Land Cover/Land Use Dynamics in Arid Mediterranean Fragile Ecosystems and its implications on Economic and Environmental Imbalances, southern Tunisia

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Received:- 10 May 2022/ Revised:- 18 May 2022/ Accepted:- 24 May 2022/ Published: 31-05-2022

Abstract - *The Tunisian arid environment has been the scene of profound territorial transformations characterized by a speculative agricultural influence on fragile steppe ecosystems. The Skhira region is a typical example through which this work proposes to follow these transformations and analyze their socio-economic and environmental impacts. To do this, a GIS database was created on QGis software, using two satellite images (from 1996 and 2020). Land cover/Land use maps obtained were supplemented by forty farmers' field surveys and interviews with decision-makers involved in agricultural activity. The results showed an extension of irrigated crops by 14.4% to the detriment of steppes and rainfed cereal crops. This intensification was the result of an incentive policy undertaken in the region since 1993 and originally aimed at small farmers but which, after 2011, was taken over by a group of large farmers who intensified the exploitation of limited resources. This has resulted in a degradation of biodiversity with the disappearance of several vegetation species, overexploitation of water resources which reached 216% in 2020, groundwater and soils salinization and greater exposure of crops to the harmful effects of climate change and desertification. On the social level, and although several productions have declined following the degradation of resources, the profits have been mainly drawn by the large farmers. This agricultural extension, especially the irrigated one, has failed to limit inequalities between social categories. On the contrary, the economy of Skhira' peasants is increasingly precarious and the social situation risks breaking out for this marginalized rural population.*

Keywords- Land cover/Land use dynamics, resources overexploitation, Desertification, socio-economic inequalities, Skhira, Tunisia.

I. INTRODUCTION

Elementary natural resources (water, soil, vegetation...) are today the object of all human lusts. Their exploitation often exceeds all limits in several countries of the World. According to Schultz (2017), the world population is expected to reach 11.2 billion by the end of the century, which will mean an increase in demand for food products (cereals, water, oils, sugars...). As a result, farmers will have to produce much more food in a competitive environment, which will require increasing farm sizes and shifting to higher-value crops. Small-scale farming will also play an important role, especially as the number of small-scale farmers grows.

In response to this demand, the world's irrigated agricultural area has already increased considerably, especially from the second half of the 20th century. Average irrigated crop production and yields have also quadrupled or quintupled to provide more than 45% of the world's food. In addition, this irrigated agriculture accounts for about 70% of the world's freshwater withdrawals (FAO 2000, Shultz 2017). In Tunisia, in 2006, it took up nearly 80% of water resources, and the overall rate of mobilization reached 91%, which constitutes an extreme limit (Bessaoud & Montaigne 2009, FAO 2018).

In the face of this situation, studies and reports prepared by international organizations (UNESCO, UNEP, UNDP, FAO, etc.) have constantly alerted countries to the gravity of the pressures their resources are under. All the ecological indicators put forward by specialists on the levels of consumption of terrestrial resources (The Earth Overshoot Day, Ecological Footprint, Living Planet Index, etc.) agree that over a year, the Earth reaches its limits more and more sooner and is therefore forced to draw on its reserves, often non-renewable (Cannet & Wackernagel 2018). For the "The Earth Overshoot Day"[1] indicator, for example, it coincided in 2021 with the date of 29 July, while it corresponded in 2000 to 1st November and in 1986 to 31 December (Saab 2012). Although widely criticized for its reliability and accuracy, this indicator leaves no doubt that natural resources are being degraded at a giant pace and that humanity is increasingly drawing irreversibly from Earth's reserves. Moreover, this pressure is most pronounced in regions with very few resources to provide, such as arid and desert regions (Abaab *et al.* 1995, Nedjraoui & Bédrani 2008, Hourizi *et al*. 2017, Nasser 2019). Studies and work that have studied this issue have always emphasized the limited capacity of the natural resources of these regions for intensive and sustained land use (Colloff & Baldwin 2010, Dougill *et al.* 2010, Linstädter *et al.* 2016). They have also shown the low resilience capacity of existing ecosystems (Floret *et al.* 1989, Neffati *et al.* 2016, Lipoma *et al*. 2021). In comparison, they have relied on traditional land use through which man has shown ingenious know-how and exceptional abilities to exploit resources in a rational manner enabling them to be sustainable and ecosystems to be resilient (Pontanier *et al.* 1995). Other studies have shown that resources pressure leading to natural balances breaking, has been carried out essentially in the last few decades of "peace" and "prosperity", during which man turned to a market economy based on high consumption in order to increase his profits without much concern for natural resources sustainability and for ecosystems resilience (Robert & Ross 1993, Greenwood & Smith 1997).

In arid Tunisia, the accelerated pressure on fragile natural resources has taken place in particular since the 1960s after the country's independence and the establishment by the Government of an agricultural development policy in order to create wealth among the peasant populations and to limit massive rural exodus during the years 1960-1970 (Elloumi 2015). In this region, while arboriculture has traditionally been practiced mainly in the mountains behind the *jessour*[2], the privatization policy will encourage its extension in plains at the expense of rangelands, promoted by the implementation of several national strategies for agricultural and rural development (Elloumi 2009, Guillaume *et al.* 2006). This has led to a rapid transformation in resources exploitation and land use supported by the Government. The results have often been catastrophic for arid ecosystems and natural resources with the degradation of the steppe, the spraying of fragile soils and the spread of desertification (Hanafi 2000, 2010). Today, the warnings issued by specialists and international organizations for nature conservation and sustainable development (FAO, IUCN, etc.) do not seem to be able to hinder public and especially private actions to make the most of resources and increase rural populations' incomes, despite the uncertainties surrounding ecosystem balances and the threats of a possible return to desertification.

It was in this context that this study was carried out in the delegation of *Skhira*, which has experienced an unprecedented Land use dynamics for the last twenty four years. The aim is to detect, using GIS tools, the changes that have taken place in this steppe landscape since the late 1990s and the early 2000s, and which is manifested by the extension of dry and irrigated olive orchards. The impact of this dynamic on the environment and on the existing rural society needs to be studied further.

II. STUDY AREA

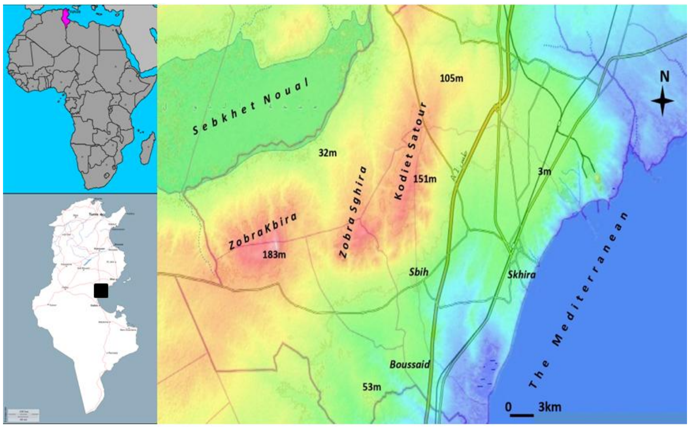

FIGURE 1: Study Area
(Source: Author personal work)

[1] The Earth Overshoot Day is an ecological indicator that has been set up by the American NGO *Global Footprint Network*. It corresponds to the date of the year from which humanity is supposed to have consumed all the resources that the planet is capable of regenerating in one year (Cannet & Wackernagel 2018).

[2] *Jessour* is the plural of *jesser* which constitutes a small traditional hydraulic structure (elevation in raised soil in the wadi-bed), designed in the arid mountains of southern Tunisia to retain the excess water and soil collected by impluviums and their exploitation for agriculture. A *Jesser* consists of an impluvium, a wadi and a soil elevation also locally called *tabia* or *katra* (Bonvallot, 1986, 1992).

The study area corresponds, in part, to the administrative division of the delegation of Skhira and belonging to the governorate of Sfax (Fig. 1). It covers 107,731 ha and lies between the parallel 34°10' and 34°32' North and the meridians 9°40' and 10°15' East. It is bordered by sebkhet Noual to the northwest and the Mediterranean Sea to the southeast.

2.1 Characteristics of the natural environment

2.1.1 A relatively flat topography with eroded and infertile soils

The study area consists of a set of plains and hills below 200 m of altitude with a slight slope generally towards the Mediterranean Sea. All these landscape units form the junction between the eastern end of the *Southern Low Plains* belonging to the Atlasique domain and the southern part of the *Tunisian Sahel* belonging to the Pelagian platform (Sghari *et al.* 2009, Hezzi 2014). The hills form what is called the *Sidi M'hadheb* subdesert plateau which represents a stripped glacis with gypsum overlaps of Pleistocene age (Fig. 2).

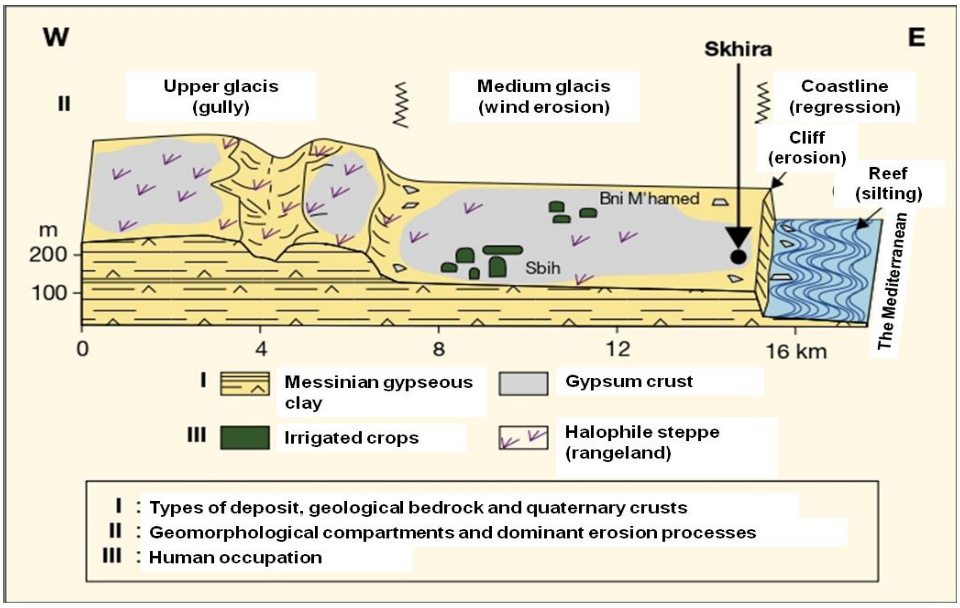

FIGURE 2: Main Topographic Units of the *Skhira* Region
Source: Sghari et al. 2009

The geological layers are essentially of recent and current Quaternary age made up of alluvium, sandy dunes or sandy loam. On the hills, the gully revealed tender clay-gypsum formations of the Mio-Pliocene and hard formations of white chalky limestone of the Upper Senonian age. The entire pattern is covered by recent stony formations, locally called *hamadas*, dissected by streams dominating an alluvial plain (medium glacis); it is also sealed by a gypsum-to-limestone gypsum crust (Zairi *et al.* 2005, Missaoui *et al.* 2013, Hezzi 2014, Chiab 2019).

Given these geomorphological conditions, the study area has a diversity of soils, which are generally characterized by low fertility. This weakness is explained by the strong presence of limestone and gypsum in the substrate or in the form of crusts. Widespread water and wind erosion, low vegetation cover and drought are factors that exacerbate this phenomenon. According the *Sfax* Governorate Atlas data (Missaoui *et al.* 2013) and the report of the Regional Commissariat for Agricultural Development (CRDA) of *Sfax* in 2017, the study area comprises four main soil types:

- Skeletal soils: They are part of non-fertile soils where the aridity prevents pedogenesis and promotes salinization (Yousfi 2013). This type of soil is most often associated with gypsum crusts. It is widespread throughout the study area, particularly in the upper glacis.

- Gypsum soils: They are also located on the upper glacis, notably in the *Sidi M'hadheb* sector. They are derived from soft evaporative rocks and have high levels of calcium sulfate (Karray 2006). As a result, they are most often covered with gypsum crusts and subjected to the actions of desertification favored by the long dry season,

- Isohumic soils: They are located in particular on the wadi-beds and correspond to the old red soils, to the colluvium of the Cretaceous marno-limestone formations (Chiab 2019). They are relatively rich in organic matter but highly exposed to gully erosion and wind deflation,

- Halomorphic soils: They are located on the edge of *sebkhet Noual* and near the coast. They are dominated by marl and clay with high salt content and are generally deposited by runoff. In the dry season, they are most often exposed to wind deflation.

2.1.2 A constraining arid climate

The study area is characterized by an average annual rainfall of 170 mm. With their weakness, these quantities show a high degree of monthly and seasonal variability, rising to over 26 mm in January and falling to only 0.2 mm in August (Table 1).

TABLE 1
AVERAGE MONTHLY RAINFALL AND TEMPERATURE AT *SKHIRA* STATION FOR THE PERIOD 1962-2016

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
T°C	12.1	12.9	15.8	18.1	21.9	25.8	27.6	27.9	26.1	22.9	17.6	13.8	**20.2**
P mm	26.3	21.1	16.2	9.2	4	2.3	1.1	0.2	9.3	38	17.6	24.8	**170**

Source: I.N.M., 2017

On an inter-annual scale, the *Skhira* station also records a large rain irregularity (Fig. 3). In a series of 50 years of observation (1968-2018), this station recorded two to three times the average rainfall, the cases of 1990 with 469.5 mm, 1996 with 395.8 mm and 2007 with 434 mm (I.N.M. 2017). However, some other years were very dry during which the average was divided by two or three, the cases of 2008 and 2005 which recorded only 38.5 mm and 36.5 mm, respectively. In addition, this great irregularity of rain is often accompanied by a torrential character since the station often records daily rain intensities around 30 mm (Bousnina 1997).

For temperature, the annual average is around 20.2°C, but it is not significant since it hides a very variable seasonal pattern with at least six hot to very hot months. Indeed, Table 1 shows that the heat settles in the region from the end of April and remains until the end of October with three relatively hot months (July, August and September) during which the average temperature reaches 27.9°C; the absolute value could exceed 40°C (Bousnina 1997). These high temperatures are related to the warm Saharan advections carried by the *sirocco*, a very hot local wind blowing especially from the southwest and southeast in spring and summer. This wind, which blows for about fifteen days a year, often causes significant damage in the agricultural sector, while causing excessive increases in the demand for drinking water and crops.

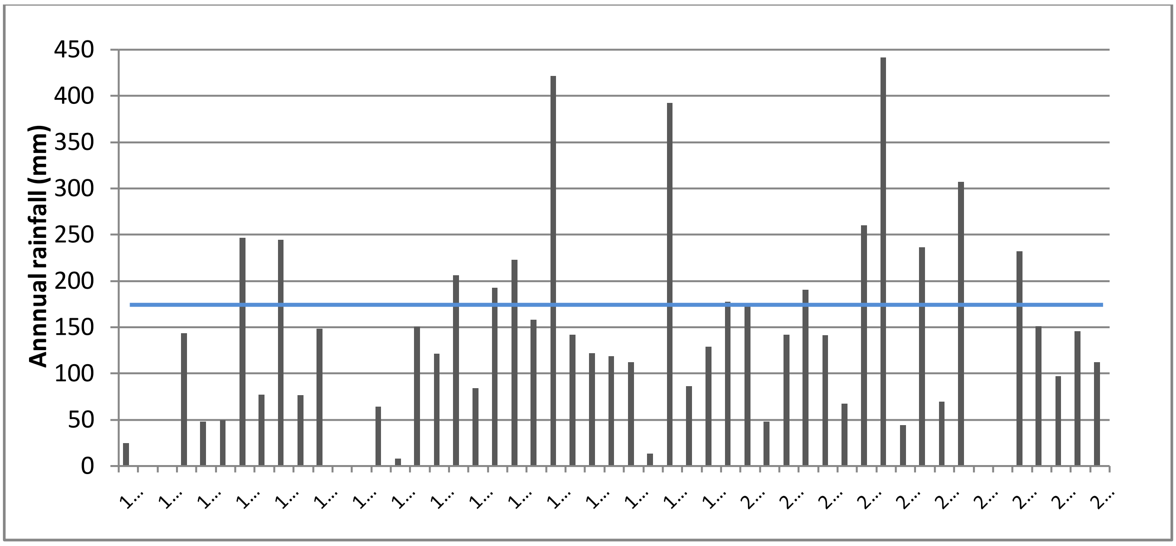

FIGURE 3: Inter-Annual Rainfall Variability at *Skhira* for the Period 1968-2018.
(Sources: I.N.M., 2017, CTV Skhira, 2018)

All of these characteristics can link the study area to the lower arid Mediterranean floor with moderate winters. This bioclimate is characterized in the region by a long and vigorous dry season, as humidity is virtually absent and the heat is often intense. The water deficit is therefore significant since the Potential Evapo-transpiration is around 1400 mm/year, which generates an average daily loss of water of around 3.8 mm while the daily intakes do not exceed the average of 0.5 mm (Ben Boubaker *et al.* 2003, Zairi *et al.* 2005). On an interannual scale, this bioclimate is characterized by the frequent and successive dry years (Fig. 4).

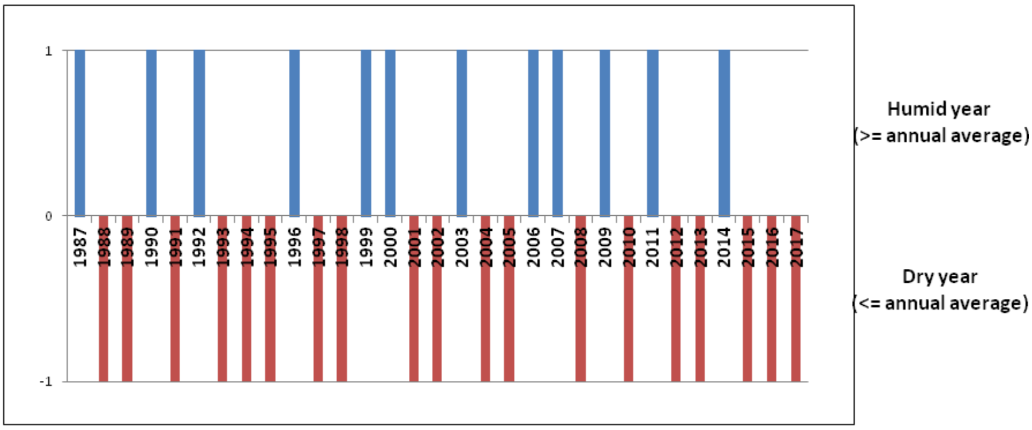

FIGURE 4: Alternating Dry and Humid Years at *Skhira* Region between 1987 and 2017[3].
(Sources: I.N.M., 2017, CTV Skhira, 2018)

This Fig. shows that during the 30 years of observation, 19 years were dry, more than 61% of the cases. In addition, this drought is most harmful to natural vegetation and agriculture when dry years are successive. However, the Fig. 4 shows that only three dry years are isolated from each other. The other dry years were successive, either to form binomials in 5 cases or to form trinomials in 2 cases. According to Floret and Pontanier (1982), the last years of these groups are the most damaging to natural vegetation and crops. For the 12 humid years, 8 of them were isolated and only 4 years formed 2 pairs. Floret and Pontanier (1982) concluded that for Tunisian arid regions, on average 3 out of 5 years could be dry, which really prevents any improvement in natural vegetation and extension of rainfed agriculture. Furthermore, the frequent sandy Saharan winds accentuate the aridity of the environment by accelerating the soil drying and the drop of groundwater piezometric level as well as the loss of soil fertility under the influence of wind erosion, which represents the main aspect of desertification (Floret and Pontanier 1982, Daoud 2003).

2.1.3 Limited and low-renewal water resources

Given the low amounts of rain, surface water resources are very limited. This is all the more true since the study area is almost flat and the *Skhira* watershed is small (64,200 ha) and drains a set of small wadis. According to Zairi *et al.* (2005), this watershed has a fairly compact appearance with a *Gravelius compactness coefficient* of 1.3. The runoff, calculated by the formula of Ghorbel (1991) is about 4 mm, which corresponds to an average annual volume of accumulated water of 2.6 Mm^3. Rainy years are most often used to accumulate and infiltrate a much larger volume of water, thanks to a large CES techniques installed in the region since 1993[4].

Groundwater is subdivided into semi-deep aquifer and deep aquifer. The first is considered one of the most important in the *Sfax* Governorate. It is housed in sandy clay layers of the Villafranchian and Mio-Pliocene (Karray 2006, Ben Cheikh 2013, Hafedh 2015). Its potential is estimated in 2020 at 4.23 Mm^3, i.e. approximately 10.7% of the total semi-deep aquifer resources of *Sfax* (Khanfir *et al.* 2017, CRDA 2020a). However, this aquifer suffers from a slow, weak and irregular supply given the weakness and irregularity of precipitation. As for the deep aquifer, it is estimated in 2020 at about 4.4 Mm^3, or 13.7% of the total deep aquifer resources of *Sfax* governorate (Hafedh 2015). In 2006, all of these resources had a relatively acceptable quality since the salinity and solid residue content were around 3 to 4g/l (Karray 2006).

2.1.4 Degraded steppe vegetation

The study area is characterized by a steppe vegetation landscape. This plant formation, characteristic of arid and desert regions, is very fragmented, essentially located at the encrusted interfluves where agricultural activities are scarce. Indeed, the original steppe has long been under severe human pressure, leading to intense quantitative and qualitative degradation (Chiab 2019). Harsh climatic conditions and young and rugged soils have often exacerbated this situation. Often used as rangeland, the remaining steppe shreds are often of low cover, dominated by post-cultivation, spiny and non-palatable

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[3] This figure is based on the interpretation of the *Skhira* station's rainfall data for the period 1987-2017 (I.N.M. 2017).

[4] This is a set of techniques that have been installed in the region since 1993 as part of the "*Sidi M'hadheb Development Project*" funded by the Tunisian Government, the Islamic Development Bank and the International Agricultural Development Fund. The objectives of this project were (i) to increase farms production, (ii) to improve soil fertility and water runoff mobilization and (iii) to fight against flooding (Zairi et al. 2005).

species (Chaieb and Zaâfouri 2000). In consequence, and regarding this environmental conditions, the study area has the following main types of vegetation:

- Gypsum-limestone steppe with *Hammada schmittiana, Gymnocarpos decander* and *Helianthemum kahiricum* which extends at hills with limestone outcrops,

- Sandy steppe with *Rhanterium suaveolens* and *Artemisia campestris* characterizing sandy plains with a strong presence of the spiny species *Astragalus armatus*,

- Lime-limestone steppe with *Artemisia herba-alba, Stipa tenacissima* and *Hammada scoparia* which extends over the calcareous encrusted hills,

- Gypsum steppe with *Anarrhinum brevifolium* and *Zygophyllum album* that characterizes the plains and hills encrusted by gypsum,

- Wadi-beds steppe with *Ziziphus lotus* and *Retama raetam* and that show a significant presence of post-cultivation species such as *Artemisia campestris* and *Devera tortuosa*,

- Gypsum-halophytic steppe with *Nitraria retusa, Salsola vermiculata* and *Suaeda mollis* which extends on the edge of *sebkhet Noual* and near the Mediterranean coast.

2.1.5 Characteristics of the human environment

The region of *Skhira* bears witness to an ancient human presence with the existence of some ancient remains scattered here and there on the hills and around the ancient water points (Chiab 2019). Moreover, the Arab period has left its mark in particular with the distribution of the inhabitants over several tribal fractions, the most well-known being that of *Sidi M'hadheb* (Belghith 2017). Today, and according to the estimation of the National Institute of Statistics (I.N.S.), the *Skhira* delegation has about 36,265 inhabitants in 2020 with a very low urbanization rate of around 38.3% (Table 2).

TABLE 2:
EVOLUTION OF POPULATION NUMBERS IN *SKHIRA* BETWEEN 1994 AND 2020.

Year	1994	2004	2014	2020
Inhabitants	25 795	29 616	34 673	36 465
Urbanization rate %	31,9	34,2	36,8	38,3

(Sources: I.N.S. 1994, 2004, 2014, 2020)

Although *Skhira* has experienced a significant increase in its number and urbanization rate since 1994 (Table 2), this Delegation has remained, for the most part, rural, despite the presence of large industrial sites (SIAPE, TIFERT, TRAPSA, TANCMED), which are supposed to promote the creation of an urban center around the city. This is one of the poorest delegations in the region with a Regional Development Indicator of 0.467 in 2018, lower than the national average of 0.486 (Boussida *et al.* 2018). The inhabitants have a strong relationship to the land since most of them practice an agropastoral activity even if they have another activity in parallel. The traditional agropastoral production system is characterized by rainfed arboriculture combined with episodic dry cereal cultivation and extensive breeding of small herds of sheep and goats. In addition, irrigated agriculture has developed in the region since the 1990s, focusing in particular on olive and vegetable crops. It took place in a context which aimed to limit agricultural production fluctuation and animal production weakness as well as the improvement of the inhabitants' incomes (Zairi M. *et al.* 2005).

III. MATERIAL AND METHODS

In order to study the landscape changes in *Skhira* following the agricultural extension that has occurred since the 90s-2000s as well as its impacts on the environment and on the economy of the inhabitants, a spatialized and qualitative approach was adopted. It was based on a diachronic Land cover/Land use mapping between 1996 and 2020. The use of this mapping is a relevant tool for detecting the changes that have occurred and for identifying the direct and indirect impacts on natural habitats, biodiversity and landscapes (Al-Bilbisi 2017, Aladekoyi *et al.* 2016, Ebro *et al.* 2017, Habte *et al.* 2020, Mohamed *et al.* 2020). Furthermore, monitoring and mapping Land cover/Land use changes are essential for environmental management, resource sustainability and to facilitate regional planning decision-making.

The choice of the date of 1996 is relevant since it corresponds to the first results of the "*Sidi M'hadheb Development Project*" undertaken by the Government since 1993 and materialized, among other things, by encouraging the agricultural land development. A first window was then extracted from a Landsat/TM satellite image with a spatial resolution of 30 m and dated 28 April 1996, and a second window was extracted from a Sentinel-2 image dated 16 May 2019 with a spatial resolution of 20 m.

In this regard, high-resolution multi-date and multi-spectral satellite imagery can be well adapted to map Land cover/Land use dynamics in the steppe region. Landsat and Sentinel-2 images have already been used to map broad classes of land cover, such as croplands, grasslands, shrubs and trees, in sparsely vegetated environments, and also to monitor land cover in several regions of the world (Hanafi 2000, Malatesta *et al.* 2013, Gil *et al.* 2014, Belgiua & Csillik 2015, Kraemer *et al*. 2015, Aladekoyi *et al.* 2016, Nino *et al.* 2017, Khebour Allouche *et al.* 2018, Gxokwe *et al.* 2020, Henchiri *et al.* 2020, Chouari 2021, Dashpurev *et al.* 2021). In addition, the spatial resolution of Landsat TM (30 m) and Sentinel-2 (20 m) images are perfectly suited to the average size of the agricultural fields in the study area. Finally, the free access to historical archives with multi-date satellite images makes it possible to reconstruct the land use.

The two retained images were then georeferenced and then they were integrated into the QGis software, in free access, in order to achieve, through a visual photo-interpretation, a delimitation of the homogeneous zones. The GIS database created was also fed by the 1:200,000 topographic maps of *Sfax*, *Mahares* and *Meknassi*, each covering, in part, the study area (Kaim *et al.* 2014). In order to improve the quality of the photo-interpretation for 2020, it was also necessary to work on an extract of the satellite platform Google Earth©.

Following this cartographic work, and with the aim of validating the interpretation of the first results obtained, a field mission was carried out in March 2020. It allowed, through the visit of a hundred points spread over the entire study area, to verify the delimited units and to validate their content. Interviews were also carried out with about thirty small agro-breeders and about ten large farmers[5] in order to understand their motivations, their problems in relation to the farms in possession as well as their perceptions of their natural environment, the resources at their disposal and finally their awareness of challenges and risks they incur in relation to their farm management and their methods of exploiting the available resources. Some meetings are also realized with local and regional decision-makers involved in agricultural activity (CRDA of *Sfax*, Territorial Cell of Vulgarization - CTV of *Skhira*).

With regard to the data from 1996 and following years, it was necessary to use regional and local services reports as well as the main bibliographic sources that have worked on the region and the neighboring regions (Auclair *et al.* 1996, Chaieb and Zaafouri 2000, Hanafi 2000, Talbi et al 2000, Karray 2006, Sghari et al 2009, Yousfi 2013, Chiab 2019). However, since it was difficult to carry out a detailed cartography of this period and in order to be able to establish a reliable comparison between the two chosen dates, a simple occupation typology was preferred, summed up in 4 main types:

- Dominant natural or post-cultural steppe
- Mainly dry farming (cereals, legumes, etc.)
- Mainly dry arboriculture (olive, almond, etc.)
- Irrigated arboriculture + irrigated vegetable cultivation.

The cartography of these types of occupation fairly representative of field reality in the two chosen dates made it possible to obtain two maps of Land cover/Land use and to fully appreciate the landscape dynamics *Skhira*.

IV. RESULTS AND DISCUSSION

4.1 Land cover/Land use dynamics between 1996 and 2020

4.1.1 Profound landscape change

A review of the 1996 and 2020 Land cover/Land use data (Table 3, Fig. 5 and 6) shows that in twenty four years the landscape of *Skhira* has undergone a significant change. Indeed, the steppes experienced a quantitative degradation of 8.5% with a decline in their area from 45,660 ha in 1996 to 36,549 ha in 2020, and with an average annual rate of decline of about 0.34%. This annual steppe degradation rate is almost comparable to neighboring regions (0.45% in *Menzel Habib* and 0.41% in *Jeffara*) (Hanafi 2000, 2010).

[5] It should be noted here that, unlike small agro-breeders, it has been difficult to meet and collect information from large-scale farmers and managers of agricultural development enterprises. Many of them are absentees, while others refused to provide information on their holdings.

TABLE 3:
LAND COVER/LAND USE DYNAMICS IN *SKHIRA* REGION BETWEEN 1996 AND 2020

Year	1996		2020		Evolution 1996-2020
Type of occupation	Area in ha	%	Area in ha	%	
Dominant natural or post-cultural steppe	45 660	42.4	36,549	33.9	-8.5
Mainly dry farming (cereals, legumes, etc.)	21,562	20.0	6.205	5.8	-14.3
Mainly dry arboriculture (olive, almond, etc.)	25,419	23.6	34,358	31.9	8.3
Irrigated arboriculture + irrigated vegetable cultivation	15,090	14.0	30,619	28.4	14.4
Total	**107 731**	**100**	**107 731**	**100**	**-**

(Sources: Topographic maps at 1/200.000 of Mahares, Meknassi & Sfax; Satellite images Landsat/TM & Sentinel-2; Chiab, 2019; Author's Field Work, 2020)

It should be noted, however, that this rate of decline is much greater for former dry farming land (-14.3%) which is located mainly on foothills and encrusted sandy-loamy-gypsum plains as well as in the wadi-beds with loamy-sandy soils that receive extra water from surface runoff during rainy years. As a result, these lands were cultivated episodically (at least two years out of five) by rainfed cereals (barley, durum wheat, etc.) associated with dry vegetable crops (lentils, peas, broad beans, chickpeas, onions, garlic, carrots, etc.). Today, the land lost by these crops and by the steppes has been recovered by irrigated crops and dry arboriculture.

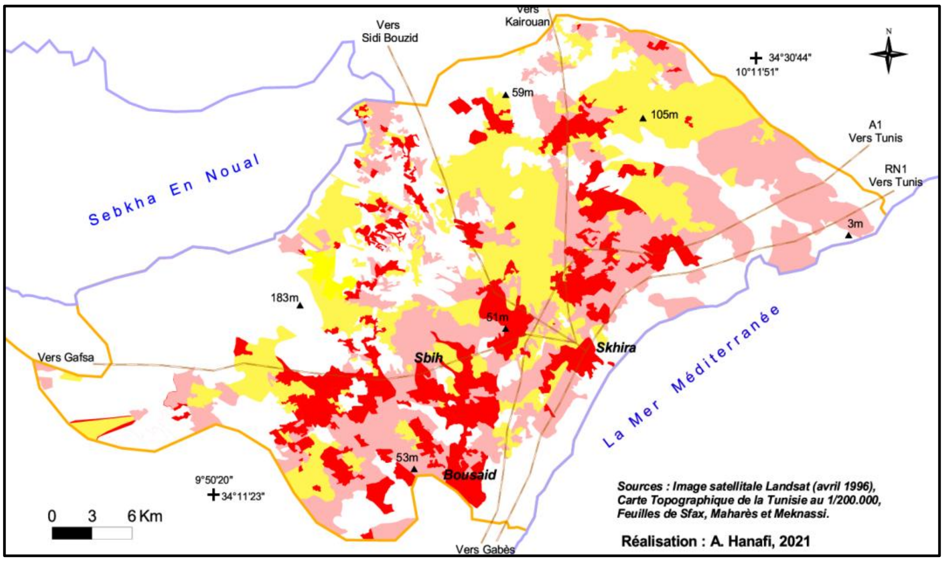

FIGURE 5: Land Cover/Land Use in the *Skhira* Region in 1996.

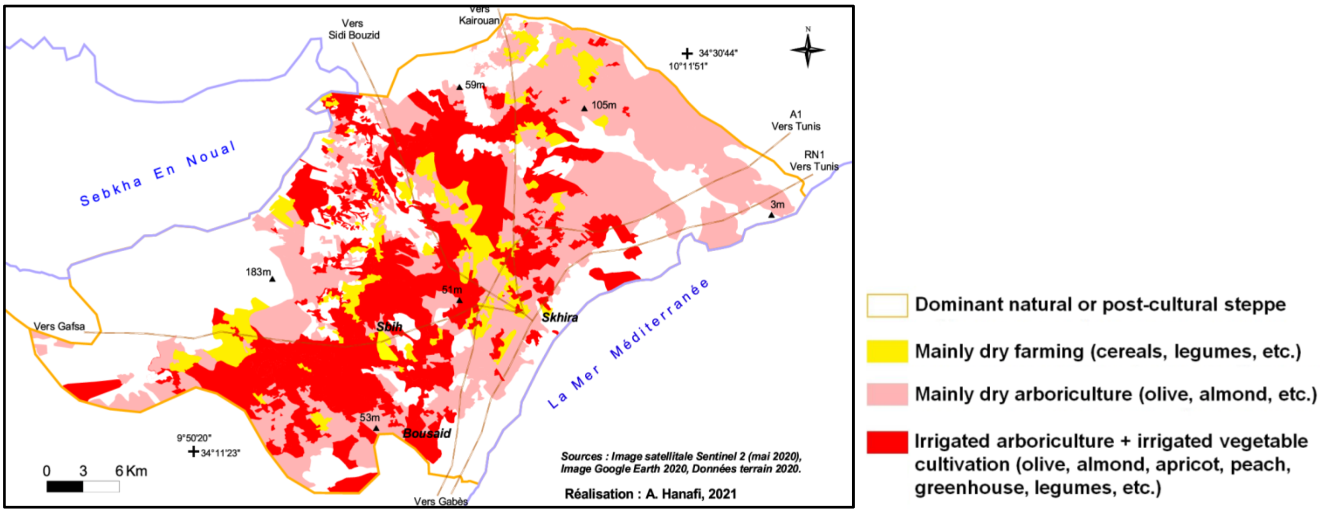

FIGURE 6: Land Cover/Land Use in the *Skhira* Region in 2020.

As for the increase in arboriculture, it is essentially based on olive cultivation. This speculation, which accelerated after 2011, was implemented by investors mostly from outside the region. They became interested in olive cultivation following the surge in olive oil prices and the increase in its demand on the national and international markets (Chiab 2019). Moreover, this agricultural influence took place, first at the expense of the degraded steppes with encrusted gypsum-calcareous soils, then at the expense of the rainfed cereal cultivation.


A: Irrigated olive tree B: Pepper greenhouse cultivation

FIGURE 7: Importance of Irrigated Crops in the *Skhira* Region in 2020.

(Source: Author's field work)

4.1.2 A preponderant place for irrigated crops

In 2020, the total area of arboriculture reached 64,977 ha (Table 3) with more than 18,000 ha characterized by olive monoculture (CRDA 2020b). This activity, which dates back to the late 1990s, was first concentrated on the coastal plains and around *sebkhet Noual* where the gypsum crust is discontinuous and the soils are rather sandy-loamy to sandy. Subsequently, and during the last decade, it has spread to the detriment of steppes of the central hills with rugged and crusted soils. These new lands acquired for irrigated olive cultivation (Table 4) have proliferated thanks to the implementation until 2020 of 105 agricultural development projects whose owners are, for the most part, non-farmers by profession[6] (Chiab 2019, CRDA 2020b, *Author's Field Work*). These projects were undertaken by companies which, originally, were intended for the export of olive oil, and which converted into production companies taking advantage of Government subsidies for the development agricultural land and olive plantation (Fig. 8).

TABLE 4

EVOLUTION OF AGRICULTURAL DEVELOPMENT PROJECTS IN THE SKHIRA DELEGATION BETWEEN 2000 AND 2020.

Period	Number of projects	Area in ha
2000-2005	02	30
2005-2011	23	1 054
2011-2015	42	1 625
2015-2020	38	2 486
Total	**105**	**5 195**

(Sources: Chiab 2019, CRDA, 2020b, Author's Field Work 2020)

FIGURE 8: Irrigated Olive Plantations Extension over Several Hectares in *Skhira* Region

(Source: Chiab, 2019)

[6] We cite for example the agricultural projects implemented by the companies *Yakin, Chabane, TODOLIVO, El Eutha and Syala-Donia* (*Author's Field Work*).

On the north-western side of the *Skhira* region at the level of the *Hmila* sector, persistent disputes between the inhabitants belonging to different tribal fractions (*Ghrayra, M'hedhba* and *Beni Zid*) have encouraged rights holders to plant the land in order to assert their ownership (Chiab 2019). The desire of these inhabitants, to accelerate and increase their gain has encouraged most of them to resort, first, to irrigate the olive tree in order to increase the chances of its success, and then, to plant introduced varieties known by their entry into production after 3 to 4 years, the case of the Spanish *Arbequina* variety (Karray *et al.* 2019, *Author's Field Work*). For this variety, used in intensive cultivation systems, it can be planted at a height of 200 vines / ha. As for local varieties planted dry with a density of less than 50 vines / ha, and which come into production after an average of 10 years (*Injassi, Hchichina, Chemlali* and *Ghraiba*), they are less and less cultivated (Allalout and Zarrouk 2013). Thus, in a few years, the constraints of rainfed agriculture in *Skhira* (poor and crusted soils, scarce and poor quality water resources, etc.) have been transformed into profits thanks to this activity guided by speculators, like several other neighboring regions (*Regueb, Menzel Chaker*, etc.).

In addition to irrigated olive cultivation, the landscape has seen an increase in irrigated vegetable crops mainly around urban agglomerations (*Skhira, Sbih, Jerouala, Khadhra, Boussaid,* etc.). This activity has also increased since the 2000s, either through the acquisition of new land, or through the intensification of old dries production systems. The CRDA of *Sfax* (2020a), showed that the area of these pure crops in the *Skhira* delegation increased from 4,643 ha in 2000 to 8,215 ha in 2020, an increase of around 77%. Dominated by greenhouse cultivation, this activity is largely monopolized by farmers from the region who have taken advantage of the increased demand for food products and the improvement in prices, as well as Government support for digging surface wells to intensify their cropping systems.

According to Chiab (2019), the rise of the *Skhira* region in several products from this agricultural activity is national. In two decades, *Skhira* has become a real center for fruits and vegetables production, taking advantage of its position between two major consumption centers, namely the city of *Sfax* 55 km to the northeast and the city of *Gabès* 53 km to the south. This is how melon, watermelon, peas, peppers, tomatoes and onions have become the specialty of the region. In 2020, *Skhira* delegation counted about 48% areas of melon and watermelon areas in *Sfax* governorate, about 39% of tomato and pepper areas and about 36% of onion areas (CRDA 2020a, *Author's Field Work*). In the same date, watermelon production was estimated at 22,820 tons, or about 51% of total production in the entire governorate.

4.2 Impacts of Land use dynamics on natural resources

It is sometimes very difficult to assess and monitor the true extent and impact of agricultural encroachment on resources, as farmers often mask the effects of degradation by converting their land to less demanding uses or by increasing the levels of compensatory inputs (Scherr & Yadav 1996). There is rarely an unequivocal relationship between the degree of degradation and the effect on yields. For example, on relatively deep soil, erosion can be quite severe for long periods of time before there is a measurable effect on crop yields. There is little empirical evidence of the critical thresholds at which degradation processes produce economic or environmental effects for different soil types, climates and crops (Bourque 2000). Most measurements have traditionally been taken at the parcel level, which may not always be appropriate for drawing conclusions at the farm level or the policy implemented. To make economic assessments of the impact of land degradation, various approaches are used such as calculating the replacement the cost of replacing lost nutrients, the value of lost yield, the value of increased agricultural inputs needed to maintain yields, or the cost of returning the parcel to its previous state. More aggregate estimates of degradation costs should be taken with caution, as these aggregates are mostly based on standard formulas linking certain levels of degradation to estimated yield losses. Based on these losses, the market value of lost output is determined, as well as the amount of inputs needed to raise productivity to previous levels (Scherr & Yadav 1996, Daoud 2003, Doukpolo 2014, Lavorel *et al.* 2017).

According to Scherr and Yadav (1996), the most important effect of land degradation on farms is the reduction in potential yields. But the degradation of agricultural land can also have significant negative effects off the farm. Examples include soils depletion through the transport of fertility, the pulverization of the most fragile soils and their transport and accumulation around CES, the overexploitation of water and competition for it with other economic sectors, the biodiversity loss, the landscape and ecosystems fragmentation, the economic income fluctuation and the persistence of production systems precariousness, etc. These impacts that will be analyzed here based on field data and reports drawn up by the various regional and local services in the *Skhira* region.

4.2.1 Environmental impacts, an ever-threatening desertification

4.2.1.1 Increasing demands on water resources

For several years, many studies have alerted the various actors of the Tunisian agricultural sector to the need to limit the use of water resources. According to Massin *et al.* (2016), the irrigable areas of the country will have to stabilize in the coming years and the new areas that will be developed in the future will just have to compensate for the losses caused by several factors, in particular by the reduction in water availability following overexploitation of some aquifers. For these authors, if the national average water consumption per hectare for irrigation is high compared to the potential (around 5,500m³), it would be much higher in the Tunisian arid environment around 15,000m³ / ha. In the *Skhira* region, although the record of the exploitation of aquifers is more than alarming, farmers do not seem to be in a position to respect the alerts (Table 5, Fig. 9).

Indeed, since the 1990s, farmers of *Sbih, Boussaid, Khadhra, Rouibta, Sidi M'hamed Nouigues*, etc., who were not concerned about the scarcity of this resource, have irrationally intensified its exploitation by multiplying wells digging and practicing submersion irrigation of vegetable crops (greenhouses). In the 2000s, and despite the implementation of the policy to encourage CES techniques[7], a frantic increase in well digging was recorded, since the number of wells increased from 1,582 in 2002 to 2,768 in 2020. With this figure, *Skhira* ranked 1st in the number of wells in the governorate of *Sfax*, far ahead of *Jebeniana* (CRDA, 2020a). In addition, this increase was accompanied by an upsurge in the annual quantities exploited, which raised from 6.25 Mm³ to 9.48 Mm³ during the same period, reaching an exploitation rate of more than 216% in 2020.

TABLE 5:
EVOLUTION OF GROUNDWATER EXPLOITATION IN *SKHIRA* REGION BETWEEN 2002 AND 2020

	2002	2004	2011	2016	2020
Potential resources in Mm³	4.52	4.51	4.48	4.44	4.39
Number of wells	1582	1775	1872	1963	2768
Annual volume used in Mm³	6.25	7.4	8.38	9.02	9.48
Exploitation rate (%)	138	164	187	203	216

(Sources: CRDA 2020a, Chiab 2019)

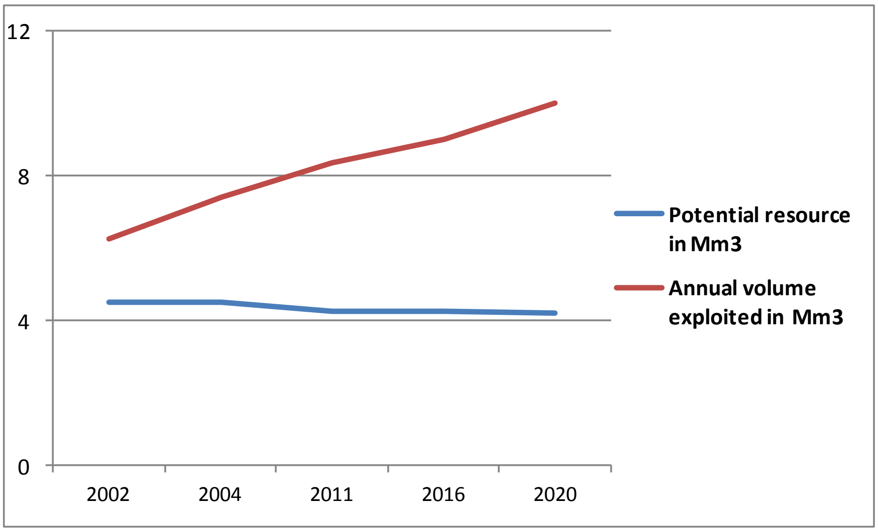

FIGURE 9: Overexploitation of Phreatic Aquifer in *Skhira* Region.
(Sources: CRDA 2020a, Chiab 2019)

[7] According to FAO 2018, incentives for the use of CES techniques include the recovery of 60% of farmers' costs; 20% of the amount in the form of a grant and 40% in the form of a loan.

This overexploitation has led to an acceleration of the aquifer salinization as a result of the intrusion of marine waters. The figures given by the CRDA of *Sfax* (2020a) indicate that the aquifer salinization has reached, in some places, 8g/l. However, it should be noted that this degree, although it is very limiting for several crops, especially since salinization seems to increase from year to year, it remains relatively tolerable for the olive tree (Palluault & Romagny 2009a, Khanfir *et al.* 2017). To compensate for its losses in fresh water, the aquifer benefits during good rainfall years from a quantity of water recharge which is around 800,000 m³ thanks to CES techniques. Moreover, it also feeds from the semi-deep aquifer with which it communicates easily, taking advantage of the semi-permeability of the clay-sandy layers that separate them (Hafedh 2015). But even this situation is not guaranteed, since the semi-deep aquifer has not been spared from exploitation, especially since 2011, following the digging of several illicit wells by new irrigated olive cultivation projects owners. According to Chiab (2019), more than 28% of the wells dug in these projects exceed the authorized depth of 50 m. Government control over these wells is very limited or even non-existent since many of these projects use solar energy to power their motor pumps, which does not allow the authorities to control their electricity consumption.

In addition to salinization, the *Skhira* groundwater aquifer suffers from a rapid decline since the piezometric level decreased by about 12 m between 1995 and 2020 (CRDA 2020a). This situation has led to the drying up of several surface wells owned by small farmers who cannot afford to dig them further. Some other farmers may have illegally overdug these wells beyond the authorized depth (Khanfir *et al.* 2017).

4.2.1.2 Agriculture affected by climate change

Although the figures on climate change in Tunisia are not precise, the reports of competent national and international organizations agree on the fact that this phenomenon has affected the country for several years and that it is constantly growing, thus threatening human activities particularly agriculture (Rubio *et al.* 2009, Troudi 2013, Gafrej 2016, MALE 2020, Yousfi 2020). This phenomenon is all the more serious as the Tunisian climate is intrinsically characterized by a pronounced variability and aridity, which would further increase the environmental and socio-economic vulnerability of the country and in particular its arid part.

In the *Skhira* region, this phenomenon has been felt for several years as dry periods are increasingly recurrent and vigorous, aggravated by *sirocco*. And it is agriculture that pays the cost, especially since most irrigated crops have a life cycle of about 6 months between February and July, which coincides with the onset of heat. In addition, they are very water-intensive plants and require frequent irrigation. This is probably one of the reasons why these crops have, for several years, experienced a decline in production and a decrease in their area (Fig. 10), a phenomenon that has particularly affected small farmers who have found themselves increasingly deprived of water resources and, therefore, of financial income (Chiab 2019). Only tomato production has increased from 480 tons in 2000 to over 23,800 tons in 2020 (CRDA 2020a & 2020b, *Author's Field Work*).

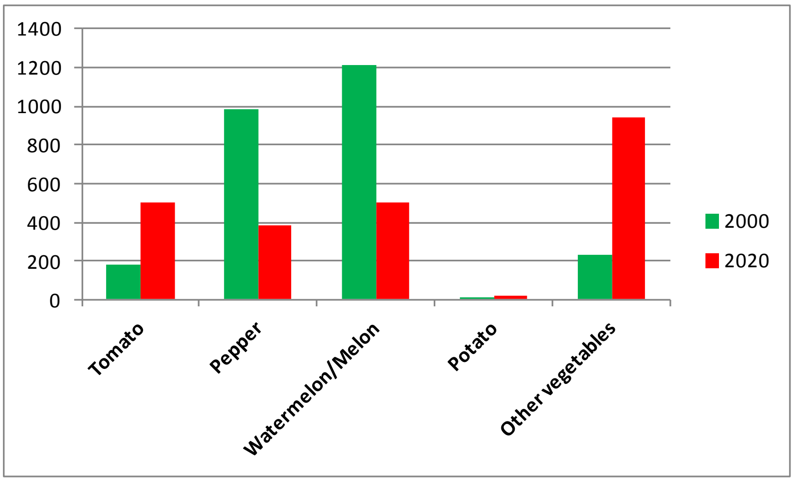

FIGURE 10: Evolution of Some Vegetable Cultivated Areas (In Ha) in *Skhira* Region
(Sources: CRDA 2000 & 2020b, Author's Field Work)

4.2.1.3 Soils affected by salinization, crusting and loss of fertility

Like the entire Tunisian arid environment, the soils best suited for crops in *Skhira* are those sandy to sandy-loamy and which benefit from coastal influences or from CES techniques (Massin *et al.* 2016). However, the intensification of agricultural activity did not respect this restriction, since crops, especially irrigated ones, were widespread on most types of soil. Indeed, intense irrigation with high-salt water, particularly in the presence of gypsum crusts, has led to soil structure degradation that is sometimes irreversible. This phenomenon is often exacerbated by the hydromorphy caused by submersion irrigation, which is very often used for certain crops such as peppers, tomatoes, watermelons and melon. According to Massin *et al.* (2016), about 60% of soils in public irrigated perimeters and about 86% of private perimeters in Tunisia are moderately to strongly sensitive to secondary salinization.

Moreover, the irrigation of gypsum soils rich in Calcium sulfate generates an accelerated concentration of salts at their first horizons which easily indurate during dry years. During these periods, soils are exposed to wind deflation, following the uprooting of woody plants and land plowing. In addition, the fertility decrease of irrigated soils constitutes a dominant form of degradation in relation to the modification of physical, mineralogical, chemical or biological soil properties (degradation of the structure due to lack of organic matter, loss of major fertilization elements, etc.). Furthermore, chemical pollution is increasingly strong in these irrigated areas as a result of the excessive or inappropriate use of mineral fertilizers and phytosanitary treatment products for crops (Chiab 2019).

4.2.1.4 Unbalanced ecosystems with a loss of biodiversity

The strong agricultural extension in the *Skhira* region has taken place at the expense of already fragile steppe ecosystems. Woody extraction, crust breaking, plowing with polydisks and soil spraying, etc. are all actions that have profoundly altered the old traditional balances based on a relatively acceptable floristic richness and ecosystem diversity as well as on a more or less rational management of territories (agricultural and pastoral) and resources (vegetation, water, soil).

Today, after twenty four years of intense agricultural activity, the ecological bill seems to be increasingly heavy with a significant loss of species richness and ecosystem diversity. Indeed, plant diversity based on more soil-conserving steppe species with good pastoral value (such as *Helianthemum kahiricum, Helianthemum sessiliflorum, Gymnocarpos decander, Stipa lagascae, Anarrhinum brevifolium, Rhanterium suaveolens, Pennisetum setaceum ssp. Asperifolium*, etc.), has been replaced by a floristic homogeneity dominated by post-cultural, ubiquitous, thorny, nitratophilous species of low to no pastoral value (notably *Astragalus armatus, Deverra tortuosa, Asphodelus tenuifoliosus, Ononis natrix ssp. Polyclada, Peganum harmala, Haplophyllum tuberculatum, Cleome amblyocarpa*, etc.) (Hanafi & Jauffret 2008, Hanafi 2010).

Around crops, natural vegetation is scarce; only weeds can grow with extra irrigation water. However, their valorization by livestock is difficult since most of perimeters are fenced in order to protect plantations. The animals are then forced to move away and concentrate on the remaining strips of steppes, which lead to extensive overgrazing (Fig. 11), biodiversity destruction and habitats fragmentation.

FIGURE 11: Some Ecological Indicators of Ecosystem Degradation in *Skhira* Region.
(Sources : Chiab 2019, Authors' Field Work)

The generalization of crops in the *Skhira* landscape has also led to the degradation or even disappearance of several natural ecosystems. This is the case of the ecological system of wadi-beds with *Ziziphus lotus* and *Retama raetam* with sandy-loamy soils and which has been characterized, in addition to the rich and well-conserving steppes of the water and soils, by dry crops that optimized the use of water and soil resources without eradicating woody trees. However, since the region has experienced agricultural intensification, the soils of this ecosystem have increasingly shown signs of amplified salinization due to irrigation. The steppe has completely disappeared to be replaced by crops, which has led to sand deflation and its accumulation around the fields. The situation is even worse in the more fragile ecosystems of *Hammada schmittiana, Gymnocarpos decander* and *Helianthemum kahiricum* with gypsum-calcareous soils, located in hills, and whose plowing has favored the deflation of gypsum and limestone and their dusting in lowlands.

It is important to note here that the development project of *Sidi M'hadheb* implemented in the region during the period 1993-2002 had as its main objectives the water and soil conservation, the groundwater load improvement and the fight against ecosystems degradation and desertification. Twenty four years later, it seems that this project has not achieved these objectives, on the contrary, the encouragement for agricultural development and supplementary irrigation that it has provided has degenerated to produce an alarming finding as regards environmental balances and the risk of desertification. The severe drought that has occurred in the region over the past two years (2020-2021) is a witness to this, since it has resulted in serious damage to water aquifers, soils and consequently crops. Even the olive tree, which is supposed to be very rustic, has sometimes been completely dried out despite the proximity of the sea and its moisture (Fig. 12).

Even if the ecosystems natural balance is, today, replaced by another artificial balance based on a heavy device of installations and an almost continuous presence of farmers to maintain their fields, it is clear that farmers are powerless to cope with drought and desertification if they are there. In order to save the tree and its production during very dry years, some farmers are forced to resort to exceptional measures such as supplementary irrigation by towed tanks of the oldest and the most vulnerable olive trees, the protection of fields against wind deflation, the over-fertilization of impoverished soils, etc. But since droughts are recurrent, these measures supposed to be exceptional, are more and more practiced, thus contributing to increase in the bill for farmers' expenses. In addition to this supplementary cost, several studies have shown the limits of these practices, particularly with regard to the irrigation of old olive trees (Ben Rouina 2016, Jackson *et al.* 2016).

FIGURE 12: Drying Up of Olive Tree Due to the 2021 Drought in *Skhira* Region
(Source: Chiab, August 2021).

4.2.2 Socio-economic impacts: low viability of production systems and precarious family economies

On a socio-economic scale, the acceleration, since the 1990s, of the *Skhira* landscape dynamics, has been accompanied by profound changes in the production systems and by a landscapes fragmentation. Moreover, and although agricultural production and income are attractive in good years, the high exposure of irrigated agriculture to climatic hazards has increased their fluctuation.

4.2.2.1 A trend towards spatial fragmentation and landscape heterogeneity

As it has been observed in similar regions in the Tunisian arid environment (*Menzel Habib, Jeffara, Tataouine,* etc.), the acceleration of agricultural area and diversification of its forms has, most often, given rise in addition to the quantitative and qualitative loss of steppe, to a landscape fragmentation and a greater heterogeneity of its units under the effect of a significant intervention of local and regional actors as well as the Government. According to the classic scheme proposed by Hanafi (2010) and valid for the entire Tunisian arid environment, the landscape experienced a dynamic that is summarized in 4 stages (Fig. 13).

This dynamic is characterized by a transition from the pure steppe (Stage 1) to a steppe-crop mosaic with a dominant steppe (Stage 2), favored by a land tenure transition from a family or collective status to a private status and the clearing of a large part of the steppes. The second process is characterized by an increase of agricultural activities with the generalization of CES techniques and the increase in dryland plantations to the point of outpacing steppes in terms of area (Stage 3). The steppes remain in the landscape but are confined to the rugged and encrusted "bad land", or at the graveled bottom of wadis. Contrary to the first two phases which do not last long, the landscape, once it reaches stage 3, tends to stabilize since the environmental and economic conditions (aridity, rigorous Government control over the groundwater exploitation, farmers' poverty and fluctuation of Government support) do not allow for an easy return to the steppe, nor an easy intensification of activities through the creation of irrigated perimeters. Moreover, the latter are generally very limited in area (Stage 4). In *Jeffara* and *Menzel Habib* the average size of irrigated perimeters does not exceed 1 ha (Hanafi 2000, 2010). Their contribution to the rural families' economies and those of the region is very low.

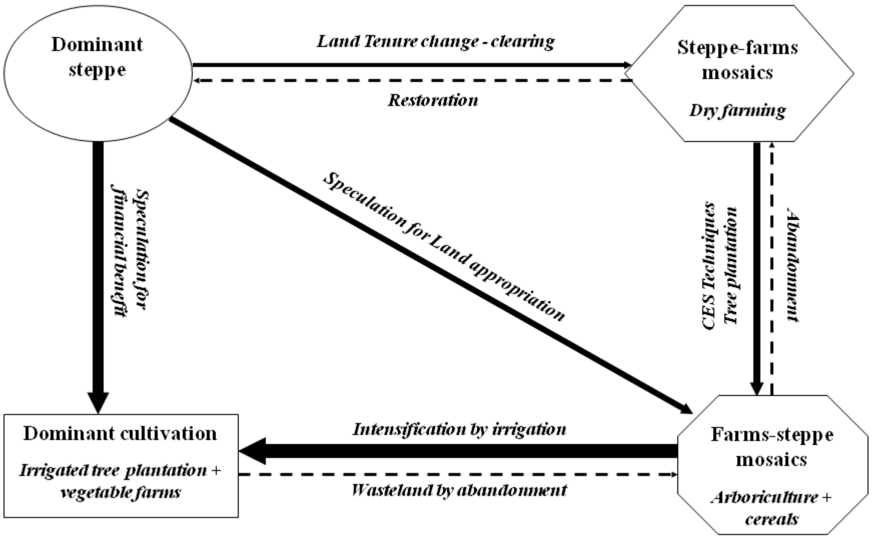

FIGURE 13: Theoretical Diagram of Landscape Dynamics in The Study Area[8]
(Source: Hanafi 2010, modified)

However, and despite many similarities with the rest of the arid Tunisian environment, the landscape of *Skhira* has undergone a relatively different process. Indeed, observations of recent dynamics in this region have shown that the classic evolution based on a passage through all the stages in their respective order, has been curtailed since the pure steppe (Stage 1) has been cleared for several years entirely either for the planting of dry olive trees (Stage 3), or for the creation of irrigated perimeters around wells dug on site (Stage 4). Speculation around olive crops, which began in particular in the 2000s, tends to gain momentum on this dynamic. Moreover, the frantic race to dig wells has increased the chances of passing from the first three stages directly to the last. In short, this dynamic has generated a fragmented, artificial and heterogeneous landscape in which the steppes are either cramped and nested in the crops, or pushed back to their margins at the level of the "worst lands". Furthermore, this extension of irrigated agriculture has led to a socio-territorial restructuring and a spatial disparity between an "economic performance cluster" around *Skhira, Sbih, El Khadhra* and *Boussaid* and marginal sectors with low potential, particularly in the vicinity of *sebkhet Noual*.

4.2.2.2 Fluctuating and uncompetitive production

Like all the Tunisian arid environment, the dependence of a large part of the crops on climatic conditions has led to a fluctuation in agricultural production, despite the research work which has shown the limits of this activity in these regions, especially when it is carried out in a manner that does not respect the fragility of natural conditions (Palluault *et al.* 2009a,

[8] The thickness of the arrows indicates both the magnitude and speed of transition from one stage to another.

Rubio *et al.* 2009, Hanafi 2010, Requier-Desjardins 2010, Ben Rouina 2016, Gafrej 2016, Karray *et al.* 2019). In the case of rainfed crops, such as the olive tree, production at *Skhira* delegation has significantly fluctuated going from single to double, despite the extension of areas over the years. It has, for example, increased from 3,215 tons in 2000 to 5,346 tons in 2010, to drop again to only 3,934 tons in 2020 (Table 6).

TABLE 6:
FLUCTUATION OF DRY OLIVE PRODUCTION IN THE *SKHIRA* DELEGATION.

Year	1995	2000	2005	2010	2015	2020
Production (tons)	870	3 215	2.102	5 346	3 308	3 934

(Sources: CRDA 2020a & 2020b, Author's Field Work)

Faced with these production constraints of dry olive cultivation, farmers have since the early 2000s turned to irrigation, taking advantage of the political and economic context which has encouraged farmers to increase the productivity of olives and olive oil (Chiab 2019). Twenty four years later, most of the crops that made up *Skhira's* agricultural "success story" have seen their production plummet from year to year (Table 7).

TABLE 7:
EVOLUTION OF PRODUCTION AND AVERAGE YIELD OF SOME IRRIGATED VEGETABLE CROPS IN SKHIRA BETWEEN 2000 AND 2020.

	Total production (tons)		Average Yield (tons/ha)	
Type	**2000**	**2020**	**2000**	**2020**
Tomato	5 119	16 247	28.6	32.3
Pepper	11 240	2 477	11.4	6.5
Watermelon	56,237	17,862	46.4	35.3
Potato	76	295	15.2	16.4
Other vegetables	2 808	13,782	11.9	14.6
Total / Average	**75,481**	**50,663**	**22.7**	**21.02**

(Sources: CRDA 2000, 2020b & 2021, Author's Field Work)

Indeed, total vegetable production of irrigated crops fell by more than 24,818 tons between 2000 and 2020. This overall decline is even greater in some crops such as watermelon and melon, which saw their production drop from 56,237 tons to only 17,862 tons during the same period. Only tomatoes experienced an increase in their production from 5,119 tons to 16,247 tons. This general drop is explained, in addition to the problems of aquifers drawdown, by the rapid degradation of soil fertility and its rapid salinization following the practice of intensive irrigation. This is, moreover, confirmed by the general decline in yields per hectare of these products. Watermelon and melon, for example, which are very sensitive to salt, saw their average annual yield drop between 2000 and 2020 from 46.4 tons/ha to 35.3 tons/ha. Problems of marketing these products have amplified their difficulties. This is probably the reason why the tomatoes production has increased since they are easily processed into canned foods, and well marketed in the internal and external market.

4.2.2.3 Still precarious production systems and uncertain family incomes

The new orientations of agro-pastoral production systems since the beginning of the 2000s, with in particular the decline in extensive livestock farming, the trend towards specialization in olive, fruit and vegetable farming and the use of irrigation to limit the harms of climatic hazards (Requier-Desjardins 2008, Gafrej 2016), were supposed to bring them more economic stability and greater sustainability. Twenty four years later, paradoxically these systems are economically very unstable and unviable since the breakdown of traditional pastoral and agro-pastoral systems, the transformation of agrarian structures and the organization of farms, the development of a market economy, the increased pressure on resources both quantitatively and qualitatively, the breakdown of traditional family structures, etc. resulted in a significant reduction in complementarity not only between families but also between territories and activities (Hanafi 2010).

This situation is often the cause of a serious family economies precariousness, since a large part of farmers, without substantial and constant incomes, have found themselves deprived of means to cope with climate change harms and to cope natural resources degradation. In addition, their productions, less and less competitive, were exposed to the market law which spared only the strongest of them. The latter are essentially among the large producers who have managed to acquire new land and have intensified their activity to obtain the maximum profit. Composed mainly of businessmen and liberal professions, these investors have taken advantage of the crisis in peasant agriculture since the beginning of the 1990s with the entry into force of the Agricultural Structural Adjustment Plan (PASA) and the Government Disengagement (Elloumi 2015). As for the small agro-pastoralists who plunged into a socio-economic crisis, they first of all abandoned, in part, their activities to seek employment elsewhere. Worse still, many of them were forced to sell their land at low prices (Daoud 2010). According to interviews with farmers, the average price of a hectare of uncultivated land has increased from around 500 TND in 2000 to more than 8000 TND in 2020[9].

Equipped with significant financial resources and supported by the regional authorities, the owners of large farms in *Skhira* were able to profit from their farms (Table 8). According to the estimates of the CRDA of *Sfax* and the CTV of *Skhira*, the average yield in olive trees (in tons per hectare) and the average income of the large farmers are more than three times what the small farmers in the region produce and earn. Factors that explain this variation include the difference between techniques and means of production used, density of trees planted and their varieties, techniques and schedule of irrigation, quantities and types inputs used, etc.

TABLE 8:
YIELD AND INCOME VARIATION OF OLIVE CROPS ACCORDING TO FARM'S TYPE IN SKHIRA REGION IN 2019

	Dry olive growing	Irrigated olive cultivation
Average production of small farm (tons/ha)	0.25	0.92
Average production of large farm (tons/ha)	0.52	2.10
Average income of small farm in 2020 (TND/ha)	262	966
Average income of large farm in 2020 (TND/ha)	624	2 520

(Source: CRDA 2020 & 2020a, Author's Field Work)

Moreover, the difference in yields and incomes also lies in the better position that large farmers have to negotiate the selling price, since they are, in most cases, producers-traders capable of controlling the entire economic chain and thus optimizing their expenses and earnings. In 2020, while the average price per kilo of olives sold locally was between 1 and 1,1 TND for small farmers, it was between 1,1 and 1,4 TND for large farmers (*Author's Field Work*, CRDA 2021). This explains the difference in average income per hectare between farms. It should also be noted that the figures presented in Table 8 only concern 2019, which was a pass agricultural year, but during bad agricultural years such as 2021, the incomes of small farmers is rudimentary or even non-existent.

V. CONCLUSION

It emerges from this analysis that the balance of the territorial dynamics initiated in the arid plains and hills of *Skhira* since the end of the 1990s, is more than mixed, since this Land use dynamics has not taken into account the limits of natural resources availability, natural hazards, and above all, climate change. Originally considered as a tool for the private appropriation of collective land and for improving the living conditions of *Skhira's* peasants, the quick development of olive cultivation turned into an opportunity to develop the earnings of a group of speculators unconcerned about resources fragility. It is for this purpose, for example, that irrigation has moved from relatively rational governance in the hands of local authorities and small farmers to a management that is almost monopolized by these private investors. Irrigation, which was then supposed to reduce economic inequalities in this region, has become a factor of disparity between social categories (Elloumi 2009).

In order to overcome their handicaps and maintain their farming activities, small farmers are often forced to go into debt with banks and/or input retailers or agri-food companies, which leads them to increased dependency and impoverishment (Requier-Desjardins 2008, 2010; Yousfi 2020). This indebtedness is all the more serious for them as the annual fluctuation of yields and selling prices do not help them to get rid of it, especially in the absence of an effective mechanism to cover the

[9] In 2000, a Tunisian dinar (TND) was worth about 0.665 euros, while in 2020 it was worth about 0.306 euros.

risks of climatic and economic hazards. As a result, the agricultural activity that was supposed to boost their economies and improve their living conditions has turned into a burden, sometimes dragging this population dramatically into precariousness. The result is an accentuation of the rural exodus, especially of young graduates, to seek employment in big cities such as *Sfax, Gabès* and *Tunis*. At the imadat[10] of *Noual*, the migration balance was negative by -9.5% between 2004 and 2014 as it registered a departure of 138 young people in 10 years (INS 2004, 2014).

The crisis in these marginal sectors in an already marginal delegation is accentuated by an unfavorable trend in agricultural prices, by the fragmentation of properties and increasingly restricted access to land, sold to speculators at low prices, by a small farmers exclusion from financing and credit system and finally by the inefficiency of the support services. The current economic uncertainty that hangs over the country, affecting all social categories more closely, and in particular small farmers, implies that all possible environmental and rural social events in *Skhira* are to be expected. Let us remember here that neighboring regions with similar conditions, such as *Sidi Bouzid*, experienced the same situation in the 2000s, which led to the outbreak of the 2011 revolution. Today, despite the multiplication and the diversity of strategies and programs[11] implemented by the central and regional authorities, it seems that their effect is not immediate, whereas the environmental and economic crises are. Moreover, it seems that most of these programs are "tailor-made" to favor large farms more (Bessaoud and Montaigne 2009, Palluault & Romagny 2009b, Bouarfa *et al.* 2020).

Furthermore, this agricultural intensification and the monopolization of resources accentuate the threat of desertification. Past experiences in neighboring regions have often led to the same result and have cost the Government and international funds enormous sums to limit its consequences, the cases of *Menzel Habib, El Hamma, Bled Ségui, Sidi Makhlouf* , etc. (Floret and Pontanier 1982, Auclair *et al.* 1996, Hanafi 2000, Jauffret 2001). This environmental result is accompanied by a deterioration of the population living conditions despite their continuous attempts to solve their economic difficulties.

It is therefore important today that the central and regional authorities pay more attention to the implementation of a planning and development policy that is really oriented towards the environment and the peasant society of *Skhira* and the other arid regions, which are more affected by the impacts of climate change. This policy must be spread over several periods ranging from the immediate to the long-term and must really target farmers and their environment from a perspective of sustainability. To this end, Tunisia has acquired a number of achievements in this area[12] that should be implemented. This sustainability must affect the environmental (soil, water and biodiversity conservation) and human aspects, in particular with sustainable agriculture that reconciles the environment, the economy and society (Massin *et al.* 2016, Benoit 2017) and which favors the peasants and small farmers of today and tomorrow within the framework of a social and solidarity economy capable of creating employment and wealth and of conserving a share of resources for future generations.

ACKNOWLEDGEMENTS

This work was funded and conducted between 2019 and 2021 within the "G&G" Laboratory attached to the Faculty of Letters, Arts and Humanities of the University of Manouba. The author would like to thank the managers of this lab for their logistical and financial support, as well as all the local decision-makers and farmers in the study area.

[10] *The Imadat* is the smallest administrative subdivision in Tunisia. It is generally a small urban (city) or rural area (village, *dachra, douar*) with the surrounding land.

[11] In order to solve the problems related to the crisis of agriculture and peasantry in Tunisia, the Government has implemented several programs which have affected, in part, the *Skhira* region. Examples include the National Climate Change Strategy (NCCS), which has been implemented by MARHP and GIZ since 2012, the Agricultural Land Management and Conservation Strategy (ACTA) developed by MARHP in 2017 and which includes CES actions geared towards ‘the development of sustainable and climate-resilient agriculture by 2050’ (MARHP, 2017) and the National Action Program to Combat Desertification 2018-2030 (Tounsi 2020). On a local scale, the *Sfax* CRDA has already implemented since 2016 a program that has aimed to develop more than 1500 ha in *Skhira* with a total cost of around 1,285,000 TND (CRDA, 2020b, 2021). The actions undertaken mainly concerned the control of groundwater (salinity, piezometric level, exploitation, etc.), the improvement of water retention techniques, the extension and the promotion of water economy.

[12] According to the report of the General Direction of Sustainable Development - DGDD (2011), the achievements of Tunisia in terms of sustainable development have mainly concerned the environmental pillar with the extension of organic agriculture over more than 200,000 ha, the extension of conservation agriculture over about 10,000 ha, the intensification of water saving programs that reach more than 80% of irrigated areas, the development of alternative resources such as the extension of the use of non-conventional water, the desalination of water in the South and the use of treated wastewater in irrigation, the intensification of environmental protection and natural resource management programs (CES strategies), the setting up of several pilot projects to exploit waste and the development of renewable energies, including solar energy. On a social scale, these achievements have included, inter alia, the establishment of sustainable consumption and production, the promotion of a well-functioning social economy, the strengthening of social equity and the fight against regional disparities, etc.

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