. Mapping of compressibility and swelling of Algiers soil

The cartography of the swelling and compressibility of Algiers region is very useful for the choice of sites by the engineering offices. The distribution of the maximum compressibility index has been presented in Fig. 6, which indicates the areas where the layers are prone to compressibility risks. It is noticed that the "moderately compressible" class is represented in most of the study area, with an average of 76% of the total area of the study area; the other classes (incompressible and very compressible) are almost negligible.

Table 2. Descriptive statistics for collected samples.

		γ_h	Cu	φ	σ_p(h=2)	σ_p(h=3)	σ_p(h=4)	σ_p(h=5)	Cc	Cs	σ_c	Vs
N	Valid	878	297	297	57	98	77	65	878	878	878	292
	Missing	0	0	0	240	199	220	232	0	0	0	0
Mean		2.0073	0.4330	11.3473	2.0634	2.6467	2.5947	3.5943	0.1670	0.0428	2.0900	321.1692
Median		2.0000	0.4200	10.0000	1.9102	2.2476	2.3320	2.7493	0.1720	0.0381	1.7900	307.5952
Mode		1.95	0.44	9.00	1.18[a]	1.23	2.80	1.55[a]	0.19	0.04	1.68	279.04
Std. Deviation		.09380	.16579	5.24089	.70801	1.27494	.90885	2.82930	.05251	.02198	.90633	94.82699
Variance		.009	.027	27.467	.501	1.625	.826	8.005	.003	.000	.821	8992.157
Skewness		-.108	.852	1.278	1.628	2.059	2.257	3.845	.072	1.063	1.648	1.465
Std. Error of Skewness		.083	.141	.141	.316	.244	.274	.297	.083	.083	.083	.143
Kurtosis		.529	1.053	2.079	2.600	4.230	6.013	17.714	1.655	1.966	3.705	5.387
Std. Error of Kurtosis		.165	.282	.282	.623	.483	.541	.586	.165	.165	.165	.284
Range		.65	.93	33.69	3.01	6.14	4.83	18.07	.45	.17	6.96	787.95
Minimum		1.65	0.05	0.86	1.18	1.23	1.39	1.55	0.01	0.00	0.24	112.05
Maximum		2.30	0.98	34.55	4.19	7.37	6.22	19.62	0.46	0.17	7.20	900.00

On the other hand, some highly compressible zones were detected in the lower region. These results explain that most of the lands in the study area are relatively not exposed to the risk of compressibility. The same method was used for analyzing the maximum swelling index, presented in Figure 7. Areas containing layers prone to swelling risk can be distinguished according to the evaluation scale. The results show that most sites in the study area are exposed to the swelling risk.

3.3. Mapping of ultimate bearing capacity of Algiers soil

The bearing capacity of the soil is the most important and required design parameter; it plays an important role in engineering decision-making, either in progress or after construction. Fig. 8 to Fig. 11 present the ultimate bearing capacity maps, in the different depths of the Algiers area, calculated by laboratory tests. This type of analysis provides engineers and planners the initial prediction of the bearing capacity supporting most of the loads (of structure and equipment), and their depth, for safely designing the foundations.

4. Conclusions

The current research presents a scientific contribution to the geotechnical engineering study of superficial foundations, to help builders, planners, researchers and engineers in decision-making for future building works in the capital Algiers. In order to achieve the objective of our research, a geotechnical database of 1200 boring surveys was collected and organized in the "Géo-Base" information system, integrated later into the GIS software in order to visualize the geotechnical maps. The results drawn from this research are summarized in the following:

- The use of the "Géo-Base" information system developed in this study allows for gathering all the information extracted from geotechnical studies, in a very flexible manner for the manipulation and management of information, storing and generating all the results of the tests in the normative context. The integration of the "Géo-Base" using GIS software allows for the presentation of information in the form of geotechnical maps, which are tools of practical help for the computations of foundations with an optimized recognition.

- The results presented in the maps indicate the presence of highly compressible zones in the lower region due to the presence of under-consolidated soils with a bearing capacity of around 1 bar. The areas of medium compressibility generally present a bearing of approximately 200, 300 and 400 kPa, which are very favorable to future projects. Furthermore, some areas of swelling occur on the heights in consolidated soils composed by marly formations.
- This research constitutes a working platform to develop different themes (stability, swelling, seismic risk) used in the geotechnical engineering studies of Algiers region.

For future works, the use of "Géo-Base" by laboratories in other regions can assist in the establishment of local geotechnical maps that will be supplemented with survey works in order to refine the results of mapping for the purpose of wider use in engineering offices, geotechnical laboratories and local administrations.

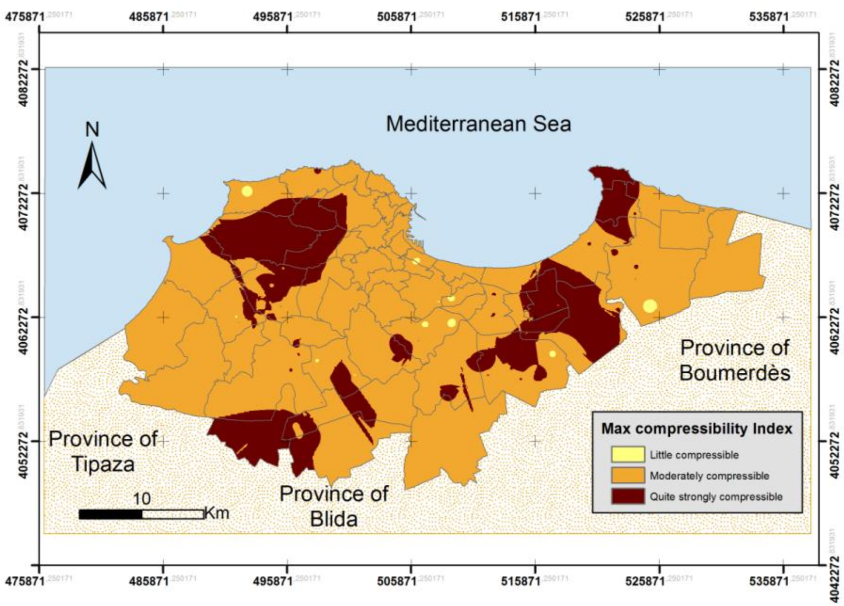

Fig. 6. Max compressibility map of Algiers area.

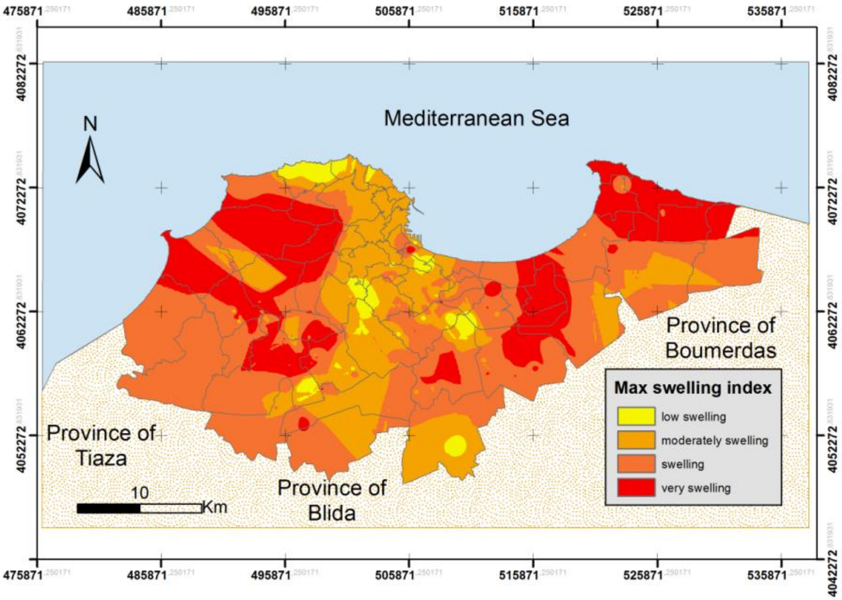

Fig. 7. Max swelling map of Algiers area.

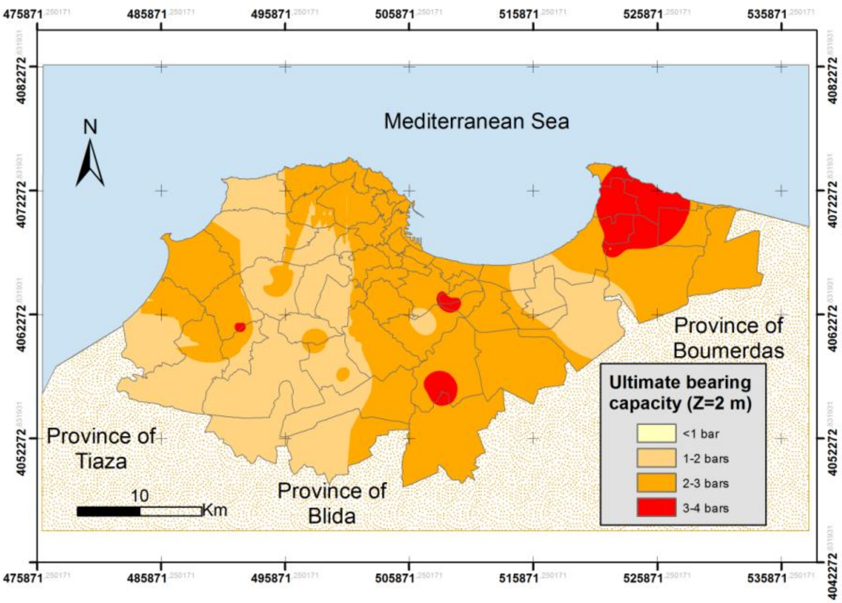

Fig. 8. Ultimate bearing capacity map of Algiers soil (Z=2m).

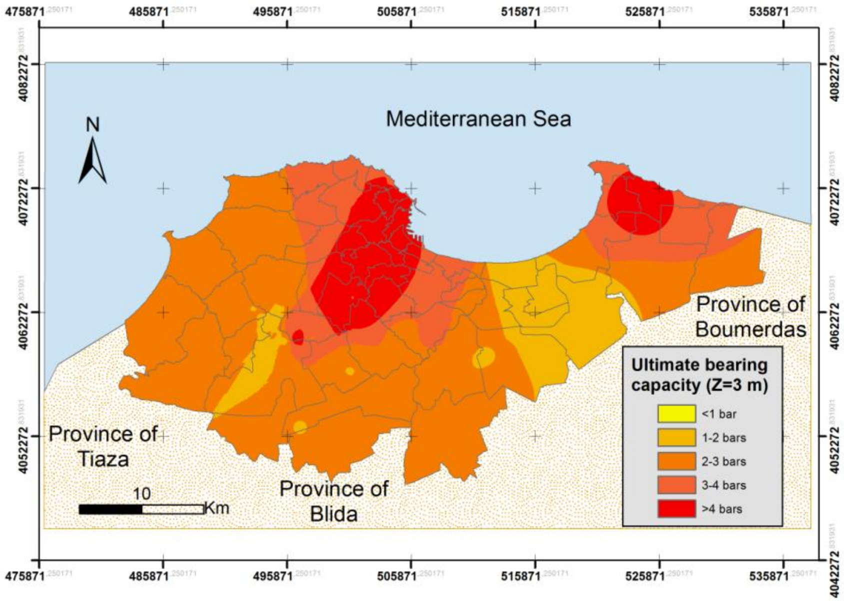

Fig. 9. Ultimate bearing capacity map of Algiers soil (Z=3m).

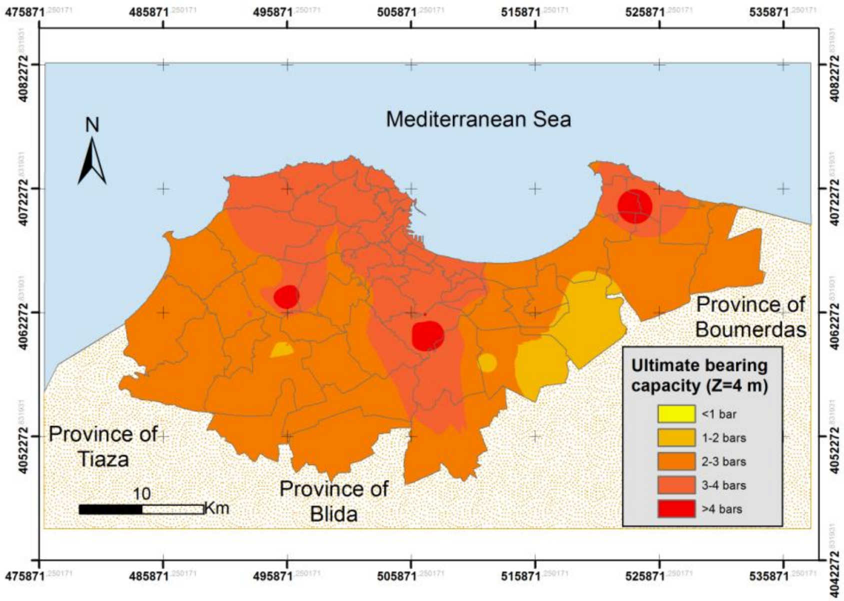

Fig. 10. Ultimate bearing capacity map of Algiers soil (Z=4m).

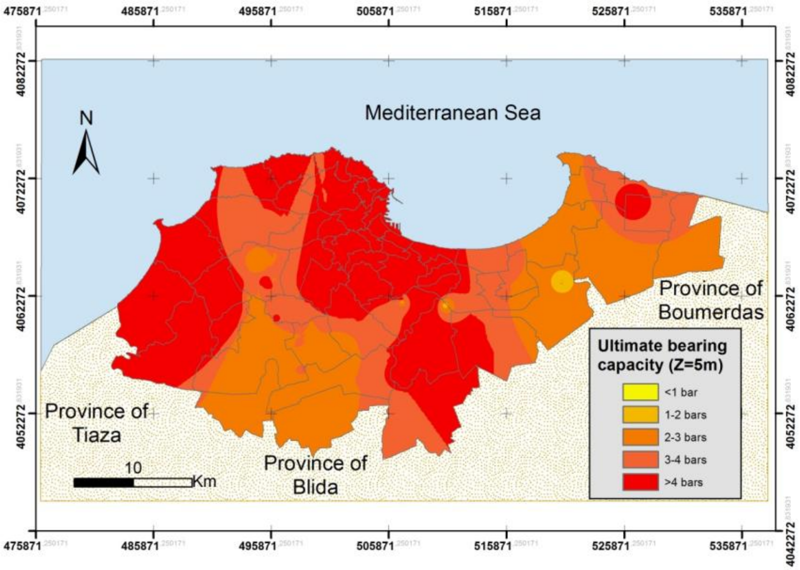

Fig. 11. Ultimate bearing capacity map of Algiers soil (Z=5m).

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