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Climate change and its influence on shrinkage–swelling clays susceptibility in a semi-arid zone: a case study of Souk Ahras municipality, NE-Algeria

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ABSTRACT

Dry summers and irregular rainfall have been affecting our daily life in the last decades. These climatic changes influence the susceptibility of shrinking and swelling phenomenon of clay and marl formations. Clay soils are found in many areas in north Algeria, but they are more common in the sub-arid highlands belt. By combining intrinsic factors that influence shrink–swell behavior as well as the climatic data, a susceptibility map has been established for Souk Ahras municipality. This map shows sensitive areas, which are going to become the future extension territories, toward shrink and swell phenomenon. The adopted methodology begins with the establishment of a synoptic map of clay and marl formations. This procedure allowed the identification of 17 argillaceous formations. Then, they were subjected to a hierarchy in terms of their susceptibility to the phenomenon. The classification was established by a combination of lithological, mineralogical, and geotechnical criteria. The use of GIS technology has permitted the combination of several predisposing and trigging factors such as the annual average rainfall, the evapotranspiration, the land use, and the orography. The result of the adopted approach was a shrink–swell susceptibility map, which can be used as a regulatory tool in land use and planning procedures.

Keywords: Shrinkage–swelling; Susceptibility; Clay; Souk Ahras municipality; Climate changes; GIS

1. Introduction

The shrinkage and swelling are mainly caused by the volume variations of argillaceous formations as a result of the changes in water content. These volumes change result in differential movement of soil, which may cause distress in buildings and infrastructure facilities. The shrinkage–swelling phenomenon is triggered as a result of moisture sensitive clay minerals

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belonging to the Smectite group and with less extent to the vermiculite group and interstratified minerals like swelling chlorite type C–V (chlorite–vermiculite) or V–Cs (vermiculite swelling chlorite) [1]. The shrink–swell susceptibility over a given area is defined as the spatial distribution of the controlling conditions, the predisposition conditions on one hand and the triggering factors, that is, moisture changes, on the other. The poor mechanical properties of the soil in the Souk Ahras municipality cause considerable damage recorded in the roads (Fig. 1), water supply network, and dwellings (Fig. 2) [2].

These damages are related to changes in clay and marl formations volume in relation with the presence of water from the basement to the first three meters of soil. They shrink, when they dry out in summer (Fig. 3) and swell when saturated during winter. This differential movement sometimes causes considerable damage to facilities [3]. Shrink–swell behavior of the soils is not taken into account in geotechnical investigations practices for local land use project (POS) [4] despite the large damages, caused by this phenomenon. The purpose of this study is to propose a regulatory tool to assist decision-makers for urban planning and development. For this purpose, a shrinkage–swelling susceptibility map is elaborated for Souk Ahras municipality.

Shrinkage–swelling of natural susceptible soils is mainly related to the variations in the water content and the type of clay minerals contained in the formation. Factors, such as soil structure, density, water content … can significantly affect the phenomenon intensity. The characterization of the sensitivity of clayey soils to shrinkage and swelling parameters is determined; such as the size of the constituents, shaliness, the nature of the clay minerals, carbonates content, soil microstructure, plastic properties, moisture content, and density.

Fig. 1. Cracking of the NR 82 roadway as a result of the argillaceous substratum.

Fig. 2. Cracking of constructions in the study area.

Fig. 3. The desiccation of the study area clays during the dry period.

The causal factors of the phenomenon can be divided on predisposing and triggers factors. Among the predisposing factors, the nature of the first 10 meters of soil or bed rock is the most important influent factor. This work is mainly based on the exploitation of the geological map of the study area, the mapping of the clay, and marl outcrops. The vegetation cover is usually taken into account in the assessment. Unfortunately, the forests in the study area are in a bad state. Due to fires, we recorded significant annual losses in the forestry area.

The geomorphological factors have been taken into account in the mapping process. Water content changes between the downstream and upstream parts of a slope. The main triggering factors are those related to climatic phenomenon, they are precipitation, temperature, and evapotranspiration. As a result of climate change, rainfall deficit has reached maximum values during period of draughts of 1993–1994, 2000–2001, 2005–2006, and 2007–2008. The influence of the climate has been considered in the modeling using two factors (precipitation and evapo-transpiration distribution).

2. General setting

Souk Ahras municipality is located in the east-central part of Souk Ahras province; it occupies a total area of 81.2 km^2; it has a northwest-southeast elongated hexagonal shape. The location of its downtown is 36°17´15´´ latitude and 07°57´15´´ longitude (Fig. 4). The study area has a population of 180,572 inhabitants (in June 2012) with an annual growth rate of 2.9% and a density of population 222 hab/km^2 spread over 28,745 households in 14 neighborhoods. Souk Ahras is characterized by a semi-humid climate with a hot summer and cold, wet winter; precipitation average is around 760 mm/year.

The study area is located in a trough surrounded by woody mountains and crossed by Medjerda Wady. Souk Ahras region is dominantly formed by sedimentary rocks, from the evaporitic Trias to the Tertiary marl and carbonaceous formation, finally the upper Quaternary deposit. A range of lithological formations can be encountered: limestone, clays, marls, sandstones, gravels, and alluvium [5] (Fig 5). Tectonically, the study area is cut by three sets of discontinuities, where two major faults (NE–SW and NW–SE) cut through the municipality. The analysis of climatological measurements over 30 years obtained from the

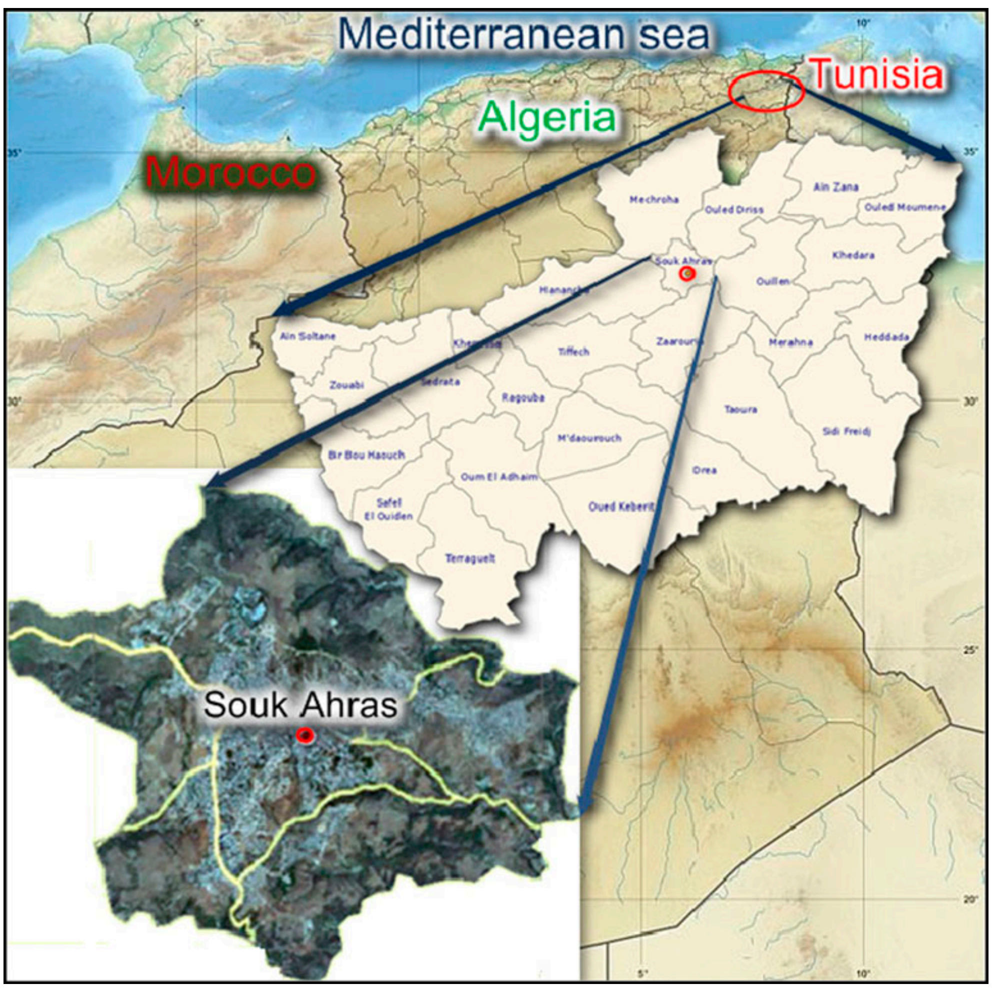

Fig. 4. Geographical location of the study area.

meteorological station (ONM 90) of Souk Ahras ($x = 972.3$, $y = 344.5$, north Algeria kilometric coordinates, $z = 655$ m) has allowed the representation of local precipitation repartition in a contour line map (Fig. 6).

The water balance over three decades of observation (1980–2010) (Table 1) shows the extent of the draught that lasts several years, we can note; the precipitation levels reaching their maximum on January (131.3 mm) where the ETP reaches its minimum (16.91 mm). The ETP reaches its maximum in July (160.90 mm), where precipitations are at their minimum (6.94 mm). Soil moisture deficit coincides with the dry season of the year and extends from May to November where we note a significant depletion of the hydric reserves. The recharge of groundwater starts from the month of November to May; the soil become saturated in December, January, February, March, and April, and demands for irrigation are satisfied.

3. Materials and methods

GIS technologies can provide an ideal platform for the integration of the various dataset, their analysis, their combination, and their mapping along a study area. It permits the modeling of several layers of information related to lithology, mineralogy, geotechnic, and environment. They are used to define a mathematical model, which leads to the production of the susceptibility map according to specific criteria [6].

The collection of datasets from the previous studies, internal reports, sinister survey folders, *in situ* and laboratory tests and measurements, satellite imagery, DTM, geologic maps, pluviometric data … allows the editing of the study project database using (*Arcgis 9.1*®) GIS software. The adopted method permits the valorization of a large amount of data collected along four years of fieldwork. The flowchart of the methodology which applied in susceptibility mapping is shown in Fig. 7.

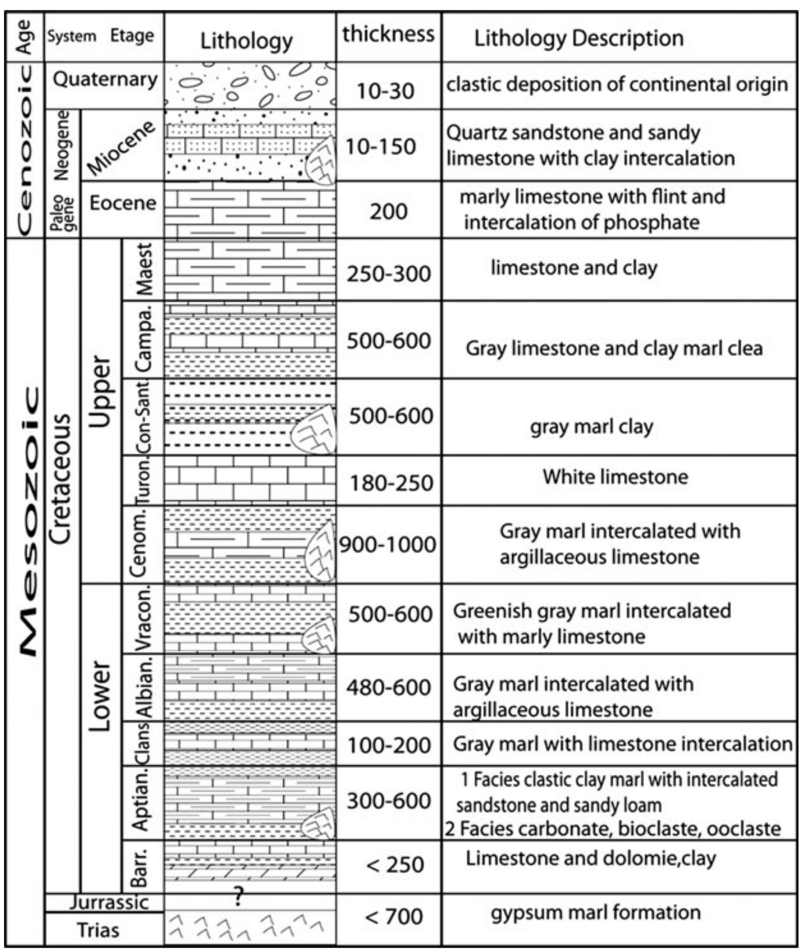

Fig. 5. Stratigraphic column of the Mellegue Mountains (David [5]).

The adopted methodology has been developed by the French Bureau of geological and mining research (BRGM), from research expanded gradually by several authors [7–11]. This method has been validated by the French Ministry of Ecology, Sustainable Development and Energy. According to the geological map, this qualitative approach depends on the establishment of a synthetic map of argillaceous and marl formations, these later are ranked according to their susceptibility to the shrinkage–swelling phenomenon. This ranking was established on the basis of their lithological properties, their mineralogical criterions, and their geotechnical behavior [12]. The lithological criterion is used to characterize the dominant materials in the formation, and to distinguish clayey land, from those where the clay is minor. After the digitalizing of all recognized argillaceous and marl formations, the first step consists of a characterization of the proportion of clay material in each formation. This criterion includes the shaliness, the thickness, continuity, and the heteroge-

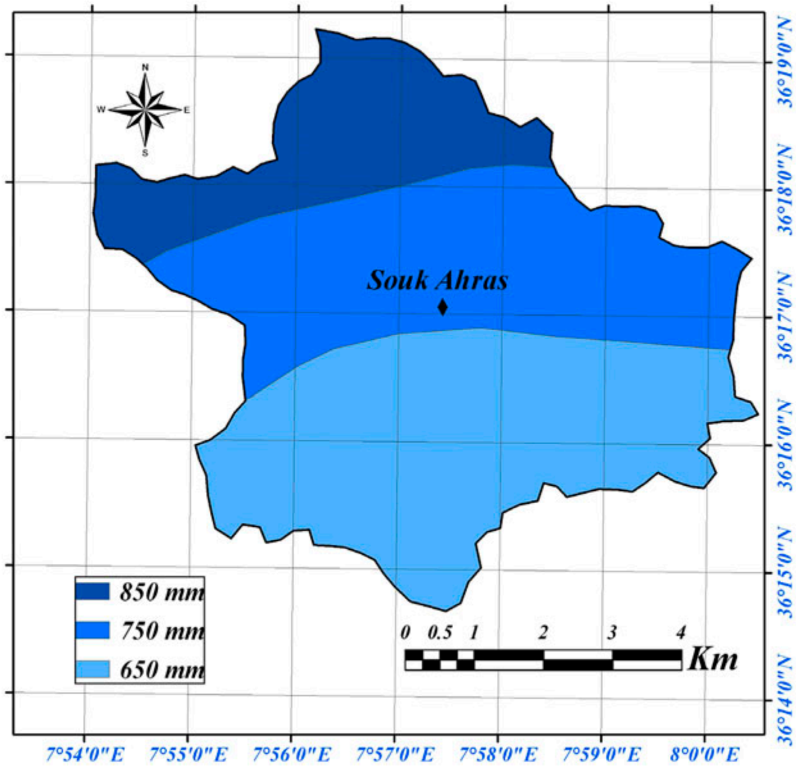

Fig. 6. Inter-annual average precipitation contour line map of the study area.

Table 1
The water balance of the study area (ONM; 90), (1980–2010 measurements period)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
T	22.55	18.89	13.07	10.57	9.12	9.46	12.84	14.51	18.81	23.7	26.18	26.8	17.20
K	1.03	0.9	0.85	0.84	0.87	0.85	1.03	1.1	1.21	1.22	1.24	1.16	
i	9.78	7.48	4.28	3.10	2.48	2.62	4.16	5.01	7.43	10.54	12.26	12.70	81.84
ETPnc	99.18	72.11	37.16	25.35	19.44	20.76	35.99	44.85	71.56	108.47	129.75	135.33	799.95
ETPc	102.15	64.90	31.58	21.29	16.91	17.64	37.07	49.33	86.58	132.33	160.90	156.98	877.66
P	42.56	45.54	80.3	124.2	131.3	80.53	74.41	79.29	59.72	22.01	6.94	16.4	763.2
P-ETP	−59.59	−19.30	48.72	102.91	114.39	62.89	37.34	29.96	−26.86	−110.32	−153.96	−140.58	
ETR	42.56	45.54	80.3	124.2	131.3	80.53	74.41	79.29	59.72	22.01	6.94	16.4	623.49
RFU	0.0	0.0	60.5	70.0	70.0	70.0	70.0	70.0	23.3	0.0	0.0	0.0	
Da	69.6	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.7	145.7	139.4	441.7
Ex	0.0	0.0	0.0	73.0	79.9	57.9	21.0	5.8	0.0	0.0	0.0	0.0	237.6

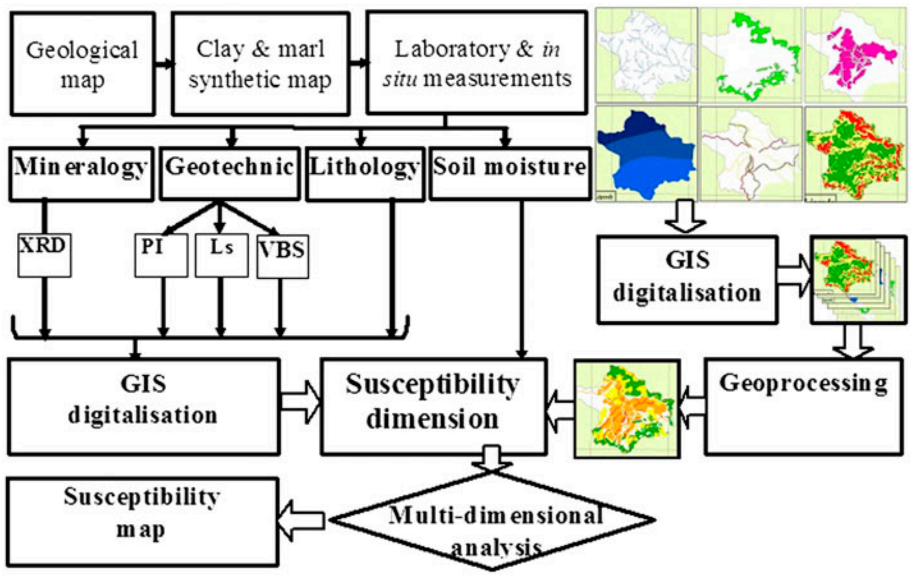

Fig. 7. Methodological flowchart of shrinkage–swelling clays susceptibility analysis.

neity of the formations. The maximum rate is assigned to a clay or Marl thick and continuous layer [13]. The minimum is attributed to a heterogeneous, thin, and discontinuous formation without predominant clay (Table 2).

The shrinkage–swelling occurs preferentially in the presence of the Smectite (Montmorillonite, Beidellite, Saponite, Sauconite) and the interstratified phyllosilicates group.

A semi-quantitative characterization of the mineralogical composition of the clay phase by X-ray diffraction is very useful to identify swelling minerals [14]. With an (D8 Advance of Bruker AXS) device, this analysis of samples collected in the study area (Fig. 8) gives us an idea of the main clay crystalline minerals by characterizing the existence of lines of quartz (SiO_2), an amount of carbonates calcite ($CaCO_3$), anhydrite ($CaSO_4$), and alumina (Al_2O_3) represented as, kaolinite $Al_2Si_2O_5(OH)_4$, smectite $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})$, Illite $(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$.

Table 2
Conventional scale used to distinguish the different lithological classes

Type of formation	Susceptibility	Rating
Formation not containing clay but present locally or previously clay	Low	1
Formations with a term not predominant clayey	Average	2
Formation predominantly clay, with a term or a past clay, or very thin	High	3
Continuous formation mainly clay or marl, with thickness $\geqslant 3\,m$	Very high	4

To characterize susceptibility, a rating is awarded to each clay formation, depending on the Smectite and interstratified swelling minerals contained in the clay share of the material (Table 3). A geotechnical evaluation of the susceptibility is based on the soil identification tests. This quantitative characterization of the material particle size and its reactivity through the methylene blue value, linear shrinkage, (Ls) and plasticity index (PI) seem to be the most representative geotechnical measurements of the phenomenon [15]. Table 4 represents the adopted susceptibility marks on the basis of the three retained geotechnical measurements arithmetic mean.

Sieve analysis of representative samples is performed. It is supplemented by a sedimentometry analysis of 80 µ passers; these tests allow the determination of the percentage of clay in the sample. We use two devices: Standard NA 5232, NF P 94-056:1996 for the first and NA 5251, NF P 94-057:1992 for the second [16].

The measure of the methylene blue quantity (in grams) adsorbed per 100 g of fine soil (Standard NA 5288, NF P 94-068:1998) provides an idea of the clay content of the material and the nature of clays via its specific surface. The evaluation of the susceptibility of soil to shrinkage–swelling according to moisture variation can be established from this criterion [8]. The sensitivity of clay material toward the phenomenon according to VBS is described in Table 5.

PI is calculated from the Atterberg limits with the cone of penetration method (NA 16213, P 94-052-

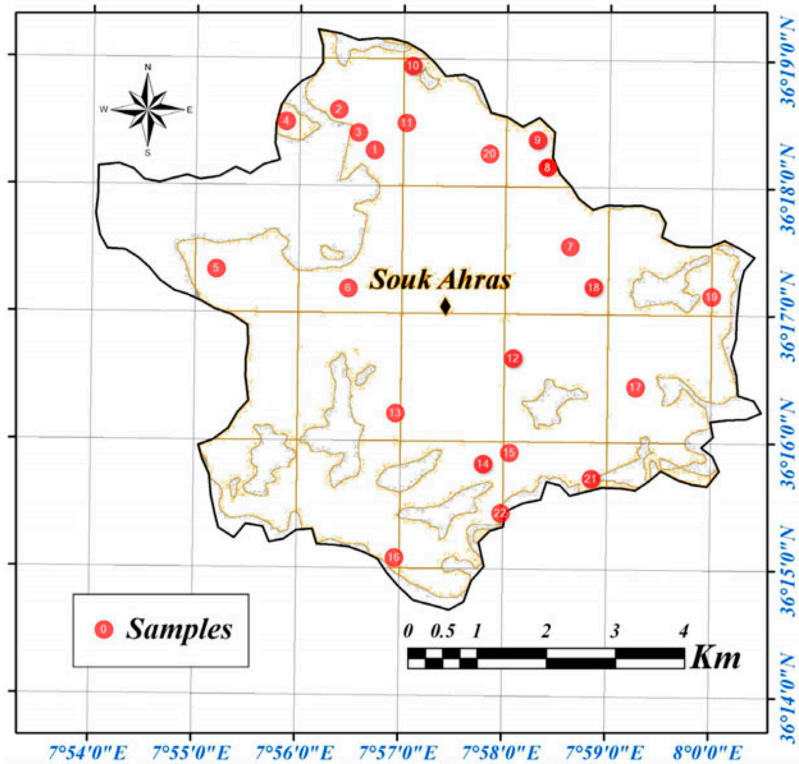

Fig. 8. Collected samples location map in the study area.

Table 3
Mineralogical criterion scale applied for the susceptibility assessment

Average percentage of swelling minerals (%)	Susceptibility	Rating
<25	Low	1
25–50	Medium	2
50–80	High	3
>80	Very high	4

Table 4
Geotechnical marks of the retained formations

Average marks	Susceptibility
Value ⩽ 2	Low
2 < Value ⩽ 3	Average
Value > 3	High

1:1995). It indicates the range of water contents where the soil exhibits plastic properties. The (PI) corresponds to the difference between the liquid limit (LL) and plastic limit (PL). Therefore, it represents the extent of the plastic part and gives an indication of the ability of the clay material to acquire water. The

Table 5
Geotechnic susceptibility marks according to blue value (VBS)

Blue value	Susceptibility	Rating
<2,5	Low	1
2,5 à 6	Average	**2**
6 à 8	High	**3**

evaluation of the susceptibility of shrinkage–swelling clay depending on the PI is indicated in Table 6.

The evaporation of water content in the soil appears generally by a total volume decreases. This process results in two phases, firstly the change of soil volume is proportional to the decrease of the water content, until the contact of grains. The water content corresponding to this level is called withdrawal limit. The Ls is the incline of curve giving the compaction of the sample in accordance with the decrease of water that the water content remains above the withdrawal limit. To characterize the potential withdrawal with this parameter, Table 7 cuts have been proposed by [17].

The measurement of the soil water content and its comparison with the withdrawal limit is a useful test to characterize the soil water status. Monthly

Table 6
Geotechnic marks according to the PI

PI	Susceptibility	Rating
PI < 12	Low	**1**
12 ⩽ PI < 25	Average	**2**
25 ⩽ PI < 40	High	**3**
PI ⩾ 40	Very high	**4**

Table 7
Geotechnic marks according to Ls

Ls	Susceptibility	Rating
Ls < 0.4	Low	**1**
0.4 ⩽ Ls < 0.65	Average	**2**
0.65 ⩽ Ls < 0.75	High	**3**
Ls ⩾ 0.75	Very high	**4**

measurements of soil moisture and its vertical displacement were undertaken during a period of four years. It permits the establishment of water profiles in contrasting hydrological situations.

The implementation of an electrical resistivity prospecting, 2D, surface resistivimeter TE 3300 devise with a dispositive characterized by a reduced spacing between electrodes was also used for a periodic monitoring of soil moisture. The device was calibrated after comparison with soil moisture data of *in situ* measurements. This geophysical prospecting provides the recording of humidity in the soil.

For the measurements of vertical displacement from the ground surface at different depths, a conventional one-dimensional (TELEMAC type) device is installed in cylindrical boreholes of 60 mm diameter. Extensometer rods are sealed to the base levels and the space between the seals has been filled with Bentonite in which the initial position is adjusted. The set of

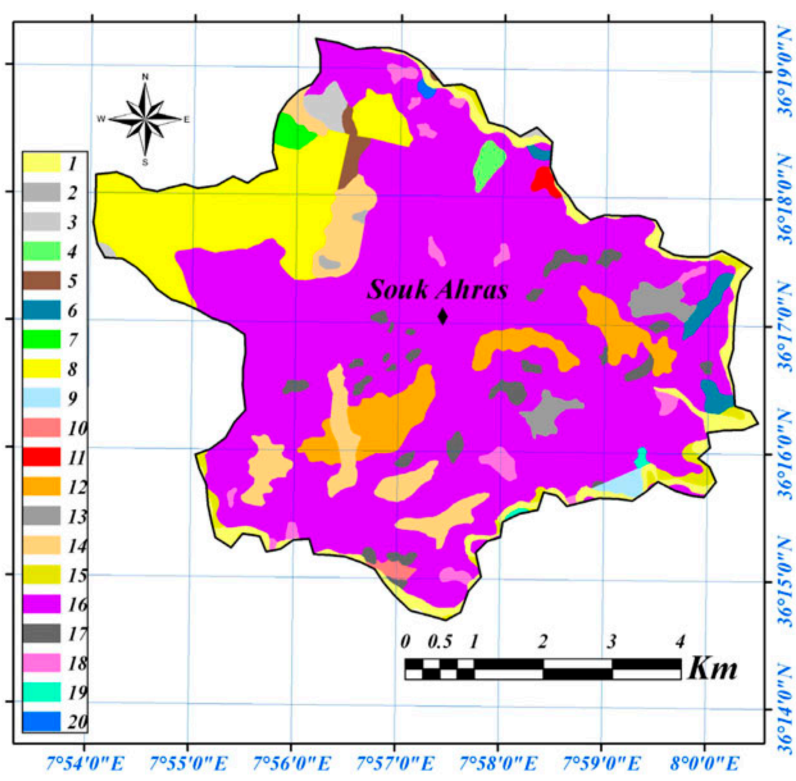

Fig. 9. Digitalized lithological map of the study area. (1) and (15) Quaternary and current alluvial deposit; (2) Gypsum and clay; (3) Marl with traces of black bituminous limestone and brown Globigerina; (4) Marl and clayey- gray marl with past marly limestone; (5) Marls and gray limestone, with Midiola; (6) Mudstones and micaceous sandstone, with calamities; (7) and (12) Marly-clay; (8) Greenish clays; (9) Gray limestone, with rare intercalations of marl; (10) Marl, sandstone and conglomerates; (11) Gray clay and sandstone with red patina; (13) Limestone, marly limestone and sandy limestone; (14) Gypsum; (16) Triassic clayey-gypsum formations; (17) Conglomerates, sandstones and clay; (18) Alternation of thin red or blue altered marl, with mudstones; (19) average alluvial terraces (pebble gravel, sand); (20) White chalky limestone, marl limestone, gray Marl.

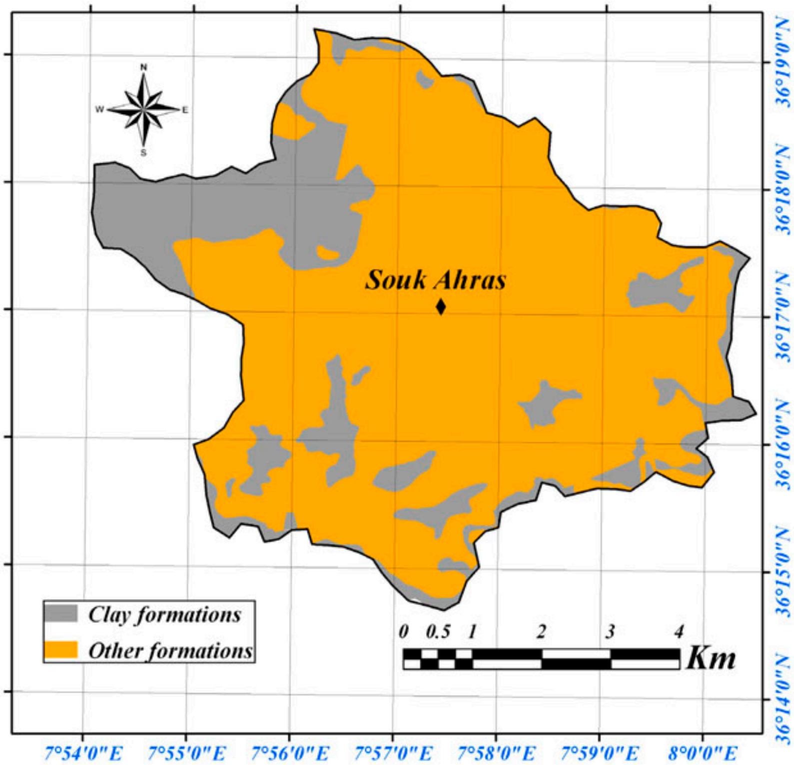

Fig. 10. The synthetic map of predominantly clay and Marl formations in the study area.

Table 8
Lithological marks attributed to different formations outcropping in the study area

Code	Age	Lithological rate	%
Af	Actual	1	12.5
q^3	Recent quaternary	Not clayey	3.13
$q^2{}_{dp}$	Average quaternary	1	9.62
$q^2{}_{dg}$	Old quaternary	1	4.46
pq	Villafranchian	1	15.6
g^3m^1	Higher Oligocene. Lower miocène	2	7.11
g^{1-2}	Lower and average Oligocene	4	1.43
$e_t{}^{4-5}$	Higher Eocene	2	2.88
m^{2-3}	Higher and average Miocene	3	0.79
m^{1-2}	Lower and average Miocene	2	0.80
c^{6a}	Lower Maestrichtian	2	1.40
$c^{5b}{}_{M}$	Higher Campanian	4	1.82
c^{5b}	Campanian	2	2.18
C^{4b5a}	Higher Santonian. Lower Campanian	4	0.47
t	Trias	3	20.2
t_{ca}	Trias (1)	Not clayey	4.89
t_{gy}	Trias (2)	Not clayey	2.05
t^2	Average Trias	1	6.94
t^3	Higher Trias	4	0.44
hr	Permo-carboniferous	1	1.18

measurement points has been transferred on the same vertical [18]. Each measurement provides the difference (ΔH) between the reference point and the depth of monitoring. An increase of this difference reflects the swelling of the layer, while a decrease reflects a slowdown.

4. Results and discussion

4.1. Lithological criterion

A lithological map has been completed from the digitalization of the geological formations outcropped in the study area (Fig. 9). The edition of an attribute table with characteristic column allows the insertion of characteristics as; lithology, age, symbol, color, and lithological rate... As mapping background, we use an original geological map No. 77 of Souk Ahras (1:50,000) scanned and geo-referenced according to the *WGS84, UTM 32N*. A synthetic map of argillaceous and marl formations has been completed from this lithological map (Fig. 10). According to the followed methodology, the map explanatory notice and from summarizing different study reports (LTPE, Geoconseil, Taghaste engineering, technical service of the municipality…), we concluded that the marls, the clays, and the Triassic clayey outcrops are the most susceptible formations to the phenomenon. A rating is affected to each geological formation shown in Table 8.

Among 20 different lithological formations, (from Permo-carboniferous to the actual) within the study area, only 17 formations are finally considered by the research as clayey.

4.2. Mineralogical criterion

Eighteen samples extracted from different site in the municipality (samples 1, 2, 3, 4, 16, 17 were excluded because of their very low clay content) have been characterized by a XRD in laboratory of mechanics, University of Setif. Laboratory treatment

Table 9
Mineralogical marks attributed to the retained clay formations

Code	Number of samples	Swelling minerals		K	I	C	Rate
		Interstratified	Sm				
		x/10		*../n*			
Af	0						1
q^3	0						–
$q^2{}_{dp}$	0						1
$q^2{}_{dg}$	0						1
Pq	1		Traces		8.5	1.5	1
$g^{3–m1}$	1	M/V in traces	2: of M	8			1
$g^{1–2}$	1		8.4	1	0.6		4
$e_t{}^{4–5}$	1	I/Sm	7.1	1.3	1	0.6	3
$m^{2–3}$	1	I/Sm	3	1.3	3.6	2.1	2
$m^{1–2}$	1			3.2	5.4	1.4	1
c^{6a}	1		2 of M	5	3		1
$c^{5b}{}_M$	1	I/Sm	8.5	0.7	0.6	0.2	4
c^{5b}	1		4.9	5.1	Traces	2	
$c^{4b\text{-}5a}$	1	I/Sm	4	1.8	2.9	1.3	3
T	5	I/Sm	8.1	1.1	0.8		2
		I/Sm	5.2	4.3	0.5		
		I/Sm	4.8	4.1	1.1		
		I/mica	5.1	4.2	0.7		
		I/mica	1.5	6.6	1.9		
		Average	4.9	4.1	1.0		
t_{ca}	0						–
t_{gy}	0						–
t^2	1	I/Sm	2.4	0.3	5.1	2.2	1
t^3	1	I/Sm	8.6	0.6	0.8	0.0	4
Hr	1		2.4	0.8	5.4	1.4	1

of samples is as follows: elimination of sulfates and carbonates, ethylene glycol treatment and heating at 500°C. The results of diffractometry are represented in the form of phyllosilicate-type percentage. Marks were allocated to clay and marl formations as mentioned in Table 9 (Sm = Smectite; I = Illite; K = Kaolinite; V = Vermiculite, C = Chlorite).

4.3. Geotechnical criterion

The term clay refers to both a grain size class <2 μm and the mineralogical nature corresponding to the phylum silicate family [19]. The geotechnical criterion allows the determination of the intrinsic characteristics of the soil. As was already mentioned, the tests used are generally the Atterberg limits, linear shrinkage, the methylene blue test, sieve and sedimentometry analysis (Table 10). PI represents the extent of the plastic interval. It gives indication on the ability of the clay material to acquire water. The resulting (PI) values from the Atterberg limits are given in Table 11. The VBS values allow the assessment of behavior of the soil to shrinkage–swelling. The most important values were obtained for samples from holes located on RN16 highway (VBS≈8). The values of the Ls are an indication of the importance of volumetric shrinkage of a saturated soil during its drying. Their results are given in Table 11.

4.4. Geotechnical characterization

PI, VBS, and Ls have been determined for the 17 retained formations from laboratory tests, field work, and *in situ* analysis. The main geotechnical data collected during the study and their attributed marks based on the arithmetic mean of the three measurements are summarized in Table 11. According to Fig. 11, we note that the vertical deformation (Δh) of the soils on the test site (6) recorded positive values in the wet period of the year and negative measures in dry period. We note also that negative values are significantly higher than the positive ones. Which reflect a general compaction of surveyed area and the accentuation of shrinkage comparatively to the swelling. This finding confirms that climate change is the responsible phenomenon of the drying of the soil, which is manifested by an accentuated shrinkage sometimes irreversible in clayey soils.

5. Determination of the susceptibility degree

Each formation has been characterized by three notes, one for each criterion taken into account according to the classifications presented above. The average of these scores is calculated for each formation, to get a degree of general susceptibility toward the shrinkage–swelling phenomenon, included between one and four [20]. The clayey and marl formations susceptibility is obtained by the average score as shown in Table 12. The susceptibility classes determined from the average value of the last three geotechnical characters are exposed in Table 13.

Table 10
Fine particles proportion at different depths (eight core samples)

Sample	Depth (m)	Particle size	
		<2 mm	<0.08 mm
1	1.0–1.5	81.2	75.1
	2.0–3.5	83.4	75.6
	4.0–5.5	97.0	93.5
	6.0–8.0	92.4	91.0
2	1.5–2.0	62.4	42.5
	2.5–3.0	88.0	73.9
	3.5–4.0	98.9	96.6
	5.5–6.0	97.2	91.5
3	2.0–3.0	91.1	86.5
	5.5–6.0	99.1	92.8
	6.5–7.0	97.5	91.8
4	1.0–2.0	81.8	72.3
	2.0–4.5	77.5	71.4
	5.0–5.5	88.9	81.5
	6.5–7.0	92.1	84.5
5	1.5–2.0	81.7	76.6
	2.5–3.0	83.6	76.6
	4.5–5.5	93.9	88.2
6	2.0–2.5	63.7	51.2
	3.0–3.5	91.1	85.8
	4.0–4.5	99.2	95.5
7	2.0–3.0	90.4	87.2
	5.0–6.0	97.5	92.1
	6.5–7.0	95.2	91.1
8	1.5–2.0	81.9	75.0
	2.5–3.5	76.7	70.1
	4.5–5.0	91.1	82.0

6. Susceptibility map

The shrinkage–swelling susceptibility map of Souk Ahras municipality was prepared on the basis of the

Table 11
Average value of geotechnical criteria and approved rate for selected formations to the shrinkage–swelling phenomenon

Code	% < 2 µm	PI		VBs (g/100 g soil)		Linear shrinkage		Arithmetic mean	Remark	Géo^{tech} rate
Af	56	14	2	1.33	1	0.36	1	1.33	Low	1
q^3	–	–	–	–	–	–		–	–	–
q^2_{dp}	51	16	2	1.65	1	0.35	1	1.33	Low	1
q^2_{dg}	42	25	3	0.68	1	0.33	1	1.33	Low	1
pq	48	9	1	1.67	1	0.27	1	1	Low	1
g^{3-m1}	39	11	1	5.06	2	0.39	1	1.33	Low	1
g^{1-2}	59	30	3	5.16	2	0.46	2	2.33	Average	2
e_t^{4-5}		–	–	–	–	–		–	–	–
m^{2-3}	54	23	2	4.16	2	0.41	2	2	Low	1
m^{1-2}	47	18	2	3.66	2	0.50	2	2	Low	1
c^{6a}	39	21	3	5.60	2	0.36	1	2	Low	1
c^{5b}_M	45	17	2	3.83	2	0.45	2	2	Low	1
c^{5b}	40	10	1	1.24	1	0.24	1	1	Low	1
$c^{4b\text{-}5a}$	42	24	2	2.02	1	0.051	2	1,66	Low	1
t	68	31	3	1.83	1	0.66	3	2.33	Average	2
t_{ca}	–	–	–	–	–	–		–	–	–
t_{gy}	–	–	–	–	–	–		–	–	–
t^2	70	32	3	6.33	3	0.76	4	3.33	High	3
t^3	72	28	3	7.83	3	0.77	4	3.33	High	3
hr	54	6	1	0.34	1	0.17	1	1	Low	1

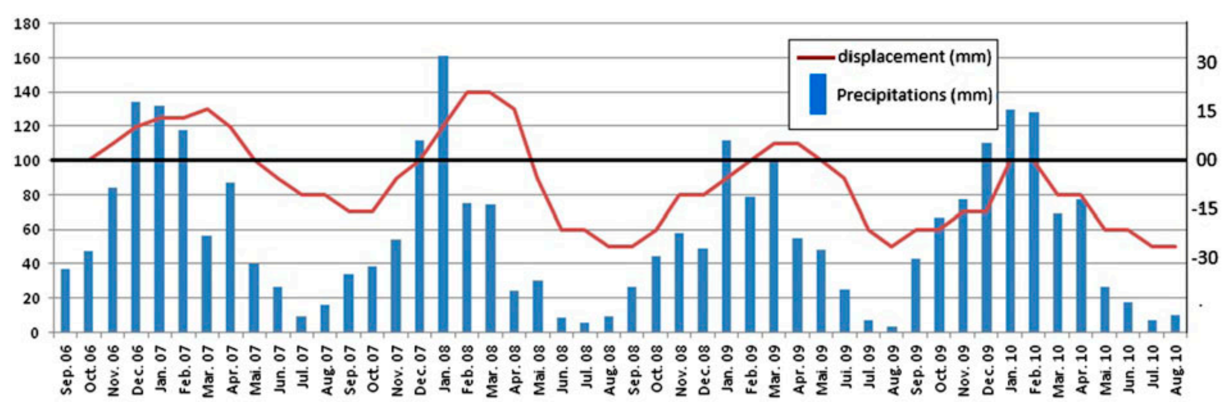

Fig. 11. Vertical deformation measured at the site (6) compared to the monthly recorded rainfall of the study area.

argillaceous and marl formations synthetic map. The criterions used to establish the hierarchies of various formation outcropping in the study area are the lithological, mineralogical, and geotechnical characterizations [21]. On the basis of the relationship between the mapped phenomena and causal factors, the equal rates were attributed to each of the layers. All layers raster maps are normalized and values have been affected. To generate the susceptibility map, the standardized causal factors distribution layers were combined and sum together. This summation is dividing by the number of the layers retained for the

Table 12
Clay and marl formations susceptibility degree

Average rate	Degree of susceptibility
Value ⩽ 2	Low
2 < Value ⩽ 3	Average
Value > 3	High

computing as shown in Table 14. The result was summed with the three retuned values (lithological,

Table 13
The resulting susceptibility classes according to the three characteristics mean

Code	Litho. mark	Mineralog	Géotech	Mean	Susceptibility
Af	1	1	1	1.00	Low
q^3	No	–	–	–	–
$q^2{}_{dp}$	1	1	1	1.00	Low
$q^2{}_{dg}$	1	1	2	1.33	Low
pq	1	1	1	1.00	Low
g^3-m^1	2	1	2	1.66	Low
g^{1-2}	4	4	2	3.33	High
$e_t{}^{4-5}$	2	3	No	2.50	Average
m^{2-3}	3	2	2	2.33	Average
m^{1-2}	2	1	2	1.66	Low
c^{6a}	2	1	2	1.66	Low
$c^{5b}{}_M$	4	4	2	3.33	High
c^{5b}	2	2	1	1.66	Low
C^{4b-5a}	4	3	1	2.66	Average
t	3	2	2	2.33	Average
t_{ca}	No	–	–	–	–
t_{gy}	No	–	–	–	–
t^2	1	1	3	1.66	Low
t^3	4	4	3	3.66	High
hr	1	1	1	1.00	Low

mineralogical, and geotechnical criterions); and the result was divided per four. This can be illustrated by the following formula:

$$\text{Suscepibility} = \frac{\left[\frac{\left(\sum_{J=1}^{6}[\text{La}J(x)]\right)}{\sum_{J=1}^{6} NJ} + (\text{L} + \text{M} + \text{G})\right]}{4}$$

With: L = lithological criterion; M = mineralogical criterion; G = geotechnical criterion; La = considerate factor layer.

The resulted susceptibility map (Fig. 12) shows the formations more potentially susceptible to the phenomenon of shrinkage–swelling by assigning the susceptibility each geological unit. All formations outcropping in the study area are represented by one of three colors (yellow, orange, and red) interpreting three hierarchy of susceptibilities. The gray areas on the map correspond to the non-argillaceous formations.

The partition of high and average susceptibility terrains shows that many areas planned for future extensions are exposed to shrinkage–swelling hazard (Fig. 13). To validate the realized susceptibility map, the distribution of sinister in 14 neighborhoods of the study areais used to compare the shrinkage–swelling map. The validation proved that most of the sinister occurred in Souk Ahras municipality pointed out as high or average level in the maps; statistically, it shows 91% agreement between the resulting model and the validation sinister location.

7. Synthesis

After the determination of all the criterions retained in the assessment, and the GIS affectation of a degree of susceptibility for each formation, the results can be resuming as follows:

Table 14
GIS Layers input attributes, for the retained susceptibility factors

Class No (i)	Category	Layer (j)	Weighting (W_j)	Class
1	Orography	Slope angle	1.0	<5° (×1.00)
2				5–15° (×0.50)
3				>15° (×0.25)
4	Environment	Precipitations	1.0	>850 mm (×1.00)
5				750 mm (×0.50)
6				650 mm (×0.25)
7		Stream network	1.00 (buffer = 50 m)	Yes
8				No
9	Land use	Roads network	1.00	Yes
10				No
11		Forest	1.00	Yes
12				No
13		Buildings	1.00	Yes
14				No

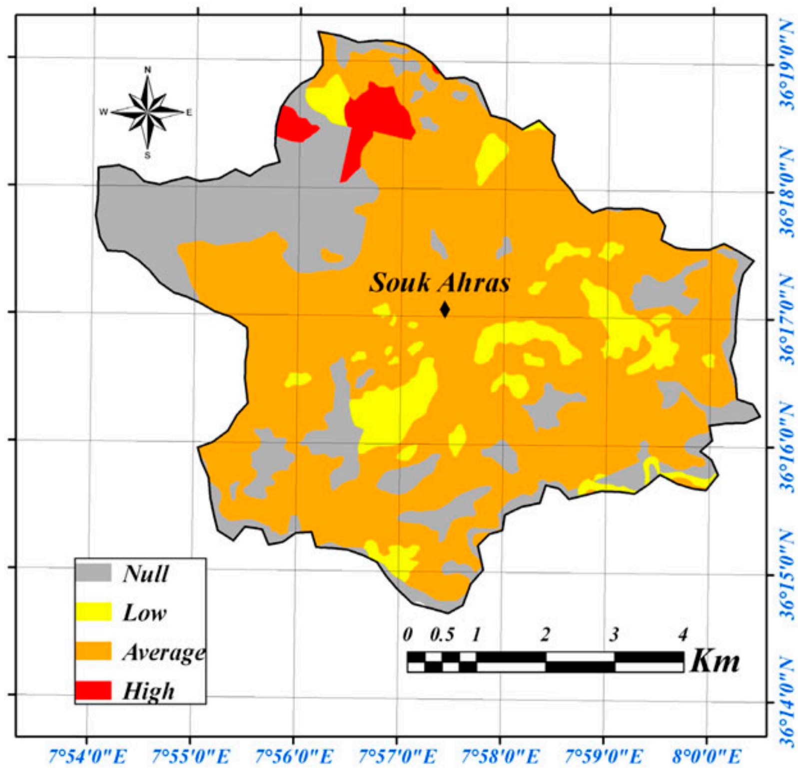

Fig. 12. The matic shrinkage–smelling susceptibility map of the study area.

The formations highly susceptible cover two small areas in the north of the municipality. Three formations have been linked to this category, they are as follows:

(1) Alternation of thin red or blue altered marl, with mudstones, (t_3);
(2) Marne, clay, (c^{5bM});
(3) Greenish clays (g^{1-2}).

The moderately susceptible formations extend through the most part of the municipality, especially in the Triassic clay. Four formations have been linked to this category, they are as follows:

(1) Triassic clayey–gypsum formations, covering most of the surface of the study area (t);
(2) Marl and clayey-gray marl with past marly limestone (C^{4b-5a});
(3) Marl–clay (m^{2-3});
(4) Marl with traces of black bituminous limestone and brown *Globigerina* (e_t^{4-5}).

Formations weakly susceptible to the phenomenon scattered mainly in the middle part of the municipality; 10 formations were related to this category:

(1) Mudstones and micaceous sandstone, with calamities, (h);
(2) Marls and gray limestone, with *Modiola*, (t_2);
(3) Gypsum and clay (T_{gy});
(4) Gray limestone, with rare intercalations of marl (T_{ca});
(5) Limestone, marly limestone and sandy limestone (C^{5b});
(6) White chalky limestone, marly limestone, gray Marne (C^{6a});
(7) Marl, sandstone, and conglomerates (m^{1-2});
(8) Gray clay and sandstone with red patina, (g^{3-m1});
(9) Conglomerates, sandstones, and clay (pq);
(10) Three Quaternary and current alluvial deposit (Q_{2D}) (q_{2dp}) (Af) constituting the bed of the Medjerda and Edjedra Wadies have been also attached to this group.

It should be noted that non-argillaceous formations border the study area corresponding to Medjerda Mountains, mainly represented by:

(1) Gypsum (T_{gy});
(2) Gray and black limestone with rare intercalations of yellow dolomites (T_{ca});
(3) The average alluvial terraces (pebble gravel, sand), (q_3).

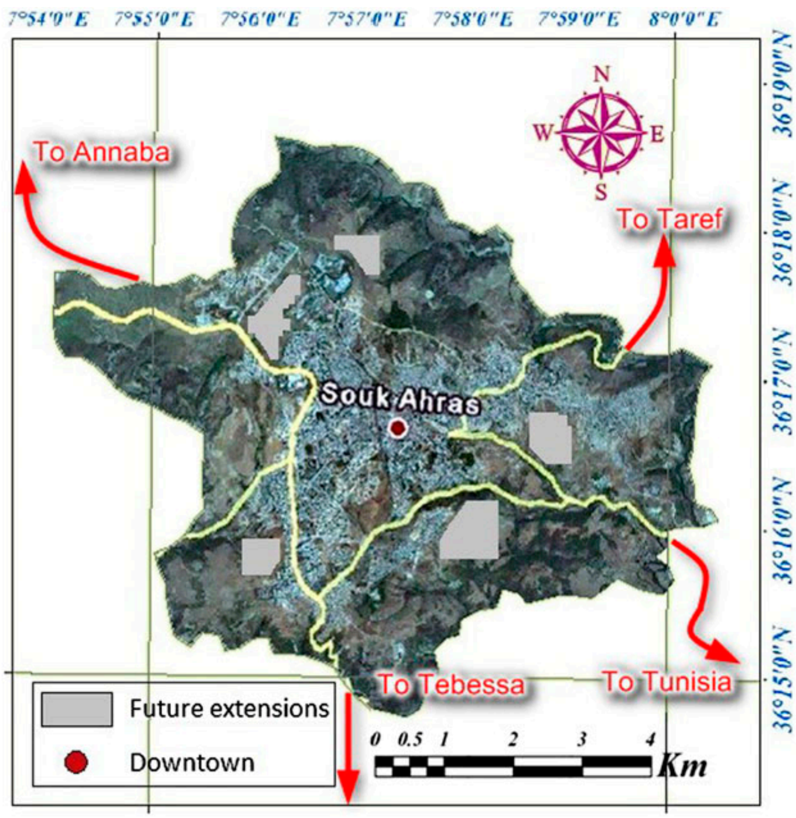

Fig. 13. The territories designated for development in the study area.

8. Conclusions

The geological setting of Souk Ahras municipality is characterized by the dominance of plastic clay, marl formations, and cracked layers that can store water and facilitate its flow. The establishment of the shrinkage–swelling susceptibility map of Souk Ahras municipality was essentially based on an interpretation of the geological map N° 77 (1: 50,000) associated with the synthesis of a large amount of information about the phenomenon and of clay formations. This approach is a part of the general methodology developed by the BRGM. The process of the study consists first on the mapping of synthetic clay and marl formations map, from the synthesis of geological map, field observations, and existing literature. This map identifies 17 dissimilar formations related to their deposition conditions or weathering.

Formations were identified and prioritized on the basis of their susceptibility to shrinkage–swelling. This classification was established on the basis of three main quantifiable characteristics: the dominant lithology of the formations; the mineralogical composition of the clay fraction, and the geotechnical behavior. Chemical analysis and Atterberg limits allow appointing these fine soils such as inorganic plastic clays composed mainly of Smectite, Kaolinite, Illite, and interstratified minerals. The qualitative and quantitative descriptions of the clays studied characteristics were the basis of diagnosing the shrinkage–swelling phenomenon. Three levels of susceptibility (high, average, and low) were adopted to characterize clay and marl susceptibility toward the phenomenon, conceptualized as red, orange, and yellow, indicating that 4.35% of the municipal area is classified as high hazard, medium hazard in 57.65, 14.48% in low hazard, whereas 23.52% of the surface area is not clayey. The risk which presents such argillaceous composition is not only related to the mineralogical composition itself, but also in the abundance of these minerals amount which when added to water they will have a very detrimental effect on the land behavior.

The final susceptibility map can be used as a basis for preventive information campaigns in the municipality, in order to sensitize the builders, owners and decision-makers on the need to respect constructive rules in the areas subject to shrinkage and swelling. This regulatory tool should emphasize the importance of a geotechnical investigation to the plot for any new construction project. Otherwise, it will be necessary to implement constructive rules to reduce the destructiveness of the phenomenon.

References

[1] D.M. Moore, R.C. Reynolds, X-ray Diffraction and the Identification and Analysis of Clay Minerals, 2nd ed., Oxford University Press, New York, NY, 1977, p. 378.

[2] H. Mahtali, Identification of swelling potential of a of Souk Ahras Area soil, Proceeding of International Symposium of No Saturated Soil and Environment, Tlemcen, 2009, p. 156.

[3] R. Hadji (2012) Proceeding of 6th International Conference of Water Resources in the Mediterranean basin, Watmed 6 (2012).

[4] A. Talhi, S. Barkati, Realization of a POS of Fatouma Saouda neighborhood, Souk Ahras municipality, memory of engineer in geology (2010), University of Setif.

[5] L. David, Geological study of high Medjerda Mountains, PhD thesis, University of Paris, 1956.

[6] M. Vincent, GIS mapping of hazard shrinking and swelling clays for preventive purposes - France, Geographic Information Systems and Risk Management, publication ISTED, January 2005, pp. 12–15.

[7] D. Chassagneux, L. Stieljes, P. Mourou, G.H. Ducreux, Shrink-swell hazard mapping in the region of Manosque (Alpes de Haute Provence). Municipal and departmental scale. Methodological approach. Report BRGM R 38695 (1995).

[8] D. Chassagneux, L. Stieljes, P. Mouroux, F. Ménillet, G.-H. Ducreux, Shrink-swell hazard mapping at a departmental level. Methodological approach in the Alpes of Haute-Provence. Report BRGM R39218, 1996, p. 33.

[9] J.P. Prian, M. Donsimini, M. Vincent with the collaboration of L. Denis, J.C. Gallas and F. Marty, Hazard mapping of drawal swelling clays in the Essonne Department, BRGM/RP-50376-FR, 273, 2000, p. 32.

[10] M. Donsimoni, L. Clozier, M. Vincent, with the collaboration of M. Motteau and J.C. Gallas, shrinkage-swelling Hazard mapping of clays in the department of Seine-Saint-Denis. BRGM/RP-51198-FR, 2001, p. 125.

[11] P. Barchi, G. Badinier, A. Capron and M. Patin, shrinkage-swelling Hazard mapping of clays in the department of Pas-de-Calais. Report BRGM/RP- 53817-FR, 2006, p. 129.

[12] A. Norie and M. Vincent, Establishment of Natural Plans of Risk Prevention: "differential movements related to shrinkage and swelling of clay" - Methodological Approach in the department of Deux-Sèvres. Report BRGM/RP-50591-FR, 2000, p. 14.

[13] M. Vincent, The clays shrinking and swelling risk, Papers of IAURIF, n°138, October 2003, pp. 95–101.

[14] E. Eslinger, D. Pevear, Clay Minerals for Petroleum Geologists and Engineers. SEPM Short Course Notes no. 22, Society of Economic Paleontologists and Mineralogists, Tulsa, OK, 1988, pp. ix + 405.

[15] N. Bernon, P. Chrétien, B. Dècle, M. Imbault, M. Vincent, Shrinkage-swelling Hazard mapping of clay soils in the department of Oise. Report BRGM/PR-57154—FR, 2009, p. 129.

[16] IANOR, Ministry of Public Works, Directorate of Research and Forecasting, under the direction of standardization Algerian standards collection public works, December 2010.

[17] A. Mastchenko, Drought and clay soils. Industrial Project Alpha Sol. Ecole des Mines d'Ales, Final, Report, BRGM/RP-53187-FR, 2001, p. 74.

[18] R. Fabre, Analysis of shrinkage-swelling of clay soils in south-western France from an experimental site (Gironde) cumulative effect of drought and its consequences, Proceeding of the 2nd International Symposium of Unsaturated soils and environment (UNSAT 2012) Algiers, 5–6 November 2012.

[19] T. Maison, At the microscopic scale analysis of wetting-drying clays phenomena, PhD in Geology/Geotechnical Central School Paris, 2011.

[20] P. Brachi, S. Magalhaes, A. Capron, Shrinking and swelling hazard mapping of clay soils in the department of Meurth-et-Moselle. Report BRGM/RP-54860-FR, 2006, p. 150.

[21] D. Athmania, A. Benaissa, A. Hammadi, M. Bouassida, Clay and Marl Formation Susceptibility in Mila Province, Algeria Geotechnical and Geological Engineering 28 (2010), 805–813.

Geologic maps

B. Kriviakine, E. Kovalenko, V. Vnouchkov, And the unpublished works of Kuscer-Dozer, geological map of Algeria. Map (number 77) of Souk Ahras in 1:50,000. Ministry of Heavy Industry, National geology, 2nd edition, 1988.