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Original Article

Mapping and monitoring of Large-Sfax wetlands (center-east of Tunisia) using radiometric indexes and GIS tools

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ABSTRACT

Wetlands are characterized by temporary alterations in their structure and composition, and by multifunctionality. Therefore, identifying the boundaries of these zones is essential for appropriate characterization. In this context, this applied research work focuses on the wetlands of Large Sfax in the eastern center of Tunisia. The adopted methodology is based on a combined approach based on multivariate analysis and multi-dates analysis for the identification and the spatial delimitation of wetlands in the study area. The radiometric indexes of humidity NDWI, vegetation NDVI and brightness IB were calculated for the years 2003 and 2015 by using satellite imagery coming from Landsat ETM+7 and Landsat OLI 8. The classification maps of the calculated indexes enabled the identification and spectral delimitation of the wetlands of the study area. The multi-dates analysis was based on the visual interpretation of the panchromatic aerial photographs and the Google Earth snippets for the update of the results. This allowed the spatial delineation and the monitoring of marine, inland, and artificial wetlands in the study area. The importance of using the combined approach is that it allows a better characterization of wetlands.

1. Introduction

Water is the determining factor for the functioning of wetlands. Its characteristics, notably salinity, mineral and organic compositions and submersion undergo periodic fluctuations that depend on the climatic conditions and their location in the catchment. These fluctuations cause the formation of particulate solids together with specific vegetation and fauna.

Although water is the identifier of a wetland system, in practice, it is a poor descriptor for humidity in the site because of its fluctuating character [1]. The wetness of the site varies in intensity and the diagnostic elements are not the same during the hydrological year. All of these factors explain why the definition and the delimitation of wetlands are complex and often controversial issues. At the international level, the Convention on the Conservation and the Rational Use of Wetlands (Ramsar convention) adopted the broadest definition. According to the Convention, wetlands are defined as: “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters” [2].

In the field, the delimitation and the characterization of wetlands are based on two other criteria: hydromorphic soil and hygrophilic vegetation [3]. In wetlands, soil and vegetation from a specific way and persist after periods of waterlogging and fitting out [4]. Plants develop adaptations that represent excellent indicators of hydromorphy, level variations and water composition [5]. Wetlands are considered among the most valuable natural resources in the world.

Therefore, their mapping and monitoring have become increasingly important with the development of remote sensing technologies [6].

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Indeed, remote sensing offers a range of diverse data, aerial photographs and satellite imagery, which are increasingly used to study wetlands at different scales [10]. Panchromatic, color and infrared aerial photographs are used as background materials in several studies to identify, delineate and map wetlands ([7], [11], [12]). Multispectral satellite data have also been a valuable tool for mapping and monitoring wetlands. The maps obtained from spectral indexes calculation are used to identify, characterize and delineate wetland components ([8], [13]).

The boundary spotting and the mapping of these complex and polymorphic ecosystems is now a major challenge to ensure the best characterization, inventory, and monitoring [14]. In this context, this research work is applied to Large Sfax wetlands in Tunisia. The methodology adopted consists in using a combined approach. It is based on the visual interpretation of panchromatic aerial photographs, Google Earth snippets, digital processing of Landsat imagery and GIS spatial analysis.

1.1 *Study area*

The spatial framework of this study is "Large Sfax". It belongs to the Sfax governorate located in the center-east of Tunisia (fig. 1). The study area is limited to the east by the Mediterranean Sea and the west by the road «belt km 11». It covers about 285 km² with 515,000 inhabitants in 2014 (INS, 2019). Its coordinates in comparison to north latitude and east longitude are respectively 34°48' and 10°39'.

As illustrated in Figure 1, the study area is characterized by a semi-arid climate where the average temperatures are 18.9°C for the 1950-2008 period with low annual precipitation, which did not exceed 237.8 mm for the same period [15]. The pedology is dominated by halomorphic soils in the coastal band, isohumic soils and regosol soils, which are currently transformed by intensive urbanization. Halomorphic soils cover wetlands such as seasonal brackish swamps and saltworks of Thyna [15].

Fig 1. Study area localization (google earth, 2021)

2. Materials and Methods

2.1. Material

Table 1 presents the data used in this study. A series of panchromatic aerial photographs, Google Earth snippets, and Landsat satellite imagery, cross-referenced with the use of exogenous data (soil maps, hydrographic network map, scan 25, 1969 maritime chart, etc.) were used for the recognition and the spatial delimitation of the wetlands in the study area. These data are processed using the QGIS 2.18 software.

Table 1. Materials used.

Stage	Tools
Digital processing	Landsat 7 ETM+ satellite imagery of 29/01/ 2003; Landsat 8 OLI satellite imagery of 03/01/ 2015;
Visual interpretation	10 panchromatic aerial photographs with the scale of 1/25.000 for 1963; 31 panchromatic aerial photographs with the scale of 1/10.000 for 1982; IKONOS satellite imagery of juin 2003; Google Earth snippets for 2003 and 2015.

2.2. Methods

The methodological approach adopted in this study is based, after collecting the necessary data, on their preprocessing and the processing.

2.2.1. Data preprocessing

- ***Satellite imagery***

Before any processing, Landsat imagery is radiometrically and atmospherically corrected using QGIS 2.18 software. These corrections are applied to the image to reassign to each pixel a radiometric value as close as possible to that measured in the field [16]. This software offers a wide range of multi and hyper-spectral image analysis tools and radiometric correction of the image using the metadata file that accompanies Landsat imagery.

- ***Aerial photographs***

The aerial photographs used in this study are obtained in paper form from the Tunisian Office of Cartography. To transform them into a digital format, we used a scanner. These photographs are orthorectified on the Bing image (extension layers in QGIS) using the same WGS 84/pseudo-Mercator projection system so that data from different dates can be perfectly superimposed. The selected calibration points must be remarkable, such as the intersection of roads, a bridge, and the angle of a building. Therefore, the geo-referencing of a photograph consisted in recalculating to replace it in the chosen projection system and thus make it superimposable in all points to a map. Georeferenced photographs were then linked, allowing the creation of a mosaic [17]. GIS can display calculated geo-referenced photographs and thus reconstruct an overview of the study area.

2.2.2. Data processing

- ***Multivariate analysis***

Radiometric indexes are multivariate analyses, that is, treatments developed from multiple channels. These are often mathematical operations aimed either at reducing the amount of information and/or at highlighting particular themes (water, vegetation, soils ...). Three indexes were calculated in this study namely:

The Normalized Difference Water Index “NDWI”, the humidity index, calculated from the Near-infrared band “NIR” and the short wavelength infrared band “SWIR”. The formula used to calculate this index is as follows:

$$NDWI_{GAO} = (NIR - SWIR) / (NIR + SWIR) \quad (1)$$

The choice of these wavelengths allowed maximizing the reflectance properties of water. In fact, the use of the SWIR wavelengths maximizes the typical reflectance of water features and the NIR wavelengths minimize the low reflectance of water features [18].

The Brightness index ‘IB’ is one of the most recognized soil indexes. It reflects the changes in the clarity of bare floors. The shift from light to dark shades is accompanied by a simultaneous increase in radiometric values in both Red (R) and near infrared (NIR) channels [19]. According to [20], it is the most significant parameter for determining soil water behavior. The formula used to calculate the Brightness index is as follows:

$$IB=\sqrt{((NIR^2) + (R^2))} \quad (2)$$

The Normalized Difference Vegetation Index “NDVI” is a function of reflectance in red (R) and near infrared (NIR) [21]. Indeed, the spectral response of a vegetal cover shows a strong reflectance in near infrared and a low reflectance in the red. These wavelength domains are therefore widely used because the difference in reflectance in these two spectral bands depends on the chlorophyll characteristics of the vegetation [22]. It is calculated by using the following formula:

$$NDVI = (NIR-R)/ (NIR+R) \quad (3)$$

- ***Multi-dates analysis***

This analysis consists of the monitoring and spatial delimitation of Large Sfax wetlands over a period of 55 years. To do this, the first step was to identify and locate the wetlands within the study perimeter by relying on the visual interpretation of the various available supports. The interpretation is based on the use of photo-interpretation criteria. The number of criteria varies according to the authors but the tint, the shape, the size, the spatial pattern, the texture, the shadow and the association of the forms are fundamental [23]. Aerial photographs are scanned photos and Google Earth images used during this study provide only one type of information compared to satellite imagery (multiple channels). It is, therefore, just recognition and an approximate delimitation of landscape units with a certain homogeneity and similarity.

In a second step, after identifying and distinguishing the different components of the landscape in Large Sfax, digitization was performed. The latter ensures a discrete representation of an object of the real world. The task consists of digitalizing the wetlands and the surrounding components at different dates by type. The areas were calculated using the spatial requests SQL.

3. Results and Discussion

3.1. Identification and spectral delimitation of wetlands

Radiometric indexes play the role of classifiers thus allowing the spectral identification of wetlands. Fig. 2, 3 and 4 show the results of the classification of humidity index “NDWI”, vegetation index “NDVI” and Brightness index “IB” for Large Sfax for 2003 and 2015.

The humidity index is the best technique for distinguishing between water surfaces and bare floors. According to figure 2, the recorded values were between (-0.7) and (0.8). In fact, the negative “NDWI” values for 2003 and 2015 indicated the presence of bare soils in the north and the southwest of the study area. The maximum value of NDWI belongs to the artificial wetland “saltworks of Thyna.” In 2003, the value of NDWI ranged between (0.2) and (0.8). This variation is explained by the variability of water volume between basins. In 2015, however, the values of this index in the southern part were lower than (0.5). This discrepancy between 2003 and 2015 may be due to the accumulation of rainwater in the basins after the rain events of January 24, 26 and 27, 2003 [24] or to the effect of the salt cycle (filling and draining the basins).

In 2003, the closed salt marshes located in the southwest of the salt works of Thyna were at a higher NDWI value than in 2015. The strip of the salt marshes on the northern coast of Large Sfax had values exceeding 0.5 and others below 0.5 for 2003. This variation was probably related to the marine flora. In 2015, the index varied between (-0.7) and (0.19) given that this sector had been converted into the Taparura artificial beach zone. However, for the seasonal brackish swamps (sebkha) on the west side of the Thyna, the NDWI values for the two studied years were less than (0.2). This can be explained by the sandy texture of the soil.

In the southwest of the study area, blue spots in Figure 2 represent the irrigated area with values ranging from (0.2) to (0.49). These spots were more abundant in 2003 than in 2015. This variation can be linked to the effect of soil humidification due to rain events and the high-water content of foliage. For the vegetation liquid water content, in accordance with Gao (1996), the NDWI is considered a good indicator because it is less sensitive to atmospheric scattering effects than NDVI.

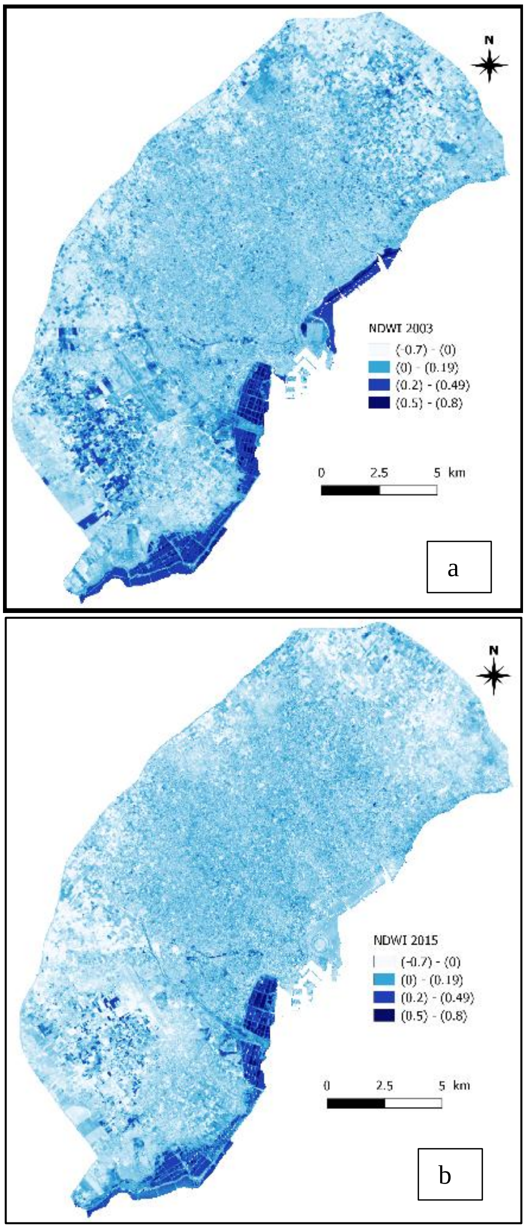

Fig 2. Map of humidity index (NDWI) of Large Sfax in 2003 (a) and 2015 (b)

The NDVI calculated for Large Sfax for 2003 and 2015 is presented in figure 3. It takes values between (-0.2) and (0.8).

For the salt works of Thyna, in 2003 and 2015 the NDVI values were negative (-0.2) owing to the presence of water and the high salt concentrations in the basins. However, a very low vegetation density with a value of (0.06) was present at the dikes of basins.

The closed salt marshes in the south of the salt works of Thyna and the salt marshes in the north of the study area recorded NDVI values below zero in 2003. In 2015, the salt marshes for the northern coast of Large Sfax transformed into Taparura zone have NDVI values ranging from (0.005), (0.18) and (0.31). Notably, NDVI is (0.31) in the Taparura urban park, planted with forest trees and olive trees. The closed salt marshes area kept the same NDVI values (below zero) in 2015.

However, for seasonal brackish swamps (sebkha) on the west side of the salt works of Thyna, the NDVI values for the years 2003 and 2015 were less than (0.3) and higher than (0.05). This can be explained by the presence of halophyte vegetation and the accumulation of salt on the soil surface.

In conclusion, in 2015, at the level of Large Sfax, the NDVI was more scattered and higher. It covered more than 60% of the study area compared to 2003. This variation can be explained by the extension of the irrigated agricultural plots and the rainy season. In the Southwest of the study area, for the irrigated area, the vegetation index varied between (0.6) and (0.8). Vegetation density was higher in 2003 than in 2015.

Dandan et al. made a comparison between the NDVI calculated from Landsat 7 and 8 imageries [25]. The result proves proved that the NDVI calculated from the Landsat 8 imagery was greater than that of Landsat 7 imagery for areas with low vegetation cover and difference was smaller for dense plant covers. This result may also explain the increase in classification values in 2015 since the NDVI was calculated from images from the Landsat 8 sensor and while a Landsat 7 image was used in 2003. Additionally, Fig. 3 proves that the study area is characterized by a low to medium vegetation cover.

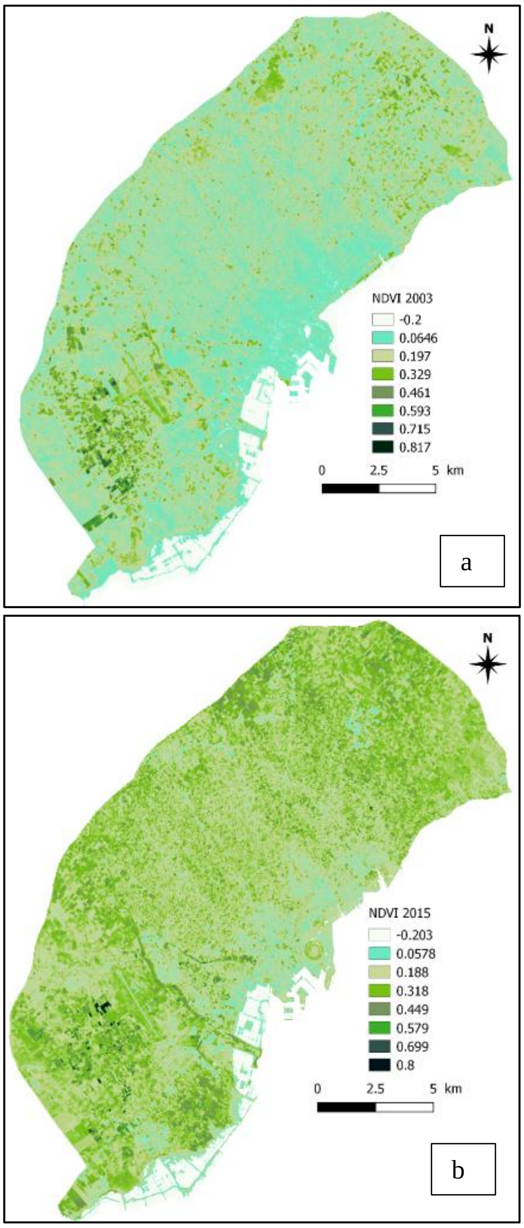

Fig 3. Map of vegetation index (NDVI) of Large Sfax in 2003 (a) and 2015 (b)

Gu et al found that NDWI values exhibited a quicker response to drought conditions than NDVI [26]. As opposed to NDWI, NDVI has a limited capability to retrieve vegetation water content information, since it provides information on vegetation greenness (chlorophyll), which is not directly and uniformly related to the quantity of water in the vegetation [27].

The Brightness index (IB) is used to distinguish wetlands from the surrounding landscape. The classification maps of this index are interpreted in shades of gray. Wetlands appear as dark spots and bare soils have the highest positive values. In fact, the minimum values oscillate from (0.62) in 2003 and (0.59) in 2015, and the maximum values between (1.18) in 2003 and (1.15) in 2015 (Fig. 4).

From 2003 to 2015, this index decreased by 0.03 for these maximum and minimum values. The IB map of 2015 was darker than that of 2003 and with more grey gradients proving the surface heterogeneity of the study area. The variability between 2003 and 2015 values may be due to the widening of the red band of the Landsat 8.

In 2003 and 2015, in the south of the study area, the saltworks of Thyna, and the closed salt marshes presented in dark tints. However, the northern basins of the salt works have lighter shades. This can be explained by the high concentration of salt in these basins and its strong reflectance.

Seasonal brackish swamps (sebkha) on the west side of the salt works of Thyna have a high IB value in 2003 and 2015. This is explained by the poverty of vegetation cover and the accumulation of salts on the surface.

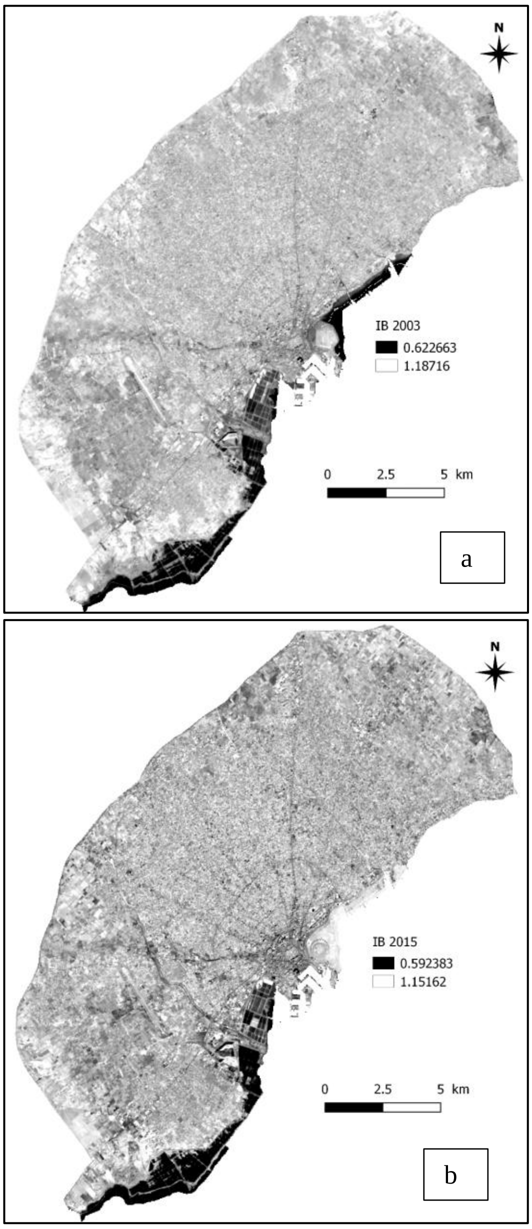

Fig 4. Map of Brightness index (IB) of Large Sfax in 2003(a) and 2015 (b)

3.2. Spatial delimitation and monitoring of Large Sfax wetlands between 1963 and 2015

Visual interpretation of the different data has allowed the spatial delimitation of wetlands: marine wetlands, inland wetlands, and artificial wetlands according to Ramsar classification [28] (fig. 5). The spatial delimitation of wetlands has made it possible to calculate and monitor the evolution of their areas and their lengths. Table 2 presents the results of the digitalization of the different wetlands identified and delimited in the study area.

Table 2 shows that in 1963, the city of Sfax had 1360 ha of "seasonal brackish swamps" (sebkha) and 38.17 km of "saltmarshes". In addition, the city is crossed by four streams whose lengths vary from 3.35 to 14 km. These values correspond respectively to the streams "Oued El Haffera" and "Oued El Maou". Similarly, it contains an artificial wetland "saltworks of Thyna" spread over 1200 ha at the southern coast of the study area.

In 1982, the area of seasonal brackish swamps decreased by 50% on the southern coast and 75% on the northern coast. This regression is caused by the intensification of urban and industrial activity. Saltmarshes have regressed following the extension of the saltworks of Thyna, the creation of the new fishing port on the southern coast and the appearance of the phosphogypsum plate. The beds of the streams "El Haffera" and "Agareb" have decreased. On the other hand, the beds of the rivers "Oued Ezzit" and "oued El Maou" increased by 0.6 km and 3 km respectively after the floods, where they restart their courses.

In 2003 and 2015, the streams "Oued Ezzit", "Oued El Haffera" and "Oued Agareb" were transformed into canals to protect the city against floods; "Oued El Maou" was preserved by the construction of a protective dike [29]. The total area of seasonal brackish swamps was in the order of 466 ha in 2015. The city contains two artificial wetlands in the southern coast of the study area. The saltworks of Thyna salt spread over 1700 ha and the South Sfax wastewater treatment station occupies 12 ha.

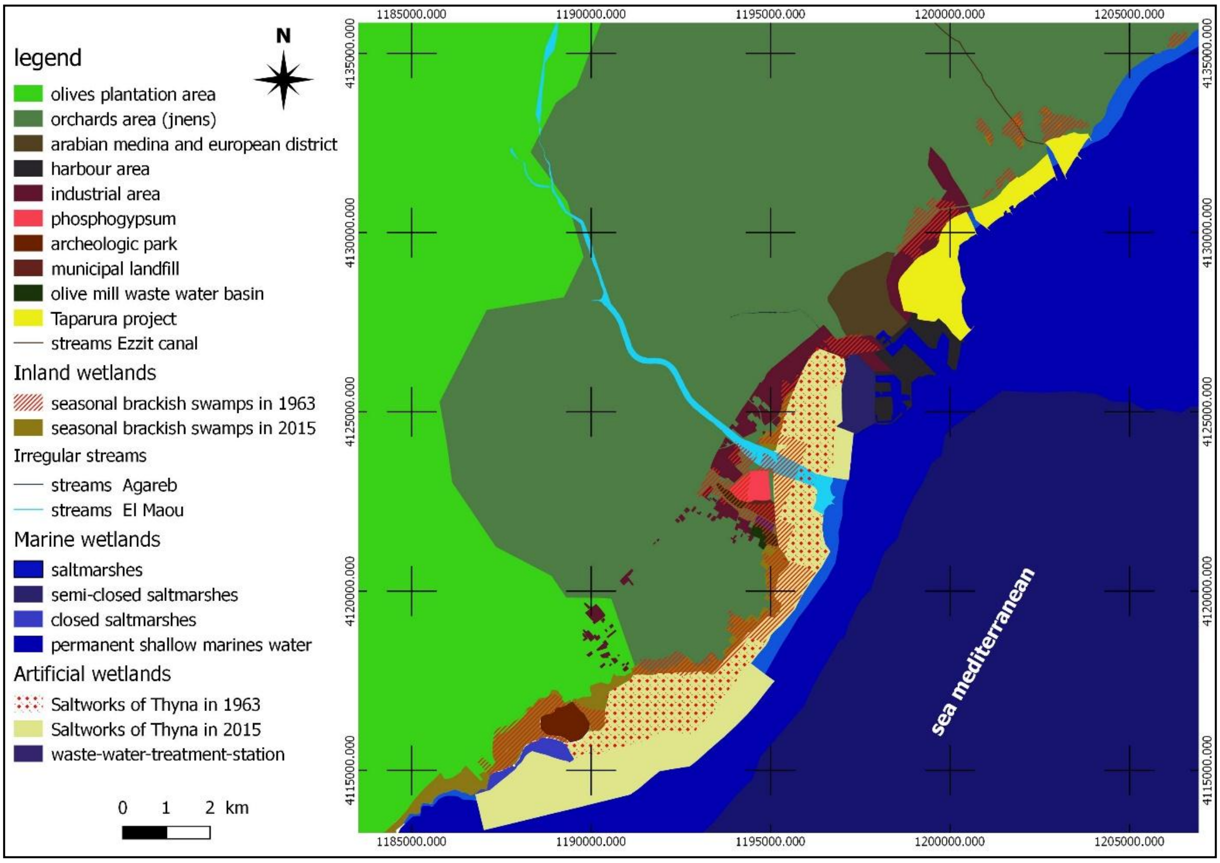

Fig 5. Wetland's map in 1963 and 2015 detected by visual interpretation

Table 2. Areas and lengths of Large Sfax wetlands in 1963, 1982, 2003 and 2015

Wetland's type	Under type of wetlands		1963	1982	2003	2015
Inland wetlands	irregular streams (length in km)	streams Ezzit	6.200	6.874	-	-
		streams El Haffera	3.354	1.845	-	-
		streams Agareb	7.699	3.665	-	-
		streams El Maou	14.114	17.847	17.847	17.847
	Seasonal brackish swamps (area in ha)	North side	301.669	78.211	53.936	18.452
		South side	1058.309	572.925	501.682	474.456
Marine wetlands	Salt marshes (length in km)	North side	16.408	14.966	13.429	7.655
		South side	21.777	sm: 9.987 scsm: 3.485	sm: 7.970 scsm: 2.032 csm: 3.339	sm: 7.970 scsm: 2 csm: 3.339
Artificial wetlands	Saltworks of Thyna (area in ha)		1224	2100	2250	2250
	Wastwater treatment station (area in ha)		-	12	12	20

* sm: saltmarshes; * csm : closed saltmarshes; * scsm: semi closed saltmarshes

4. Conclusion

Wetland detection and delineation is a complex scientific objective in remote sensing. The small size, the intrinsic heterogeneity and the variability of surface hydrompophy of the objects to be detected and delimited constitute the limiting factors. This work shows the importance of the combined use of the multivariate analysis and the multi-dates analysis for the identification and the spatial delimitation of wetlands. This will allow a better characterization of wetlands, which will help decision-makers to ensure the sustainable management of wetlands. The radiometric indexes of humidity "NDWI", vegetation "NDVI", and brightness "IB" were calculated for the years 2003 and 2015 from Landsat imagery. These indexes were used to interpret the images processed, to detect, delimit and characterize the wetlands studied. The humidity index "NDWI" allows the distinction between water surfaces and bare floors. The vegetation index "NDVI" measures chlorophyll absorption and allows having information about the vegetation cover and its status. As to the Brightness index "IB", it enables the differentiation between wetlands and the surrounding landscape. The visual interpretation of the raster data allowed the delimitation of the areas having a certain homogeneity and resemblance. The use of the spatial requests SQL allowed the calculation of areas and the monitoring of wetlands delimited.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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