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ORIGINAL PAPER

Diachronic evolution of wetlands in a desert arid climate of the basin of Ouargla (southeastern Algeria) between 1987 and 2009 by remote sensing

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Abstract The region of Ouargla is located in the bed of M'ya River (lower Algerian Sahara) that represents the main artery of dry wadis. The superficial water table outcrops in depressions in the form of salty wetlands (Chotts and Sebkhas). These humid zones are influenced by different factors that degrade its environment: natural factor, mainly the anthropic factor, leading to the fluctuation of the static level and to the augmentation of water, and land salinity, which directly influences the oasis ecosystem. The objective of the present study is to follow the evolution of the humid surface state in order to map the changes and to identify the influencing factors. The study is based on the diachronic evolution of wetlands in the region of Ouargla between the years 1987, 2000, and 2009, with the statistical analysis and mapping changes obtained from satellite images Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) Landsat. The results have shown important changes on the occupation of the land in the region where we have observed a progress of vegetation, surfaces of polluted water because of anthropic factors, urban development, inadequate management of drinking water, and water of drainage. The humid land has proved changes of humidity rates which are related on one hand to the water of irrigation that furnishes the superficial water table and, on the other hand, to the climatic factors that cause the evaporation of the underground water that is close to the surface of the land.

Keywords Diachronic evolution · Statistics · Cartography · Humid zone

Introduction

Many research studies have been conducted on the humid zones, but concerning the Saharan humid zones, investigations are very few. A study of the evolution and degradation of humid zones (region of Hoor Al Azim in the southwest of Iran) was realized through the classification of Landsat images (Multispectral Scanner (MSS) 1985) and (Enhanced Thematic Mapper Plus (ETM+) 1999, 2002, 2011). All the maps that have resulted from this study were evaluated using the geographic information system GIS. The results have shown a spatial decrease of the humid zones. The decrease is due to the augmentation of the agricultural spaces, water demand, and the anthropic activities in the humid zones (Ghobadi et al. 2012).

The detection of the changes in the humid zones (Hongze Lake), situated in the province of Jiangsu, north of China (Ruan et al. 2008), was done to evaluate the potential of temporal sequence of three MSS and TM images of Landsat acquired in 1979, 1988, and 2002. The distribution of the emerging water and its evolution in time and space were used as indicators of the evolution of the humid zone environment. The results demonstrated that a big loss of humid land took place in the zone during a period of more than 20 years.

From the satellite images of high resolution (Quick bird and Corona), taken in mid-June in the years of 1972 and 2008 in Kallar Kahar in Pakistan, classifications have permitted to analyze the change detection of the humid zones

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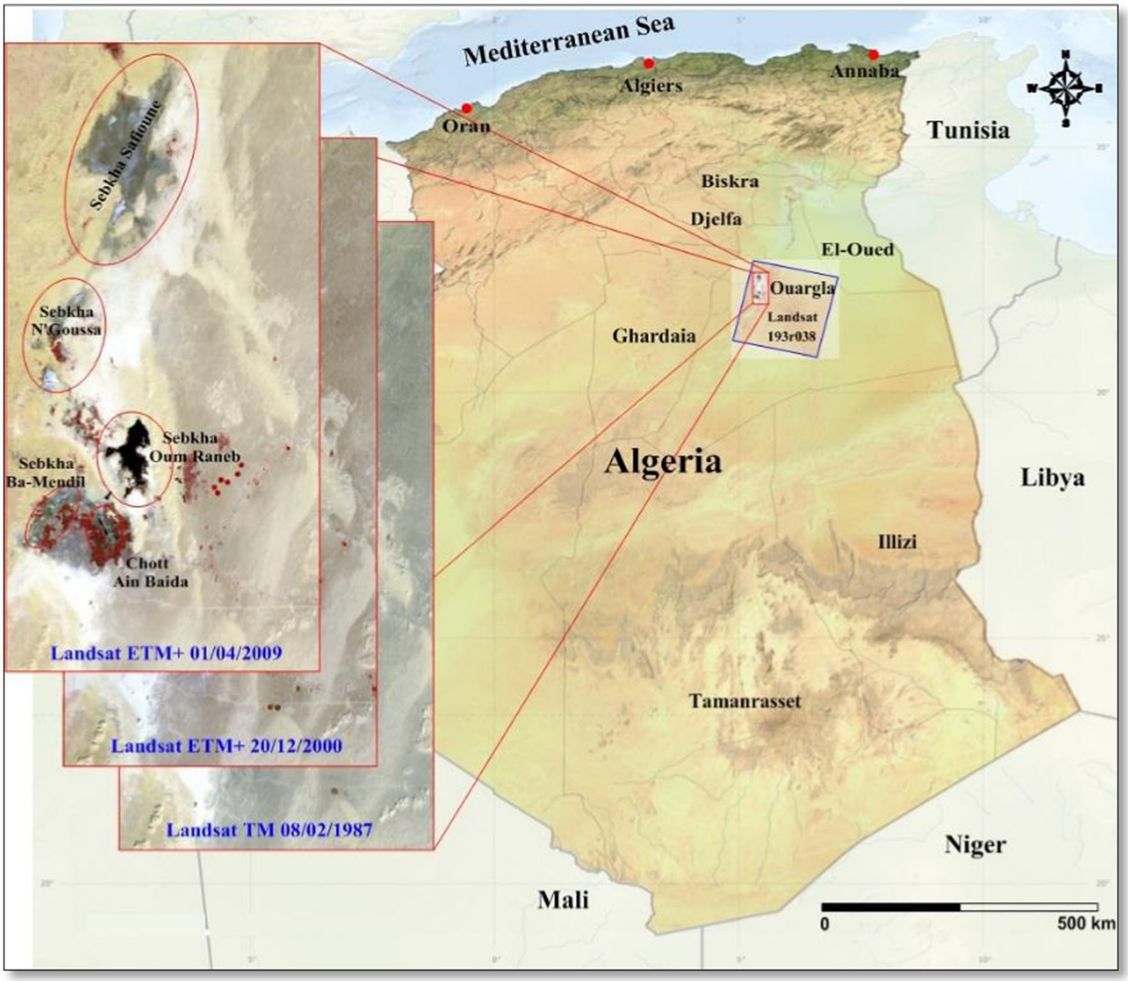


Fig. 1 Geographic situation map of the studied zone

(Sheikh Saeed Ahmed et al. 2012). The obtained results have permitted for decision taking concerning the management of the territory and for better evaluation of the implications of the observed changes in the region in order to formulate appropriate recommendations.

To quantify the dynamic and estimate the loss in humid zones in the Choke mountain chain in the superior basin of Nil Blue in Ethiopia (Teferi et al. 2010), classifications of TM and ETM+ of Landsat (1996–2005) have been done. The results have shown that the humid zones are under a continuing degradation, which requires an intervention with plans of catchment management in order to preserve these zones.

In the countries of Maghreb, humid zones in arid environment are characterized by the strong salinization. The salts accumulated in the horizons of land have engendered a degradation of their physical characteristics. These damages of salinization generally refer to a bad management of water of irrigation.

In south Algeria, the exploitation of the underground water is important because of the hydric deficit. The climatic data stemming from the national meteorological office (NMO; Ouargla station) showed that the evapotranspiration is higher than 2000 mm/year and the precipitation is lower than 50 mm/year. The rarity of rain leads the farmers to use the fossil groundwater, which is highly mineralized. Irrigated areas are largely affected by the secondary salinization (Djili et al. 2003) which contributes to the decrease in the agricultural yield.

In addition, the overexploitation of the deep groundwater has caused a rise in the superficial water table. This upwelling flush in low areas (depressions) forms the saltwater surfaces (Chotts and Sebkhas).

The following of the evolution of these humid zones requires a good knowledge of the ground and a cartography that values the potentials of this zone and its constraints. The study of the ground has been difficult because of obstacles related to the climatic conditions (elevated temperature, sandstorm, etc.) and to problems of spotting and access to a large deserted space. Therefore, the use of remote sensing has appeared as the solution to identify these humid zones as well as to follow their evolution in time.

The objective of this work is to follow the spatio-temporal evolution of humid zones in order to know their origin and to enrich a geographic information system. To achieve this objective, supervised classifications (SVM) have been realized in order to obtain the occupation of land. The comparison between different classes of two or more dates reveals this evolution.

Zone of study

The region of study is located in the northeast Algerian low Sahara (Fig. 1). It is 800 km away from the capital of Algeria (Algiers). It belongs to the wilaya of Ouargla and it has frontiers with El Oued, Biskra, and Djelfa from the north, Ghardaya from the west, Illizi and Tamanrasset from the south, and Tunisia from the east.

The region of Ouargla is characterized by a desert hyperarid climate. The climatic data from NMO (Ouargla station) in the period between 1996 and 2010 have shown an average annual temperature of 23.4 °C. The monthly hottest average of temperature has been observed in July during which it exceeded 34 °C with a maximum of 43 °C. However, the coldest temperature has been observed in January in which it is 11.55 °C with a minimum of 4.8 °C. The rainfall is weak and irregular with a monthly average precipitation of 38.65 mm. January is the most rainy month. However, the months of June and July are the less rainy (0.19 mm). These precipitations are marked by their weakness and irregularity (117.8 mm for the year of 2004, 5.9 mm for the year of 2001). The evaporation is very elevated given that the annual average is 3084.13 mm. It reaches its highest level in June, July, and August (more than 4000 mm). Therefore, the precipitations in the region of Ouargla do not play any role in the refill of the reservoirs of the groundwater. In contrast to this aridity, hydrogeological studies confirm that the Sahara is full of large aquifers and contains important reserves of groundwater. These reserves are the basis of the urban and agricultural development in this zone.

The basin of Ouargla corresponds to a big depression of a surface of around 750 km. It is situated in the stream of the low valley fossil of the river of M'ya, which is originated from the plateau of Tademaït (region d'In Salah, Tamanrasset) from the south until Sebkha Safioune, 40 km from the north of the city of Ouargla. The river of M'ya converges with the river of Igharghar that comes from a very far source in the south (Ahagar) to constitute the valley of Oued Righ, which flows to Chott Melrhir (Ballais 2010).

In the region of Ouargla, the width of M'ya wadi varies between 4 and 30 km. The average slope of the valley is very weak (1 %), from the city of Ouargla to Sebkha Safioune. The west border is marked by a cliff of the sandstone plateau of Cenozoic age covered with gravels and pebbles, associated with reddish sands, overlooking the Valley at an altitude of about 220 m (Aumassip et al, 1972). The east limit is less elevated (160 m) and quite eroded. It is composed of sandstone and reddish sand, covered with dunes in the dominating streams of wind. The basin is occupied by alluvium.

The humid zones appear as flooded depressions; they are represented by the Chotts and Sebkhas (Fig. 1). The latter are composed by gypsum salty soils. As a result, the surface occupied by the humid zones is about 25,000 ha whereas that occupied by the Palm trees does not exceed 5000 ha (Idder et al. 2011).

During the Neolithic, these Chotts and Sebkhas were furnished naturally by the groundwater (Aumassip et al 1972). Now, they receive water in an anthropic manner by the infiltration of hydric surpluses of palm trees and by the wastewater, provoking the rise of the superficial water table. During the periods of heat, the surfaces of the Sebkhas are dried under the effect of evaporation forming the gypseous salt crusts. This basin is consisted of many surface units.

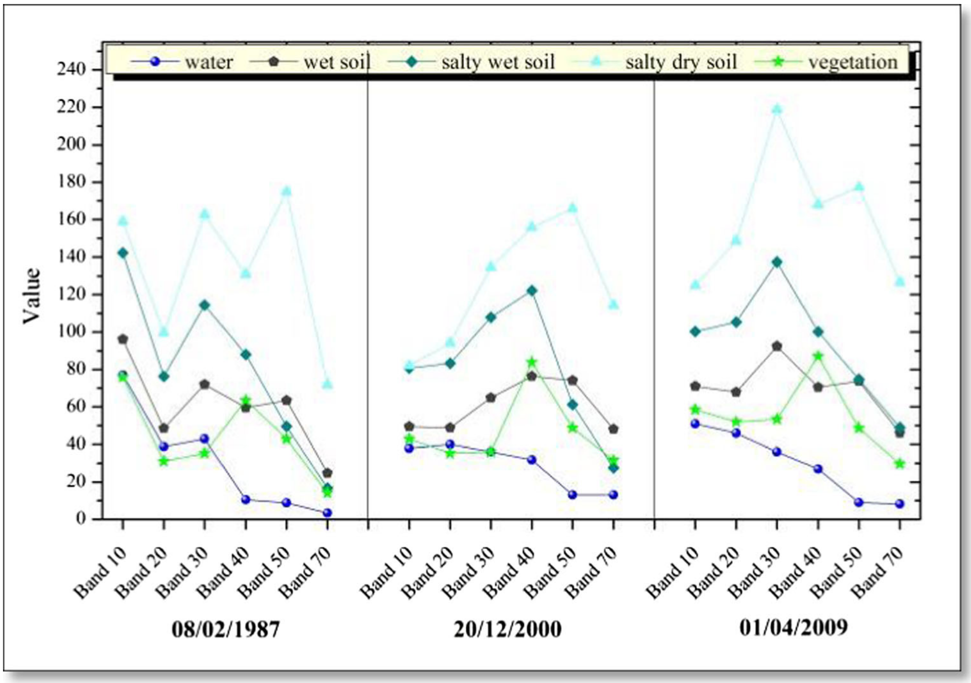
Materials and methods

For this study, three multispectral images are available: one is of TM type of Landsat 5 dated in 8 February 1987 and two are of ETM+ (20 December 2000 and 1 April 2009) of Landsat 7 (Table 1).

Table 1 Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) spectral bands

		Landsat 4 and 5 Thematic Mapper (TM)		Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	
Band	Name	Wavelength (μm)	Resolution (m)	Wavelength (μm)	Resolution (m)
1	Blue	0.45–0.52	30	0.45–0.52	30
2	Green	0.52–0.60	30	0.52–0.60	30
3	Red	0.63–0.69	30	0.63–0.69	30
4	Near Infrared	0.76–0.90	30	0.77–0.90	30
5	Shortwave IR-1	1.55–1.75	30	1.55–1.75	30
6	Thermal IR	10.40–12.50	120	10.40–12.50	60
7	Shortwave IR-2	2.08–2.35	30	2.09–2.35	30
8	Panchromatic			0.52–0.90	15

Fig. 2 Comparison of spectral responses of humid classes in 1987, 2000, and 2009.



Six classes have been chosen in which five characterize the humid zone and one mineral surface that regroups the different dried surfaces:

1. Water: Contains the water surfaces and includes the Chott “Ain Baida” and the Sebkha “Oum Ranab.” This class absorbs almost all of the solar radiation.
2. Wet (humid) soil: It represents the depressions where the static level of the superficial water table is close to the topographic surface.
3. Wet salt soil: It occupies the peripheries of the surfaces of water. It essentially represents deposits, gypsum, and salt crusts, due to intense evaporation in this climate.
4. Salt dry soil: Regroups the depressions far from the anthropogenic alimentation sources (irrigation water and wastewater). The sandy winds partially cover the efflorescence of salts crystals formed in the capillary fringe.
5. The vegetation: This class regroups the following:

    - Palm trees: situated near the agglomerations
    - Irrigated surfaces: agriculture irrigated by aspersion
    - The plant of humid zones occupying of Chotts and Sebkhas

6. Mineral surfaces which gather:

Table 2 Comparison between different methods of supervised classification (20 December 2000)

Classes		Accuracy (%)				Observation
		Support vector machine (SVM)	Maximum likelihood (ML)	Spectral angle mapper (SAM)	Neural net (NN)	
Humid zone	Water	99.42	97.74	86.78	96.52	SVM
	Wet soil	87.89	81.88	41.28	82.41	SVM
	Wet salt soil	90.58	78.58	47.78	91.36	NN
	Salt dry Soil	96.37	89.89	95.25	94.77	SVM
	Vegetation	98.47	97.78	37.7	95.63	SVM
Mineral surfaces	Sand	99.08	96.82	95.36	98.69	SVM
	Sandy limestone crust	94.87	86.75	95.07	95.73	NN
	Agglomeration	69.96	98.63	98.63	23.29	ML & SAM
	Red sandstone	98.90	95.37	83.73	99.46	NN

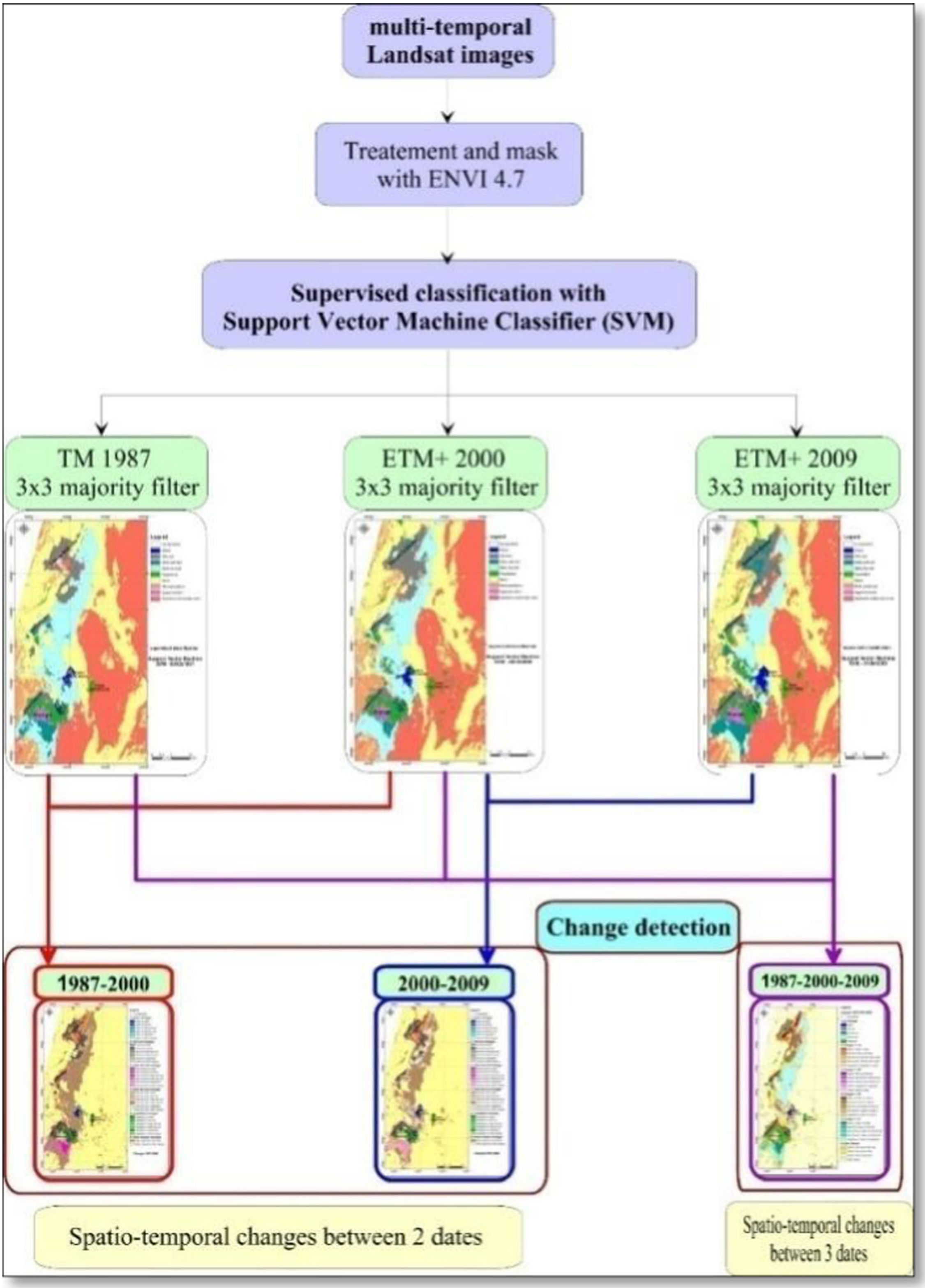


Fig. 3 Flowchart of the general methodology.

- Sandy limestone crust: Represented by the sandstone plateau in the west bank and some witness outlier in the east bank.
- Red sandstone: The most dominant and is represented under an eroded form by the effect of the dominant wind in the east bank of the wadi and in the talus of the west bank.

Table 3 Summary for the accuracy of classifications

Classification	Global accuracy	Coefficient Kappa
8 February 1987	86.83 %	0.7028
20 December 2000	92.84 %	0.8164
1 April 2009	88.23 %	0.8164

- Sand: It represents the zone where the sand covers the land with the big thickness in the form of dunes on one hand and with weak thickness in the form of sandy land on the other hand.
- Agglomerations: Represented by the city of Ouargla and the villages in the basin.

The observation of the colored compositions of the images as well as the spectral responses of certain classes has permitted to provide more precision for the discrimination of these humid classes in a hyperarid climate (Fig. 2).

The choice of the regions of interest (ROIs) as a representative sample of six classes is based on a visual field identification (62 samples), and Google map images of very high resolution (74 samples). For a better discrimination of various classes in the previous dates, we implanted all the samples (136) on the colored composition (Swir, Nir, Red) of each year. Finally, the number of samples really used for three years, 1987, 2000, and 2009, is 67, 83, and 97, respectively. Other samples were added by using the photo interpretation of each date. Two thirds of total samples of each year are used for classification, and the rest for validation.

The validation of the classification has been done by the matrix of confusion (table of contingence calculated by comparing the results of the classification and the verification samples). The lines of the matrix correspond to the ground truth and the columns correspond to the classes derived from the classification. The values of diagonal refer to the number of pixels well classified and the remaining values refer to the confusion between the classes.

Many indicators have permitted for the evaluation of classification quality:

- The overall accuracy is obtained by dividing the number of pixels correctly classified by the amount of pixels of all the apprenticeship classes. Therefore, it implies the pixels that are correctly classified compared to those badly classified.
- The coefficient Kappa is calculated by multiplying the total number of pixels of the apprenticeship by the sum of pixels classified correctly (diagonal of the matrix). We subtract the sum of products “total of the pixels of every class of apprenticeship, by total of pixels affected to each of the classes, added on all the classes.” Then, by dividing the whole by the total number of pixels of the classes of apprenticeship in the square, minus the sum of products “total of the pixels of every class of apprenticeship, by total of pixels affected to each of the classes, added on all the classes.”

The maps of humid zones of 1987, 2000, and 2009 have been produced with the method of supervised classification support vector machine (SVM) (Gunn 1998; Volpi et al. 2011). The choice of this method has been adopted after a comparison between the results of different methods of classification (maximum likelihood, neural net, and spectral angle mapper) using confusion matrices and visual verification (Table 2). Then, the majority filter on 3×3 window has been applied after each classification in order to eliminate the isolated pixels (classified differently from the majority class).

In order to study the evolution between 3 years (1987, 2000, 2009), we have used the two intervals 1987–2000 and

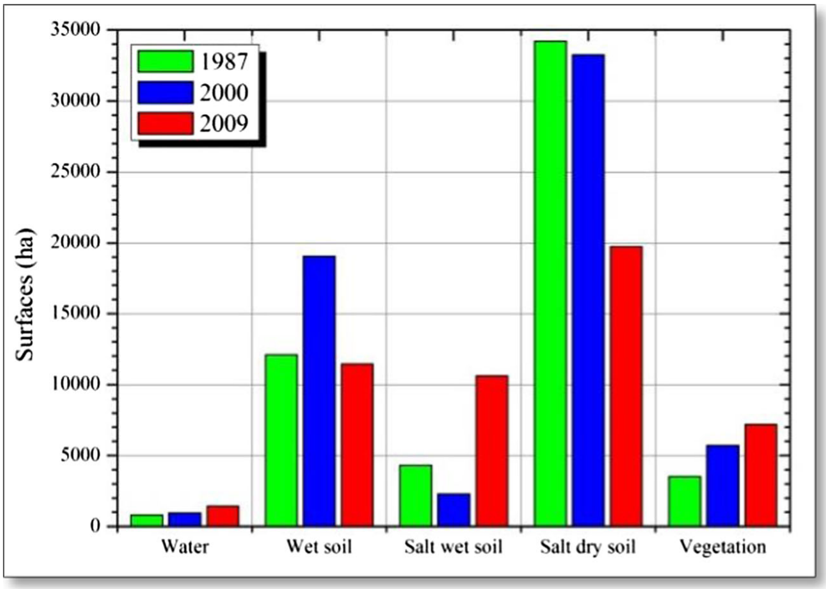
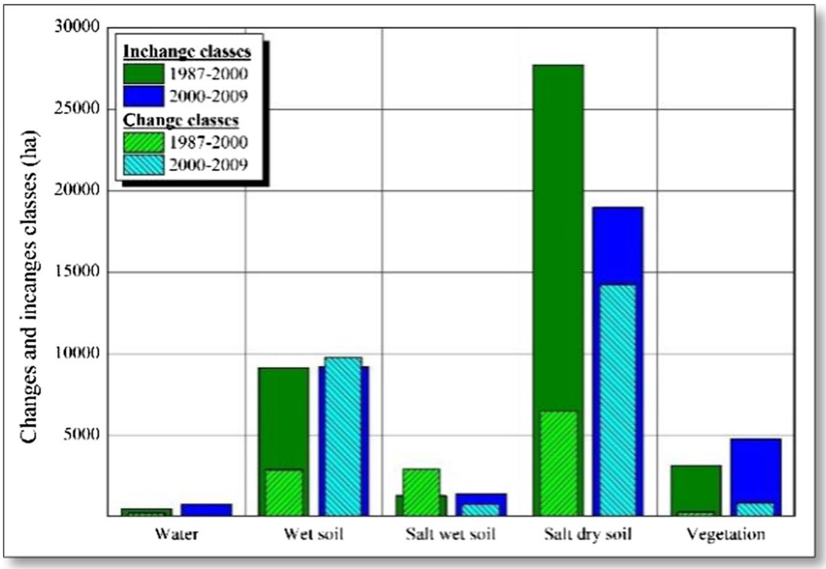


Fig. 4 Surface distribution of humid classes in the studied zone.

Fig. 5 Quantification of changed and unchanged wet classes.



2000–2009. Then, the interval of change between the 3 years—1987, 2000, and 2009—has permitted the comparison between the two preceding couples of change. Two change detection maps of “from-to” (between 2 years) and a map of “from-to-to” between the two changes have been realized (Fig. 3) using ArcGIS 9.3 software.

The evaluation of the accuracy of the procedure of change detection has been followed by the method proposed by Congalton Macleod (1994), in which the matrix of error normally used for only one classification is voluntarily modified. This new matrix has the same characteristics as the matrix of confusion of the unique classification, unless that it evaluates equally the errors in the changes between two periods (two classifications).

The matrix of error of change detection has been simplified by that of no change/change (Congalton and Green 2009). The values in hectares (ha) on the length of the diagonal expressed unchanged area; the other cellular contains the measured areas that have a transformation to other classes.

Results and discussion

Global distribution of the humid surfaces

All classifications are validated by the confusion matrices of three dates (Table 3). It can be seen that there is a very good correspondence between the mapping and field observations.

Fig. 6 Changes surface of wet zones between the 3 years.

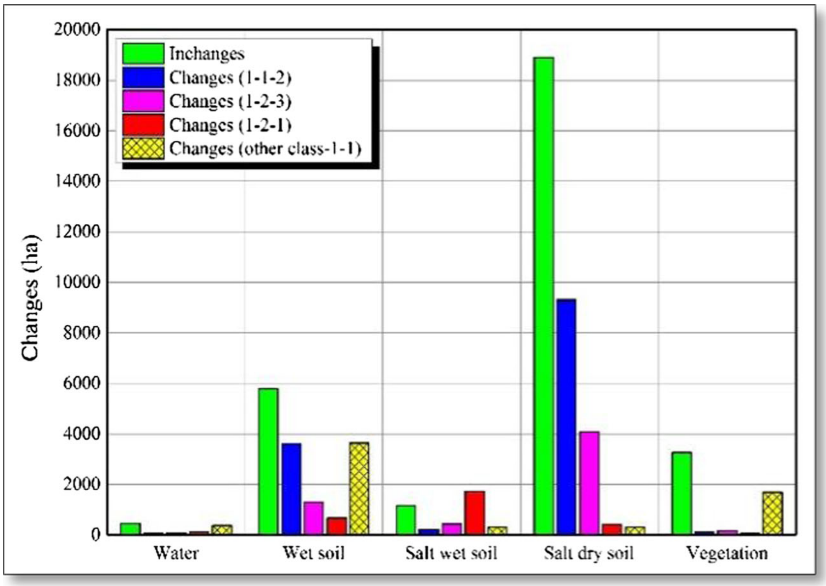
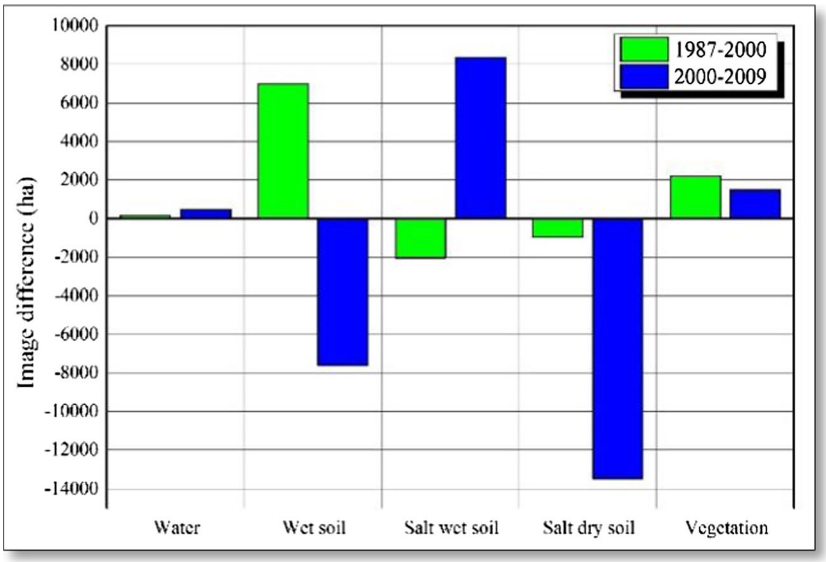


Fig. 7 Changes in the wet zones between initial and final years.



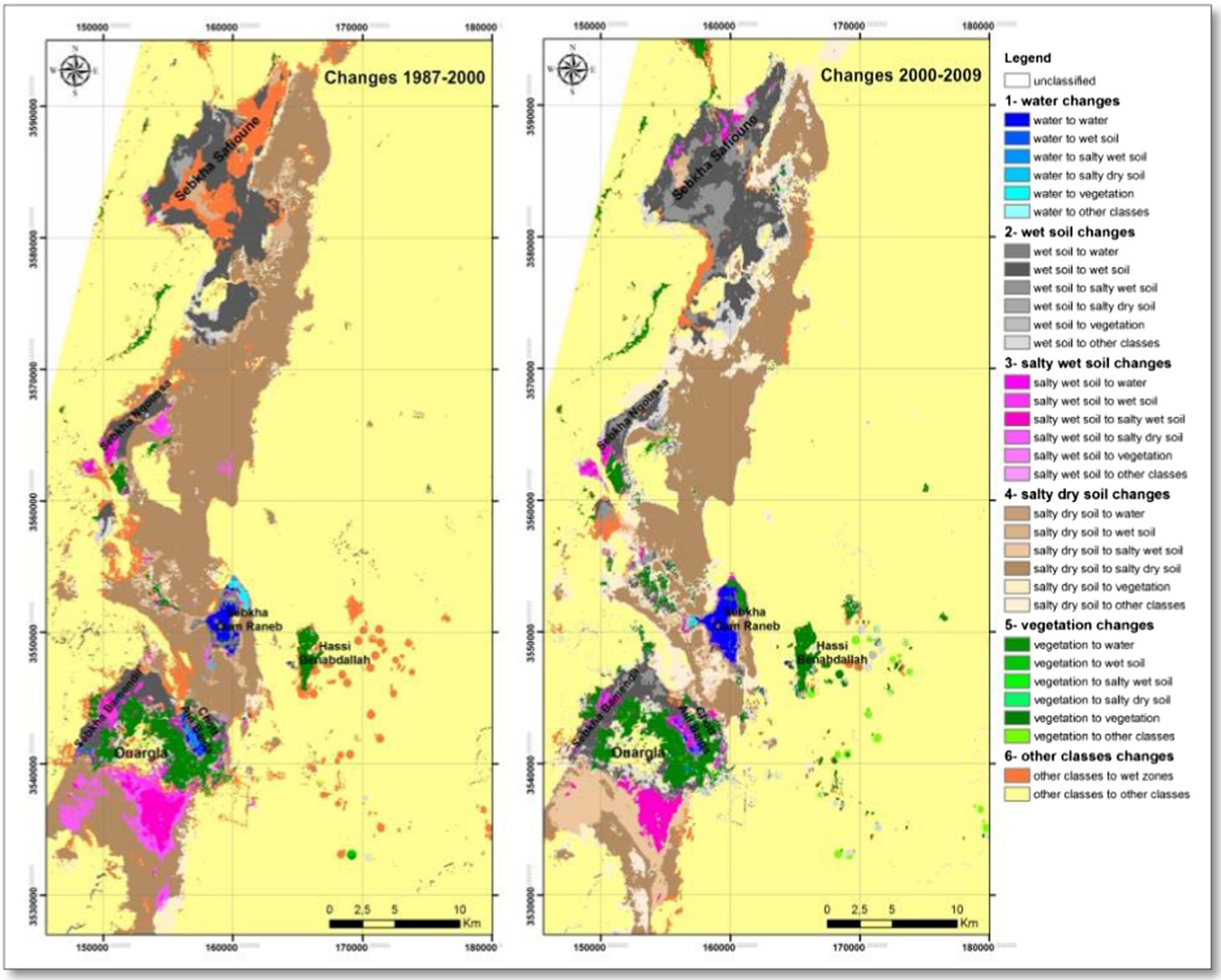


Fig. 8 Changes of the wet zones (1987 to 2000) and (2000 to 2009)

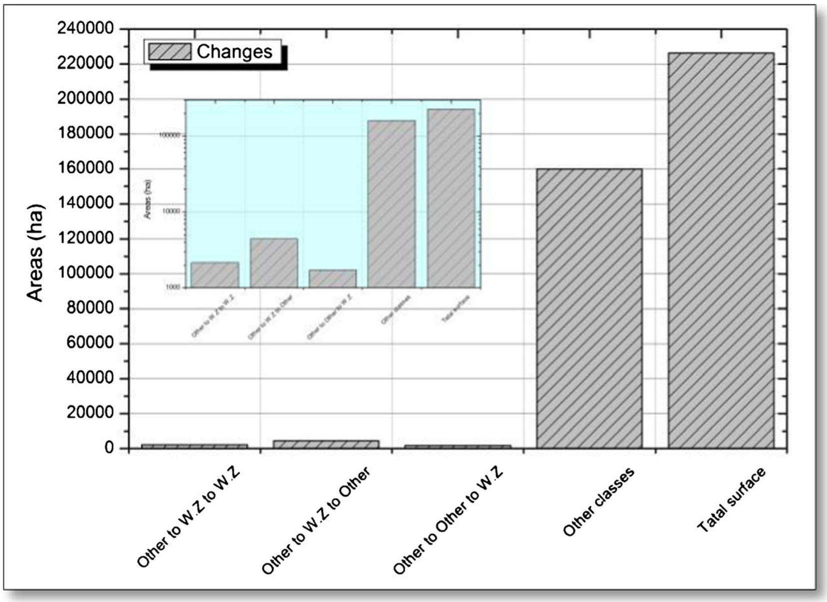


Fig. 9 Changes of sand in the 3 years.

Figure 4 illustrates the surfaces occupied by each humid class during the 3 years, where we have the following:

- The class "water" represents the most weak surface of humid zones of 790 ha: 0.35 % of the total surface in 1987, with an augmentation in time to 949 ha, 0.42 %, in 2000 and to 1424 ha, 0.63 %, in 2009.
- The class "vegetation" of 3315 ha represents 1.55 % of the total surface in 1987 with an augmentation in time to 5702 ha in 2000 and to 7194 ha in 2009, respectively, 2.52 and 3.18 % of the totality of the terrain.
- The class "salt dry soil" occupies a big part of the zone with 34207 ha (15.12 %) in 1987. It decreases in time to 33241 ha (14.69 %) in 2000 and to 19744 ha (8.73 %) in 2009.
- The class of the wet soil shows an evolution opposed to that of humid salt soil because of the phenomenon of "precipitation dissolution" of salt crystals (Berné 1978).

With a total surface of 226,270 ha, the humid zone occupies 54,920 ha in 1987, 61,235 ha in 2000, and 50,427 in 2009 and represents, respectively, 24.27, 27.06, and 22.29 %, and the rest is sand.

Study of changes

The account of matrices of changes has given a quantitative estimation of the surfaces of the unchanged classes between 2 and 3 years on one hand, and of those are changed by an increase or decrease on the other hand.

The rate of changes

In general, few changes have affected the surface of each class. The stability has appeared as a major characteristic except two classes, which have an elevated rate of change:

- "Wet soil" between 2000 and 2009 (Fig. 5)
- "Wet salt soil" between 1987, 2000, and 2009 (Fig. 6)

The changes of "from-to"

The evolution of wet zones between the initial years and the final years (Fig. 7) shows the following:

- An increase of the class "water" equals to 21.58 % compared to its initial surface in 1987–2000, then to 47.56 % between 2000 and 2009. This supply is related to the quantities of wastewater and drainage thrown in the Chotts, which play the role of a natural outlet.
- The class "vegetation" increases to 61.98 % of its initial surface, then to 28.15 %. The strong increase between 1987 and 2000 is related to the creation of new agricultural exploitations and to the development of the existing irrigated surfaces.
- A decrease of the land in the class "salt dry soil" to 4.08 and to 39.79 % because of an increase of humidity of land provoking the dissolution of salt crystals.
- The change between the class "wet soil" and "salt dry soil" is done generally between them. The enrichment of the surface of a class is accompanied with the decrease in the other class and vice versa. The enrichment of 58.42 % in the surface "wet soil" between 1987 and

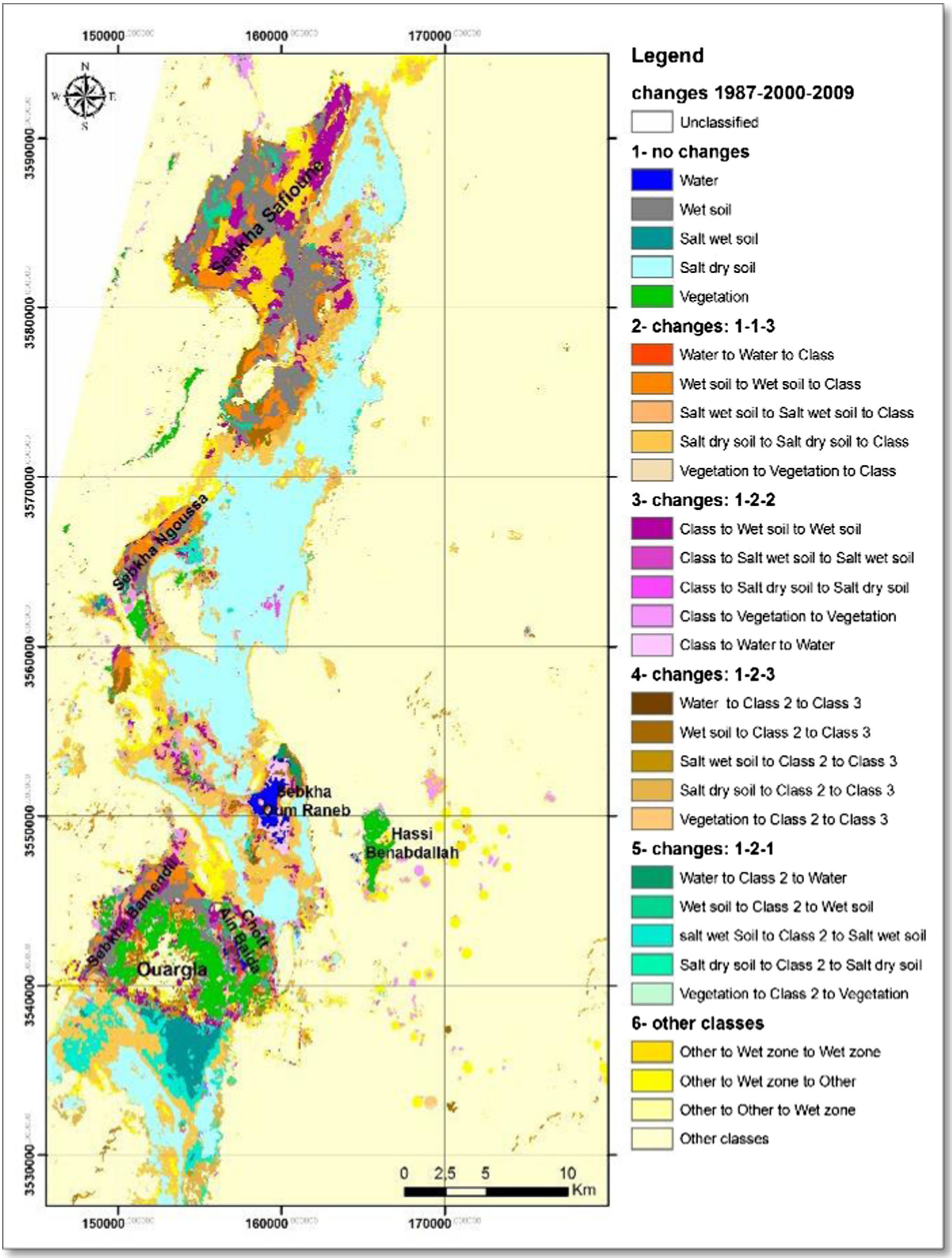


Fig. 10 Changes of the humid zones (from 1987 to 2000 to 2009)

2009 is followed by a decrease of 46.39 % in the class "dry salt land." In contrast, between 2000 and 2009, the other class replaces 40 % of the surface "wet soil."

Repartition of changes in the zone

After this quantification of changes of the surface in each class, it is preferable to have an idea about the repartition of these changes in the terrain so as to localize well the affected location mainly the surfaces of water and to give better explanation for each case.

Figure 8 shows the dynamic of change of the surface between the different classes mainly at the level of the three depressions (Chott "Ain baida," Sebkha "Oum Raneb," and Sebkha "Safioune"). We can deduce the following:

- The gain of the surface of water in the Sebkha Oum Raneb is high compared to the loss remarked in the Chott Ain baida, because it represents the direct recipient of the drainage system of the city of Ouargla. In parallel, Sebkha Safioune represents itself as humid surfaces since this zone represents the lowest and the largest depression in the region with a convergence of three wadis (M'ya, Mezab, and Nsa). The class "water," still, always was inexistent during this period due the highly deficit climatic conditions (Djidel et al. 2013). The surface of vegetation and the surface of salt soil have been augmented. In contrast, the surface of sand, wet soil, and wet salt soil has been decreased.
- The appearance of new agricultural exploitation at the level of Hassi Ben Abdallah near to Sebkha Oum Raneb which participates in the nourishment of the latter by the access of water of irrigation.
- With exclusion of sand, the humid salt surfaces occupy the majority of the terrain.

Changes "from-to-to"

The changes between three dates from-to-to with 1, 2, and 3 represent the status of the surfaces related to the three dates and successively have shown four types of changes:

- Type "1-1-3": Shows a change only in the third date
- Type "1-2-2": Shows a change in the second date
- Type "1-2-3": Shows a continuous change in the three dates
- Type "1-2-1": Shows a return to the initial status of the change

The sand class changes a little; always, we see a slight fluctuation (Fig. 9):

0.95 % toward the wet zones (W Z)
1.96 % toward wet zones and then return toward the sand
0.76 % toward wet zones except in the third date

The spatial-temporal evolution of the humid (wet) surfaces status between 3 years (Fig. 10) shows the following:

- A stable surface of 29,539 ha: It covers the class water at the level of Sebkha Oum Raneb with the small surfaces of the Chott Ain Baida. The vegetation occupies the oasis in the surroundings of the agglomeration. The wet soil occupies the depression where the static level of the shallow water table is close to that of the surface of the land (<50 cm). The wet salt soil occupies the surroundings of the surfaces of water by the evaporation of water and precipitation of salt. The salt dry soil occupies the depressions where the static level is superior to 50 cm of land surface with the formation of a white layer of salt crystals on the surface.
- A total of 13,300 ha of changes of 1-1-3 type: They are distributed at the level of the humid depressions of Oued Mya.
- A total of 6317 ha of changes of 1-2-2: They occupy mainly the Sebkhas and the agricultural extensions.
- A total of 6009 ha of changes of 1-2-3 type: They represent themselves in the limits of the humid depressions of Oued Mya.
- 2958 ha of changes of "1-2-1" type: They generally occupy the salt soil because of their sensibility toward the presence of water.
- A total of 168,146 ha of changes between the dry mineral surfaces.

Conclusion

The humid zones in a hyperarid climate are always constraints of extreme climatic factors, which give a rarity of the surfaces of free water. For this reason, this work is a study of a humid location, situated in Algerian low Sahara and characterized by the presence of three Sebkhas to follow their spatial-temporal evolution since 1987 until 2009 and to determinate the factors of influence. This was done through satellite images and software treatment of change and of cartography.

The obtained results show the important overall changes of the humid surfaces with a continuous increase of the surfaces of water (Sebkhas and Chotts) and the vegetable surfaces (agricultural exploitation). This increase depends on the conditions of the studied side. The Chott Ain Baida presents an increase of vegetation and a wet soil but presents a decrease of surfaces of water which is mainly due to drainage remanaged in this region and the transfer of the drained water toward Sebkha Oum Raneb where the surfaces of water, vegetation, and humid surfaces increase. In contrast, at the level of Sebkha Safioune, the evolution is made between the different classes, but the class "water" keeps always existing during this period since this zone represents the lowest and the vastest depression in the region with the convergence of three wadis (M'ya, Mezab, and Nsa), but until 2009, it keeps away from the anthropic factors.

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