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EVOLUTION OF LAND COVER IN THE MACTA WETLAND BETWEEN 1958 AND 2023 BY REMOTE SENSING AND GIS (NORTHWEST ALGERIA)

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Abstract

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Wetlands are ecologically and economically important habitats. In the Mediterranean region, they account for 18.5 (±3.5) million ha or 1.5% of the world's wetlands. Algeria has 1,500 wetlands, 50 of which are Ramsar sites. One of them is the Macta wetland, a specific ecosystem on the northwestern coast of Algeria. The study aims to provide data on the spatiotemporal evolution and interaction of the Macta wetland with human activities and climate. A diachronic diagnosis for the period 1958–2023 (65 years) was carried out using maps from 1958 and data collected by remote sensing for the period 1972–2023 in a Geographical Information System (GIS). The geomatics approach is based on the use of ArcGIS 10.8 and satellite imagery from Landsat and Sentinel-2. A precise cartography, close to the reality of the terrain, shows that between 1958 and 2023, the agricultural development, the urbanisation and flooding affected 26,515 ha or about half of the total area of the wetland. In 65 years, the anthropogenic pressure is five times greater than that caused by flooding. Therefore, the adaptation of the Macta wetland is an issue that should be considered and solved by the local environmental authorities.

Key words: Algeria, GIS, Macta, Ramsar, remote sensing, wetland.

Introduction

Wetlands are complex environments, consisting of a wide variety of natural and artificial habitats that are beneficial to humans (Zedler, Kercher, 2005; Mitsch et al., 2015). They store carbon, purify water (Kingsford et al., 2016; Chen et al., 2014; Zhu et al., 2021), maintain diversity, provide food (Kumari et al., 2020; He et al., 2017; Meng et al., 2020) and ensure the preservation of the environment (Vélez et al., 2018). According to the OZHM (2012), wetlands cover 1.5 billion ha worldwide or 6% of the Earth's surface (Graversgaard et al., 2021). Accordingly, Asia has the largest area of wetlands (32% of the world's surface), North America 27%, Latin America and the Caribbean 16%, Europe 13%, Africa 10% and Oceania 3% (Ramsar, 2018). Despite this, wetlands are unfortunately more vulnerable than any other terrestrial ecosystem, particularly due to agriculture and overgrazing (Shen et al., 2019; Li et al., 2021; Swain et al., 2007; Zhu et al., 2021; Mao et al., 2018; Beuel et al., 2016; Finlayson et al., 2018). Such activities affect biodiversity, reduce water quality and quantity, increase the CO_2 emissions (Mao et al., 2018) and alter soil's nutrient dynamics (Ho et al., 2018; Swain et al., 2007). Furthermore, intensive agriculture leads to high hydric stress in Asia, North Africa, Australia and the Americas (Seiffolahi-Aghmuini et al., 2019). Wetlands are also affected by anthropogenic pressures, which have led to the disappearance of half of their global area since 1900 (OZHM, 2012; Davidson, 2014). Since 1970, 35% of the wetlands have disappeared, with the highest rates of loss recorded in Africa, Latin America, and the Caribbean (McInnes et al., 2020). Despite the fact that wetlands cover 18.5 million hectares in the Mediterranean region (OZHM, 2012), their area is decreasing due to agriculture, urbanisation, industry and climate change (Davidson, Finlayson, 2019). According to Benharrat (2018), agriculture and livestock farming have contributed to the loss of about 50% of the wetland area.

Although Mediterranean wetlands have interesting specifications, their inventory is still incomplete (Beltrame et al., 2015). The study area is the Macta Wetland, located in the northwest of Algeria; it has attracted 14 researchers. The first flora inventories were carried out by Gauthier (1931), then completed by Simonneau (1952) and Quezel and Simonneau (1960), and updated by Taffer (1993), Benkada and Bechira (2005), and Abbaoui and Hamnache (2006), for example, Belgherbi (2011) and Megharbi (2016). Ghodbani and Amokrane (2013) studied the coastal part of the Macta wetland. Lakhdari et al. (2021) and Ismail et al. (2022) determined the water quality and the characteristics of the real estate of the Macta. Three foreign ornithologists, Ledant, Metzmacher and Jacobs, studied the bird communities and related parasitological issues, which interested Beghdadi (2016) (https://dspace.univ-guelma.dz/xmlui/handle/123456789/433). In this context, the forestry departments of Mascara, Mostaganem and Oran carry out bird censuses in the area. Research shows that the region's ecosystems are biodiverse, despite the degradation of their habitats, the continuous decline of their natural resources and the trivialisation of the landscapes they form (Boudjada et al., 2021). These circumstances call for urgent management to preserve the region and to know more about its function and its behaviour in the face of environmental risks. Accurate cartography, analysis and monitoring of the region are necessary to update the ecological inventory (Beltrame et al., 2015). Our geomatics approach is based on the monitoring of the Earth, which ensures the cartography of the degradation and the urban evolution of the soil for the period 1958–2023 (65 years).

Material and methods

Study area

The Macta wetland, located between latitudes 35° 81´ and 35° 58´N and longitudes 0° 23´ and 0° 06´W, has been classified as a Ramsar site since 2001 (DGF, 2001; Allout, 2014). It occupies a triangular depression close to the coast, and it is surrounded by plains (Kelbouza, 2005). The study area coincides with the Macta wetland, which covers an area of 53,250 ha: 45,000 ha are within the administrative boundary (Ghodbani, Amokrane, 2013) and 8,250 ha of buffer area around a surface. It is administratively dependent on 10 districts, which are easily accessible thanks to federal and provincial roads, and agricultural tracks (DEM, 2014) (Fig. 1).

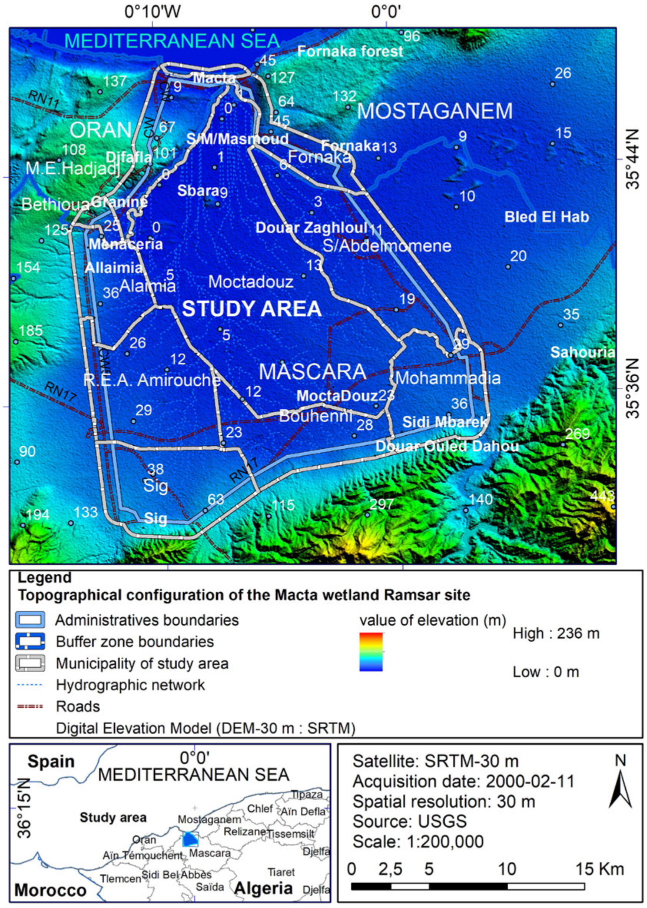


Fig. 1. Topographical configuration of the Macta wetland Ramsar site.

Cartography

The study area includes the plains of Sig, Mohammadia and the Macta. The altitude of the terrain varies between 0 and 236 m and the slope between 0 and 37%. The Macta consists of an estuary, a marsh and a flood plain, with sediments of the Secondary, then faulted layers of the Terciary (Eocene). During the Quaternary, the marine recession increased the erosion and intensified alluvial and colluvial deposition in the deeper parts of the Macta (Dalloni, 1919). Near the mouth of the Macta, saline sediments, generally composed of clays, were transported and modified (Quézel, Simoneau, 1960; Megharbi, 2009). In terms of climatic conditions, the region is subject to a semi-arid climate characterised by cold winters and seven dry months (Megharbi, 2009); the average temperature is 26.6 °C and the pluviometry is 355 mm (Aymen, Nadjib, 2020). Between 1950 and 2017, the temperature increased by 0.7 °C and the rainfall decreased by 113.4 mm or 0.02 °C/year and 3.33 mm/year, respectively; these conditions led to the aridity of the Macta (Lakhdari et al., 2021). Gauthier (1931) inventoried 262 plant species, which Taffer (1996) classified into eight groups of Salsolacées. These plants are annual and considered rare in North Africa (Simonneau, 1952; Adnane, Bensta, 2007). Agriculture covers 26,905 ha (Benabdeli, 2006), of which 68.72% are cereals, 28% citrus and 3.19% arboriculture (Megharbi, 2009). Forests are located in the south in the foothills of Sig (Mascara), in the west in Bethioua (Oran) and in the east in Fornaka. Demographically, the population of the region increased from 241,284 inhabitants in 2005 to 247,413 inhabitants in 2008 (2,043 inhabitants/year); most of the population uses the area for agricultural needs, which disturbs and alters the natural habitats (Megharbi, 2009). The main industrial activities are food processing and construction materials in Sig, fishing and maritime goods transport in Arzew, and hydrocarbon production by the national oil company (Sonatrach) in Bethioua, which covers 260 ha (ANIREF, 2020). The industrial zone of Fornaka (Mostaganem) covers 82 ha (DMI, 2005). Beach tourism is concentrated on Macta beach, which receives 3 million tourists per year (DTA, 2021). We used geomatics tools and multi-source data to map land use changes in the Macta wetland and their environmental impacts that affect it. We used ArcGIS 10.8 to georeference the maps with in the World Geodesic System (WGS84)/ UTM projection/ Zone 30 (Table 1).

We also defined the study area according to the Ramsar site boundaries of the Macta wetland as used in the GlobWetland project (Bonino et al., 2012). The GIS allowed us to assess the geomorphology and to make out an inventory of the habitats for the period 1958 and 2008; remote sensing was used to update the data.

Image processing

Thirty-six images covering the period 1972–2023 were downloaded from the United States geological survey (USGS) and the

Table 1. Cartographic documents used.Table 2. Evolution of units of land use between 1958 and 2023 in the study area.

Map and images	Scale	Source
3 Topographic maps (Arzew NI-30-XXIV-2, 1985, Sig NI-30-XXIV-4 EST, 1985 and Mohamadia NI-31-XIX-3_Ouest, 1990)	1/50,000	Algerian Institute of Cartography and Remote Sensing
1 geological map of Algeria	1/500,000	Bétier (1952)
1 Reconnaissance map of Algerian soils « Mostaganem - Bousquet »	1/500,000	Boulaine (1955)
1 Vegetation map of Algeria « Bosquet – Mostaganem »)	1/200,000	Bagnouls (1958)
1 National Forest Inventory map (NFI)	1/50,000	Algerian BNEDER (2008)
1 Digital Elevation Model (DEM)	(resolution 30m)	(SRTM)

Table 2. Evolution of units of land use between 1958 and 2023 in the study area.

CLC Classes	Year1958		Year2023		Evolution (1958 to 2023)	
	Area	Rate (%)	Area	Rate (%)	Area	Rate (%)
	(ha)		(ha)		(ha)	
Discontinuous urban fabric (CLC112)	67	0	2,545	5	2,478	5
Industrial or commercial units (CLC121)	0	0	56	0	56	0
Road and rail networks and associated land (CLC122)	2	0	351	1	349	1
Dump sites (CLC132)	0	0	70	0	70	0
Total (level-1 : Artificial surfaces)	**69**	**0**	**3,022**	**6**	**2,953**	**6**
Permanently irrigated land (CLC212)	0	0	1,479	3	1,479	3
Vine yards (CLC221)	2,097	4	165	0	-1,932	-4
Fruit trees and berry plantations CLC222)	4,718	9	7,524	14	2,806	5
Olive groves (CLC223)	1,403	3	2,992	6	1,589	3
Annual crops associated with permanent crops (CLC241)	19,695	37	19,445	37	-250	0
Total (level-2 : Agricultural areas)	**27,913**	**52**	**31,605**	**59**	**3,692**	**7**
Mixed forest (CLC313)	4,838	9	1,829	3	-3,009	-6
Beaches, dunes, and sand plains CLC331)	55	0	55	0	0	0
Total (level-3 : Forests and semi-natural areas)	**4,893**	**9**	**1,884**	**4**	**-3,009**	**-6**
Permanent/saline/brackish/alkaline/marshes/pools (CLC4114)	19,598	37	13,918	26	-5,68	11
Total (level-4 : Wetlands)	**19,598**	**37**	**13,918**	**26**	**-5,68**	**-11**
Seasonal/intermittent/irregular rivers/streams/creeks/wadis (CLC5113)	504	1	496	1	-8	0
Permanent saline/brackish/alkaline lakes with aquatic bed vegetation (CLC5127)	1	0	38	0	37	0
Seasonal/intermittent saline/brackish/alkaline lakes and flats with aquatic bed vegetation (CLC5128)	3	0	2,018	4	2,015	4
Sea and ocean (CLC523)	269	1	269	1	0	0
Total (level-5 : Water bodies)	**777**	**1**	**2,821**	**5**	**2,044**	**4**

European space agency (ESA). Thirty-six (36) images were acquired between 1972 and 2023 (51 years) from the Landsat 1, 7, 8 and Sentinel-2 satellites, which provide data several times a month, allowing an efficient monitoring of the region (Dupuy, Gaetano, 2019).

The applied image resolution is 30 m, which is considered as an average value and an acceptable compromise (Welch, 1982). The Sentinel-2 images have a spatial resolution of 10, 20 and 60 m and a radiometric resolution of 13 spectral bands covering the visible and mid-infrared (Pelletier, 2017). The multispectral image sensor (MSI) on board the Sentinel-2 satellite has a high spatial resolution, allowing an accurate monitoring of the soil (Dupuy, Gaetano, 2019). The images have been downloaded with an L2A correction level, as they have been geometrically and atmospherically enhanced (Taconet, 2019); they can be directly used for land use change cartography (Béchet et al., 2017) and ecological habitat analysis (Dupuy, Gaetano, 2019). Other methods, such as geometry, radiometry, segmentation, object-oriented and supervised classification, and spectral index calculation, can be applied. The images were classified using the GEOclassifier-1.2.3-win32, which was implemented in the ArcGis. The GEOclassifier, developed by the ESA, ensures functions

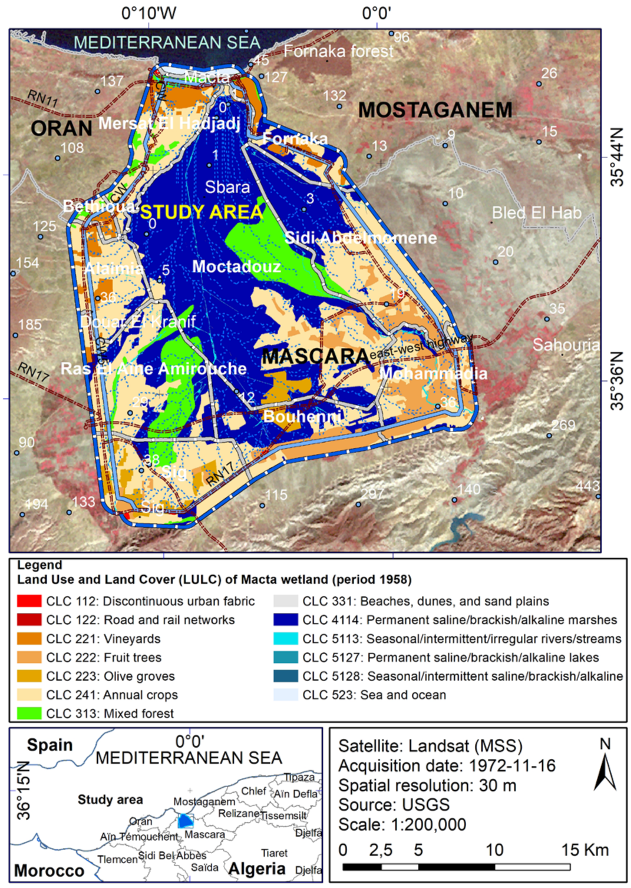


Fig. 2. Land Use and Land Cover (LULC) of wetland Macta (period 1958).

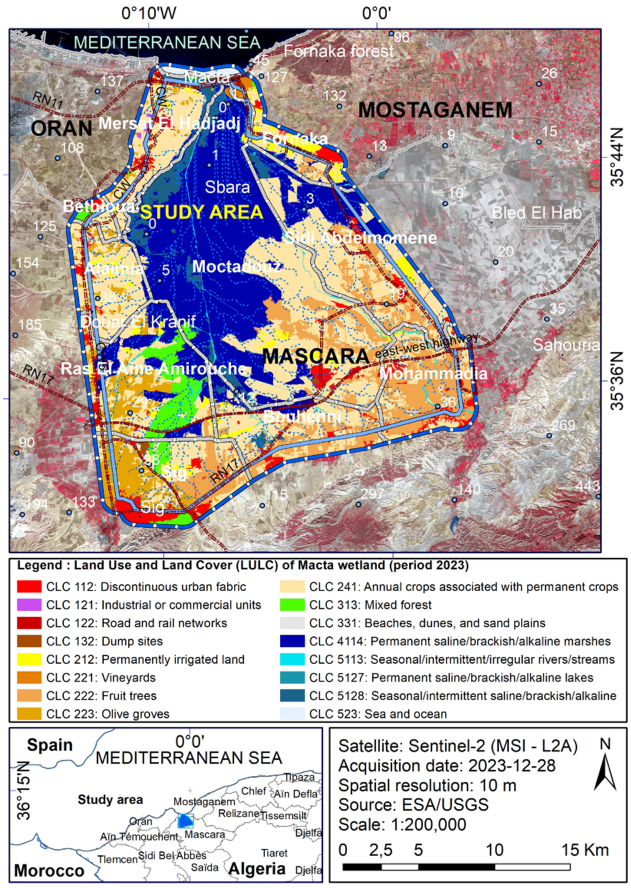


Fig. 3. Land Use and Land Cover (LULC) of wetland Macta (period 2023).

that are well adapted to the cartography of the Mediterranean wetlands (Beltrame et al., 2015). This method is suitable for the automatic object-oriented classification, which allows the grouping of similar pixels into thematic objects. The GEO classifier is applied on the basis of spectral and textural criteria, shape and neighbourhood (Gao, Mas, 2008). The tool has been proven in the characterisation of rich vegetation categories (Sellin et al., 2013) and in the accurate cartography of land use changes (Achbun et al., 2011). Exogen data combined with GIS data, Google Earths images and Microsoft Bing are also useful to ensure accurate maps of land use change (Sitayeb, Benabdeli, 2008). To refine the interpretation of the imagery, we calculated the Normalised Difference Vegetation Index (NDVI), the Normalised Difference Water Index (NDWI), the Soil Adjusted Vegetation Index (SAVI) and the Normalised Difference Built-up Index (NDBI). External data contributed to the acquisition of additional discriminative elements (Ducrot, 2005) are useful for interpretation, automatic image classification and the production of land use change maps.

Classification of units of land use

For the realisation of the land use map, we applied the Corine Land Cover (CLC) typology to the Mediterranean thematic categories (Beltrame et al., 2015). These are geographical data obtained from the interpretation of visual satellite images (ONCEA, 2014) and the Corine and Ramsar thematic classifications. This typology combines two semantic domains: geography and description of land use (Sparfel et al., 2010). We used it to identify and codify the ecological habitats observed during the fieldwork into land cover classes (CLC). The CLC classes recorded in the study area are presented in Table 2; they correspond to five territories: artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands and water bodies.

Thanks to the habitat classes, it was possible to work out the terrain, to prepare the samples, to start the supervised classification and to evaluate the post-classification. As stated by Sparfel et al. (2010), a comparison was made between the CLC classes generated through remote sensing and those obtained on the terrain. The validation protocol used in 2015 for the remote sensing monitoring of the wetland situated at La Tour du Vallat, France (Beltrame et al., 2015), was applied. In this context, a comparison was made between 495 samples extracted from the reference image of 2023, which were classified, located in the terrain by GPS and identified. The final layout was created using Global Mapper, Word, Excel and Paint.

Results and discussion

The preliminary report shows that the Macta wetland has changed in terms of its environment, socioeconomic situation

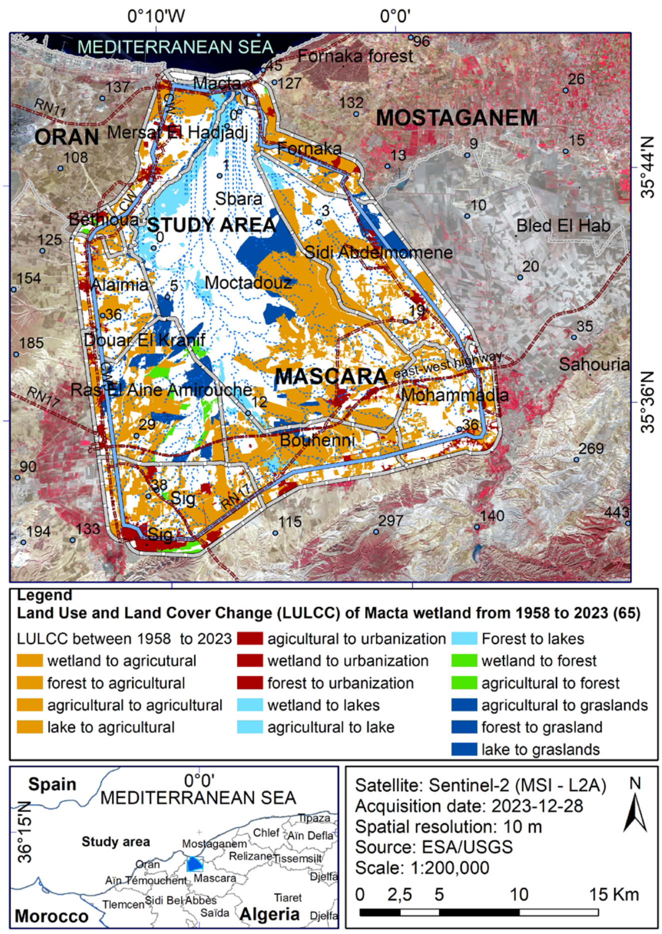


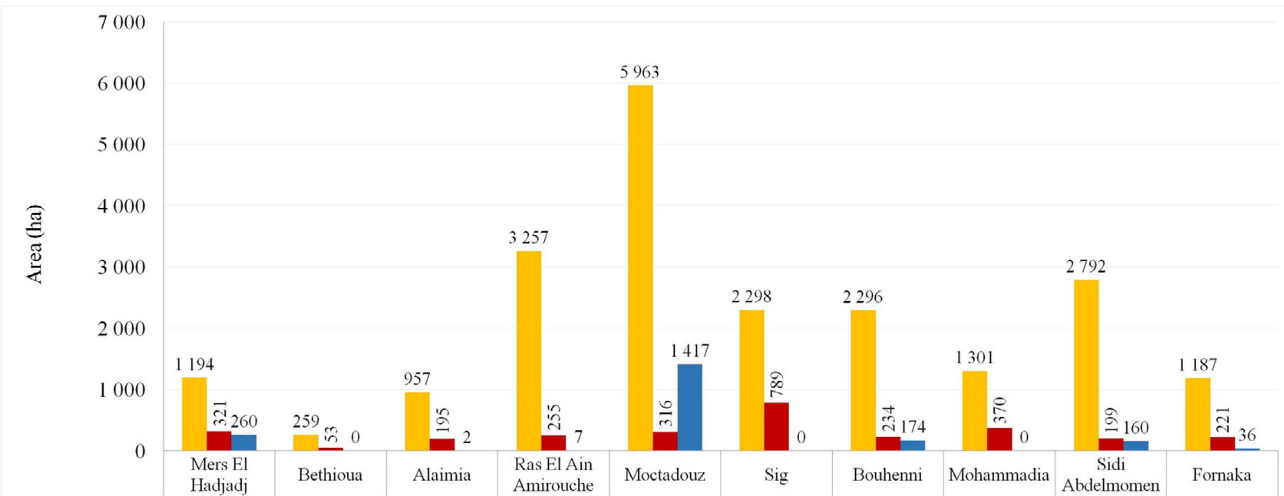
Fig. 4. Land Use and Land Cover Change (LULCC) of wetland Macta from 1958 to 2023.

and climate. However, the environmental impacts on the region are not well known to society. The maps produced were validated using the validation protocol applied to the CLC classes registered in the area. We then assigned each class a certainty level (CL) of between 1 and 5, totalling 2,450, and a reference number (RN) of between 0 and 8, totalling 2,550. The procedure of the notation system is to divide the CL numbers by the RN numbers, which confirms an average validation rate of 96% (2,450/2,550). This value confirms that the results are close to the terrain reality; they can be integrated into a GIS environment with the aim of being interpreted and finalised as a usable map (Thomlinson et al., 1999). The validation rate (96%) is an acceptable value, as it is comparable to those obtained by Beltrame et al. (2015) (87%) and Kouassi (2014) (95.03%). The results also show that the satellite images were correctly classified, which allowed the production of land use and land cover change maps for the period 1958–2023 (Figs 2, 3 and 4).

Five categories of land use were identified in 1958: central aquatic areas, halophilic vegetation (Juncus, Scirpus, Festuca, Tamarix and Halipedes) and submarine vegetation (algae and Posidonia), agroforestry vegetation and urbanised areas. Changes in land use and land cover for the period 1958–2023 are presented in Table 2.

Between 1958 and 2023, the agricultural and the urban pressure led to the loss of 5,688 ha of humid soils, 3,009 ha of forests, 1,932 ha of vineyards and 250 ha of cereals; the Macta wetland was also affected by this change, as commented by Medouni (1996).

The area always flooded by seawater, remained the same (269 ha), but the area flooded by rainwater increased by 2,056 ha in 65 years or 31 ha/year. Agriculture, urbanisation and seasonal flooding have modified the Macta wetland, affecting 26,515 ha of land or 50% in 65 years (408 ha/year). The impact on the affected districts is shown in Fig. 5.



	Mers El Hadjadj	Bethioua	Alaimia	Ras El Ain Amirouche	Moctadouz	Sig	Bouhenni	Mohammadia	Sidi Abdelmomen	Fornaka
Agriculture (ha)	1 194	259	957	3 257	5 963	2 298	2 296	1 301	2 792	1 187
Urbanization (ha)	321	53	195	255	316	789	234	370	199	221
Flooding (ha)	260	0	2	7	1 417	0	174	0	160	36

Fig 5. Distribution of ecological habitats impacted by agriculture, urbanization and flooding.

Studies show that about 35% of Europe's inland and coastal wetlands should have probably disappeared since 1970 (Ramsar, 2021). In the Mediterranean region, the surface area of the wetlands has decreased by 48% between 1970 and 2013; in Africa and Asia, the decrease is 42 and 32%, respectively (Ramsar, 2021).

Impact of agriculture

The agricultural area, estimated at 31,605 ha, represents 59% of the region. In 65 years, the development of this sector ensured the creation of 21,506 ha of arable land or 68% of the total area (331 ha/year). This led to the loss of 6,438 ha of wetlands (30%) in Moctadouz and 3,365 ha of forest (*Tamarix africana*) in Sig and Habra/Mohammadia and 9,877 ha of cereals and arboriculture in Sig and Bouhenni (Quézel, Simoneau, 1960; Sitayeb, Benabdeli, 2008). Agriculture also led to the conversion of cereals (11,200 ha) and vineyards (1,900 ha) to arboriculture (Metzmacher, 1979).

Impact of urbanisation

In 65 years, the urbanisation has consumed 2,202 ha of agricultural land in Sig, 524 ha of wetlands in Moctadouz, 128 ha of forest in Mers El Hadjadj and 99 ha of vineyards in Fornaka for a total of 2,953 ha of real estate in total. This development is partly due to the financial support provided by the Algerian government as part of the urban and rural construction programme and public facilities. Studies show that between 1958 and 2005, the rate of urbanisation around the Macta wetland was about 328.5% (Sitayeb, Benabdeli, 2008). This rate is higher than that estimated for Algeria (72%) and means that the rural population is actually decreasing by -0.4%/year (Bessaoud, 2008). In the Mediterranean region, urbanisation has transformed 9,500 ha of wetlands and 2,200 ha of agricultural land in 30 years (Beltrame et al., 2015). Comparing the Mediterranean wetlands with the Macta wetland, the urbanisation rate in Sig (34 ha/year) is almost twice lower in 65 years.

Impact of flooding

Over the period 1958–2023, seasonal flooding has damaged 2,056 ha of vegetation, 75% of which is located in the centre of Moctadouz, 11% in the east, 10% in the south and 4% in the west. This event affected 1,785 ha of wetlands, 217 ha of agricultural land in Mers El Hadjadj and Moctadouz and 54 ha of forest in Mers El Hadjadj and Fornaka. After 6 months of monitoring, we found that the total flooded area increased from 2,056 ha in March 2023 to 89 ha in August 2023, a loss of 1,967 ha of water surface (11 ha/day). Between 1960 and 2000, the water flow decreased by 45%, affecting seasonal wetlands. Compared to the three neighbouring continents, the loss of Mediterranean wetlands since 1970 is higher (48%) (Lefebvre et al., 2019). For example, the surface area of the Pantanal wetlands, located in Brazil, has decreased from 5.9 million ha in 1985 to 1.5 million ha in 2021 corresponding to the lowest water levels recorded in the last 36 years. The fall in water levels poses a serious threat to the equilibrium of the Pantanal, as this ecosystem depends on the flooding for its regeneration (https://www.greenpeace.fr/pantanal-zone-humide-en-danger/). Such a situation can be detrimental to several species that depend on this habitat and some of them may disappear. The decline of aquatic species in wetlands has been documented by studies since 1970 (Ramsar, 2021). Globally, wetlands have lost 64% of their area since 1900. Between 2010 and 2020, 41% of the French wetlands have disappeared (FMET, 2020).

Conclusion

The results show that, thanks to geomatics, it is possible to map and analyse ecological habitats in a wetland. In fact, the study made it possible to draw up an ecological inventory for the period 1958–2023 of the different ecosystems that make up the Macta wetland. Thanks to the inventory, the new data on Macta have been updated and the Ramsar classification of the study area has been confirmed. This confirmation is based on the rarity of this type of habitat in North Africa and the presence of numerous halophilic plant species, invertebrates and fish. The geomatics approach made it possible to produce three maps for the period 1958–2023, two of land use change and one of land cover change. The relief of the Macta wetland is generally flat (altitude: 0–236 m); the gently sloping land (0–3%) covers 92% of the main area, which receives rainwater coming from the side basins via the Oued Sig, Oued Habra and Oued Tinn (rivers). Between 1958 and 2023, agricultural development (82%), urbanisation (11%) and flooding (7%) have affected 26,515 ha or about 50% of the total surface of the study area. This means that the area affected by agriculture and urbanisation is five times greater than the area affected by seasonal flooding. The data obtained will also help to understand, in retrospect, how the ecosystems of this wetland function. Anthropogenic pressures are certainly a threat to the Macta wetland and will severely limit its resilience unless conservation and management measures are taken. In this sense, local authorities and decision makers are warned to initiate actions that contribute to the permanent protection of the fragile habitats of the Macta wetland.

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