FORUM GEOGRAFIC

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **172**-**185**
http://dx.doi.org/**10.5775/fg.2022.217.d**

Ecosystem behavior face to climatic changes and anthropogenic actions. Case study: a north-eastern urban wetland, Tunisia

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Received on 02-07-2022, reviewed on 12-08-2022, accepted on 30-09-2022

Abstract

Wetlands environments are ecosystems threatened by climate change and urban sprawl. Studying the behavior of Sabkhaof Sousse, the green lung of the industrial region of Sidi Abd Elhamid in north-eastern Tunisia, is necessary to improve the living conditions of the population living within this ecosystem. This study analysis the impact of climate change and human activities on the seasonal and pluriannual behavior of this Sabkha by using multitemporal series of high-resolution satellite imagery, and a survey among the inhabitants of the area. Shorelines from 2003 to 2019 were vectorized in GIS environment using georeferenced images from Google Earth platform. Then, Land Use Land Cover changes were detected by using Environment Visualizing Imageries software. Results show that built-up and cultivated areas have increased by 4.3 % and 18.5 % respectively in the North and East side of the study area. Moreover, climatic changes during the seasons lead to changes in the soil occupation. Hence the importance of setting up strategies to preserve this brittle ecosystem. The development of an urban park around the Sabkha will enhance the local population's living conditions while also protecting the Sabkha from degradation.

Keywords: *urban wetland, climate change, Land Use Land Cover, population well being*

Rezumat. Comportamentul ecosistemului în fața schimbărilor climatice și acțiunilor antropice. Studiu de caz: o zonă umedă urbană din nord-estul Tunisiei

Mediul terenurilor umede reprezintă ecosisteme amenințate de către schimbările climatice și extinderea urbană. Studierea comportamentului Sabkha din Sousse, care reprezintă plămânul verde al ariei industriale Sidi Abd Elhamid din nord-estul Tunisiei este necesară pentru îmbunătățirea condițiilor de trai ale populației ce locuiește în cadrul acestui ecosistem. Studiul de față analizează impactul schimbărilor climatice și al activităților antropice asupra comportamentului sezonier și multianual al acestei sabkha cu ajutorul unor serii de imagini satelitare de înaltă rezoluție și unui sondaj de opinie în cadrul locuitorilor zonei. Liniile de țărm din perioada 2003-2019 au fost vectorizat în mediul GIS folosind imagini georeferențiate de pe platforma Google Earth. Ulterior, au fot detectate modificările Land Use Land Cover cu ajutorul software-ului Environment Visualising Imageries. Rezultatele arată că zona construită și cea cultivată au crescut cu 4,3% și respectiv 18,5% în partea de nord și de est a ariei studiate. Mai mult, schimbările climatice din timpul anotimpurilor au dus și la modificări în ocuparea solurilor, de unde rezultă importanța stabilirii unor strategii care să conserve acest ecosistem fragil. Dezvoltarea unui parc urban în jurul sabkha va îmbunătăți condițiile de trai ale populației locale, contribuind totodată la stoparea degradării sabkha.

Cuvinte-cheie: *zonă umedă urbană, modificări climatice, Land Use Land Cover, bunăstare*

Introduction

Wetlands are vital for the survival of humanity. They are among the most productive environments on the planet because they provide the water and productivity on which countless species of plants and animals depend for their survival (Lavoie et al., 2016). Wetlands are of serious significance in hydrological and ecological processes, as one of the world's most productive natural ecosystems. While they have many meanings in the literature, they will be defined for at least a part of the year as areas filled or soaked with water (Kaplan and Avdan, 2018). In this context, Orimoloye et al. (2018) underline that wetlands play a vital role in fostering the ecological diversity of different species. As an example, water birds, fish, amphibians, reptiles, and plant species ensure roosting, spawning, and feeding environments, particularly under severe weather conditions. Therefore, wetlands are an important wildlife breeding and feeding area. They create shelters and protection for aquatic creatures. In addition, they have significant aesthetic, educational, cultural, and

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spiritual values and provide invaluable opportunities for recreation and tourism (Millennium Ecosystem Assessment, 2005).

According to the Ramsar Convention report (2009), about 64% of the world's wetlands have disappeared since 1900 and it is recognized that the rate of loss of wetlands varies significantly from one nation to another. According to Niu et al. (2012), China has lost 33% in just 30 years from 1978 to 2008. In Tunisia, the total area of wetlands is roughly 1,250,200 ha and they are classified as 64 wadis, 62 Sabkhas, 37 ponds, 14 inland marshes, 4 coastal marshes, 16 chotts, 15 lakes, 5 natural springs and 3 peatlands (Convention on wetlands 2016). However, during the second half of the 20th century these ecosystems continued to decline and are more threatened (Chaabane et al, 2021; Hettiarachchi et.al., 2014). Recently, Abalo et al. (2021) have argued that climate change and anthropogenic pressures affect land resources, especially wetlands. From example, urbanization is one of the leading causes of species loss. It can decrease native species diversity directly by eliminating habitat and indirectly by increasing fragmentation and isolating natural habitat (McCauley et al. 2013). The negative impact of climate change can be deduced in hydrological regimes (Erwin, 2009) and on productivity of wetlands.

A lot of research around the world has been done to study and assess wetlands. From example, Li et al. (2012) have employed in their study an evaluation support system to accommodate the prevalent scenario structures of the Liaohe River Delta wetlands. Remote sensing was used to classify wetlands in central North Dakota (Rover et al., 2011) and Geographic Information System (GIS) was applied to analyze the land cover spatial dynamics of the wetlands located in Dakar (Aimée et al., 2018). Recently, Abalo et al. (2021) have calculated the Normalized Difference Vegetation Index and used Google Earth images to evaluate the land use of wetlands in Togo, particularly in the Ogou basin and have practice the «LECOS» extension of the Quantum GIS software to calculate landscape fragmentation.

Increasingly, remote sensing has has been used to generate landscape maps, information on land cover change, and tracking ecosystem status over broad scales and long-term observation (Lu et al., 2004). Therefore, a variety of research studies demonstrated the usefulness of GIS and remote sensing technology for mapping and monitoring wetlands (Adam et al., 2010; Wu et al., 2018). Recently, images from optical satellites such as Landsat are used to map the surface of Balikdami wetland, located in the central Anatolian part in Turkey (Kaplan and Avdan, 2018) at small and large-scale land cover change detection using bi-temporal and multi-temporal data (Djidel et al., 2013; Yan et al., 2019 and Liu et al., 2020). In Tunisia, Bel Fekih Bousemma et al. (2020) have used the radiometric indexes to assess vegetation, water, and salinity changes of Hergla wetland between 2007 and 2017. The spatial and temporal variation of radiometric indexes was helpful to understand the behavior of wetlands.

The objectives of this study are (i) to analyze the current state of the Sabkha of Sousse with the support of a survey, (ii) to map the spatio-temporal dynamic of the wetland between 2008 and 2019 on both global and local scales using Landsat and GE Time Series Images, iii) to analyze changes according to climate change and anthropic actions and iv) to propose the management of an urban park within the study area.

Materials and Methods

Study area

The Sabkha of Sousse is situated in the Tunisian Sahel, particularly in the south of Sousse city. It covers an area of 43 hectares and it is limited to the north by the deviation of the GP1 road; to the east by the olive groves and the district of Sidi Abd Elhamid; to the south by the railway and Zaouiet Sousse; and to the west by a wastewater treatment plant as well as the National Sanitation Office (ONAS) district (Fig. 1). The study area (35°47'31.6"N 10°38'46.1"E) belongs to the semi-arid bioclimatic stage marked by irregular rainfall. It is fed mainly by rainwater. The fauna is little abundant, because it is almost dry during the dry season. This Sabkha has been recognized and classified as a sensitive wetland by the Ministry of Agriculture since 1996. However, it continues to serve as a real anarchic dumping ground for various types of waste, to give the surrounding landscape a degraded image. In addition, this area is also used to discharge untreated wastewater from the ONAS, which manages a nearby sewage treatment plant.

According to Gammar and Boujarra (1993), soil types are largely dependent on the topographic and morphological position of the grounds and the study area has a sandy texture and therefore correspond to light soils on the hills and plateaus where they bury crusts and quaternary calcareous crusts of quite variable facies (SDARECO, 2011). On the upper parts of these hills, where an ablation dynamic prevails, whether by water erosion or wind deflation, the thickness of these soils is significantly reduced. They have decreased in this way, and little rendzine-type calcareous soil evolution has occurred. It is characterized by a stony pavement reminiscent of the landscape of regs or hamadas. These surfaces are generally arranged in impluviums called locally ≪ meskat ≫ which collect rainwater and drain them to the plots located below (≪ menkaa ≫) through a network of ≪ tabias ≫ (Elouardani et al, 2020).

Sousse city is characterized by the predominance of the topographic flatness, so as to expand the range of floodable perimeters following especially the difficulties of drainage of runoff and their evacuation to the endoreic basins or to the sea. Moreover, two main rivers control the hydrology of Sousse: Oued El Hammam and Oued Hamdoun. These exoreic wadis are essentially characterized by the smallness of their catchment areas and the weakness of their slope (respectively 2 per thousand, 6.0; 8.1 and 2.225) (Sahtout, 2015). The hydrographic network is divided from north to south between seven watersheds. These are basins constituted around the Sebkha Assa Ejjriba, El Kalbyya, Sidi El Hani, Sidi Khalifa, Oued Laya, El Hammam, and Oued Hamdoun. These last ones constitute micro-catchment areas because of their limited surface and the size of the small oueds that drain them. The few oueds of Sousse, such as Laya, Hamdoun, or Kharroub, are temporary or even completely dried up most of the time, thus preventing any development of these waterways by collectors (Ben Salem et al, 2021).

Fig. 1: Localization map of the study area and its surroundings (@Google Earth, 2020)

Methodology

As a first step, a physical analysis was carried to display the soil, vegetation, DEM, hydrographic network and main climatic parameters of the study area (so poor with only these two and only with simply variation, to reflecting climatic changes).

As a second step, a survey about citizens opinion regarding the perception of inhabitants on the Sabkha of Sousse wetland is done by studying the identity, the services, and the state of the wetland. Then, the land use changes were extracted at global and local scales corresponding to ecological, social, and urban transformation between 2008 and 2019.

Finally, the use of wetland mapping conversion and habitat distribution (spatial and temporal) lets us to understand the land changes of the wetland and its surroundings. However, for an improved well-being of the population in this region, a conception of an urban park in the Sabkha will be proposed using AutoCAD software.

Physical analysis

The physical analysis is based on the description of physical components of the study area.

Climate data are downloaded from the NASA open access (https://power.larc.nasa.gov/data-access-viewer), soil and hydrographic resources are collected from the GIS database.

Figure 2 shows that the average monthly rainfall recorded between 2003 and 2019 is highly variable from month to month. October is the rainiest month, while July is the driest. Nevertheless, we note that the winter rainy events are more important these last three years exceeding the average. Between 2003 and 2019, the rainiest year is 2003 with an average annual rainfall of 606.45 mm.

Figure 3 shows that the monthly temperature is almost constant during this period, some slight variations are recorded mainly in winter and marked by increases of 1° C.

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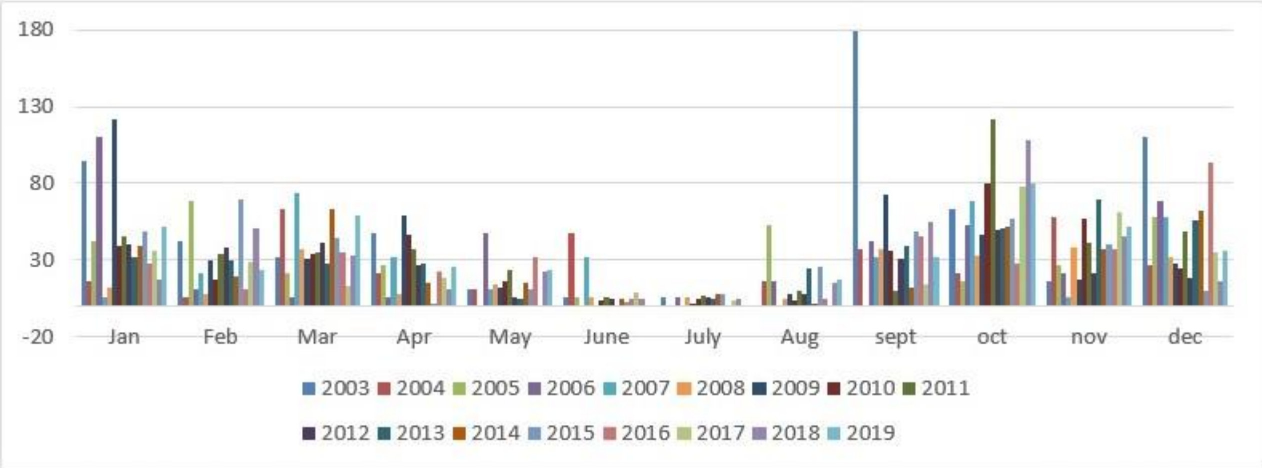

Fig. 2: Variation of the monthly rainfall average in mm per day of Sousse region between 2003 and 2019 (https://power.larc.nasa.gov/data-access-viewer/)

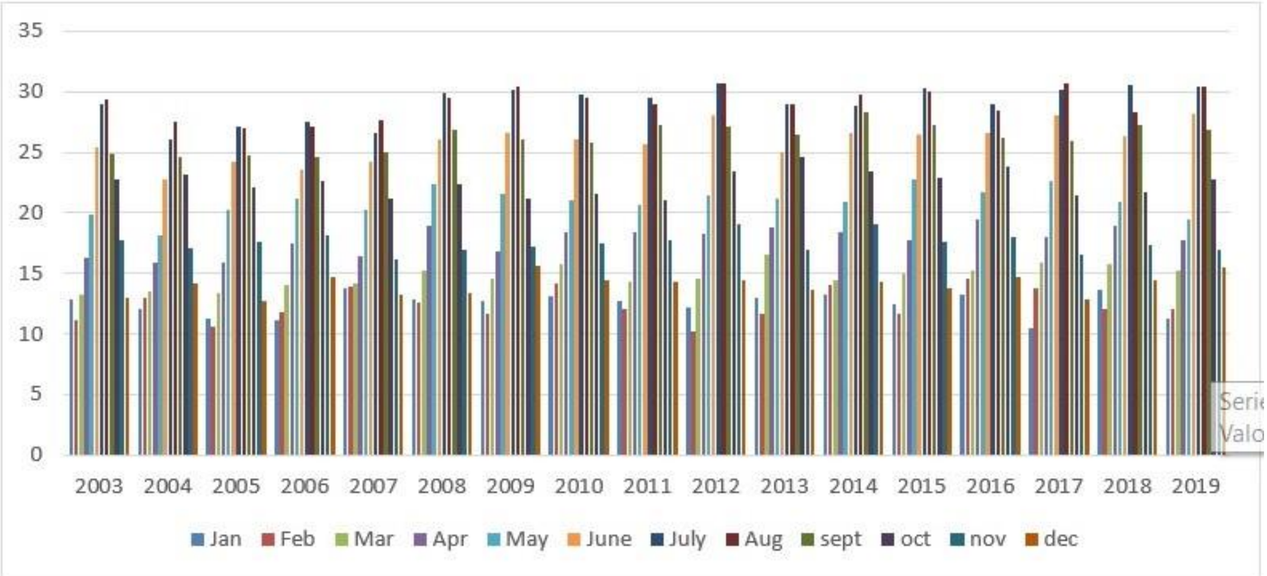

Fig. 3: Variation of the monthly temperature average of Sousse region in ° C between 2003 and 2019 (https://power.larc.nasa.gov/data-access-viewer/)

Questionnaire regarding the citizens opinion on Sabkha of Sousse

The data collection for anthropogenic and social analysis was based on a structured survey of interviewers from different categories (adults, adolescents, housewives, workers, farmers etc.).

It is composed of two sections: i) a social description interested in personal information of the respondents: age, family situation, intellectual level, and profession; and ii) a second section which includes questions that affect identity, service, and state of the Sabkha, its usefulness and the evaluation of its condition.

Data and description of remarkable changes cited by locals are considered. A total of 16 questions were asked to 60 residents and the responses from the interviewers and the key informant interviews were recorded by hand on the notebook and the results were processed in Excel. The survey is a semi-directed one, including qualitative and quantitative information.

Land Use Land Cover study

Given the important role of wetlands in Sousse, Land Use Land Cover (LULC) changes occurring in the uplands, understanding, and assessing wetland conditions requires high resolution data, the remotely sensed data currently available for this region are limited.

In this case, a spatiotemporal analysis at two different scales; global and local was made. Thus, a processing of a time series by the remote sensing tool as well as GE clips were used for a larger scale.

For the global scale, two high resolution Landsat satellite images were downloaded from the USGS platform (https://earthexplorer.usgs.gov/), with a spatial resolution of 30 m, namely Landsat 5TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) dating from 23/08/2008 and 06/03/2019 respectively (Table 1).

Table 1: Characteristics of the Landsat scenes used

	Landsat 5	Landsat 8
Acquisition date	23/08/2008	06/03/2019
Altitude	705 Km	705 Km
Duration of a revolution	99 minutes	99 minutes
Time resolution	16 daysTM	16 daysOLI
Sensors	30*30 m	30*30m
Spatial resolution Mown to	185 Km	
the groundNb of bands	7	10+1P

This kind of images has the advantage of being freely available and widely utilized in wetland mapping (Abalo et al. 2021). Atmospheric and radiometric corrections were done using the ENvironment Visualizing Images 5.1. The reflectance calibration consists of deriving the reflectance value from the Digital Number and calculating the top of atmosphere reflectance attention (Azabdaftari and Sunar, 2016). Ground verification data was obtained from sample locations using the Garmin 6S Map to enhance the consistency of the thematic resource data prepared (Singh et al. 2020; Ogato et al. 2021).

The Table 2 shows the six LULC classes determined and used for the supervised classification of Landsat images and the description of each class. Then, a maximum likelihood (MKL) classification system was applied to both images. This method aims to facilitate the development of land cover classes and is more rigorous in the classification process (Gutierrez and Johnson 2010). It is based on the probability that a pixel belongs to a particular class. However, it needs a long time of computation, it relies heavily on a normal distribution of the data in each input band and tends to over classify signatures with relatively large values in the covariance matrix (Rawat and Kumar, 2015).

That's why, Kappa method was used to assess the mapping accuracy (Bonn and Rochon, 1992), and when confusion existed, high resolution maps of GE and its online ground imagery were regularly consulted. Inputs are the original satellite or aerial image, which must be processed to calibrate the radiance reaching the sensor and to geometrically correct the image to fit a selected geographic map projection. Then, the ground truth information from the GIS is added to this mapped image. The result is an image of the land cover from the land cover and classification system. At this point new features are added to the land cover data base and the GIS data base.

Table 2: Description of the LULC classes determined for the supervised classification

LULC	Description	Picture
Urban	Areas occupied by urban residential houses, buildings, and industrial uses	
Wet areas	The wetland of Sousse	
Olive groves	Plot Land occupied by olivetrees	
Grassland	Land dominated mainly by grasses and forbs	
Uncultivated soil	Uncultivated plot with natural vegetation	
Agricultural mosaic	Land with bushes and shrubs, small trees scattered and mixed with grasses	

Six GE images were employed, at the local scale, to detect changes on the wetland and specially to identify the major land use land cover of the area and to draw the shorelines of the Sabkha. Years were chosen between 2009 and 2019 according to the seasonal variations and the visibility of the images.

Results

Characterization of the state of the Sabkha of Sousse

The wetland of Sousse is formed by a depression in which the runoff from the surrounding heights collects. The drop in the site is very low. The longitudinal plot represents an altitude variation between 6 m and 12 m. While the vertical plot indicates a variation between 11 m and 8 m (Fig. 4).

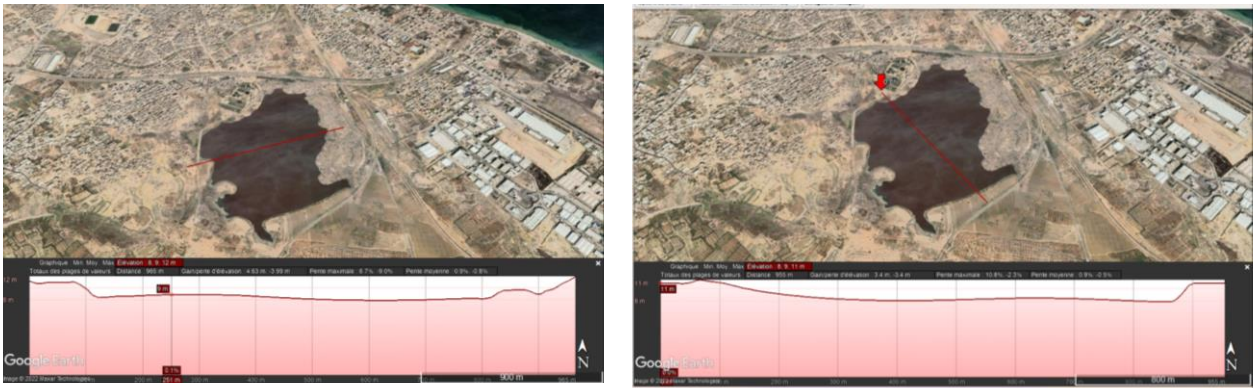

Fig. 4: Variation of the study area elevation (at left Longitudinal, at right Vertical) (@Google Earth, 2020)

Halophyte vegetation is present on the banks of the study area and invasive plants were observed all around the Sabkha. The species present are annuals and halophytes of the Chenopodiaceae family and grow in moist, sandy or clayey soils with high salinity such us *Halumioneport lacoides*, *Suaedamaritina*, *Arthrocnemumm acrostachyum*, *Salicornia arabica*, *Holocnemum strobilaceum* and *Atriplex inflata*.

To analyze the current state of the site, an assessment of the strengths and constraints of Sabkha Sousse had been made.

Constraints

(1) The soils are very salty and have undergone a natural modification by urban waste and landfills, so the species chosen to be planted must be tolerant to salts and lateral rooting. (2) The water supply of the Sabkha is very limited since the rivers are very small and the groundwater is polluted, because the treatment plant implemented on the northwest side rejects the wastewater on the wetland, so the water has a poor quality. (3) The natural flora of the study area is marked by its necrotic state. (4) The fauna is in disappearance; ecological niches are very rare as well as most of the characteristic species of the environment have disappeared. (5) The industries all around the wetland have a negative impact on the environment, the health of the inhabitants as well as the ecological state of the Sabkha. (6) The local population suffers from the problem of unemployment; we remarked a lack of craft activities. (7) There is no security, and the adjacent popular neighborhoods are dangerous. (8) The banks of the wetland are filled with household and industrial refuse.

Strengths

(1) The location of the study area is strategic. (2) Atriplex inflata takes top rank among the local species found in the study area. (3) There are aquatic insects, amphibians, and some migratory birds. (4) Agriculture is developed all around the wetland (crops, olive groves) with the absence of any use of pesticides and insecticides. (5) The wetland offers distinctive character and panoramic views over agricultural land and the urban center of Sousse.

In this situation, it is necessary to take advantage of the ecosystem services provided by the Sabkha to ensure its integration into its environment for its sustainability. Then, managers of the wastewater treatment plant must also find a radical solution to no longer disturb and pollute the Sabkha further. The rivers must be protected and the cultivated areas which delimits the wetland should not be neglected to manage and protect this area.

Land Use Land Cover changes

Global scale

Figure 5 shows that in 2008, the built-up areas are almost located near the costal side, which represented the urban core of the city, which occupied only 9.35 %. Whereas in 2019, some patches are detected in the middle- east (13.62 %). The olive fields are situated in the middle eastern and the southeastern part, with 43.74 % in 2008 and 31.55 % in 2019. The wet areas in this city are formed entirely by Sousse Sabkha, which was marked by its instability between 2008 and 2019, changed from 0.12 % to 0.10 %. Moreover, in 2008, the agriculture mosaics sited were mainly in the northeast with 11.69%, and in 2019 new fields are detected in the middle-west (30.22 %). The occupations of uncultivated soil evolved from 7.04% to 11.80% and this especially around the Sabkha. The grasslands scattered throughout the region, decreasing from 28.06 % to 12.71 %.

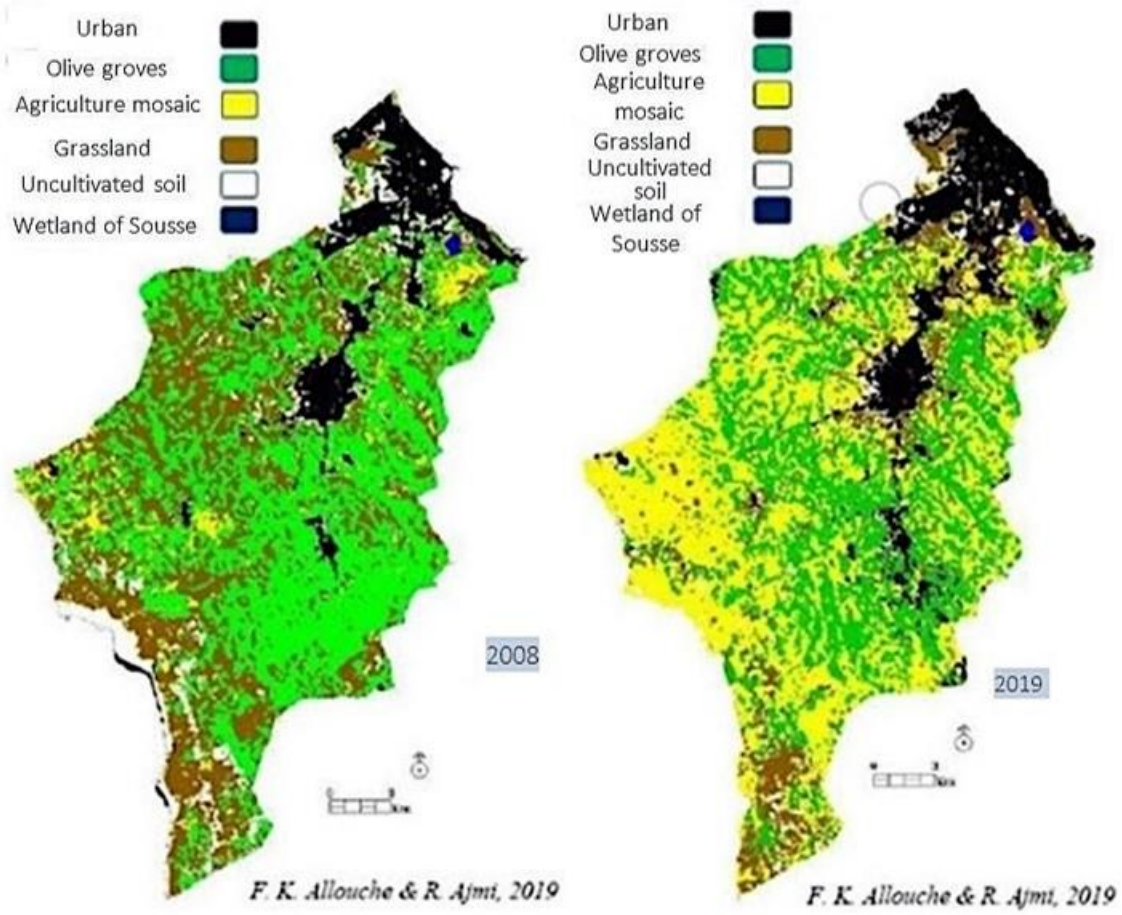

Fig. 5: LULC maps of Sousse region (at left in 2008, at right in 2019)

Local scale

Zooming in to the level of the Sabkha of Sousse, Figure 6 shows the increase in built-up areas on the west side with a reduction in the areas of olive groves.

It is due to the importance of the development of urbanization and its corresponding facilities (housing estates, roads, industrial areas, parking, landfills, etc.) mainly on the southwestern side of the Sabkha which has been achieved to the detriment of the wetland. It is thus threatened by compartmentalization and pollution. Hence, the importance of limiting the phenomenon of urban sprawl. Nevertheless, climate change will directly alter ecosystem services, for example, by causing changes in the productivity and growing zones of cultivated and non-cultivated vegetation and indirectly, by leading to sea level rise, which threatens the Sabkha and other vegetation that protect the shorelines.

Fig. 6: LULC changes in the Sabkha of Sousse at the northwest side (at left in September 2009, at right in December 2018, @Google Earth)

Figure 7 reveals that in August 2009, the Sabkha is almost dry while in January 2014, it is engorged with water. This is due to climate change during these periods, in fact in August 2009 the precipitation is equal to 8.10 mm and the average temperature are 30.4° C while in January 2014 the precipitation is equal to 38.7 mm and the average temperature is at 13.3° C (https://www.learngeom.com).

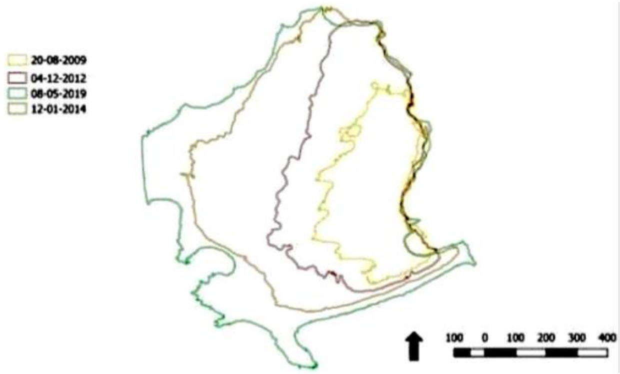

Fig. 7: Spatial-temporal variation of Sabkha Sousse shorelines between 2009 and 2019

Figure 8 illustrates that the area of the wetland changes with the season, in fact it has an area of 143 m² during the summer season of 2009 against 527 m² during the winter season of 2014. Therefore, climate elements as background for wetland change, which are mainly revealed through temperature and precipitation, influence the growth and decline of wetlands. Certainly, increased precipitation expands wetland, which makes a positive correlation between them. In contrast, the temperature effect on wetland is more complex. So, rising temperatures increase evaporation, accelerating loss of water in wetland, thus its area shrinks.

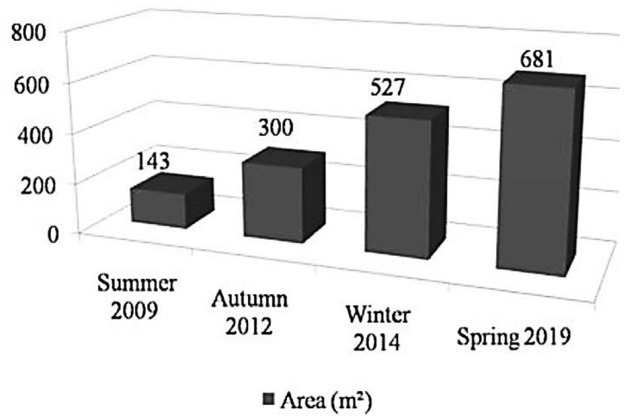

Fig. 8: Seasonal variation in Sabkha Sousse between 2009 and 2019

Impacts of Climate change actions

The Sabkha has been affected by climate change in recent decades with an increasing sensitivity gradient from West to East.

Figure 9 indicates that the Sabkha branch off several streams presented by the main course of Oued Hamdoun, which is directly connected to the sea. Thus, it plays an important role in the Oued Hamdoun watershed, from where it must be preserved from any destruction so that it retains its function of regulating floods and protecting its waterways. The water inlets and outlets of the Sabkha are not well identifiable, indeed the rivers of the Sabkha have been disturbed by the setting of the GP1 belt road on its north side as well as the railway line on the west side. This has disturbed the hydrological system of the Sabkha. Thus, the hydraulic continuity is broken, and the wetland will no longer be supplied with water and may disappear.

Fig. 9: Sousse Sabkha hydrographic network (@ Google earth, 2015)

Figure 10 shows that the lower part of the site on the south side is damaged by storm water runoff so the study field becomes very rough and makes movement very difficult. However, on this side, the rivers feed the Sabkha.

The increase in seasonal contrasts in recent years marked mainly by summer rain events and rising autumnal temperatures will have a negative impact on the biotopes of the Sabkha which will have an annual hydrological cycle marked by strong seasonal variations modeled on the rainfall rate (Fig. 11).

Fig. 10: Traces of streams on the southwest side of the Sousse Sabkha after the rain events recorded on 15/10/2019

In addition, aquatic populations will respond to water and thermal stresses through adaptive changes in biology, population dynamics and distribution, and in the taxonomic composition and richness of communities.

This climatic irregularity marked by rainy events, rising temperatures, intense evaporation (partial or total drying out) will strongly contribute to the impoverishment of aquatic fauna, the scarcity or disappearance of certain vulnerable species.

This will lead to a loss of specific biological diversity, a decrease in productivity and a disruption of the distribution of flora and habitats for fauna.

Fig. 11: Google Earth clips from the Sabkha of Sousse at west side (at left in August 2009, at right in May 2018)

The perception of inhabitants on the Sabkha of Sousse

Figure 12a illustrates that the entire population surveyed does not benefit from the Sabkha in any way and does not use it for irrigation or other purpose. 44% of the surveyed population considers the Sabkha as a space which has nothing to do with it and which does not represent anything to it, the age range of most of this category is between 25 and 35 years.

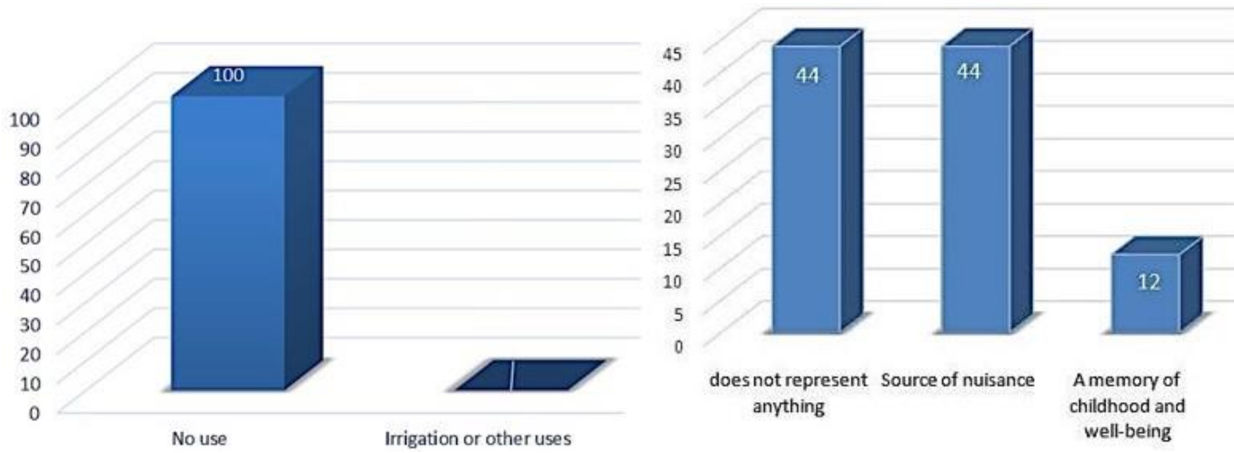

Fig. 12: Uses of the Sabkha (a); residents' perceptions of the Sabkha (b)

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The same proportion (44%) is accorded for those who consider the Sabkha as a source of nuisance and pollution and only 12 % of the interviewers have a memory of childhood and recreational role of this wetland (Fig. 12b).

Figure 13a shows that 72% of the interviewed inhabitants have noticed that the condition of the Sabkha changes with the seasons and according to Figure 13b, 72% of the inhabitants surveyed claimed that during the summer the state of Sabkha is worse than in the winter. The results of the survey carried out among farmers showed that according to their opinion, the urban extension and the climate change caused the instability of the current state of the Sabkha, a decrease in olive groves in the surroundings and deterioration of the life quality in the outlying districts.

The analysis showed the increase in cultivated areas around the wetland and the figures show this increase between 2009 and 2018 which contributed to the evolution of agricultural needs, by stimulating pumping for irrigation. The inflow of water from the groundwater to surface aquatic systems is therefore likely to decrease significantly, modifying the ecological functioning of wet-lands, interfaces between groundwater and surface water. So, we must put in place strategies to deal with these changes which have negative consequences on the wetland.

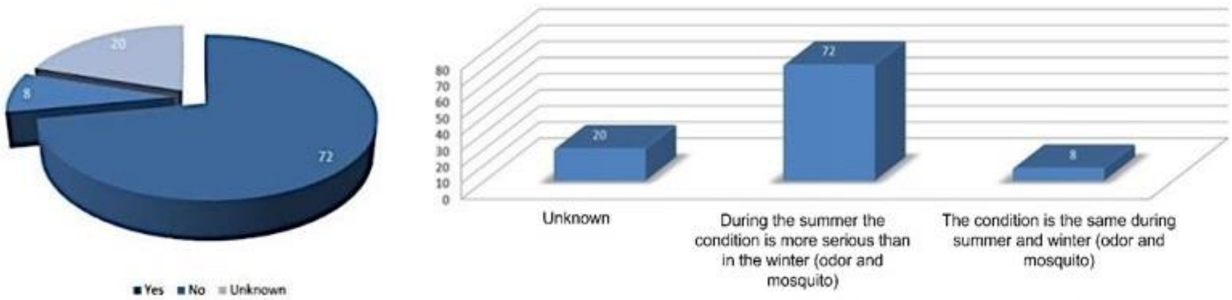

Fig. 13: Change of state of the Sabkha according to the seasons (a); state of Sabkha in the winter and summer (b)

The urban wetland of Sousse as a green lung

The analysis of the state of the Sabkha according to climatic and anthropogenic factors has shown that this ecosystem is threatened by a severe degradation. However, the deterioration of wetlands constitutes a danger, due to the role that these ecosystems play in climate regulation. Indeed, they can store water in the ground or retain it on their surface; reduce the intensity of floods and the damage caused by flooding; the water accumulated during rainy periods or during exceptional weather events can gradually feed groundwater and rivers during dry periods and they mitigate global warming. In general, carbon is sequestered by vegetation, via photosynthesis. In addition, the local population has expressed an interest in the management of this space for their well-being, hence the idea of proposing a landscaping management to reduce the impact of the various factors and improve the environment for city dwellers.

The Sabkha represents a very fragile ecosystem, which has become more and more degraded because of the mismanagement of the actors of the territory and the weakness of the means to fill its shortcomings. Nevertheless, this ecosystem still represents an ecological potential which must be developed to restore and preserve the environmental quality of this area and restore the natural functions of the Sabkha. In this context, the restoration of the Sabkha river and the development of its banks into an urban park has been adopted as a development strategy. The aim of this project is to conserve this vulnerable ecosystem and to develop recreational functions in this landscape to the residents. The Park has an area of about 42 ha. The concept is based on the "Integration". The idea derived from the principle of incorporating this "sensitive" area into its urban, social, hydrographic, and natural environment to improve human well-being and save natural resources by using ecological and social scenarios.

For those reasons, seven action programs are proposed. (1) The discovery trail is a path on planking which is composed of piles assembled by means of crossbeams. It is equipped with benches on both sides and with information panels. (2) Prairies are created to reconstitute quality habitats for fauna and flora. *Carexelata Aurea* is used as a ground cover and *Phragmites australis* will be planted as oxygenating properties for the water in the filtration zone, to fix the banks and the zones subject to erosion. (3) Wooded areas are planted mainly with eucalyptus, a species that shuns insects. They will be equipped with wooden kiosks, useful for birdwatching, in- formation and awareness panels. (4) Educational plots of minimal and composed of containers, double-bottomed bins, shaded by eucalyptus trees are designed. (5) Playground areas are equipped with wooden constructions and benches where parents can rest next to their children. (6) Observation stations, footbridges and platforms are developed to allow the visitor to discover discreetly the fauna and flora species and finally (7) two entries are arranged, a main one and a secondary one (Fig. 14).

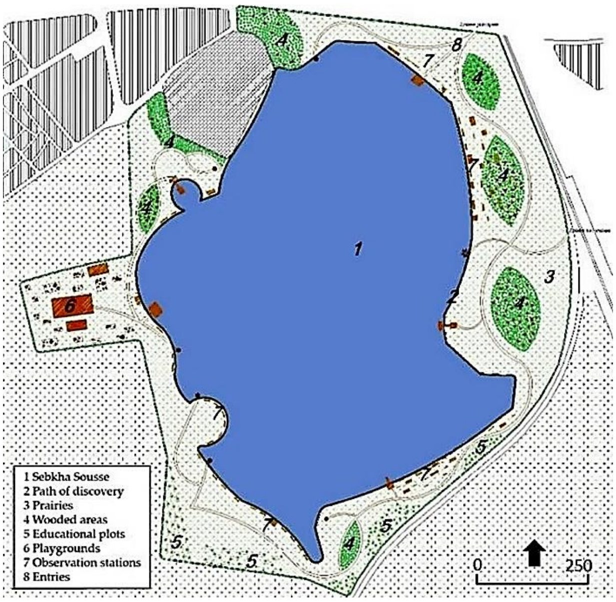

Fig. 14: Master plan of the wetland urban park, Sousse

Discussion

Wetlands are one of the most valuable natural resources in the world. They play major ecological functions, absorbing toxic chemicals and pollutants, storing natural carbon, recycling nutrients, while also contributing to groundwater recharge in arid and semi-arid regions (Chenchouni et al. 2015). While the objective of our study is to analyze the impact of climate change and human activities on the seasonal and pluriannual behavior of this Sabkha by using a multitemporal Landsat satellite imageries and other imageries obtained from GE platform, the results have clearly shown the negative impacts of urban sprawl around the Sabkha of Sousse. As has been extensively debated in previous research, urbanization is a principal cause for land-use change (Salvati et al. 2018; Dadashpoor et al. 2019; Tang et al. 2020). The results of the global and local scale analysis convey that the built-up area have increased between 2008 and 2019. Urbanization is a major cause of destruction in coastal wet-lands, and it has a serious effect on their structure and function (Lee et al. 2006; Li et al. 2010). Moreover, the decrease in water volume has far reaching environmental effects for and beyond the area. This phenomenon was demonstrated by Ogato et al. (2021), who suggested some possible causes for this decline, pointing to both human and natural influences. Therefore, climate fluctuations in various areas would have differing impacts with respect to wetlands (Niu et al. 2012). In Tunisia, Bel Fekih Bousemma et al. (2020) have studied the LULC of Halq El Mingel. So, the total wetland area Over the past ten years, more than 4% of the natural wetland has been destroyed, reducing the overall area of wetlands. and this variation is probably linked to climatic effects.

In fact, the Spatial-temporal variation of Sabkha Sousse shorelines is an urbanization impact on runoff and discharge. Ecosystem resources could be lost because of these shifts in ecosystem systems, which will have a detrimental effect on biodiversity, culture, and the environment (Wiederkehr et al. 2020).

In our study, an exceptionally anarchic extension on the banks of the Sabkha is detected, associated with a spontaneous nibbling of the agricultural belt and a deterioration of the quality of life in the disadvantaged peripheries. This process was also identified in the study prepared by Chouari (2013) on the Sijoumi wetland and many other Mediterranean wetlands. This requires the development of a management and sustainable strategy of these fragile areas to preserve them. Thus, conservation and regeneration programs and policies can be integrated with economic local development and hunger reduction practices and initiatives (Yohannes et al. 2020). According to Bel Fekih Boussema et al. (2020), wetlands are important not only for their ecological but also their social and economic effects. Their decline can generate critical consequences such as increasing costs for water quality treatment, improved infrastructure for regulation of floods and programs for elimination of invasive species.

Conclusion

The urban wetland of Sousse represents the green lung of the industrial area of Sidi Abd Elhamid and the only virgin space where the inhabitants can take refuge. It is a large place that gives the impression of freedom in the middle of nature, offering panoramic views of the different types of landscapes that surround it. In fact, the Sabkha regulates the flow of water in the river basin, preventing flooding by halting, collecting, and eventually returning water. It is therefore a true hydrological reservoir since it stores water at some periods before releasing it to another. The application of an integrated methodological approach made it possible to characterize and evaluate the state of this ecosystem. However, the use of remote sensing and GIS tools has helped to detect its spatiotemporal and anthropogenic dynamics according to the results of surveys carried out among the local population. In addition, this study made it possible to prove once again the effectiveness of such methods and tools at regional and local scale. Thus, development proposals for the banks of the Sabkha to minimize pollution, to reintegrate the agricultural practice by the development of educational plots and to integrate discovery and entertainment activities by the development of discovery trails and playgrounds will play an essential role in improving the living environment of the population in the face of climate change.

Funding

This research received no external funding.

Acknowledgements

The authors would like to express their appreciation for the municipality of Sousse, Tunisia, for the administrative and technical support.

Author contribution

Conceptualization, Faiza Khebour ALLOUCHE and Rania AJMI; methodology, Faiza Khebour ALLOUCHE and Rania AJMI; formal analysis, Faiza Khebour ALLOUCHE, Rania AJMI and Safa belfekih BOUSSEMA; writing—original draft preparation, Faiza Khebour ALLOUCHE and Rania AJMI; writing—review and editing, Safa belfekih BOUSSEMA and Gheorghe ȘERBAN. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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