ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. VIII, Issue 6/ September 2020

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

Tools and Indicators for Integrated Wetland Monitoring. Case of Hergla Wetland -Tunisia

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Abstract

Wetland ecosystems in Mediterranean regions, especially coastal, are cradles of biological diversity, providing water and primary productivity upon which countless species of plants, animals depend for survival. Recently, remote sensing and Geographic Information Systems tools have been used to assess, monitor wetlands biodiversity, and to promote awareness providing technical support to decision-makers for conservation and sustainable development of these ecosystems. This research is done in Halq El MingelSebkha, known as Hergla wetland, located in the center of Tunisia, covering an area of 12 km2 characterized by its landscape diversity. However, this ecosystem is threatened by different forms of degradation. To monitor changes in this ecosystem, Landsat 5 TM and Landsat 8 OLI images have been used successively for 2007 and 2017. Three radiometric indexes have been calculated for each year: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Salinity Index (SI). Radiometric indexes analysed between 2007 and 2017, reveal that in 2017 the NDVI of Halq El Mingel has increased and the SI has discreased. However, the NDWI had the lowest value with stabilization of the maximum value obtained in 2007. The spatial and temporal

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variation of radiometric indexes can help decision makers and researchers to understand the behaviour of wetlands.

Keywords: wetland, GIS, radiometric indexes, changes

1. INTRODUCTION

Wetlands are one of the most valuable natural resources in the world, for this reason they are recognized as important ecosystems in terms of biodiversity and functional roles (Burton and Tiner, 2009; Tiner, 2015b and Wu, 2018). These ecosystems include a remarkable range of habitats that are ecologically considered among the most productive ecosystems worldwide, with large socio-economic importance and high heritage values for humanity (Chenchouni et al, 2015). The United States Geological Survey (USGS) defined wetland as a general term applied to land areas which are seasonally or permanently waterlogged, including lakes, rivers, estuaries, and freshwater marshes; an area of low-lying land submerged or inundated periodically by fresh or saline water (Cowardin et al, 1979 and Dong et al, 2014). In Tunisia, the wetlands are defined by the Forest Code; enacted by Parliament on 13 April 1988; as areas of lakes, sebkhas, 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 (Convention on wetlands, 2016). This definition resumes largely the defenition of wetlands on the Ramsar convention, signed in Iran on 2 February 1971 (IUCN, 1999). Orimoloye et al. (2018) underline that wetlands play a key role in supporting biological diversity of various species: waterbird, fish, amphibian, reptileand plant species during important life stages, they assurate roosting, nesting and feeding habitat mainly in extreme weather conditions. So wetlands are an important breeding and feeding regions for wildlife and create shelters and protection for sea creatures. They play crucial and major ecological functions, including trapping, absorbing and eliminating of potential toxic chemicals and pollutants, storage of natural carbon, recycling of nutrients, as well as they contribute to groundwater recharge in arid and semi-arid regions (Chenchouni et al, 2015). Also they establish an environment for recreation and tourist attraction thus contributes to the economy of a particular area.Tunisia contains a large number of natural and artificial wetlands distributed throughout the country. The national report on the Tunisian Environementl, in 2003, highlights this distribution as: 64 wadis, 62 sebkhas, 37 ponds, 14 inland marshes, 4 costal marshes, 16 chotts, 15 lakes, 5 naturel sources and 3 peatlands. The total area of Tunisian's wetland is about 1,250,200 ha, in order, about 80 wetlands stretch from north to south and the most of them located within a short distance of thecoast although not usually connected to the sea (Convention on wetlands, 2016). They play a major hydrological role in stockingflood waters, recharging and/or discharging groundwater and are prime habitats for a diverse andtypical fauna and flora thus generating many benefits to local communities and society as a whole (Halls et al, 1997). To resume, wetlands assurate great ecosystem services in particular: provisional, regulatory, supportive, cultural and recreational services (Russi et al., 2012). Wall (1998) describes recreation as the most important economic activity in wetlands; with different uses like: waterfowl hunting, saltwater fishing, freshwater fishing, recreational shrimping, recreational crabbing, wildlife observation, nature study, photography, etc (Everard et al, 2017). Unless the economic importanceof this uses, wetland managers cannot profit directly because the rarety of informationandfew policies have been implemented regarding wetland recreational activities (Zhang et al, 2012; Russi et al, 2013; Park et al, 2017 and Yu et al, 2018). Regarding thenumber of wintering waterbirds, Paracuellos (2006) noted that is depended on the size of such wetlands, so more the wetland is larger more it contains a large number of species (Preston, 1962). Arrhenius (1921); May (1975); Wu¨rtz&Annila (2008) and Afdhal et al (2012) in their researches have shown that the area–species relationship is basic theory in spatial ecology. Erwin (2009) enhanced that global climate changethrough alterations in hydrological regimeshadanegative impact on wetland ecosystems. In the report of Ramsar Convention (2009) it was estimated that since 1900, 64% of the world's wetlands have disappeared. It is recognized that the rate of wetland loss varies considerably from a country to another. For example, in the United States 53% of their original wetlands was lost for a period of 200 years, between the 1780s and the 1980s, estimated Dahl (1990). In China, from 1978 to 2008, they lost a 33% in just 30 years (Niu et al, 2012 and Wu et al, 2018).In Tunisia also, wetlands are subject to strong anthropogenic and natural pressures, resulting in degradations of these environments.Therefore, several researches haveproven that Geographic Information System (GIS) and remote sensing technologies serve as mapping and monitoring wetlands: Sader et al. (1995) ; Lyon et al.(2001) ; Ozesmi and Bauer (2002); Chris et al. (2002); Weiers et al. (2004) ; Rebelo et al. (2009); Adam et al. (2010); Dong et al. (2014) ; Lang et al.(2015) and Wu et al.(2018). In facttheyprovide powerful tools for data acquisition, spatial analysis, and graphical display.The present article emphasizes how wetland has evolved between 2007 and 2017 and the nature of changes performed by this wetland thanks to radiometric indexes. The study aims also to describe how to monitor and assess these changes.

2. MATERIALS AND METHODS

2.1 Study area

Halq El Mingel (35°59'23"N, 010°30'10"E), is a natural sebkha, is located at 25 km on north-west of Sousse city (Figure 1). This wetland is state-owned and it was declared as a Ramsar Site in 2006, the site consists of the complex of Sebkha Halq El Mingel and OuedEssed, which feeds the sebkha directly. Its permanent surface is about 1450 ha and during wet periods it increases to 2050 ha. The depth varies from 0.5 m to 1 m.

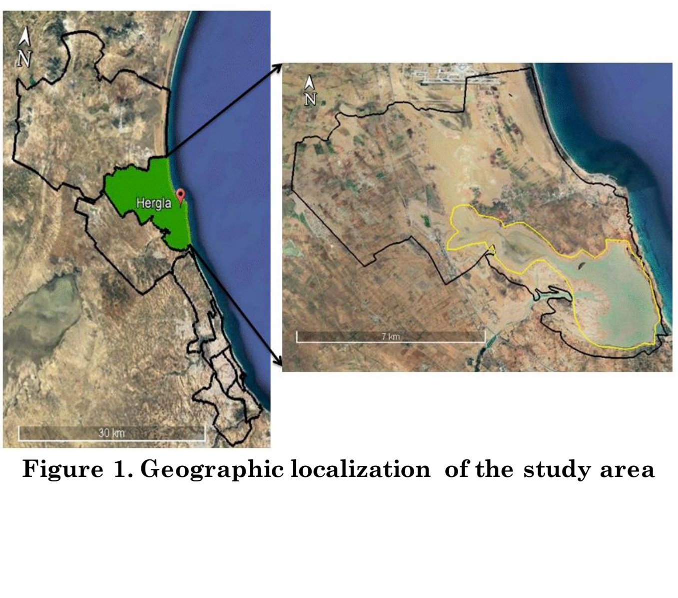

Figure 1. Geographic localization of the study area

2.2 Methodology

The Earth Observation and the remote sensing information including derived radiometric indexes have provided opportunities to study natural landscapes and land environments.Landsat imageries has been used in different researches to extract satellite information about biological community, land surface properties andtomap land cover patterns (Nguyen et al, 2012; Adefisan et al, 2015; Nsubuga et al, 2017; Onamuti et al, 2017; Stephen et al, 2017 and Orimoloye et al, 2018). Several researchers have been usedtoremote sensing information for identifying, describing and mapping the distribution of wetlands at different scales (Sahagian and Melack, 1996; Darras et al, 1999; Lehner and Do¨ll, 2004; Fernandez-Prieto et al, 2006 and Rebelo et al, 2009). After obtaining Landsat data, different processes were applied to create thematic maps; figure 2 summarizes the whole flowchart of this research.

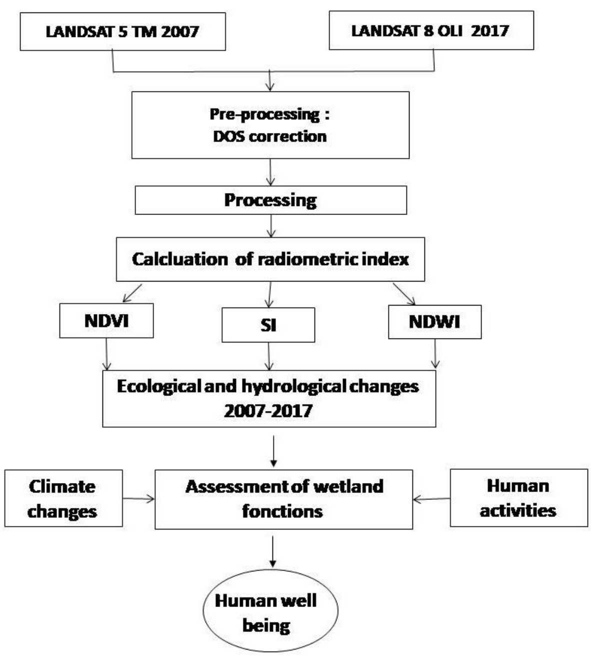

Figure 2. Flowchart of the methodology adopted

2.2.1 Satellite data

Two Landsat images were downloaded for free from the USG "Earth Explorer" server (**https://earthexplorer.usgs.gov/**): the Landsat 5

TM and the Landsat 8 OLI. Then georectified to a Universal Transverse Mercator (UTM) coordinate system, using World Geodetic System (WGS) 1984 datum, assigned to north UTM zone 32 and Path 191 Row 035.

Table 1.Characteristics of satellites imagesused

Acquisition date	Satellite	Sensor	Path	Row
22/04/2007	Landsat 5	TM	191	035
01/04/2017	Landsat 8	OLI	191	035

2.2.2 Preprocessing

In order to remove or reduce the influence of the atmosphere an atmospheric correction with the dark-object-subtraction (DOS) method is uesd. From Teillet (1986), Richards (1993), Olsson (1995), Chavez (1996), Jensen (1996) and Richter (1997) the method includes the correction of atmospheric transmittance through optical thickness values at a given wavelength or using the default transmittance values derived from the in situ atmospheric.The remotely sensed images were processed using the Quantum GIS® 2.2.

2.2.3 Radiometric indexes

GIS and remote sensing techniques may contributetoidentify and delineate wetlands by analyzing a combination of indicators such as: vegetation, hydrology, soil types (salinity), and topographic position. Three radiometric indexes: NDVI, NDWI and SI, are calculated in the month of April 2007 and 2017.

Vegetation index

Remotely sensed data are frequently used to identify specific plant species of wetlands. The most well known and commonly used index to detect green vegetation from multispectral remote sensing data is the normalized difference vegetation index (Rouse and Haas, 1973 and Tucker, 1979). The formula for calculating this index is:

$$NDVI=(NIR-RED)/(NIR+RED)$$

Where:

- NIR: the spectral reflectance value obtained in the near-infrared.
- RED: the spectral reflectance value obtainedin the red portions of the electromagnetic spectrum.

The NDVI values range from -1 to +1; the negative value or close to zero indicates no vegetation, but the positive one signifies the greatest concentration of green vegetation (Wu et al, 2018).

Water index

NDWI allows to highlight and delineate water-like features and high soil moisture areas (McFeeters, 1996), but it has positive values only in water elements (Gao, 1996). Hydrology isthe most important factor that affects the formation and functions of a wetland, who received the water from multiple sources like: precipitation, snowmelt, surface water runoff and groundwater discharge. So high wetness wetlands are easier to identify than the dried one.The NDWI is computed as follows:

$$NDWI = (GREEN-NIR) / (GREEN+NIR)$$

Where :

- NIR: the spectral reflectance valueacquired in the near-infrared.
- GREEN: the spectral reflectance value acquired in the green portions of the electromagnetic spectrum.

The NDWI values range from -1 to +1; a negative or close to zeroonesignifies no water, yet the highest wetness is indicated byapositive value (Wu et al, 2018).

Soil salinity index

Salt – affected soils are broad over the world particularly insemi arid regions, it can lead to desertification and other form of land degradation, such as salinization (Richards et al, 1999 and Congalton et al, 2009). Foudy et al. (2002) indiquates that about 20% of irrigated agriculture overall is affected by salinization (Baaziz et al, 2018). Dehni et al. (2012) proved that SI is very useful for identifying and delineating saline soils. The values range from -1 to +1 and the formula used to calculate is:

$$SI = SQRT (RED * NIR)$$

3. RESULTS

3.1. NDVI indicator of vegetation change

In 2007, the values ranged from -1 to 0.1 for the sabkha. The highest NDVI registered was 0.1 around the sabkha; however the lowest value registredwas -1 which correspond to no vegetation. The NDVI values has slightly increasedin 2017, the values ranged from -1 to 0.5.This variation is explained by the importance of rainfull enregistred in 2017 early spring. This indicates that the vegetation coverage has increased in the area during this period. The highest NDVI registered is 0.5it is higher than in 2007, which indiquatesthe high concentration of halophytes. The growth of wetland vegetation areas recorded in April 2017 may be the result of the high rainfall recorded in March 2017.

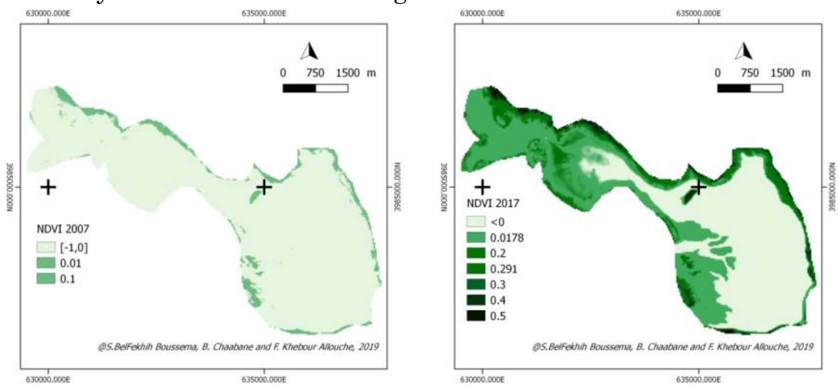

Figure 3. NDVI maps of Halq El Mingel

3.2. NDWI indicator of water change

In 2007, the minimum NDWI values remained for the sabkhais around 0.6 during this decade, while the maximum NDWI remained above 0.9. In 2017, the NDWI values ranged from -1 to 0.9. As the NDWI values allowed the localization of humidareas, the values below 0.7 reflect areas richeinvegetation that are more noticeable in 2007.It can also be denoted by the result that theyear 2017 had the lowest NDWI (-1) and this might have a significant impact on biodiversity including plants as well as animals.For 2007 and 2017, the results showthat the NDWI was higher which explain that recent human activities might play a vital role in the wetland extinction.

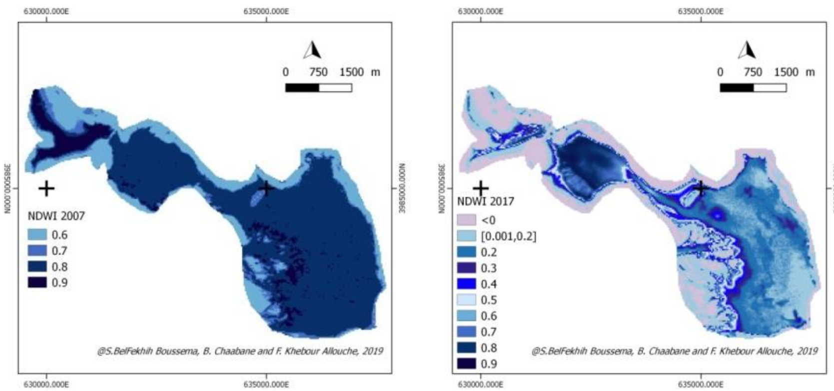

Figure 4. NDWI maps of Halq El Mingel

3.3. SI indicator of salinity change

In 2007, the SI values rangedfor the sabkha from 0.0015 to 0.8. In 2017, the minimum SI values remained for the sabkha around -0.3 and the maximum SI remained above 0.1. However, its reduction detected is explained by the rainy events enregistred in March-April 2017.

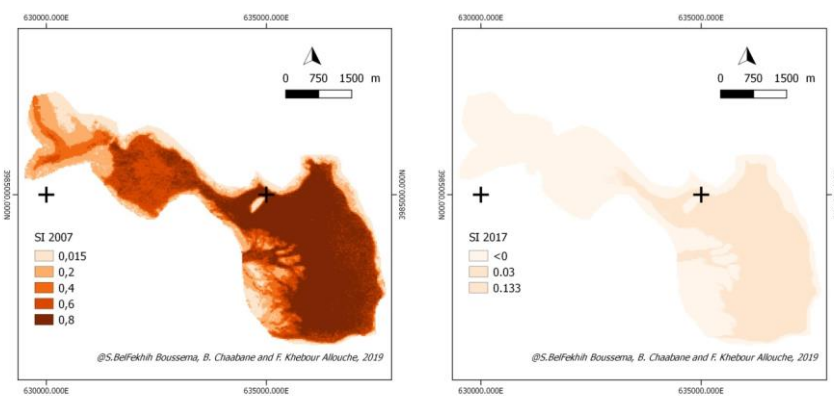

Figure 5. SI maps of Halq El Mingel

As a result of the radiometric indexes analysis between 2007 and 2017, successfully revealed in Halq El Mingel that in 2017 the NDVI has increased and the SI has discreased. However, the NDWI had the lowest value with stabilization of the maximum value obtained in 2007.

Table 2. Variation interval of radiometric indexes in the sabkha between 2007-2017

Year	NDVI	NDWI	SI
2007	(-1) – 0,1	0,6 - 0,9	0,0015 - 0,8
2017	< 0 – 0,5	< 0 – 0,9	<0 -0,1

3.4. Wetland behaviour

Halq EL Mingel plays an important ecological, hydrological and socio-economic roles, it serves a variety of functions and values beneficial to the general public and to the environment. Hydrologically, it assures the regulation of hydrological flows, attenuation of floods, erosion effects and the conservation of surface and under ground water resources. It also provides many benefits to the society such as: support fisheries, agro-silvo-pastoral and artisanal activities, recreation and outdoor environmental education, maintenance and improvement the quality of the water, etc…. The wetland contributes significantly in the stability of micro climatic environments, the development of a specific biological and landscape diversity by maintaining the biodiversity characteristics. So it serves as a habitat for biologically important species, it is a spawning ground for fishes such as *Mugil sp*., *Mugil cephalus* and *Lisa sp*. It support also a wide variety of water birds such as: the migrators (*Limosa limosa, Calidris minuta, Numenius arquata* and *Numenuis tenuirostris* inscribed on the International Union for Conservation of Nature (IUCN) World Red List under the status Critically Endangered (CE)); the flamingos (*Phoenicopterus sp*.); the breeders (*Grusgrus, Sterna albifrons, Sterna hirundo, Charadrius alexandrines* and *Marmaronetta angustirostris* inscribed also on the Red List as vulnerable) (IUCN Red List, 1994). The range of plant species in the wetland ensures a rich diversity of associated animals: the banks of the lake, the halophytes plants such as the salicornes of the kind *Athrocnemum* and *Salicornia*. Towards the less salty zones, there are carpets of filamentous seaweeds. The species diversity and high production levels of wetland plants support even more diverse animal communities. In fact, the sabkha is a river basin regulator while it controls floods by slowing down, storing and returning gradually water. Also it is a real hydrological reservoir, because it store water at certain times to give it back to others. Furthermore, it plays an important role in regulating floods and reducing risks flood. The technological advances of GIS and remote sensing technologies have provided wetland mapping services. In particular, radiometric indexes who have largely contributed in this study. In addition to their function of regulating ecosystems, habitat for wildlife and coastal defence against marine erosion, this wetland play several essential roles. The application of this suitable radiometric indexes revealed areas changes such as: vegetation change, water change and salinity change. These wetland indicators can be represented as various wetland indicator layers in a GIS environment, which can be integrated to understand the behaviour of Halq ElMingel and how it assurates his different functions. The changes accorded to those indexes may help to characterise seasonal and pluriannual behaviour of wetlands.

4. DISCUSSION

Wetlands are one of the most productive environments in the world. According to Siles et al. (2018), human activities as well as severe climate changes have led to grave loss and degradation of these ecosystems, despite their importance for water, regulation of carbon cycle, wildlife survival and economic value. The NDWI analysis between 2007 and 2017 successfully revealed a significant depletion of the water surrounding wetland area which might be as a result of natural or human effects including climate change, urban sprawl and agricultural activities which is adequate with the result of Bobbink et al. (2006); Mitsch et al. (2009) and Chenchouni et al. (2015). This fact enhanced that the main causes of wetland degradation are the decrease of water quantities, urban expansion, and discharge of solid and liquid waste owing to severe transformations related to intensive human activities. Wu et al. (2018) emphasizes that wetland maps and inventoriesgiveessential information for wetland conservation, restoration, and management. For exemplein Canada, efficient strategies and public awareness measures are necessary to protect the wetland's area that meseares a notable percentage of the territory (14%) (Siles et al, 2018). On the one hand, Rebelo et al., (2009) and Sun et al. (2016) provied the useful tools of satellite imagery for mapping, inventory and monitoring of wetlands. On the other hand, Siles et al. (2018) established the crucial role of GIS in integration and analysis of data that can be shared and visualized via Web GIS applications.The study of relationships between spatiotemporal variation of wetlands and ecological parameters provides valuable information for conservation assessment and restoration planning, it may efficiently guide the implementation of future management programs of wetlands.

5. CONCLUSION

This study has revealed that the transformation of wetland and shifts in biodiversity induced by both natural and human processes can be accurately appraised by remotely sensed data. This study has presented a novel quantification of wetland depletion that had occurred in the study area using radiometric indexes give us quantitative informations about vegetation, humidity and salinity changes. Thoses indexes should be integrated in the development of strategic plans in order to assess and monitor wetland behaviour. It is recommended to use some measures of erosion control through the planting of Acacia forest around the Halq El Mingel sabkha's.Wetlands are important not only for their ecological but also their social and economic effects. Their deterioration can yield to critical consequences such as increasing costs for water quality treatment, improved infrastructure for regulation of floods and programs for elimination of invasive species. These results open up new opportunities to decision makers to use this assessment, deduced according to wetlands, as a reference point for future initiatives that will be taken in order to develop land conservation policy.

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