Article submitted to the Proceedings Book of the VI[th]. International Symposium–2022, *Theme: "Biosphere & Environmental Safety"*	Biosphere and Environmental Safety VI.th International Symposium-2022	ISBN: 978-963-449-285-6 Online May 5-6, 2022 ICEEE, Óbuda University, Budapest, Hungary

SOIL QUALITY IN THE SEBKHAS ENVIRONMENT (SOUTH-EASTERN CONSTANTINE), ALGERIA.

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The sebkhas (Sabkhet Djendli and Garaat Ank Djemel) considered in our study are part of the Boulehilet plain (ex. Lutaud) located on the southern edge of Constantine's high plains. The soils surrounding these sebkhas are dotted with very sparse vegetation consisting mainly of halophytic plants. These two lakes are drained, respectively, by Oued el Madher and Oued Chemora. Chemical analyses of the soils (about 150 samples) show relatively high concentrations of sodium and sulphates. The latter are more present in the vicinity of Sebkhet Djendli, the source of which would be the leaching of the Triassic formations that lie just to the north-east of the Sabkha. However, the CaCO3 content does not show a significant variation across the plain. As for sodium levels, they increase significantly with depth, especially on the eastern edge of Sebkhet Djendli. The soils of the Boulehilet plain are relatively salty and have a pastoral interest. Conductivity measurements carried out in 70 farmers' wells on the outskirts of Sebkhet Djendli indicate values that are sometimes quite high, exceeding 2000µs, thus corroborating the salinity of the water that is used for domestic supply. Trace elements analyses (Zn, Cu, Cr, Ni, Ba, etc.) of soil samples taken from auger-digged boreholes (12 samples) show relatively high levels. The presence of these metals is thought to be linked to mining waste from previous operations near these sebkhas.

***Keywords**: Salinity, Sebkhas, Sodium, Sulphates, Soils, Trace elements, Triassic formations.*

INTRODUCTION

"Stop soil salinisation, increase soil productivity", was declared in 2021 by the FAO in the World Soil Day. In Algeria, as in the rest of the world, soil salinisation and sodification is one of the most harmful scourges for agricultural production, food security and sustainability, especially in arid and semi-arid regions. More than 1,000,000 ha of agricultural land are affected by this problem in Algeria (INSID), part of which is located in the irrigated areas of the country's north-eastern region.

The alluvial plain of Boulhilet constitutes a vast irrigable area (more than 26,586 ha), located in the southern part of the high plains of Constantine; the country of the salt lakes or sebkhas. The soils surrounding these sebkhas, which are of pastoral and agricultural interest, are relatively salty, dotted with very sparse vegetation consisting essentially of halophytic plants.

The objective of the present study is therefore to assess the quality of the soils and to quantify the rate of their degradation with regard to salinisation, sodification and contamination of this plain.

MATERIALS AND METHODS

The physical originality of the study area

Located in one of the semi-arid regions of North-Eastern Algeria (Figure 1), the Boulhilet alluvial plain is part of the wetland complex of the Constantine High Plains. It extends over an area estimated at 26,586 ha from the town of El Madher (Batna) to Aïn Kercha (Aïn M'Lila) in the north, the towns of Chemora (Batna) and Khanchela in the south. From a paleogeographical point of view, it corresponds to a transition zone between the Tellian Atlas and the Saharan Atlas (pre-atlasic domain). It is situated at an altitude of between 840 and 850 meters (an important factor in agricultural development).

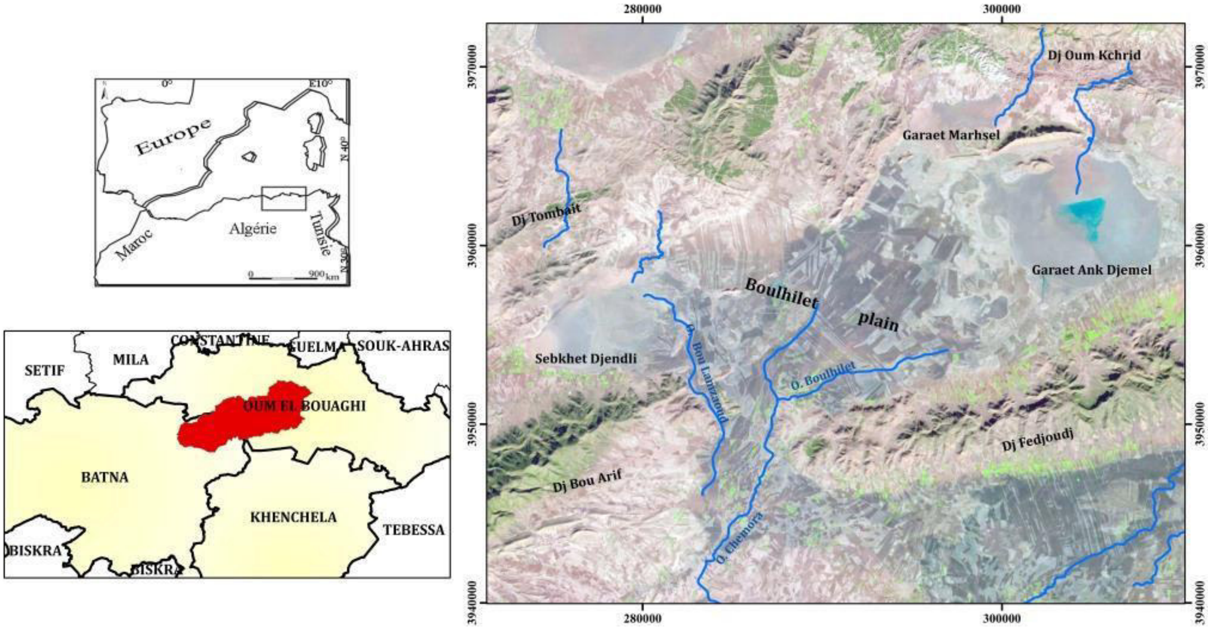


Figure. 1. Geographical location of the Boulhilet plain (South Constantinois)

Given its location, rainfall is deficient (350 to 400 mm maximum/year, 4 to 5 dry months), climatic constraints are strong (many days of frost, sirocco, etc.), the soils are not very developed and favourable, and it is necessary either to irrigate or to insert crops that are resistant to drought. The irrigation of the plain will be ensured by water from the Beni Haroun dam and the spreading of flood waters from Oued Chemora.

Geological setting

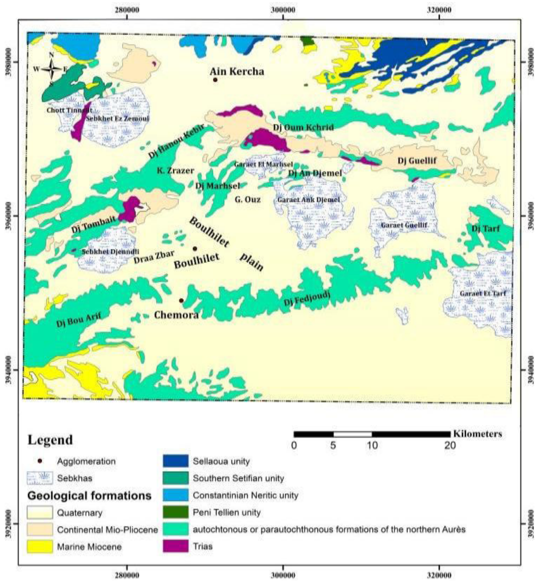
The area of the sebkhas, including the Boulhilet plain, belongs to the foreland of the Maghrebid belt of north-eastern Algeria. Limestone Mountains whose geological formations are essentially carbonate with a dominant Cretaceous age. These basins are filled with detrital sediments whose thickness can exceed 150 metres. They are generally covered by a thin layer of salt water during wet periods and dry during dry seasons. These Sabkhas occupy a gullied area, generally oriented in a SE-NW direction (Fig.ure 2).

Lithologically, it is important to note that:

- **-***All the massifs surrounding the plain are made up of Mesozoic limestone; thus providing important limestone stocks for runoff. Calcimorphy will therefore play an important role in the areas lower than these limestone foothills (glacis) and the flat areas beyond.*
- *-If these large reserves of limestone can be made available to glacis and terrace soils, the movement of this element (due to its low solubility and the low rainfall of the region) will remain limited.*
- *The alluvium of Oued Chemora in the plain has a fine texture (the coarser elements are deposited upstream between Timgad and Chemora). So we will have heavy soils in the flat parts of this region.*
- *These alluviums come essentially from the purple mio-pliocene marls of the Timgad basin and the southern slope of the Dj. Bou Arif: they will be quite loaded with salt and gypsum.*

On the geomorphological level, the plain includes 4 closed basins (endoreic) (Figure 2)

- To the west, sebkhet Djendli, which is fed mainly by oued Bou Lamzaoud, is supported by a faulted anticline, very rectified (Dj. Tombaït). At the base of the latter appear limestones and dolomites of the Jurassic, surmounted in places by Triassic points,
- To the north, Garâet el Marshel, bordered to the west by Dj Marhsel, to the south by the limestone table of guelâat Ouz, to the south by Dj Ank Djemel and to the north by Dj. Oum Kchrid (predominantly Triassic formations);
- To the north-east, Garaet Ank Djemel, fed by oued Boulhilet and Rhezal, this Garâa is only separated from Garâet Guellif by a threshold of a few metres,
- To the east garâet Guellif.



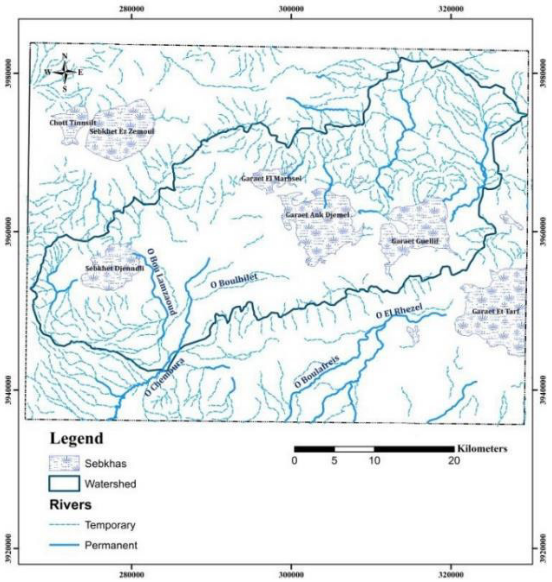


Figure 2. Simplified geological map of the study area (after Vila, 1980) **Figure 3.** The hyrography of the study area

HYDROGRAPHIC NETWORK

The hydrographic network characterising the Sebkhas area is of the endoreic type: the rivers do not reach the sea, but flow towards the Sebkhas (Figure 3). It is relatively dense but rare wadis are perennial (Oued Chemora). It is a region with low rainfall (350-400 mm/year).

The Chemora wadi take its source in the northern heights of the Aurès and is then lost, after a journey of about 50 km, in the sebkhas of the southern part of the high plains of Constantine (sebkhet Djendli and Gareat Ank Djemel). This situation explains the dissymmetry of its watershed (Figure 2 and Figure 3), characterised by its upstream, mountainous part, culminating at more than 2000 m, with ve ry steep longitudinal and transverse slopes, whereas, downstream of Timgad, these reliefs give way to a vast spreading plain where the Chemora wadi meanders as far as the town of Chemora. The configuration of the basin and its lithological components facilitate the supply of an important material to the wadis, heterometric material, ranging from limestone blocks and pebbles to sands and silts. The former are stopped by the various channels corresponding to the synclines and the exit into the plain, the latter go much further (Boulhilet plain and surrounding sebkhas) [1].

The boundaries of the sebkhas on the topographic map are irregular because their extent depends on the climate and the load of the wadis that feed them.

SAMPLING

In the case of Sebkhet Djendli, the methodology adopted to achieve the objective is based on field work and laboratory analysis. The investigations were mainly based on in situ measurements and sampling in trenches reaching a depth of between 2 and 2.5 m (58 samples, to estimate the $CaCO_3$ content) and 4 hand augering holes with an average depth of 250 cm in the flooded areas, (12 samples, chemical analyses on trace elements).
Soil sampling across the Boulhilet plain was carried out according to soil profiles, with an irregular mesh, to an average depth of 140-150 cm, exceptionally reaching 190 cm by drilling. Samples were collected from different horizons for each profile at more or less regular intervals (Figure 4).

Physico-chemical analyses
The physico-chemical analyses (pH, electrical conductivity at 25°C, total limestone, active limestone, soluble salts, sulphates, gypsum) were carried out by the laboratory of the scientific studies department of Constantine.
From the analysis data, we established thematic maps using the IDW (Inverse Distance Weighting) method to study the evolution of certain parameters vertically (on the profiles) and spatially across the Boulhilet plain.

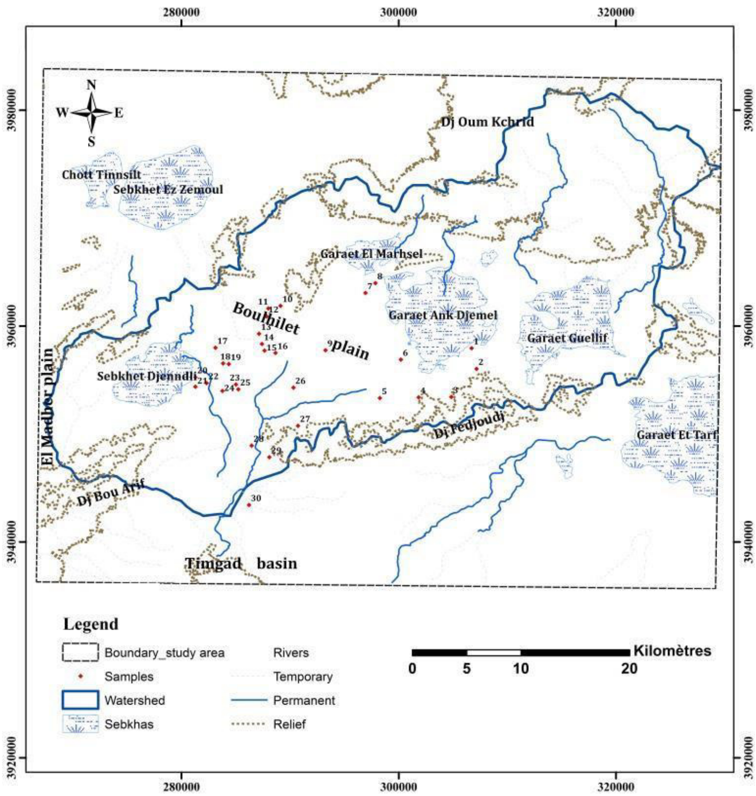


Figure.4. Spatial distribution of soil profiles

DATA PROCESSING

Analysis of pedogenetic factors
Climate is an important factor in pedogenesis and agricultural development; it intervenes through all its components

- In the plain, rainfalls are low, they are concentrated in autumn, winter and early spring: the phenomena of entrainment of certain elements will be limited, these rainfalls are also characterized by a significant variability from one year to another: this will have a considerable influence in the development, the success of the cultures in dry will be aleatory

- During the summer period (which actually starts in mid-spring), rainfalls are almost non-existent and the temperature is high; their combination with the wind action will have the effect of increasing evaporation and evapotranspiration (Figure 5), creating a water deficit that will have repercussions on the evolution of the soil, the soil reserves and the cultivation methods that allow to reduce these losses somewhat.

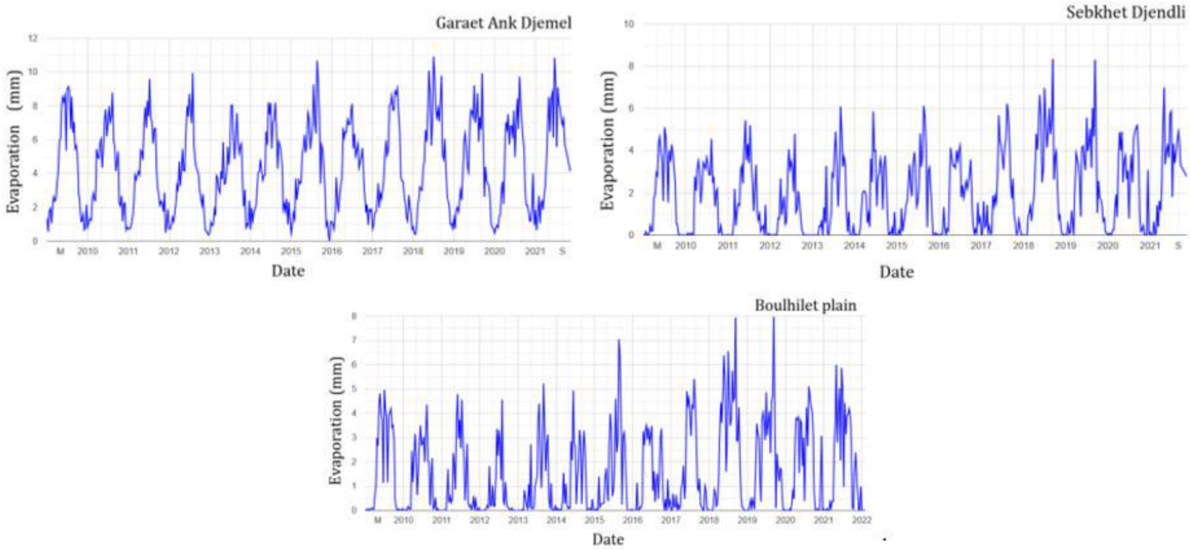


Figure 5. Evaporation across the study area

In addition, all sebkhas and gareats are temporary lakes with a very flat topography; they are located at a lower altitude than the rest of the plain (overdeepening). They receive floodwater and runoff as well as run-off water and form a generally shallow water table where they settle their troubles. During the dry season, these closed basins constitute ideal evaporation surfaces, so that the water table disappears, leaving a whitish crust of concentrated salts on the surface.

In the sebkhas

- *Major and trace elements*

The analyses of the samples taken from the trenches and boreholes showed average grades where the major elements (oxides) can be classified in decreasing order of magnitude as follows: SiO_2 (38%), CaO (15%), Al_2O_3 (12%), Fe_2O_3 (~ 5%), MgO (3%), Na_2O (~ 2%), K_2O (1%). The remaining elements (MnO, TiO_2 and P_2O_5) each constitute less than 1% (Figure 6)

✓ *SiO_2, Al_2O_3, Fe_2O_3*

Comparing the chemical analysis results, we notice that the high values of SiO_2, Al_2O_3 and Fe_2O_3 are provided by the samples from borehole SD1 (Djdli borehole). The latter is located near the mouth of the rivers coming from the north of Sebkha Djendli. The proximal detrital deposits, carried by run-off water, would be richer in quartz grains and iron and aluminium oxides in relation to the geological environment (presence of carbonate and sandstone rocks).

✓ *Na_2O, K_2O*

The average Na_2O content, exceeding 2%, is found in boreholes SD1 and SG1 (Gaaret Guellif borehole). The K_2O content (~ 1.5%) comes from the SD3 samples. These elements could result from the alteration of sodium and potassium aluminosilicates and/or the dissolution of halite contained in the sedimentary rocks in general and in the Triassic formations in particular, which are located not far from the sebkhas.

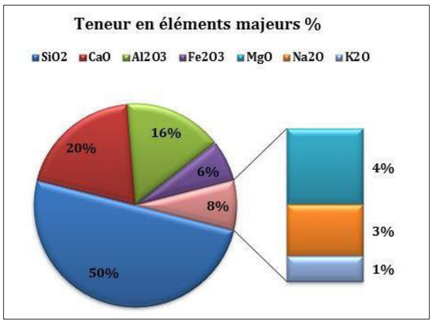


Figure 6. Major element ratios in sebkhas

Some of the authors have proposed mobility patterns of major elements during weathering [9], [13] and [17] evolving in a decreasing order according to the following scheme::

Ca^{2+}, Mg^{2+}, Na^{+} > K^{+} > Fe^{2+} > Si^{4+} > Ti^{4+} > Fe^{3+} > Al^{3+} [13]

Gravity flow from surface waters to endoreic depressions is the main dynamic factor in the enrichment of Sebkhas sediments in certain chemical elements. Physico-chemical conditions (Eh, pH) also play an important role in the behaviour of mineralisation in a secondary environment.

The mobility of elements in a secondary environment, particularly metals, is at the origin of the dispersion haloes used in geochemical prospecting [2], [12].

Most of the trace elements have fairly low average levels. However, some elements such as Sr (702 ppm), Ba (224 ppm), Zr (124 ppm), V (105 ppm), Cr (98 ppm) and Zn (67 ppm) are characterised by relatively high average levels compared to the rest of the elements.

- *Calcimetry (58 samples)*

The calcimetric results obtained from the trench samples (Figure 7) are more reliable and correlatable in their natural and real context. This made it possible to understand the relationship between variations in $CaCO_3$ content on the one hand and facies changes in the vertical sequence of sediments on the other (well-cleared soil profiles without any contamination between horizons). However, the levels are generally low in the Sebkha with average values not exceeding 20%.

Indications of climatic variations can be seen in the presence of laminae within the deposit, the existence of traces of desiccation cracks marked by colours different from those of the host rock and the addition of eolian gypsum sand.

The succession and alternation of laminae pairs (light and dark) could be explained by the climatic contrast, dry and wet periods, influencing the watershed inflow [5].

The existence of thin beds of Ostracods with complete shells, interspersed in the soil horizons, indicates a non-displacement post mortem and would also inform on ecological and climatic variations sometimes favouring the proliferation of this microfauna (figure 7).

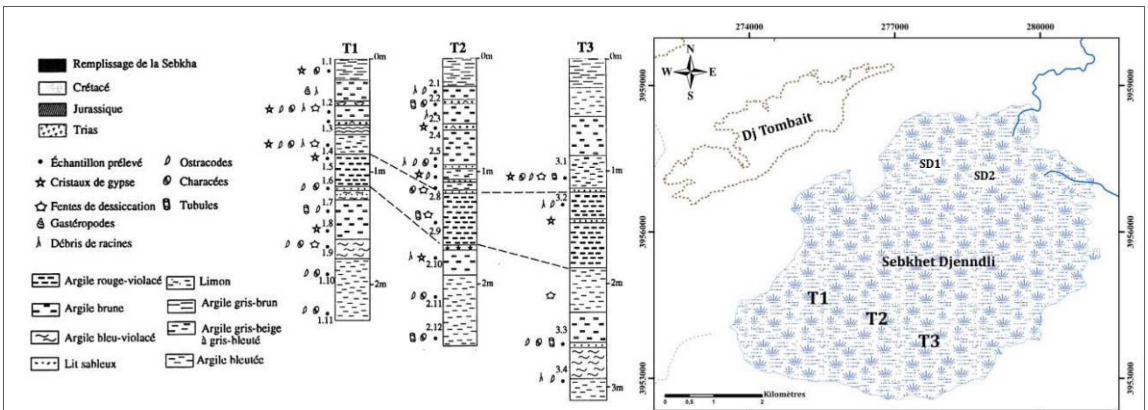


Figure 7. Soil profiles from the Sebkhet Djendli trenches (Marmi, 1995)

- *Electrical conductivity (70 water points)*

The work undertaken on Sebkhet Djendli concerns hydrogeological measurements from which a conductivity map has been drawn up (Figure 8). It appears that the salinity of the water increases progressively from the outside (periphery) to the inside of the Sebkha. Where it can exceed 10,000 µs. This observation refers to surface water at a depth of 15-20 m, as deep boreholes (60 m and more) drilled by mechanical probing have reached the freshwater table (conductivity ~1500 µs). This water table is probably separated from the upper (superficial) water table by an impermeable clay screen, thus isolating the two water tables.

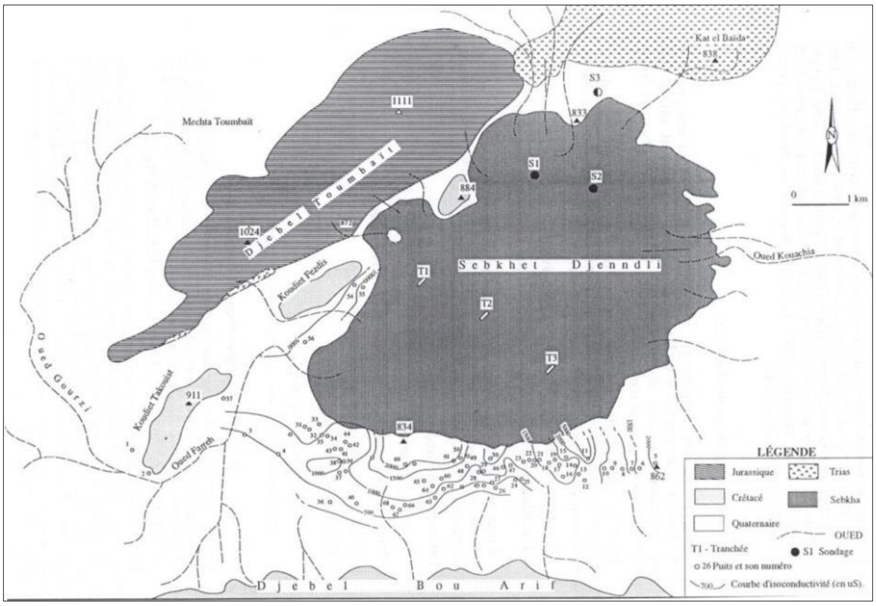


Figure 8. Electrical conductivity map (Sebkhet Djendli) (Marmi, 1995)

The salinity of the surface water could be induced by the leaching of the Triassic terrain in the vicinity (Djebel Toumbaït and Koudiet el Baïda foothills) during run-off, transporting dissolved salts to the Sebkha. In the dry season (June-September) the bottom of the Sebkha is covered with a whitish gypsum-salt pellicular crust.

In the Boulhilet plain

About 30 soil profiles were carried out across the plain, sampling five horizons at more or less regular intervals. Approximately 150 samples were collected from all the profiles.

Horizon 1

- *The distribution of «EC / Na»*

On both maps (Figure 9), the EC and Na anomalies are comparable and are located near the Sebkhas: Djendli, Garaets el Marhsel and Ank Djemel. However, the high values occur along a well expressed N-S corridor, passing through Garaet el Marhsel and skirting the Ank Djemel garaet in its western part. It is worth noting the presence of large outcrops of Triassic formations north of Sebkhet Djendli and north of Garaet el Marhsel.

Probably the anomalies of the high values of CE and Na would have as origin these saliferous deposits following their leaching by the waters, whose flows of the wadis are made towards the South. As for the strong anomaly just southwest of Sabkhet Ank Djemel, the source of these salts would be located on the edge of the southern flank of Djebel Bou Arif where triassic deposits were outcropping and the salts are transported via Oued Chemora-Boulhilet which has its source in the Timgad plain.

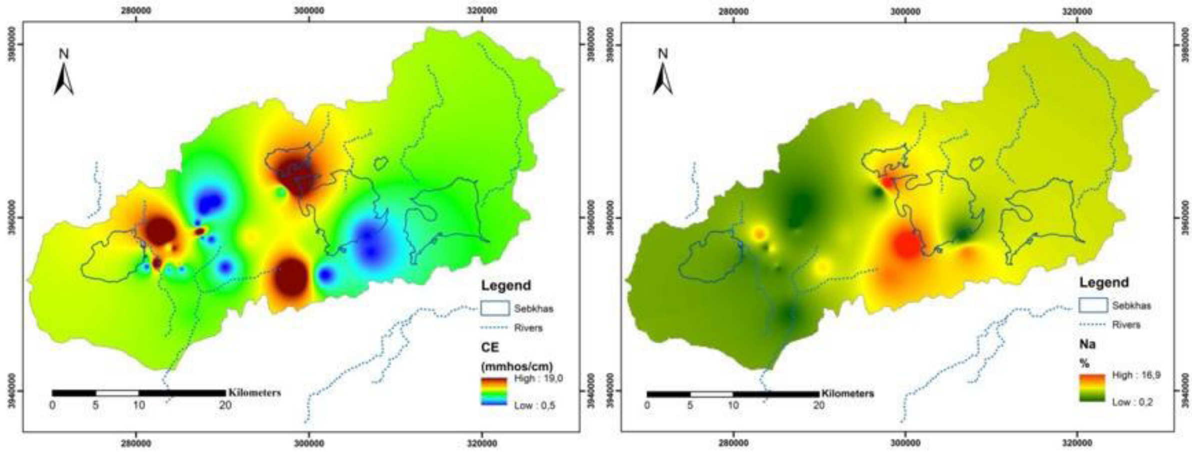


Figure 9. Distribution of electrical conductivity (EC) and (Na) across the soils of the sebkhas area of South Constantinois (Horizon1)

- *The distribution of «SO4 / gypsum»*

The two main anomalies of high SO_4 and gypsum values are located at the same places (superimposable anomalies), and the supply of these two elements of these zones would be respectively from the North, concerning the anomaly which is just west of Sbkhet Djendli and from the South for the anomaly which is located south-west of Sebkhet Ank Djemel.

The inputs would be carried respectively by the wadis coming from the North, washing the Triassic formations which outcrop just N-E of S. Djendli and Oued Chemora-Boulhilet. This last wadi has its source in the plain of Timgad and receives during its course several small wadis descending from the southern flank of Dj. Bou Arif. They then leach the salts from the Triassic deposits outcropping along the southern edge of Dj. Bou Arif, while feeding the Chemora-Boulhilet wadi which flows into the Boulhilet plain (Figure 10).

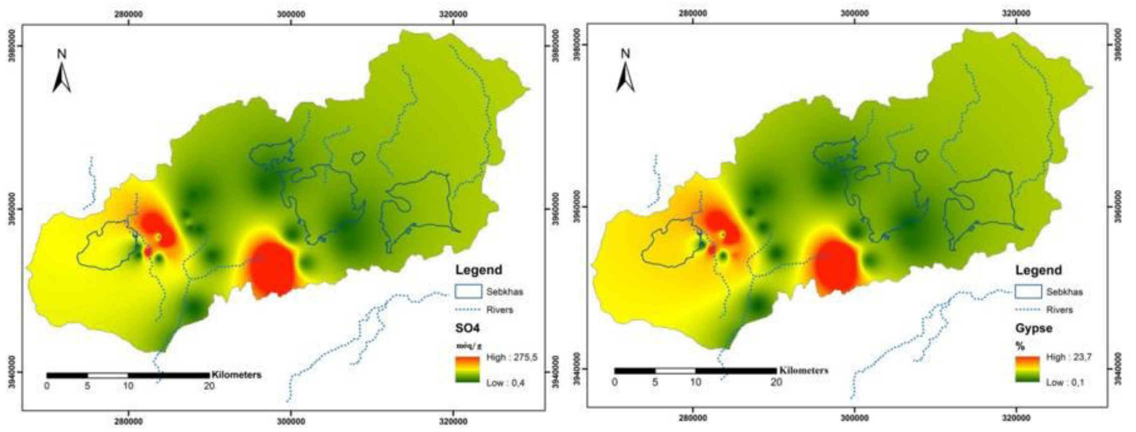


Figure 10. Concentrations of (SO_4) and (gypsum) in the soils of the sebkhas area of South Constantinois (Horizon 1)

Horizon 2

- *The distribution of «EC / Na»*

In horizon 2 (between 55 and 65 cm depth) there is no concordance between the locations of the high EC values on the one hand and Na on the other. The N-S anomalous corridor observed in the case of horizon 1, still remains expressed only for Na on horizon 2 (deeper). This enrichment in Na could be explained by the contributions coming from the North and South via the wadis and facilitated by infiltration through a more permeable soil of the upper horizon (Figure 11).

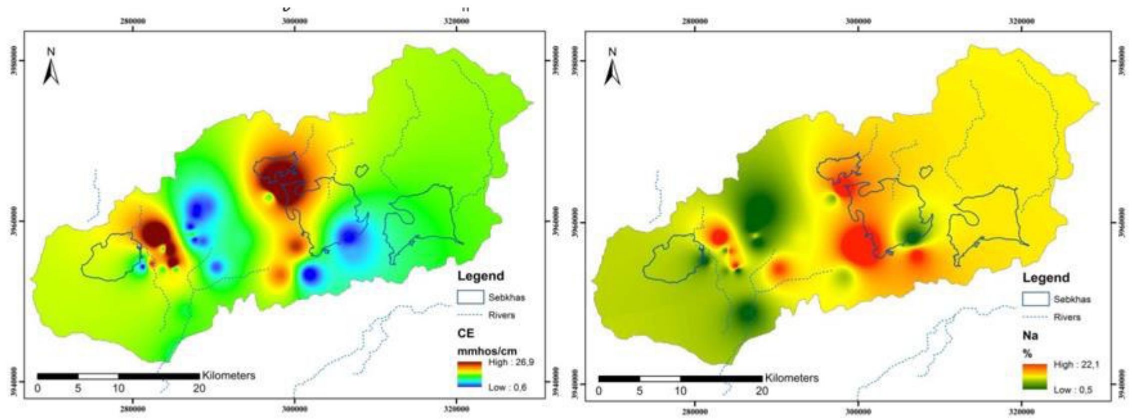


Figure 11. Distribution of electrical conductivity (EC) and (Na) across the soils of the sebkhas area of South Constantinois (Horizon 2)

- *The distribution of «SO_4 / gypsum»*

The high SO_4 and gypsum contents are located in two similar sites for both elements and are respectively, SW of Garaa Ank Djemel, at the mouth of Oued Chemora-Boulhilet (relatively more extensive anomaly) and NE of Sebkhet Djendli (less expressed and less developed anomaly) (Figure 12). The source and transport of these elements would be similar to those reported in the previous case (horizon 1).

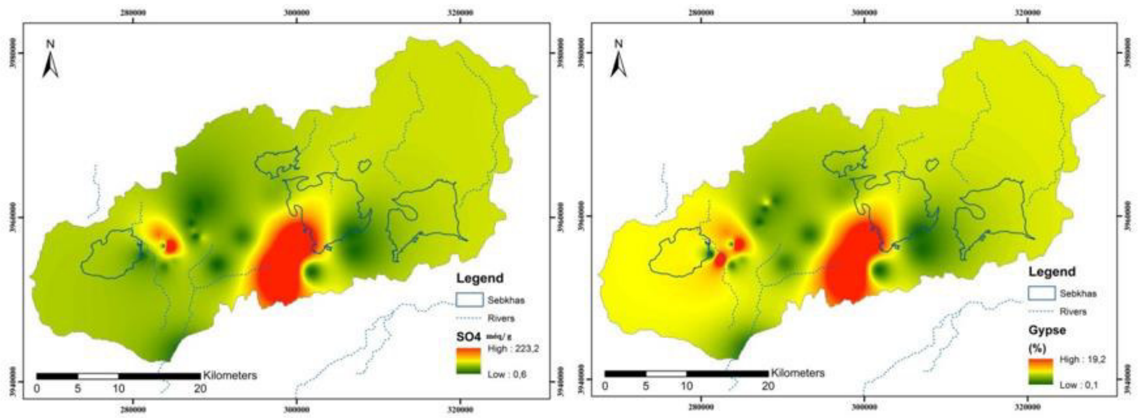


Figure 12. Concentrations of (SO_4) and (gypsum) in the soils of the sebkhas area of South Constantinois (Horizon 2)

Horizon 3

- *The distribution of «EC / Na »*

This is a deeper horizon than the previous horizons (Horizon 1 and 2), lying at about 90 to 110 cm depth. The mapping shows a large funnel-shaped CE anomaly, quite wide in its northern part, which narrows towards the south (Figure 13). On the other hand, the high Na values show an anomaly, relatively smaller than that of EC, located at the mouth of Oued Chemora-Boulhilet. So for these two elements their anaomalies are not concordant (not superimposable), this dissociation would be in relation with the evolution of the soil in depth which favours a perceptible percolation and an increase of the values with depth.

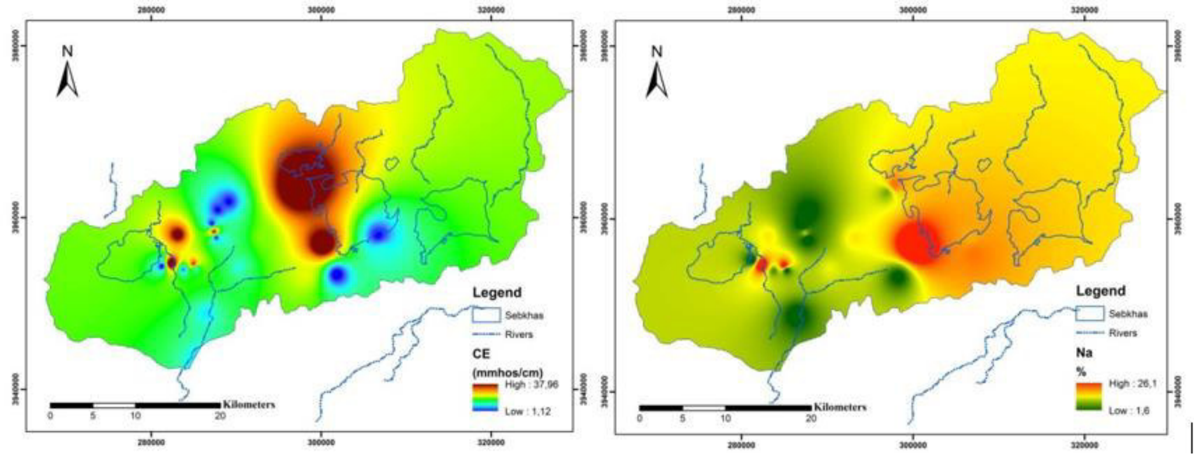


Figure 13. Distribution of electrical conductivity (EC) and (Na) across the soils of the sebkhas area of South Constantinois (Horizon 3)

- *The distribution of «SO4 / gypsum»*

For sulphates, the mapping shows a clear similarity between the spatial distribution of high levels of these two variables (anomalies), they are better expressed in the western part of the plain. However, a fairly small anomaly of high sulphate content stands out and is isolated at the mouth of Oued Chemora-Boulhilet (Figure 14).
It should be noted that the grades of these two elements decrease significantly with depth in the profiles.

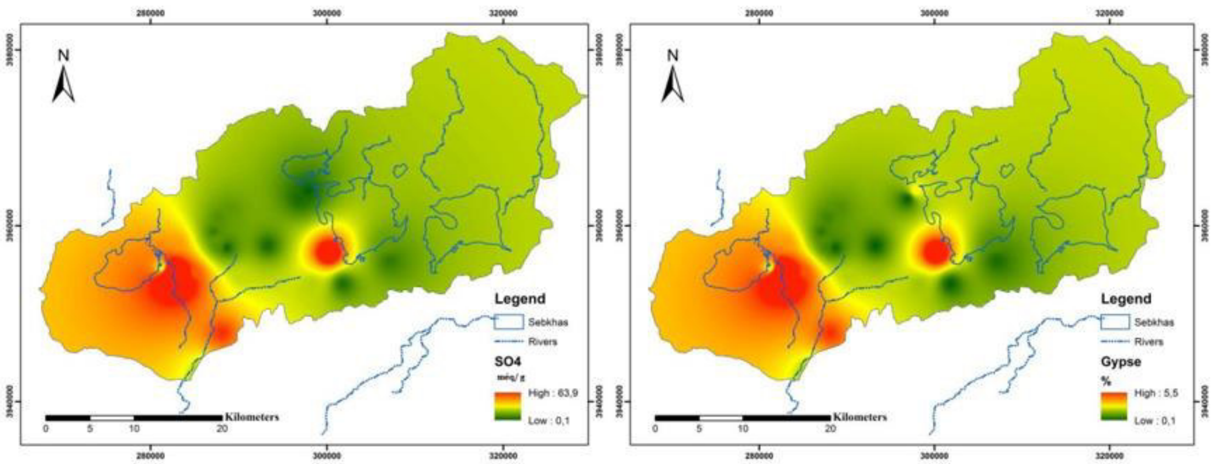


Figure 14. Concentrations of (SO_4) and (gypsum) in the soils of the sebkhas area of South Constantinois (Horizon 3)

- *The concentration of "Total $CaCO_3$" in soils*

The total limestone contents are certainly somewhat abnormal (relatively high) in the lower parts of the plain, after the glacis (east and west of Boulhilet, between Chemora and Boulhilet, west of Henchir Seffane and south of Coudiet Zrazer and between the glacis north of Sidi Bouzid -Thimendanine). These contents are characteristic of calc-magnesic soils; they are higher at depth (Figure 15): total base exchange capacity.
The $CaCO_3$ concentrations show the influence of the important calcareous stock surrounding the plain.

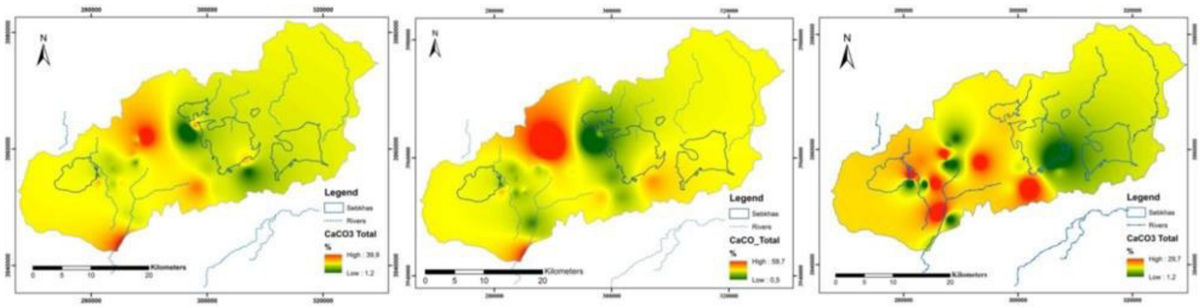


Figure 15.: Concentrations of $CaCO_3$ in soils of the Southern Sebkhas area (Horizons 1, 2, 3)

- *The « pH »*

The most relatively low pH values are found in the area between Sabkha Ddjendli in the east and Garaat Ank Djemel in the west, for all three horizons considered. However, at the level of horizon 2, this sector is characterised by lower values.
The pH is too high on the eastern edge of sebkhet Djendli as well as in the southern part of gareat Ank djemel (reaches a value of 8.9), it increases as one descends in depth (Figure 16).

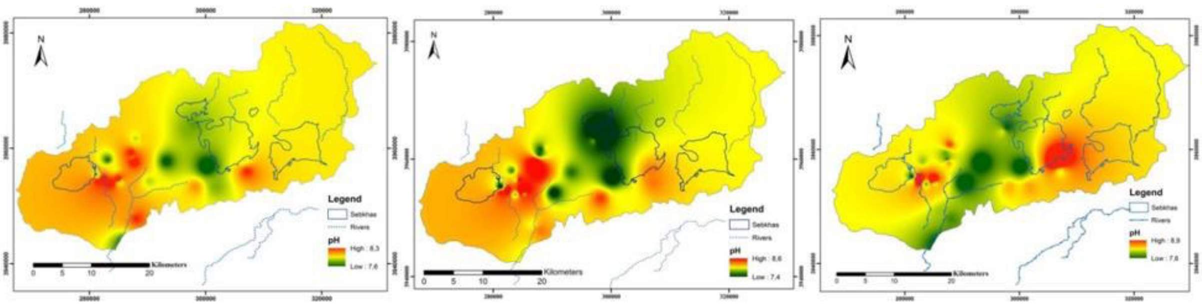


Figure 16. Distribution of pH across the soils of the sebkhas area of South Constantinois

If we summarise, EC and Na values increase in depth across the plain and on the contrary gypsum and sulphate concentrations decrease in depth (Tables 1 and 2). The values of $CaCO_3$ and pH remain globally less variable across the different horizons but in detail, these two parameters show a slight increase with depth (Tables. 1 and 2).

Table 1. The different parameters analysed and their vertical distribution (average values)

Parameters Horizons	EC (mmhos/cm (moy)	Na% (moy)	Gypsum % (moy)	SO4 méq/g (moy)	$CaCO_3$ total% (moy)	pH (moy)
Horizon 1	6,4	6,14	3,7	42,72	20,3	7,9
Horizon 2	8,8	8,3	3,6	36,7	21,8	8,0
Horizon 3	14,1	9,2	1,3	14,8	24,0	8,2

Table 2. The different parameters analysed and their vertical distribution (maximum values)

Parameters Horizons	CE (mmhos/cm (max)	Na% (max)	Gypsum % (max)	SO_4 méq/g (max)	$CaCO_3$ total % (max)	pH (max)
Horizon 1	19,0	16,9	23,7	276,0	40,0	8,3
Horizon 2	27,0	22,1	19,2	223,5	60,0	8,6
Horizon 3	38,0	26,1	5,5	64,0	61,0	8,9

DISCUSSIONS

Thematic mapping (performed by IDW interpolation), based on soil analysis data, facilitates the analysis and interpretation of the results. It makes it easier to visualise the spatio-temporal evolution of abnormal concentrations of the different variables. The soil sampling was carried out in the 1970s, when rainfall was relatively higher than at present. It is likely that this rainfall was the cause of the dissolution of the salts and consequently of their infiltration into the ground. The hydrographic network has played a decisive role in the contributions, by leaching of the surrounding geological formations and more particularly those of the Triassic period which are rich in salts and sulphates. The relatively high level of $CaCO_3$ reflects the dominance of the carbonate rocks surrounding the sebkhas zone, which constitute a source of calcium carbanate.

CONCLUSIONS

In the study area, the useful agricultural area is already limited and is further threatened by degradation processes (salinisation, sodification) and even by contamination with trace elements such as Zn, Cu, Cr, Ni, Ba..., especially the well water used to feed the inhabitants (AEP).
Through the mapping, the EC and Na contents increase with depth from the upper to the lower horizons (H1 to H3), whereas the gypsum and SO_4 contents decrease with depth (H1 to H3) through all the soil profiles.
In the first case, this can be explained by the solubility of Na, which facilitates its leaching from the superficial horizons to the deeper horizons in relation to the character of the soils of the different horizons where little evolved alluvial soils are generally dominant. In the second case, sulphates are not very soluble and tend to crystallise to give minerals that are retained in the superficial levels, which consequently results in their low percolation at depth.
The distribution of $CaCO_3$ will remain limited due to its low solubility and reduced rainfall over the region. The average pH value across the plain soils is around 8, but through the horizons considered, the pH increases with depth. Certain factors are responsible for these concentrations across the Boulhilet plain:

- The nature of the geological formations (the Triassic gypsiferous formations of Djebel Tombaït, the violet Mio-Pliocene marls of the Timgad basin and the south-western slope of Bou Arif and the large stock of limestone surrounding the plain),
- The irregularities of the climate, characterised by a drought that becomes more pronounced with each passing year,
- The wind action (wind deflation) is marked in all seasons and has become more pronounced especially in areas without vegetation. The existence of sebkhas and garâas, and their drying out for long periods, favours the deflation of salts and their spreading on the plain accentuates the salinity of the soils,
- Leaching by runoff and infiltration through horizons....etc.

RECOMMENDATIONS

- *If these halomorphic soils are left uncultivated, and under current climatic conditions, they will evolve very little or not at all.*
- *On the other hand, if they are worked and cultivated (e.g. some fodder crops adapted to clay textures and high salinity), the salts will be leached out and the soils will evolve into poorly developed soils or green soils (see profile N°16) [1].*

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