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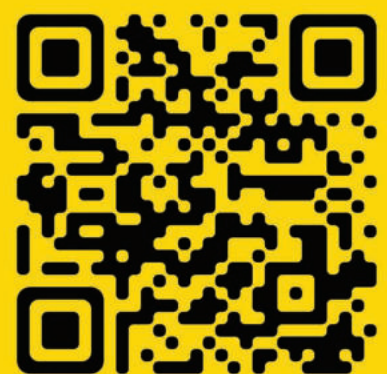
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GIS and remote sensing – desertification and progression of silting-up in the high plains of Oran in Western Algeria

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Abstract. The expansion of silting in the Algerian High Plains of south Oran (northwestern Algeria) is the ultimate manifestation of desertification. The presence, accumulation or deposition of sands in areas that previously did not contain any is the most visible sign of this silting up phenomenon that has begun to appear in recent decades. The present study focuses on the evolution and progression of silting up in the region under study. It is worth noting that assessing the narrowing of the vast endorheic depressions in this area is a very complicated task due to the vastness of the place. In order to deal with this problem in an efficient manner, it was deemed necessary to use remote sensing as it offers possibilities of global vision of the area to be studied and allows a precise description in time and space of this region. In order to efficiently identify and apprehend the phenomenon mentioned above, it was decided to adopt an analysis methodology that is based on the processing and interpretation of multi-date satellite images, combined with exogenous data. It should be noted that the topographic maps of Mecheria and Ain Sefra are given at a scale of 1/200,000 and are supplemented by some field data, along with some wind data. The analysis of data brought from different sources has made it possible to locate, characterize and map the evolution and the spatio-temporal dynamics of the recent extension of sandy accumulations, old Quaternary dune belts, and shrinking of vast endorheic depressions (Chott El Gharbi and Sebkhât Nâama). It is widely acknowledged that areas that are most affected by the progression of silting are the Plain of Naama, that is surrounded by the first Saharan Atlas ranges and by the orographic corridor formed by the double SW/NE alignment of Djebel (Mount) Morhad, Djebel Suigua, Djebel Aïssa and Djebel Mekter located south of Ain Sefra. It is important to note that all this information, which is extracted from satellite images and exogenous data, will be integrated into a GIS.

Keywords. Desertification; Siltation; Sand mobility; Wind erosion; Remote sensing

1. Introduction

Desertification is generally defined as the transformation of a non-desert natural environment into an environment with desert characteristics, such as the strong regression or disappearance of plant cover, dunes, and regs (stony plains).

It is useful to remember that the High Plains of Oran (Algeria) have been the subject of numerous research works which investigated the degradation of steppe vegetation and the

disappearance of certain plant species, such as Alfa, White Mugwort, Sparta that have been replaced by other significant species from very degraded soils [1].

The region under study is particularly characterized by various landscapes. It should be remembered that this area is a vast plain that is located between the Tell Atlas (Mounts of Tlemcen, Mounts of Saïda) and the Western Saharan Atlas (Mounts of Ksour) to the south; it is enclosed by the first ranges of the Mounts of Ksour, namely Djebel (Mountain) Antar, Djebel Getoub, Djebel Hafid, Djebel Suigua, Djebel Melah, Djebel Ar'Ar, Djebel Gaaloul, Djebel Kerouch, Djebel Morhad, and Djebel Mekter, as is clearly illustrated in (Figure 1)

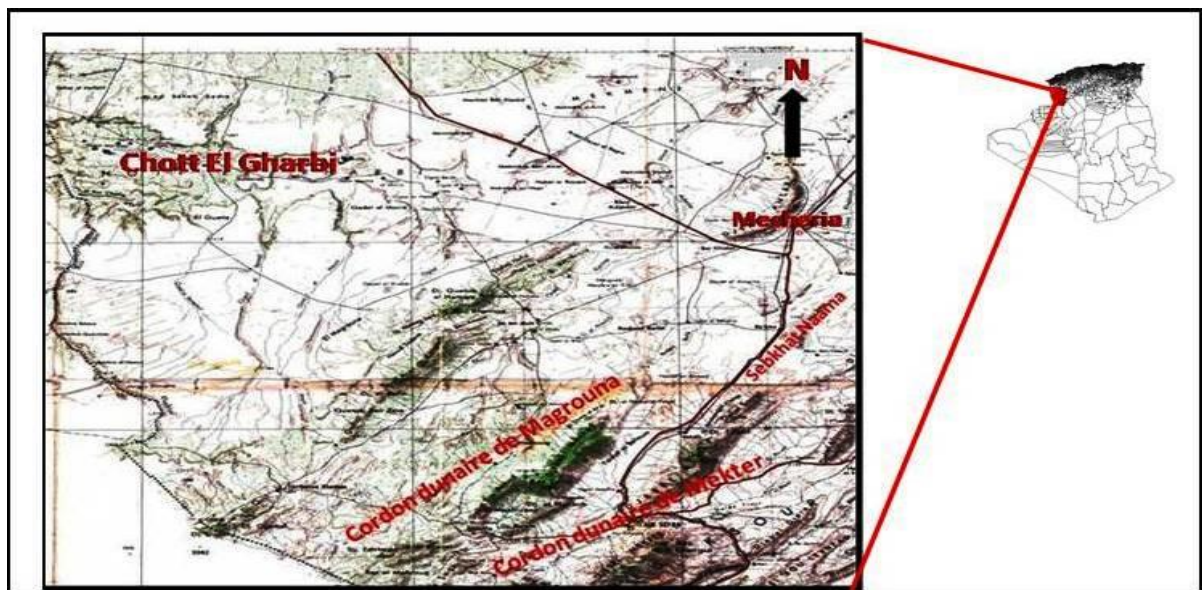


Figure 1: Geographical location of the High Plains of Oran (Western Algeria)

The plain is situated at an altitude that varies between 1100 and 1400 m. It is irregular and has many endorheic basins of various sizes and origins, such as the Aeolian deflation basin, oplat, dayas, mekmene, chott, sebkhat, and lakes

The rather old Magroune dune belt, which dates from the Quaternary period, extends parallel to the western piedmonts of Djebel Oum El Ar'ar and Djebel El Hadjret Toual, and on the NW side of Djebel Morhad. In addition, it stretches in the SW/NE direction, over a long distance of about 31 km, and a width of 4 km on the NE side and 3 km on the SSW side.

The other dune belt of Mekter, which is located south of the city of Ain Sefra, is parallel to the foothills or piedmonts of Djebel Mekter. This belt extends over 17 km long, and 2 to 3 km wide in the SW/NE direction.

Dune fields border the Sebkhah of Naama in the SW of Djebel Gaaloul, at the southern end of the great dune belt of Magrouna, and on the foothills of Djebel Hafid, Djebel Kerrouch, Djebel Ar'Ar, and other Djebels

Chott El Gharbi is a vast depression 90 km long. It extends from WNW to ESE, over a width that varies between 1 and 20 km. Chott El Gharbi has clear contours that are marked by very steep slopes and are very indented by the downstream terminations of the Wadis (Rivers). Most of the bottom of this chott is occupied by steppe.

Regarding the High Plains of Chott El Gharbi, they constitute a topographic entity. In the North, they have a disorganized hydrographic network with slopes often lower than 0.3%.

In the south, the slopes are smaller than in the north; they are equal to 0.15% near the Chott. One should notice the presence of wind forms in the NW, NE, SW and SE parts [2].

With regard to the South Plains of Oran, we note the presence of 1.2 million hectares of dense esparto steppe that were affected by silting between the years 1983 and 1990. In addition, dense stands extend through this plain over an area of about 500,000 ha. Moreover, the esparto cover dropped on average from 30 to 2%, while the open stands, which cover an area of approximately 700,000 ha, exhibited a total decline of this species [3].

It should be noted that currently, the steppe vegetation based on *Artemisia herba alba* and *Stipa tenassicima* is in an advanced state of degradation, as shown in **(Photo 1)**. Fortunately, lately the *Lygeum Spartum* formation has shown some dynamism since it has been gradually extending in certain areas as it partially colonizes the esparto facies. It has also been noted that white mugwort and esparto are among the species that are gradually replacing alfa which is progressively disappearing. Similarly, it has been noted that Harmel is present in the most degraded places, where human activity has been particularly present. Harmel is synonymous with the ultimate degradation of the environment.



Photo 1: The steppe has a very slow recovery rate, which is synonymous with degradation (May, 2005)

The major contribution of this study is to show the impact of desertification through the spatial extension of sandy deposits in the High Steppe Plains in the South of Oran. For this, it was deemed more appropriate to conduct this study in five stages, in order to better understand and monitor this phenomenon of desertification (Figure 2).

The causes of this state of the ground surface are complex and varied. They are generally attributed to the impact of the bioclimatic shift of the lower semi-arid stage and to the arid climate that generates the drought which is taken here in its climatic sense. Drought is synonymous with rainfall deficit with respect to the average of a long precipitation series. This deficit is characterized by the standard deviation. The most severe and longest drought phase is undoubtedly the one that began in 1965 and lasted for more than 30 years. However, it was noted that there has been a trend for improvement since the year 2000. This drought certainly favored the desertification phenomena because it coincided with the strong demographic growth

of the country and a voluntarist attitude in planning policy. It should be remembered that since the first years of independence, great efforts have been made to bring the steppe and Saharan regions out of their isolation and to launch real economic development projects [4].

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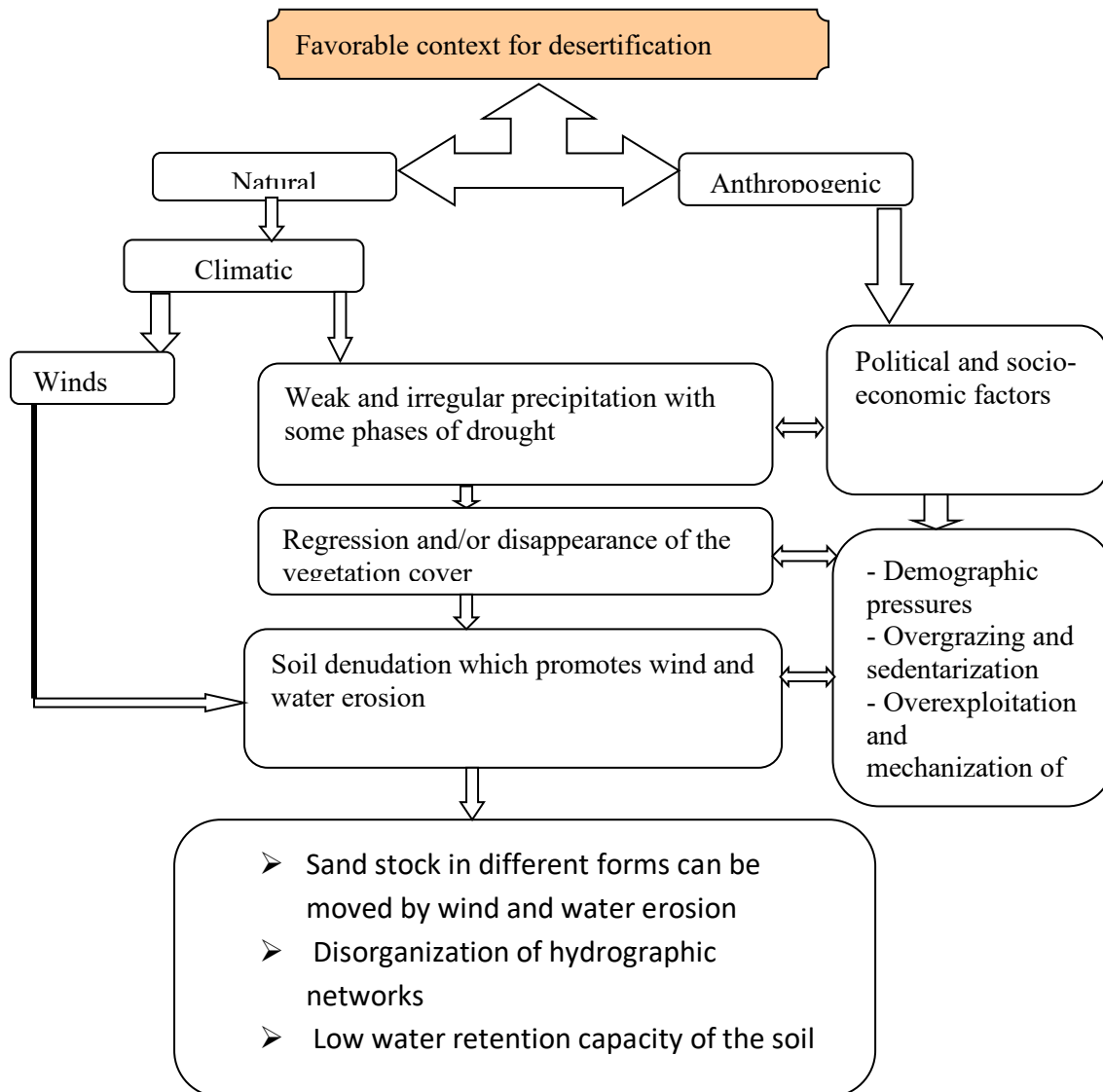


Figure 2: Diagram representing the favorable context for desertification

2. Methodological approach

An appropriate and well thought-out methodology has been adopted for the purpose of better identifying and understanding the problems cited above. It includes several parts

A bibliographic research on steppe in the South of Oran, in particular on the region of Naama, Mecheria, Ain Sefra and the Mounts of Ksours, because the explanation of

desertification is not limited only to the local scale and local factors, but obviously to a more global scale.

The cartographic documentation and satellite images that served as the basis for the approach adopted include:

The topographic map of Ain Sefra with a scale of 1/500,000 to delimit the study area and also to characterize the major morphological units on a global scale. [5].

The topographic map of Ain Sefra and Mecheria with a scale of 1/200,000 to illustrate the morphological characteristics on a larger scale and also delimit the sand contributions that already exist there.

DTM SRTM (Shuttle Radar Topography Mission) data, to represent the terrain in three dimensions and bring out relief forms with greater precision.

Satellite images at several different dates from AISat A, Landsat, and Google Earth images

3. Characteristics of the southwestern part of the High Plains in the South of Oran

3.1. Two geomorphological units - Plains linked by highly diversified foothills and mountain ranges (Figure 3)

The High Plains of Oran are located south of the northern Tell which is composed of the Mountains of Tlemcen and Saïda. They form a transition zone with the Western Saharan Atlas, i.e. the Ksour Mountains. These plains are mainly characterized by vast flat surfaces, with an average altitude of 1000 m, rugged Dayas or lowlands, with a Sebkhha generally referred to as Sebkhhat Naama in the east, and Chott El Gharbi in the west

These plains are also surrounded and fragmented by mountain ranges belonging to the Mountains of Ksour. These mountains all possess the same orientation (SW/NE), with a wider spacing to the north, i.e. between Djebel Hafid and Djebel Kerrouche (1801 m) to the west, and Djebel el Maleh (1625 m) to the east, and a narrowing to the south (Djebel Bou Amoud, Djebel Morhad and Djebel Aïssa-Souïga). Note that these Djebels (mountains) divide the Mekalis area into two or three orographic corridors along the same direction, but they have different widths. We should also know that corridors are relatively closed by the southern end of Djebel Aïssa which has a WSW / ENE direction. The cluse of Ain Sefra is a zone of passage. We note also the presence of the quaternary dune belt of Magrouna and the dunes of the same age of Sebkhhat Naama

The High Plains of Oran are located south of the northern Tell (Mountains of Tlemcen, and Mountains of Saïda) and form a transition zone with the Western Saharan Atlas (Mountains of Ksour). The main characteristics or originalities of this region can be summed up in vast flat surfaces, 1000 m in altitude on average, with rugged Dayas or other lowlands, in addition to a Sebkhha and a Chott (Sebkhhat Naama in the east and Chott El Gharbi in the west). These plains are surrounded and separated by mountain ranges belonging to the Mountains of Ksour. These mountains show the same SW/NE orientation, with a wider spacing to the north, i.e. between Djebel Hafid (1407 m) to the west and Djebel el Maleh (1625 m) to the east, in addition to a narrowing in the south including Djebel Bou Amoud, Djebel Morhad (2136 m) and Djebel Aïssa-Souïga (1758 m). These Mounts divide the Mekalis area into two or three orographic corridors, which are oriented in the same direction, but they have different widths. They are relatively closed by the southern end of Djebel Aïssa (2236 m) that is oriented along the WSW/ENE direction. It is worth emphasizing that the cluse of Aïn Sefra is a transition zone

It should also be noted that the quaternary dune belt of Magrouna and Mekter and the dunes of the same age of Sebkhata Naama, as well as Chott El Gharbi have the morphological characteristics of High Plains. [6].

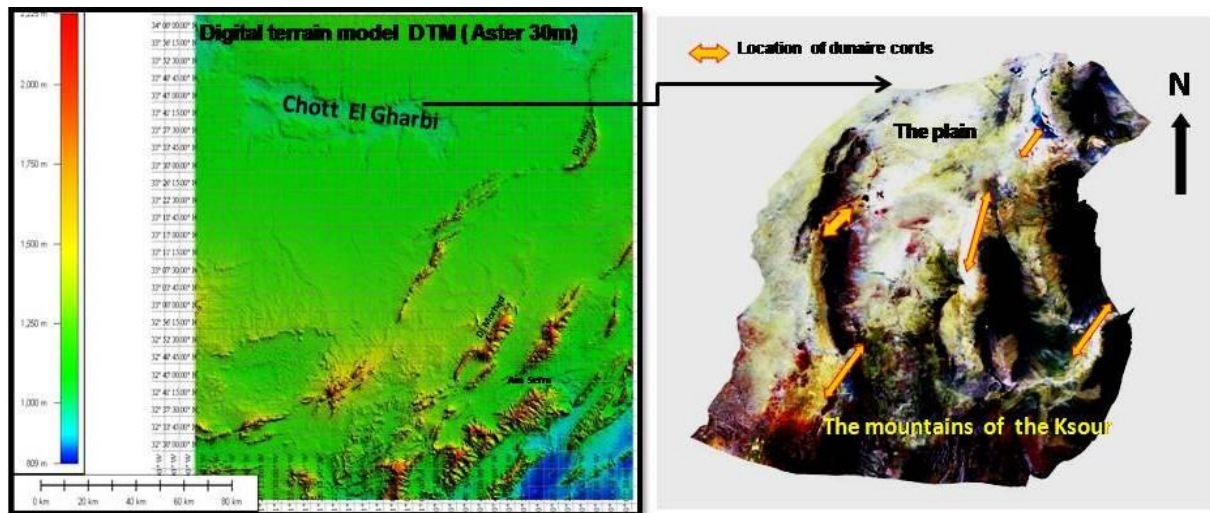


Figure 3: Draping a satellite image onto the digital terrain model - The morphological characteristics of land

3.2. The Quaternary dune belts of Magrouna and Sebkhata Naama

3.2.1. The Magrouna dune belt

The dune belt of Magrouna is quite old; it dates from the Quaternary period. It extends parallel to the western piedmonts of Djebel Oumm El Ar'ar and Djebel el Hadjret Toual, and to the NW of Djebel Morhad. This dune belt extends, along the SW/NE direction, over a length of approximately 29.85 km with a width varying between 3.70 km (NE) and 2.45 km (SSW), with an orientation of 37.29° SW and 43.15° NE.

3.2.2 Ancient dunes around Sebkhata Naama and Chott El Gharbi

The old dunes of the two large depressions constitute real dune fields (Heights of more than 2 to 3m). They are located at the W, SW, SSE and ENE ends of Sebkhata Naama, and also in the SW, NE and SSW regions

3.2.3 The dune belt of Mekter

The quaternary-age dune belt of Mekter is old (more than 10,000 years). It extends parallel to the foothills of Djebel Mekter (2062 m). This belt extends over a length of almost 18 km with an orientation identical to that of Djebel Mekter (SW/NE). It is also parallel to Oued El Bredje which flows in the SW/NE direction

4. Results

It is worth indicating that a clear extension of the areas affected by silting has been noticed in recent years, with the shrinkage or narrowing of Sebkhata Naama and Chott el Gharbi.

The methods of analysis of the process were carried out based on an estimation of the distance over which this silting phenomenon has progressed during several years, as shown in (Table 1).

Table 1: Spatio-temporal evolutions, progression of dunes, and shrinkage of closed depressions

	1984	1992	2004	2012	2022	Results
Old dune formation in Magrouna	28.20 Km	28.77km	29km	29.98km	30.48Km	- Western Piedmont of Djebel Morhad, Quaternary dune belt. - The direction of progression is SW/NE
Old dune formation in Mekter	12.39 km	12.89 km	14.5 km	16.99 km	18.98Km	- Western Piedmont of Djebel Mekter (Ain Sefra); Quaternary dune belt. - Direction of progression is WSW/ENE
Chott El Gharbi (Mekmen Ben Amer)	75.76 km	52.57 km	45.03 km	30.5 km	25.9 Km	- West of Mekmen Ben Amer. - Very clear narrowing of Chott El Gharbi due to silting (recent sandy deposits).
Sebkhat Naama	24.35 km	23.88 km	22.86 km	21.75 km	18.15 Km	- Presence of old quaternary dunes east of Naama (higher than 3m), on the W-N and South edges. - Narrowing of Sebkhat Naama due to silting (extension of old dunes).
Spatial extension by mobile dome and barchan sand dunes	The silting progressed according to two different scenarios: - Extension of quaternary old dunes - Formation of recent mobile dunes such as <i>dome</i> and <i>barchan sand dunes</i> . Presence of sand topping and sand heaps.					

4.1. Extension of silting

The evolution of silting was assessed by superimposing the processed satellite images. It should be noted that three types of aeolian deposits have been taken into account.

The Quaternary dune belts of Magrouna and Mekter, with two classes of recent mobile dunes (*dome* and *barchan sand dunes* with a height greater or smaller than 2 m). Overall, we can say that the dune belts have progressed, in a regular way, at a rate of 3.85 Km/year during the past 34 years, i.e. between the years 1984 and 2022. It should be noted that the surface of the dune belt of Magrouna (western piedmont of Djebel Morhad) has almost doubled. In addition, the surface of large dunes higher than 2 m increased by about one third.

Further, it has been revealed that the silting progressed according to two scenarios. First, the extension of old quaternary dunes and formation of new dunes and second the progression of recent aeolian deposits.

4.1.1 Expansion of ancient dunes

The old dunes are located in four major sites: at the northern end of Djebel Antar which is not taken into account in this case, at Mangoura (western piedmont of Djebel Morhad, on the borders of Sebkhata Naama and near Lake Haoud Daïra), west of Ain Benkhelil, south of Chott El Gharbi, and finally in Mekter, south of Ain Sefra.

It is worth indicating that in Mangoura and Mekter, the quaternary dunes are barchans more than 10 m high, as shown in (Photos 2 and 3). These barchans by adjoining gave birth to a belt about 30 km long and 3 to 4 km wide, stretched parallel to Djebel Morhad for Magrouna, and 19 km long and 3 km wide, running parallel to Djebel Mekter, for the dune belt of Mekter

The evolution took place in the form of an enlargement of the dune belt itself as well as an extension of its edges and its northern and southern extremities, in the form of small dune fields. The quaternary dunes bordering Sebkhata Naama in the west are 3-10 m high, with a narrowing of the Sebkhata due to silting up. The same wind system also applies to Chott El Gharbi which has suffered a narrowing following the formation of quaternary dunes on the SW, NE and NW sides.

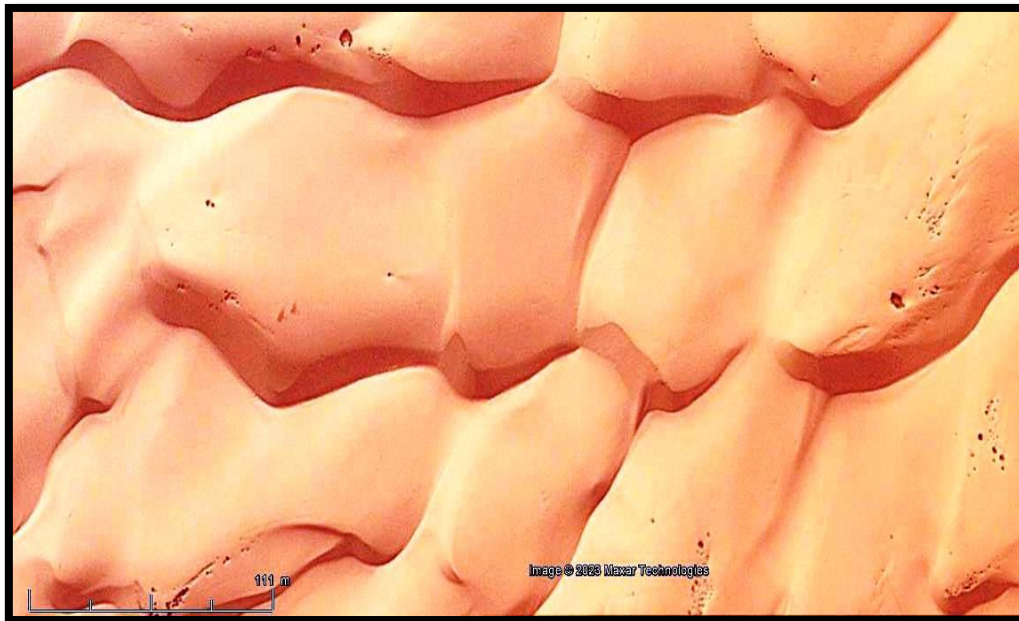


Photo 2: Dune fields of Mekter



Photo 3: Dune fields of Magrouna

4.1.2. Genesis and progression of recent sandy deposits

The areas recently occupied by sands and in which they extend are:

- The SW part of the Naama plain, between Djebel Bou Amoud to the west and Djebel Morhad-Mangoura to the east
- The cluse of Oued Saadane (Djebel Hafid and Djebel Guetob) is in spatial continuity with Lake Haoud Daïra. There are small domed dunes with a height of less than 2 m.

5. Explanation and interpretation of the shapes and arrangement of sand deposits

The silting forms and their spatial arrangement are explained by the wind regimes and the arrangement of the small advanced links of the Mountains of Ksour in this region of the High Plains in the South of Oran.

Figure 4 shows the annual resultant DPS calculated from anemometric data recorded during the day, every 3 hours, during 10 to 12 years. It indicates the directions N - 298° and WNW/ESE for Mecheria, and N - 284° and WNW/ESE for Ain Sefra. No potential displacement of sands was observed over long distances, except during the months between September and April ($M_r/CT > 0.3$), along the direction N 295° - 300° (WNW/ESE). The rest of the year was characterized by a strong mobility of sands, but without notable displacement. In May, the month of transition, the DPS was NW/SE (N - 327°) at Mecheria, and WSW/ENE (N 253°) at Ain Sefra. [7].

Furthermore, the morphological context is characterized by the NE/SW to N/S orientation of the small advanced ranges of the Mountains of Ksour, which gives an overall topography where narrow Djebels and more or less wide plains alternate. The two entities are connected by glacis or spreading areas (alluvial aquifers rich in sand).

This type of arrangement of small Djebels (mountains) oriented almost perpendicularly to the resulting directions of the DPS favored the trapping of sands on the western foothills and on the edges of wetlands. [8]. In addition, the reduction in spacing between dunes towards these

reliefs is quite revealing because everything happens as if the apparent advance of the silting up towards the North and the East is in fact the consequence of the filling of the area by the accumulation of sands blocked by ranges and the residual relief resulting from their erosion. This is also the case, for example, for Rokbet Harchaïa in the north of Naama. [9].

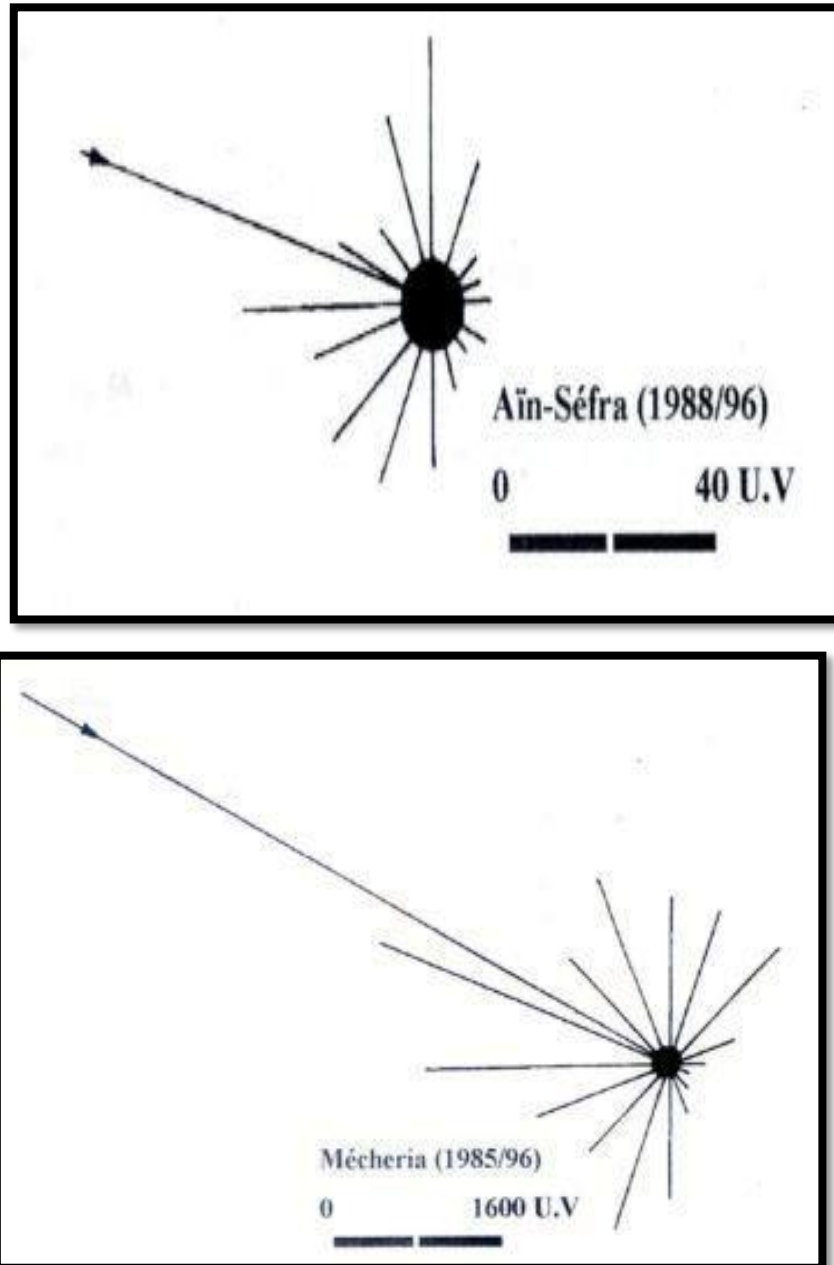


Figure 4: Average annual result of DPS in Mecheria and Aïn Sefra

Conclusion

Between the years 1984 and 2022, silting, the most visible and formidable process of desertification, has almost doubled in area in the High Steppe Plains in the south of Oran. Thanks to satellite images acquired at different dates and archived in recent years, it has been possible to establish diachronic studies in order to highlight and locate the areas that are most affected by silting. This also allowed determining the variations of the vegetation cover.

Desertification has found favorable ground with the virtual disappearance of steppe vegetation. The landscape took on significant forms such as very mobile small dunes, often barchans. The spatial arrangement of the sandy accumulations is the result of the double interaction between the relief and the DPS. Indeed, the study of the mountainous reliefs (orography) has confirmed the presence of an alternation of small mountain ranges and rugged plains, with numerous lowlands receptacles of all the runoff (including the sediments carried by this runoff). The whole presents a NE/SW or NNE/SSW orientation that is nearly perpendicular to the annual resultants of the DPS (N 298-300°).

This has resulted in the trapping and accumulation of sand on all the foothills or slopes facing west and north, as well as on the edges of wetlands. Over time, these foothills and slopes fill with sand that is mobilized by the West and North winds. In addition, the barchans stick together to form belts parallel to the main reliefs and gradually colonize the region to the north and east. The endorheic-type flow of Wadis (rivers) contributes to accelerating, maintaining, and also perpetuating this process by reworking the sands trapped on the foothills and depositing them in the lowlands of the plains.

Then the wind remobilizes them in turn and so on. Desertification thus takes forms that make it permanent if appropriate developments, relating to both wind and water phenomena, are not made to this steppe zone that is weakened by the negative anthropogenic action that was present during several decades

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