Article

Evaluation of water quality and risk of water level declines in semi arid wetland: case of study in the Macta marshes, Algeria

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Abstract
The main objective of this research is to diagnose the environment of the Macta marshes located in North-western Algeria by taking into account their wealth and ecological functioning as a site of importance for Mediterranean biodiversity. This study is aimed in particular at managers of remarkable sites and those interested in the protection of the environment in Algeria. The methodology adopted is based on a spatiotemporal analysis of climatic and hydrologic data as well as on physicochemical analyses of surface water The results obtained demonstrate a long-term risk of the marshes desiccation and pollution by a concentration of high nitrates and phosphates, and high dissolved oxygen levels that induce eutrophication, as well as higher BOD_5 values that indicate a high organic load. The follow-up of the organic pollution index "OPI" shows that the water of the Macta marshes is heavily polluted due to untreated domestic and industrial wastewater discharges as well as the intensive use of fertilizers which threaten the different habitats and the ecological functioning of this ecosystem.

Keywords climate change; pollution; water; eutrophication; the Macta marshes.

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1 Introduction

Wetlands are particular rich ecosystems that are very important especially for biodiversity preservation. Many definitions have been given to them; according to RAMSAR Convention (concerning wetlands of international importance especially water birds habitats) of the 21st Feb. 1971, they are zones where water (fresh, briny, or salty) stagnates permanently or temporarily (Perillo et al., 2018). This space is an important natural heritage that has essential role for marinating the biodiversity especially that of the migrating birds (Barnaud and Fustec, 2017).

The wetlands geographic situation is generally near the coast, or in the favorable valleys for the socio-economic development what may make them a target for urban, agricultural, or industrial expansion. Internationally, their surface diminished to 64% and 71% since 1900 (Davidson, 2014).

These fragile ecosystems are in danger due to the climate change whose consequences may be irreversible (Zhang and Liu, 2012). Arid and semi-Arid regions are fragile due the potential repercussions of precipitation decrease and temperature increase. (Winter, 2000; Bouldjedri et al., 2011).

Eutrophication is the main danger of wetlands of fresh or salt waters pollution. It manifests when the water receives an exaggerated input of nutritional substances (wastewater or agricultural fertilizers); this increases algae and aquatic plants production (Doddsw et al., 2009; Le Moal et al., 2019).

The lack of protection measures led the effects of the increasing human activities such as pumping, draining, culturing, and grazing to cause the regression of the majority of these ecosystems in the mid or the long run (OZHM, 2012).

Algeria contains 1451 wetlands composed of 762 natural zones and 689 artificial ones (DGF, 2017). Among these, we find Macta marshes in North-western. They have been part of RAMSAR since 2001 (list of wetlands of international importance) (Ghodbani and Amokrane, 2013), due to the rarity of this type of habitat in North Africa and the milieu diversity. Macta marshes are characterized with a big diversity of amaranthaceae annual groups, something that is not found in the rest of the region. The site holds a biological diversity with big numbers of halophytic plants species, invertebrates, and fish (Megharbi et al., 2016). This floral diversity provides multiple opportunities for the avifauna especially birds that depend on the aquatic habitats *Podiceps cristatus* (great crested grebe) and *Phoenicopterus roseus* (Greater flamingo) (Samraoui et al., 2006).

The previous studies that shed light on wetlands of Macta marshes (Simmoneau, 1952; Tafer, 1993; Sitayeb and Benabdeli, 2008; Belgherbi and Benabdeli, 2010; Belgherbi, 2011; Ghodbani and Amokrane, 2013; Megharbi et al., 2016; Souidi et al., 2016) described the organization, the structure, and the diversity of the vegetal community of the marshes. They described many plant groups dominated respectively by *Arthrocnemum macrostachyum*, *Atriplex halimus*, *Bolboschoenus maritimus*, *Juncus maritimus*, *Limbarda crithmoides*, *Phragmites australis*, *Sarcocornia fruticosa*, *Schenodorus arundinacea*, *Suaeda vera*, *Tamarixa fricana* and *Typha domingensis*. However, pollution does not only impact the vegetal diversity, but the touristic nature of Macta marshes wetland.

This study mainly aims at adding to the existing knowledge on the spatiotemporal variations of the wetland of Macta marshes during 2017-2019. Furthermore, it aims at contributing to the unknown evaluation of surface water physico-chemical quality during the study period.

2 Study Area and Methodology

2.1 Study site

The Western Algerian wetlands eco-complex is composed of 7 vast water bodies (Fig. 1) that are not much shed light on. They contain an important biological diversity. Six of them are RAMSAR statute and play a vital role for the aquatic avifauna; many faunal species use it during the whole year. Regional climate is semi arid to a tempered variant of the Mediterranean climate, with a cold winter and a very hot summer, with average monthly temperatures between 5°C and 35°C. The annual precipitations are at 350 mm. Most of the sites which rely on pulviometry for their water supply become arid starting from June. The dominating soil substrate is rich in magnesium chlorides, itonly allows the development of halophilic flora adapted and composed mainly of Chenopodiaceae (*Atriplex halimus, Atriplex patula, Salsola fruticosa* and *Salicornia fruticosa*) and of Cruciferae (*Moricaundia arvensis, Matthiola fruticosa* and *Plotaxis muralis*) (Beghdadi, 2017).

The Macta wet zone (35°41’ N, 0°10’ E, of -2 m till 50 m of altitude) is a national property managed by “forest conservation of Mascara” for the biodiversity tracking. It has 44500 acres occupied by a coastal low, limited from the East by the Mediterranean, and from the South by Beni-Chougrane Mountains. It is supplied by rain water, with ground water resurgence, and intermittently by wadis of Sig, Habra, and Tinn (Megharbi et al., 2016) (Fig. 2).

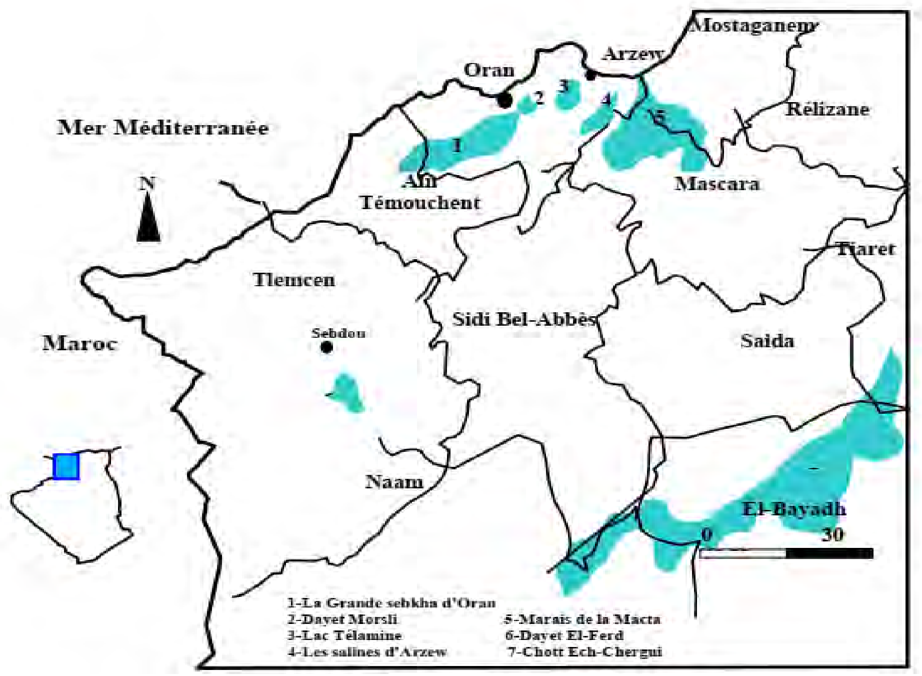

Fig. 1 West Algerian wetlands map (Beghdadi, 2017).

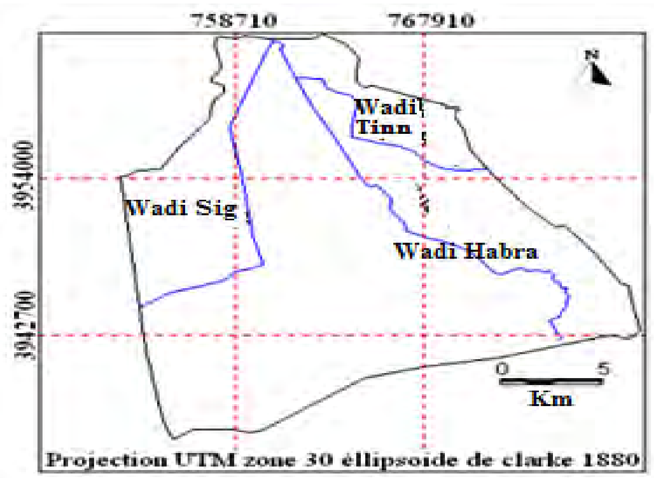

Fig. 2 Main wadis draining Macta marshes.

It is a coastal low with a mouth in the East on the Mediterranean (Arzew Gulf) that is delimited in the South, East, and West by agricultural lands mainly, and plants formations working as a route especially in the East (Sahraoui, 2002). Several variants that determine the zone limits exist. The delimitation that seems the most realistic is the one made by forest services of the region. The file that contains georeferential points of the boundary determination of the study zone has been got from Mohamadia Forest District. The points have been reported on the remote sensing image; they form a delimitation polygon of the study zone (Fig. 3)

2.2 Methods

The study takes two aspects: a spatiotemporal tracking of the flooding zones with the help of spatial remote sensing during 2016, and physicochemical analysis of stagnant waters during the last three years: 2017, 2018 and 2019.

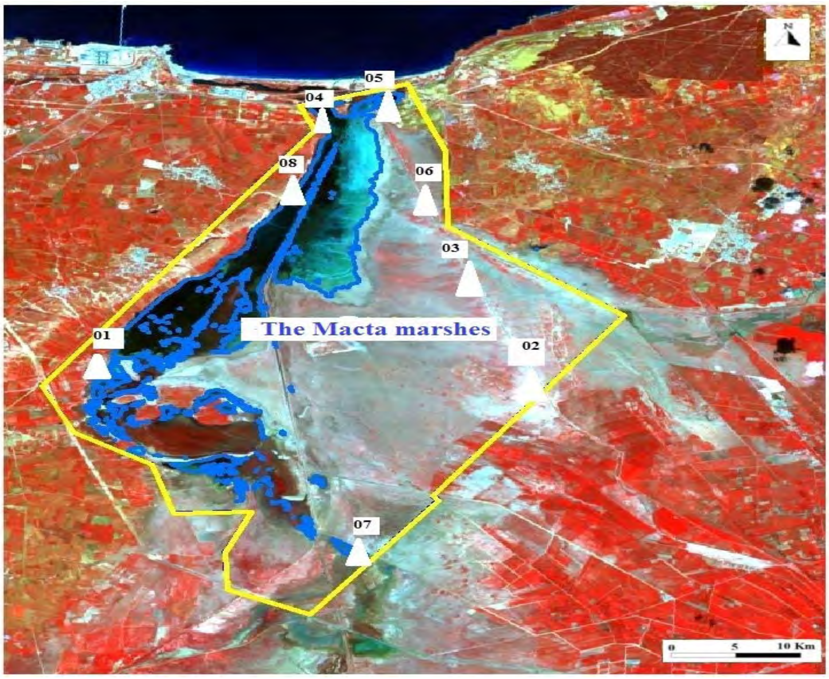

Fig. 3 Delimitation of the reserved zone of Macta marshes following the boundary determination of the forest services (yellow line). Localization of 8 observations stations. Image OLI-Landsat 8, August 2016.

2.2.1 Spatiotemporal tracking

Climatic data analysis (Average temperature and total precipitations) classified into two periods (1950-1983 and 1984-2017) has been realized to estimate the climatic evolution in this region since 1950. The exploited climatic data are those of the nearest Metrologic station of Sidi Abd El Moumen (35°41’ N, 0°10’ E, 21 m altitude).

As for the spatial analysis, we used Landsat 8 satellite images, with free access that cover Macta region during 2016. To measure the variation of surface water coverage, we relied on the index of water content by Normalized Difference Water Index (NDWI) called GAO (1996) that uses Short Wave Infra-Red (SWIR) and a Near Wave Infra-Red (NWIR):

$$NDWI = (NWIR - SWIR) / (NWIR + SWIR).$$

2.2.2 Physicochemical analysis

Eight representative stations of the flooding zone have been implemented for the marshes physicochemical characteristics tracking on the field. These eight measuring stations have been chosen to maximize Macta marshes water physicochemical quality diversity according to different points for water sampling and analysis. The priority was given to 3 main wadis that feed the marshes: wadi Sig (Station 1), wadi Harba (Station 2), and wadi Tinn (Station 3), and at the marshes mouth (Stations 4 and 5) where the wadis pour in the Mediterranean (Fig. 2). Furthermore, we took into consideration the zones that are close to the agricultural fields (Stations 6 and 7) and the zones polluted by the illegal dumping (Station 8).

For every station, since 2017 till 2019, many parameters have been measured on the site (conductivity, temperature, dissolved oxygen, and pH) using portable measuring devices. In every station, water samples were put in 1.5 L flasks and analyzed in the laboratory (Orthophosphates, sulphates, ammonium, nitrites, nitrates and Biochemical oxygen demand (BDO_5) by approved methods (RODIER, 1996).

3 Results and Discussion

3.1 Seasonality and climatic evolution

In order to understand Macta marshes desiccation phenomenon, an analysis of the climatic data has been made. The examination of the temperatures and precipitations registered by the meteorological stations of Sidi Abd El Moumen during 1950-83 and 1984-2017 reveal important variations.

Moreover, the temperature witnessed an important increase between the two analyzed periods (Fig. 4). If, between 1950-83 and 1984-2017, from January to April temperatures saw a slight decrease between -0.1°C and -0.5°C, from May to December, a big increase had been witnessed especially in the beginning of the summer period with +1.5°C in May and +2.1°C in October. Generally, the annual average temperature increased +0.7 between the two analyzed periods, passing from 18.3°C during 1950-83 to 19°C during 1984-2017.

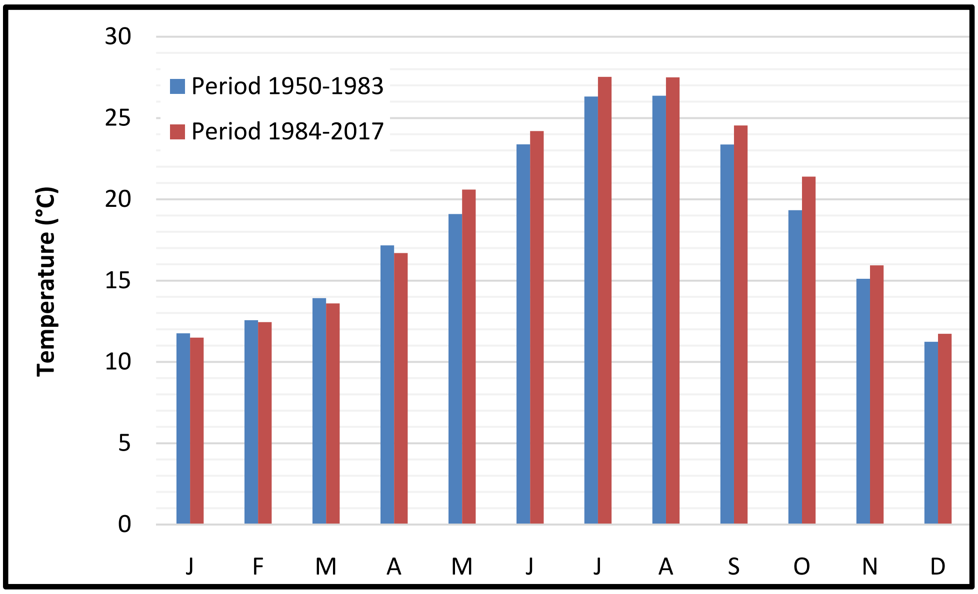

Fig. 4 Average monthly temperature evolution between 1950-83 and 1984-2017 at the Metrologic Station of Sidi Abd El Moumen.

We notice clearly seasonality in these temperature variations. Furthermore, the summer period (May to October) witnessed a net temperature increase (+1.3°C) passing from 23°C to 24.3°C. On the other side, the average temperature of the other 6 months (November to April) kept almost unchanged, passing from 13.6°C to 13.7°C. The hot months, when the annual average temperature is superior to 20°C, were 4 (June to

September) during 1950-83, and they are 6 months for the period 1984-2017. On the other hand, cold months (between 10°C and 15°C) kept unchanged between the two analysis periods (December to March).

Precipitation evolution between 1950-83 and 1984-2017is presented in Fig. 5, It reveals that the period 1950-1983 was much wetter with an average annual precipitation of 356.4 mm, whereas the precipitation recorded during the period 1984-2017 was only 243 mm, i.e. a decrease of -32% in the precipitation between these two 34 year periods.

This precipitation deficit is almost generalized; only the month of September has become slightly wetter (17.6 mm during the recent period against 11.7 mm during the years 1950-1983). July, August, and November have an unchanged pulviometry (Fig. 5). Contrary to this, the other 8 months witness a precipitations decrease, systematically superior to 10%. It is December that witnesses a big change: in the past it was the most humid month (62.8 mm), it is the 5thwatered month during these last decades (24.3) causing a major deficit of -61%. It is clear that this major pulviometric deficit registered in these last decades had a significant impact on Macta marshes drying.

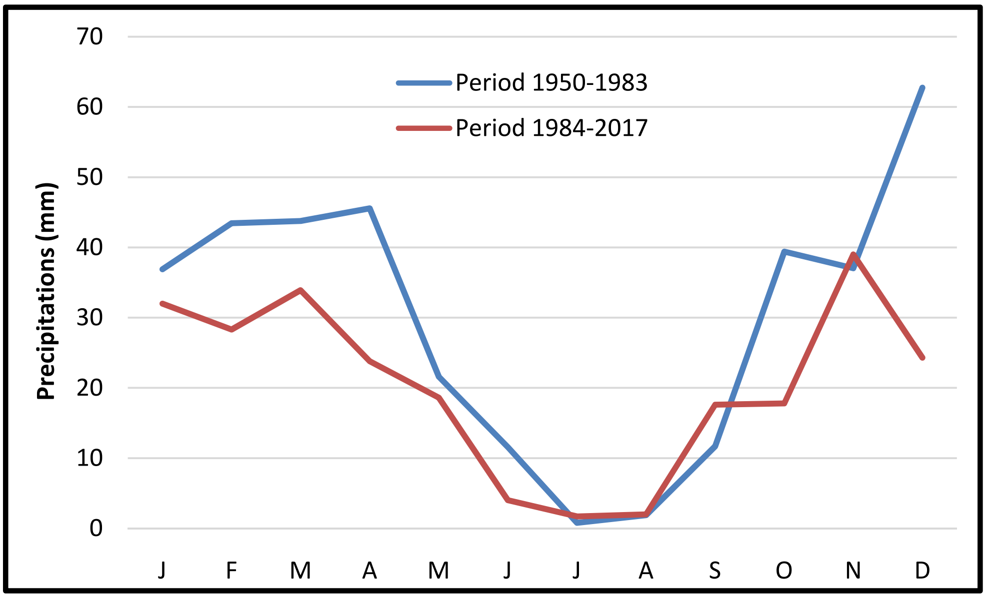

Fig. 5 Monthly precipitations evolution between 1950-83 and 1984-2017 at Sidi Abd El Moumen Meteorological Station.

From the ombrothermic diagrams of Bagnouls and Gaussen (1953) (Fig. 6), it appears that the dry period extended between the two periods. In fact, temperature increase combined with precipitation decrease led the dry period, from (May to September)during the period 1950-1983, to extend with two additional months (April to October).

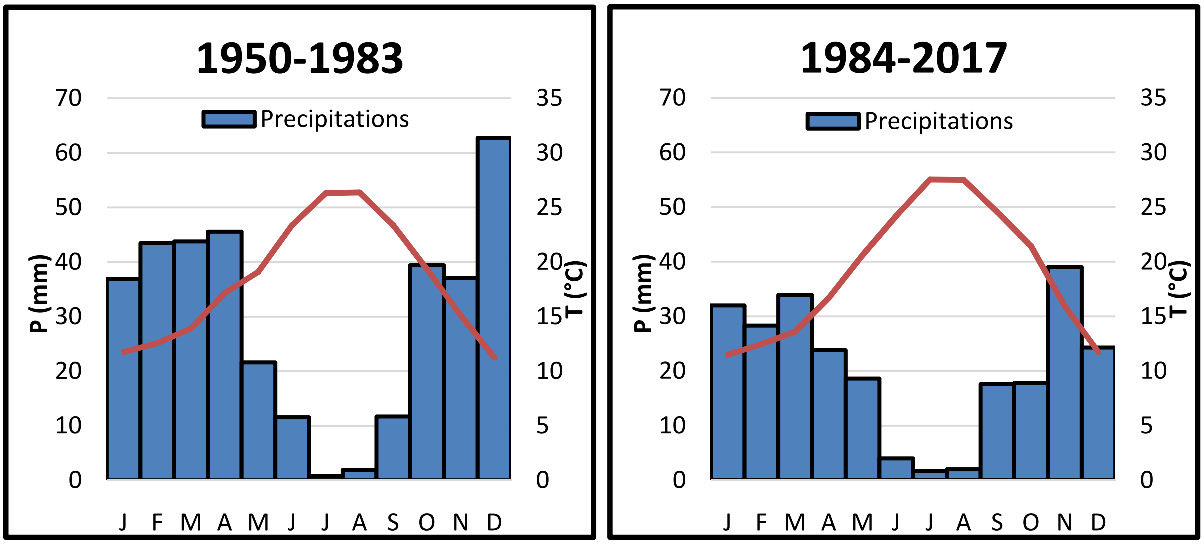

Fig. 6 Ombrothermic diagrams of Bagnoul and Gaussen for the periods 1950-83 and 1984-2017.

The biological diversity that characterizes Macta marshes preserved zone is a biotic and favorable abiotic environment. In fact, the humid milieu that characterizes the region is the key of the appropriate floral and faunal diversity existence. However, this humid milieu remains conditioned by essential climatic factors that manifest in the quantity of precipitations that allow the accumulation of flood water in the marshes during winter, in addition to the evaporation rate of the ground humidity related to the high temperatures in summer.
The desiccation has been accentuated by the dams that poured out Macta basin and the important large suction pipes for wadis water on the tributaries. These operations provoked the decrease of flows that supply the marshes, and hence, the alteration of the ecological equilibrium of this wet zone (Meddi et al., 2009).

The seasonal desiccation of Macta marshes has generally 3 phases (Fig. 7):

Contraction phase and water column reduction: after the winter (April and May) cause more or less important modifications in the physicochemical and hydrological traits of the habitat.

“Desiccation phase: in the peak of the summer period (July and August) characterized with a complete disappearance of the water column.

Re-watering phase: in winter (February and March) corresponds to the temporary coming back of the water column.

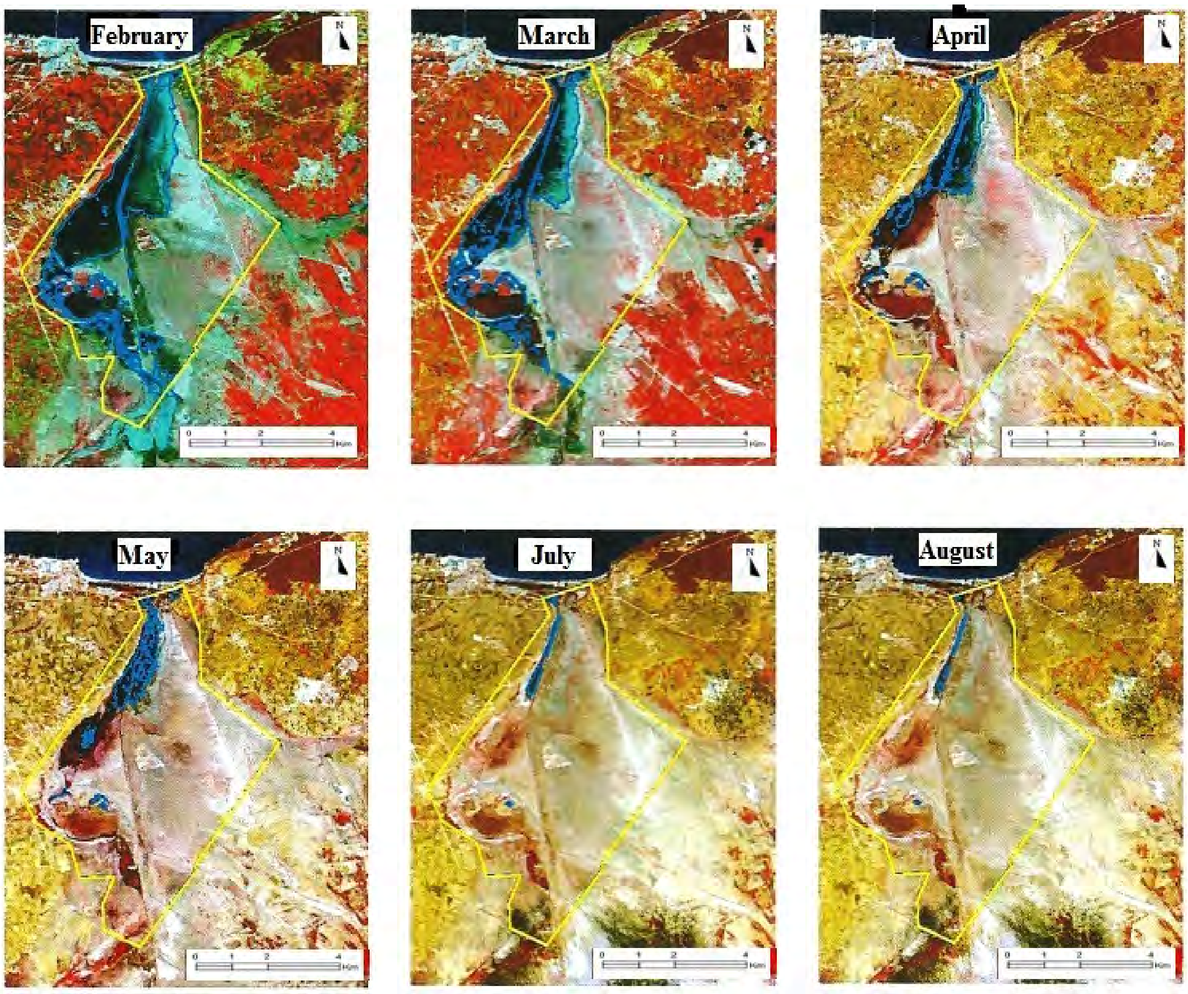

Fig. 7 monthly variations at the level of water (in blue) in Macta marshes (wet zone delimitation in yellow) (Images OLI Landsat 8; 2016).

The desiccation due to the water volume decrease increases the organic and mineral nutriments concentration, and significantly amends the trophic state of the hydro systems, in the stagnant waters particularly (Lofgren, 2002)

A big part of the Macta marshes desiccation since 1990s encouraged the local residents to use this ecosystem. Agricultural fields expansion (mainly cereal) has been observed. Herbaceous layer richness attracted the nomads and their flocks (Benabdeli and Mederbal, 2004).

Water receding in the dry months and the change that may appear in the state of the biotic and abiotic milieu highlights the need for dynamic map of waters during the year (Fig. 8). Two periods mark this wet zone: the flooding period (December to March) marked with a maximal water volume due to winter rains (Fig. 5), and desiccation period (July to August) where the quality of water decreases to the lowest due to a lack of precipitations and the high summer temperatures (Fig. 4).

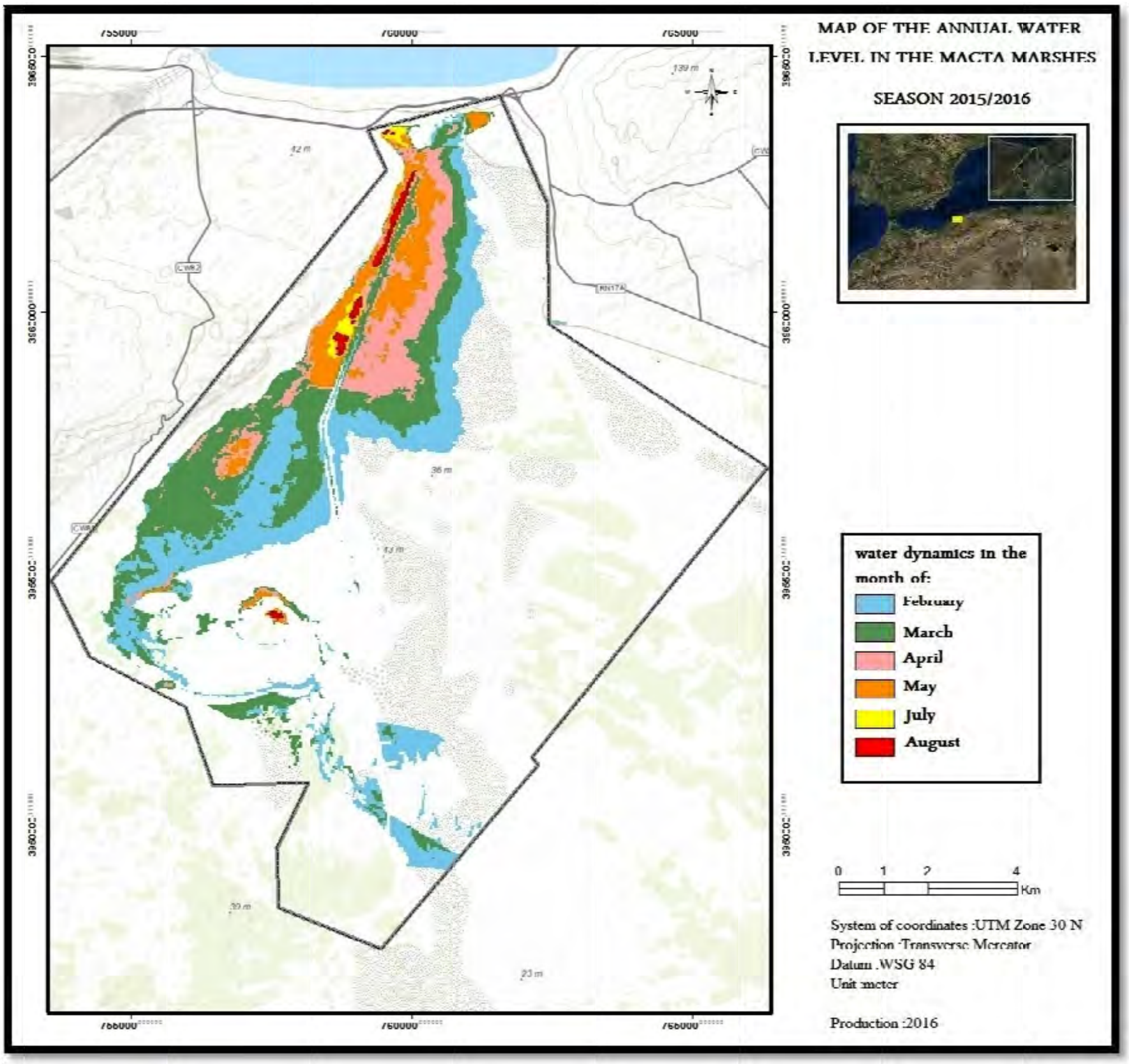

Fig. 8 Macta marshes water dynamics (2016).

3.2 Water quality in Macta wetland

Due to the physicochemical quality characterization of the marshes water, we got interested in some physical and chemical parameters namely temperature (°C), pH, conductivity, dissolved oxygen (O_2), nitrate (NO_3^-), nitrate (NO_2^-), ammonium (NH_4^+), orthophosphate (PO_4^{-3}), sulphates (SO_4) and biochemical oxygen demand (BDO_5) in different stations of the marshes. The obtained results allow us to characterize the milieu in Macta marshes according to the sampling stations.

3.2.1 Temperature (°C)

It is important to know the water temperature precisely as it plays a role in solubility of salt and gas especially, drying out of dissolved salt and hence the electrical conductivity, pH determination, finding water origins and eventual mixtures, etc.

Moreover, this measure is so useful in limnology studies and the industrial view for thermal exchange calculation (Rodier, 2005). In aquatic ecosystems, water temperature controls all chemical reactions and affects fish growth, reproduction, and immunity. All biological and chemical processes depend on temperature. It affects water O_2 content (dissolved oxygen levels decrease when the temperature increases).

Temperature variations results in the studied stations are represented in Fig. 9. Temperature at the level of the 8 stations of the marshes varies from 18 to 25.6 °C. Fish in the Macta marshes are mainly those which need a temperature between 18 to 25°C to reproduce especially during summer such as cornflower, carp, and sardine. The highest temperatures were registered in stations 6 to 8 where water innovates slowly (stagnant) what may accelerate the eutrophication in these spaces (Fig. 9).

3.2.2 Hydrogen Potentials (pH)

pH is an important parameter for the definition of aggressive or encrusting traits of water. It intervenes in this process with other parameters such as hardness, alkalinity, temperature, etc. It corresponds to hydrogen ions, and measures the acidity or basicity of the water (Aminot and Kerouel, 2004).

Natural water pH is related to the nature of the land crossed (Djezzar et al., 2018). It is an important element to determine the aggressive or encrusting traits of water. It depends on the characteristics of the drainage basin, seasonal variations, and streams crossed. It must be between 6 and 8 to allow Macta marshes fauna and flora to grow normally.

pH monthly values of Macta marshes water vary between 8.2 and 8.4 indicating a weak water to mildly alkaline; hence, a big CO_2 consumption leading to an increase in bicarbonates' concentration (Bou Saab et al., 2007). This provokes a reduced photosynthetic activity responsible for pH increase in the marshes; this coincides with high temperatures during summer and weak oxygen values (Gouasmia et al., 2016). pH results show that pH is systematically above 8. Highest values are registered in Station 1 (wadi Sig: 8.4) and Station 2 (wadi Habra: 8.3). Alkalinity in these stations is due to the presence of substances, micro-organisms and elements of natural origin coming from the wadis that cross the marshes, and can be related to anthropogenic effects through wastewater evacuation and industrial waste (Two factories are found ahead the wadis) and drainage of agricultural lands loaded with fertilizers (Fig. 9).

3.2.3 Conductivity

Conductivity is a general measure for water quality and total quantity of dissolved salt. Conductivity measurement allows evaluating water global mineralization (Rejsek, 2002) that may cause a salty taste depending on the salt nature. Conductivity is water temperature function. Variations of factors climatic conditions are also a source of variation of mineralization. Indeed, during the rainy season, concentrations decrease due to dilution by rainwater. On the other hand, during the dry season, significant evaporation leads to an increase in the concentrations of mineral ions (Boulaksaa et al., 2020). Conductivity measurement allows evaluating water global mineralization and following its evolution (Han et al., 2011). Surface water must have an ideal conductivity for dwellers of the aquatic milieu between 300 and 1200 µS/cm. If water has a conductivity that is inferior to 100, we can conclude that it is poor in ions. Water whose conductivity is superior to 1000 µS/cm indicates strong mineralization. Electrical conductivity fluctuates between 804 and 1420 µS/cm (Fig. 9) is indicated a strongly mineralized water. Electrical conductivity is mainly high at stations 1 and 2.

Wastewater rejected by wadis characterizes generally the very high concentrations of dissolved elements which increase electrical conductivity in the marshes due the chloride presence, phosphate, and nitrate. Marshes water conductivity average increases to 1126 µS/cm. The marshes zone geological nature affects conductivity values, clay soils that characterize the Macta basin seem to increase the conductivity due to the presence of materials that ionize during runoff. Thus, we can say that marshes water mineralization is as important compared to the standards.

3.2.4 Dissolved Oxygen

Dissolved oxygen is mainly composed of water. It allows fauna and flora life, and conditions the biological reactions that take place in aquatic ecosystems. In waste water treatment, it is necessary for the degradation of polluting materials that are made mainly in aerobiosis (Cardot and Gilles, 2013).

According to the Algerian standards, water has a good quality when dissolved oxygen content is superior to 95%. From 50% to 95%, water is considered of mediocre to little pollute. When dissolved oxygen content is inferior to 50%, water is considered polluted and of poor quality (ONA, 2014). Dissolved oxygen contents are relatively homogenous in Macta marshes, of a mediocre quality at the 8 sampling stations with an average rate of 74.7% (Fig. 9). Extreme values are 68.3 at station 7 and 83.7% at Station 1.

Macta marshes waters present a poor oxygenation. Domestic wastes contribute to the decrease of dissolved oxygen contents, the latter being consumed by micro-organisms to degrade the risk of the organic substance of being late and to endanger the marshes aquatic life.

3.2.5 Orthophosphates (PO_4^{-3})

Elemental phosphorus (P) is rare. In the nature, it generally exists in the form of phosphate molecule (PO_4). Organic or inorganic phosphorus may be dissolved or in suspension in water (Spellman, 2014).

Phosphorus is considered as a main nutritional element for the development of trophic chains (Rodier, 1996). It induces an excessive development of phytoplankton. Inherited phosphorus in sediments can exert control over wetland condition; this is a critical factor that typically hinders restoration efforts in freshwater systems affected by anthropogenic activity (Kim et al., 2021). Enrichment in orthophosphates is considered to be due, at the origin, to eutrophication phenomenon (Hennizurgui, 2009). There are many sources of phosphorus, natural (rocks) and anthropogenic (fertilizers, dung, wastewater, detergent, etc). High concentrations of phosphorus may trigger an undesirable chain of events such as plants accelerated growth, algae proliferation, weak dissolved oxygen content, and death of some fish, invertebrate and other aquatic animals. Based on the values of national office of sanitation (ONA, 2014) in Algeria, the ideal phosphate content for a good quality of natural water is at 0.1 to 0.2 mg/l. Orthophosphates concentrations (PO_4^{-3}) are very low at the sampling stations and are systematically under the threshold of 0.1 mg/l (Fig. 9). Registered values at the station of the marshes mouth are due to water supplies of streams and wadis, rich in fertilizers used in agricultural fields that accumulate and concentrate to the point of confluence of the 3 wadis (Station 4). In fact, the cultivated area was 9751 acres in 2001 to 14.688 acres in 2008 i.e. an increase of 50% in 7 years. Arboriculture developed as well, passing from 8075 acres in 2001 to 8819 acres in 2008 (Belgherbi, 2011).

Phosphorus ions presence in the marshes has domestic and industrial origins. Wastewater from different districts in the study zone is at 35104 m³/day, equal to equivalent to 12.812.960 m^3/year. Potassium used in nutritional oil conservations thrown in wadis is another cause. In fact, more than 494 institutions have been numerated near the two agglomerations of the study zone, namely Moahmadia and Sig. Cattle rising, namely poultry farming, is an important activity in the study zone.

3.2.6 Sulphates (SO_4)

Natural origins of sulphates are of the rain water and evaporitic sedimentary rocks solutionizing, especially gypsum ($CaSO_4\,2HO_2$), but also pyrite (FeS) and more rarely magmatic rocks (galena, blende, pyrite) *(*Ghazali and Zaida, 2013).

Sulphates are necessary elements for the growth of aquatic plants; however, an excess may limit the biological production (Rodier, 2005). Surface waters have very variable sulphates contents. In an ordinary situation, these contents are inferior to 20mg/l; in a dubious situation (polluted water), they are between 20 to 120 mg/l; and in an abnormal situation (very polluted water), they are superior to 120 mg/l (Devillers et al., 2005). Registered values of sulphates vary from one station to another (Fig. 9). A maximum of 34.3 mg/l is noticed at Station 1 (wadi Sig) tough the minimum is 19.2 mg/l at Station 8 (illegal dumping). Six stations out of eight have “polluted” water with contents superior to 20 mg/l. Marshes waters are polluted mainly by wadi Sig discharge. This may be due to the increase of sulphide-containing waste of urban and mainly industrial waste (industrial zones of Sig and Fornaka) though the important contents registered at Stations 6 and 7 near the agricultural field may be due to extensive agricultural activities, also the use of copper sulphates $CuSO_4$ as rodenticides. Agricultural field’s expansion of the region is mainly due to nomadic settlements and the sheep and cattle ranching increase (DSA, 2009). But, in arid and semi-arid regions, causes of sulphates increase may be due to soluble salts that may accumulate 15 cm of the terrestrial surface (APHA, 2005).

3.2.7 Nitrites (NO_2^-)

Nitrites presence in water may be due to incomplete oxidation of nitrogenous composed (organic nitrogen or ammoniac); it corresponds to an intermediate level and their concentration is generally inferior to 1 mg/l (Rejsek, 2002).

According to De Villiers et al. (2005), nitrites values of surface waters vary between 0.01 to 0.1 mg/l indicating a dubious situation (polluted water).

Our findings show that nitrites contents vary between 0.16 and 0.29 mg/l with an average concentration of 0.21 mg/l. The highest values are registered at the mouth station (Fig. 9). This indicates a water pollution of the wet zone. These concentrations of nitrites in water of Macta marshes may be explained by the organic substance decomposition with the nitrification phenomenon that comes from the decrease of nitrates under the influence of bacteria (Dovonou et al., 2011).

3.2.8 Nitrates (NO_3^-)

Nitrates are found in naturel and soluble states in the soil. They penetrate underground water and pour in water streams. But, they are also synthetic substances brought by fertilizers (Haller et al., 2013). They are one of water quality degradation causes.

They are used as a pollution index. They fertilize plants that assimilate nitrogen in the form NO_3^- (Djermakoye, 2005).

Nitrates contents histogram (Fig. 9) shows a variation of 0.26 mg/l at Station 2 with much lower concentrations (0.024 mg/l) at station 8. These nitrates values in Macta marshes water are acceptable according to the standards that vary between 2.21 to 10.17 mg/l. Eutrophication risk starts at a nitrates concentration superior to 10 mg/l (Corriveau, 2009). Nitrates can be carried by runoff into the wadis that supply the marshes. These concentrations, though they are low, may be subject of organic substance decomposition by nitrification phenomenon; this confirms the wastewater discharge and the illegal dumping in wetland of Macta on the most important concentration at the wadis.

3.2.9 Ammonium (NH_4^+)

NH_4^+ presence in relatively important quantities may indicate of pollution due to human, industrial wastes and fertilization in agriculture (Martínez-Dalmau et al., 2021). NH_4^+ ideal content in surface water is normally between 0.04 and 0.08 mg/l (ANRH, 2008).

The measured values in marshes waters vary between 0.076 to 0.21 mg/l (Fig. 9). The highest values are registered at Station 1(wadi Sig) and 4 (mouth). This indicates that the presence of NH_4^+ in these two stations comes from dejections of living organisms and the decrease biodegradation of waste, without forgetting the domestic and agricultural causes. The demography of all the municipalities in the study area a total population of 269,860 inhabitants, i.e. an average density of 222 inhabitants/km². This agglomerated population of almost 80% concentrates in big cities around the marshes mainly the city of Sig (DE, 2014). This confirms the important discharge of wadi Sig with a very polluting effect on the marshes. The concentrated discharge at the mouth may have a negative impact on the Mediterranean, namely in region swimming areas which may cause allergies and diseases to the habitants.

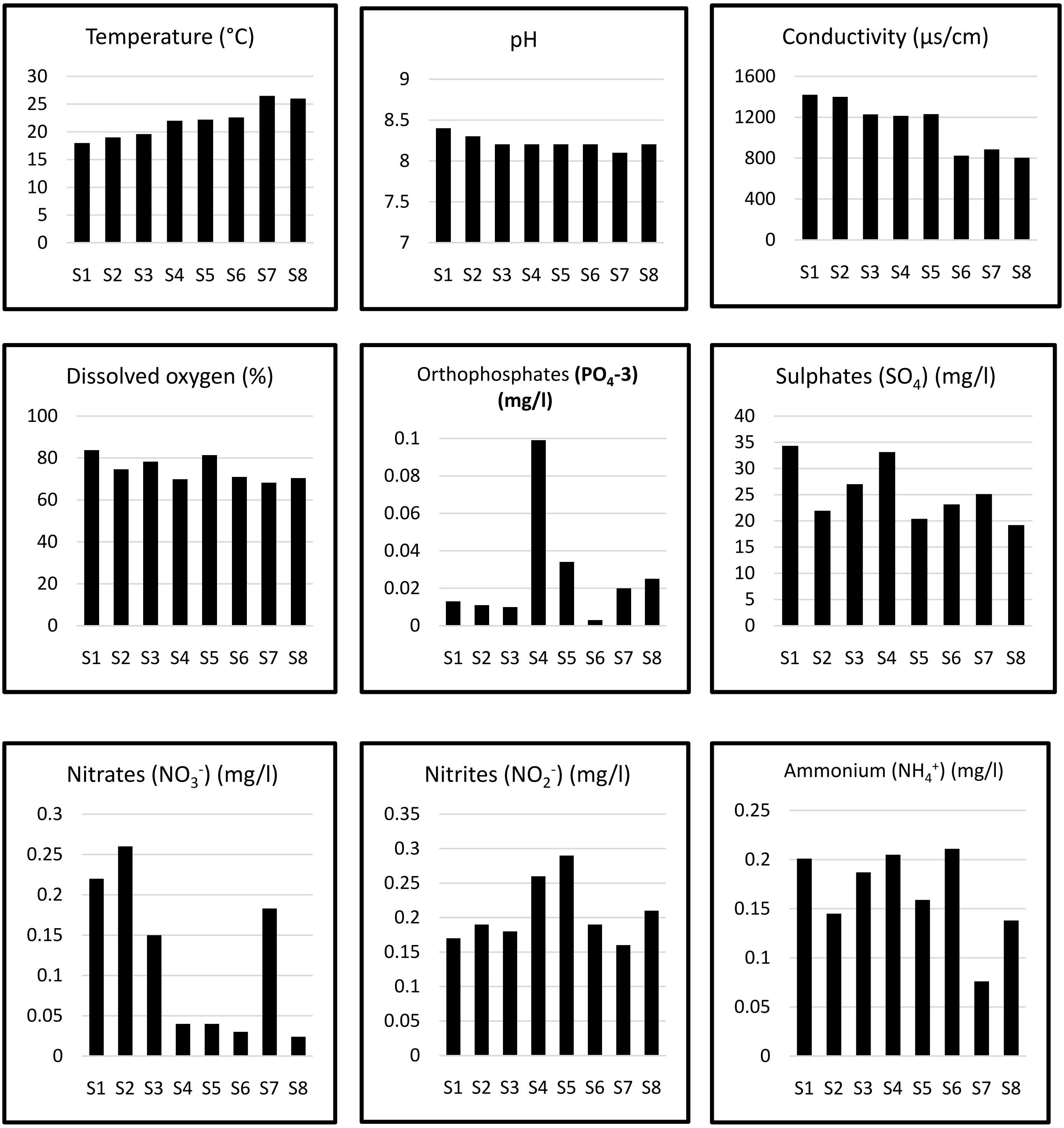

Fig. 9 Physicochemical parameters variations at the eight stations (S1 to S8) in Macta marshes in the years (2017, 2018 and 2019).

3.2.10 Biochemical oxygen demand (BOD_5)

The aerobic decomposition of organic substances in water by microorganisms is a sort of slow oxidation. Aerobic microorganisms require a quantity of oxygen proportional to the organic load (Copin-Montégut, 1996). As long as there is consumable oxygen, microorganisms will use it for their microorganisms will use it for their degradation work. The quantity of oxygen required by them is the biochemical oxygen demand (Djouamaa, 2011).

The highest values are recorded at Stations 1 (wadi Sig) and 4 (the mouth) between (20 and 50 mg/l) where the dissolved O_2 content reaches the lowest value of 69.85% in the mouth with a more or less high temperature. When the temperature rises, the O_2 content decreases due to its increased consumption by living things (plant respiration) and bacteria which multiply using organic carbon as an energy source which translates into a high biochemical demand for O_2 (high DBO). It is a phenomenon of natural self-purification in water (Rodier, 2005). It is admitted that a DBO_5 value above 25 mg/l can be an indication of polluted water quality (Beaux, 1998). These high values correspond to a high load of organic matter coming mainly from the agro-food industries (Daiekh, 2015), and the use of fertilizers, pesticides and insecticides in agriculture near the marshes.

3.2.11 Organic Pollution Index (OPI)

The Organic Pollution Index (OPI) was first proposed by Leclercq and Maquet (1987). This index makes it possible to assess the chemical quality of waters impacted by actual organic pollution from the parameters biological oxygen demand (BOD_5), Orthophosphates (PO_4^{-3}), nitrite (NO_2^-), ammonium (NH_4^+) (Table 1).

The principle of the OPI is to spread the values of polluting elements in 5 classes (Table 2) and then determine, from its own measures, the number of corresponding class for each parameter and then to make the average. It is therefore, a revealing indicator of pollution of organic origin (domestic or agricultural) (Mezbour et al., 2018).

Our results show that the OPI values varied between 2.25 and 3.25 with an average value is 2.87 (Table 3). We note that the water changes from one quality to another (moderate organic pollution to strong organic pollution), the lower values indicate a strong organic pollution (OPI = 2, 25 and 2.75) are recorded at the stations of the mouth (Stations 4 and 5), wadi Habra (Station 2) and wadi Tinn (Station 3). These values of the OPI in the water of the Macta Marshes can be explained by a marked degradation of the water quality of the wetland by the discharges of sewage and industrial waste from the agglomerations of Fornaka and Mohammedia.

Table 1 The quality grid (OPI).

Classes	**BOD_5 ($mg\ O_2.L^{-1}$)**	**Ammonium ($mg\ N.L^{-1}$)**	**Nitrites ($\mu g\ N.L^{-1}$)**	**Phosphates ($\mu g\ N.L^{-1}$)**
5	< 2	< 0.1	5	15
4	2-5	0.1-0.9	6-10	16-75
3	5,1-10	2,4	11-50	76-250
2	10,1-15	2,5-6	51-150	251-900
1	>15	> 6	>150	> 900

OPI = average of the class numbers of the 04 parameters.

Table 2 Classes of OPI and degrees of pollution.

Average of classes	Level of organic pollution
5,0- 4,6	Nothing
4,5- 4,0	Low
3,9- 3,0	Moderate
2,9-2,0	Strong
1,9-1,0	Very strong

Table 3 Organic pollution index (OPI).

Station	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
OPI	3,25	2,75	2,75	2,25	2,5	3,25	3,25	3

4 Conclusion

The Macta wetland represents a particular very diverse territory. It is appreciated for its aquatic landscape and the faunal and floral abundance and variety; they are the most visible elements. However, this ecosystem's specific properties give other major functions namely regarding the water resources and the ecologic quality of this milieu.

Current climatic changes in the region of Macta are incarnated in a decrease of precipitations and a big increase of evapotranspiration menacing this ecosystem. In the absence of protection measures, the growing human activities may cause the regression of the majority of the site in the mid or long term. These factors are one of the causes of desiccation risk.

Obtained results show phosphates are very important in addition to their superior dissolved oxygen contents wit conductivities between 804 and 1420 µs/cm. Thus, the site is polluted raising eutrophication risk.

The analyses carried out have shown that the Macta wetland is affected by strong organic pollution in the majority of the stations. This pollution was mainly caused by an excess of ammonium and high values of the biological oxygen demand.

One of the last aggressions against this natural milieu is domestic wastewater discharge (there is no epuration station ahead) and industrial waters in the wadis coming from the activity zone of Sig and Fornaka cities which accumulate and stagnate in the wetland. Unfortunately, it is the main cause of pollution.

The results of this work confirm therefore a risk of degradation the water of this wetland.

In order to preserve and improve sustainably the ecosystem of Macta marshes, the authorities must stop these negligence that lasts and leads to an irreversible destruction of this site that has been classified since 2016 as a zone of international importance for the fauna and flora and birds by the International United for the Conservation of Nature; the zone is a hotspot of the Mediterranean region biodiversity.

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