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Spatio-temporal structure of natural and anthropogenic land use in a semi-arid watershed: Northwest Algeria

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Abstract: The objective of this study is to map through multisource data, the change in land use structure and quantify its evolution around the semi-arid watershed of Wadi Sarno of Sidi Bel Abbès between 2000 and 2021. To this end, satellite images of 2000 and 2021 have been exploited by remote sensing and GIS, as well as field surveys for verification and validation of the results obtained. The methodology is based on supervised classification by maximum likelihood from the processing of satellite images. The analysis of the dynamics of land use shows that the areas of natural formations (dense forest and bare land) have decreased from 17,560 ha to 15,516 ha, that is to say, a regression of 8.04%, while the anthropised formations (Agriculture, open forest and rangeland, built-up areas, water bodies) have experienced an increase in their surface area, they have gone from 7901 ha to 9945 ha, that is to say, 10.4% of the total surface area of the basin. In the light of these results, it is possible to define priority areas for restoring degraded zones and enhancing natural formations. by giving priority to perennial crops to fix the soil in place and benefit from additional income for the region's farmers. By planting hardy species such as olives, figs, almonds, carob trees and so on. These species have proven their effectiveness and adaptation to local soil and climate conditions.

Keywords: Algeria, GIS, land use, natural and anthropogenic formations, remote sensing, semi-arid watershed, Wadi Sarno

INTRODUCTION

Soil as a fundamental natural resource performs key environmental, economic and social functions. These functions of soil vary over space and time governed by a soil quality (Wubie and Assen, 2020). Land degradation is one of the most important and challenging issues of the recent decade (Omran, 2016; AbdelRahman *et al.*, 2018; Afifi and Semary, 2018; Kumar *et al.*, 2020; Wubie and Assen, 2020) (as cited in Jamali (2020), p. 1). Soil degradation, which often has a more dramatic character, is the result of many factors, including climatic, lithological, natural, topographical, vegetative cover and environmental ones (Melalih and Mazour, 2021). This process occurs when rainfall erosion coincides with inappropriate anthropogenic practices, such as slope tillage, land clearing, deforestation, expansion of urban areas and road construction for the benefit of agricultural land, as well as overgrazing and lack of control, which aggravate the problem (Woldemariam *et al.*, 2018) (as cited in Melalih and Mazour (2021), p. 1).

On a global scale, the FAO considers in 2015 that 40% of the currently cultivated areas are subject to degradation processes. During the last decade, the average rates are estimated between $20{\cdot}10^{12}$ kg·y^{-1} and more than $30{\cdot}10^{12}$ kg·y^{-1} (FAO and ITPS, 2015) (as cited in Melalih and Mazour (2021), p. 2).

Soil degradation is one of the most important and difficult problems to control in North Africa. For Algeria, the surfaces threatened by degradation due to desertification and water erosion are estimated at 50 mln ha (Ministry of Agriculture and Rural Development, 2015). It represents more than 20% of the total surface of the country which is about 238 mln ha

(Mostephaoui *et al.*, 2013) (as cited in Meddi (2015), p. 317). The threatened surfaces are divided into 14 mln ha of mountainous areas in the north (affected by water erosion), 32 mln ha in steppe areas (threatened by desertification) and 4.1 mln ha of forests subject to threats induced by the effects of climate change (Mostephaoui *et al.*, 2013) (as cited in Meddi (2015), p. 317).

The region of Tessala in general and the watershed of Wadi Sarno in particular, undergo a strong human and animal pressure on their natural resources, which contributes to a strong degradation of the soil and plant cover. In addition, land clearing, fires, overgrazing and agricultural practices, often inappropriate (ploughing in the direction of the slope, fallow, monoculture), are anthropogenic factors that have accentuated this phenomenon. In addition, the natural causes are generally climatic, in particular the prolonged drought and the aggressiveness of the precipitations, which are marked by a modification of the landscape by erosion. These impacts make it necessary to provide the public authorities with a database and information on the status and dynamics of land use, in order to implement more sustainable management solutions.

Although, the sector under consideration has been the subject of several works and studies dealing mainly with the formation of the vegetation of the region, namely Ferka Zazou (2006), Baraka (2008), Bouzidi *et al.* (2009), Faraoun *et al.* (2016), and Cherifi *et al.* (2017), but none of them has used remote sensing to measure the degree of diachronic change in the structure of land use except for two outdated studies that of Sitayeb and Benabdeli (2008) and Bouiadjra, Zerey and Benabdeli (2011).

In this perspective, the main objectives sought through this study are to assess the changes in the land cover system over a period of 22 years, from 2000 to 2021, through a supervised classification of satellite images in a geographic information system (GIS) and remote sensing. This study is increasingly essential, both for the knowledge of the spatio-temporal evolution of the landscape units of our territory and for its development. It is thus judicious and essential to provide decision-makers with maps relating to the occupation of the ground of their sector and information on their state and their dynamics for a better management of the environment. This is to ensure a certain balance between natural resources and the very high demand of the local population.

MATERIALS AND METHODS

STUDY AREA

The Wadi Sarno watershed has an area of 254,61 km^2. It is located in the northwestern part of the Algerian territory, at the southern foot of the Tessala Mountains. It is bounded between longitude 0°35'00" and 0°52'30" W, and between latitude 35°8'00" and 35°19'30" N (Fig. 1).

The relief of the study area is analysed through the digital terrain map (DTM) obtained from an shuttle radar topography mission (SRTM) image with a resolution of 30 m, which shows that its distribution is very heterogeneous. The highest region is at an altitude of 1042 m located in the north and northwest of the basin, while the lowest region is located in the south and southeast at 408 m (Fig. 1).

Hydrographically, the drainage water feeds the Sarno dam area, which is located downstream of our watershed (Fig. 1).

The main soil types that characterise the Tessala Mountains are iron oxide soils, red or reddish brown soils. They are little affected by erosion processes and are occupied by cereals and fodder. Similarly, the brown calcareous soils, with a clayey texture and a highly leached surface horizon, are used for rangelands and

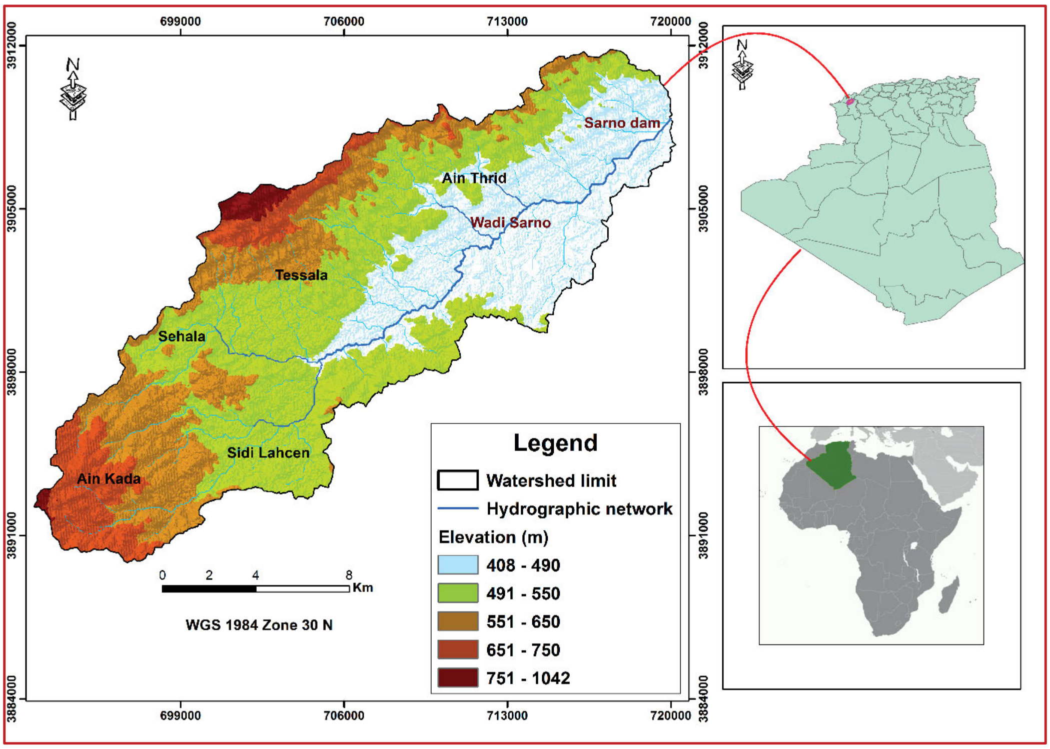

Fig. 1. Geographic location of the Wadi Sarno catchment area; source: own elaboration

open forests located in the north of the basin. Finally, Vertisols, present heavy soils of blackish or dark brown colour, their silty-clay texture is generally lumpy and their depth varies between 30 and 50 cm, sometimes exceeding 50 cm, and are located in the centre and southeast of our watershed (Chihab, 2019).

CLIMATE REGIME

From a climatic point of view, Algeria has a Mediterranean climate, characterised by a dry and hot season coinciding with the summer season and a cold, rainy season corresponding to the winter season (Otmane *et al.*, 2018).

According to the climatic data observed by the services of the National Meteorological Office (Fr.: Office National Météorologique – ONM) of the wilaya of Sidi Bel Abbès (Office National Météorologique, 2022), the climate of the Tessala region is marked by two seasons: a dry season (from April to October) and a wet season (from November to March). Rainfall is low and irregular, with average annual rainfall exceeding 400 mm for the period of 2000–2021 recorded in 2004, 2008, 2010 and 2018, which are 404, 405, 415 and 458 mm respectively (Fig. 2). The average temperature varies throughout the year between 9.3°C (January) and 27.4°C (August). Indeed, this climate is harsh in summer with temperatures reaching 47°C in July and August.

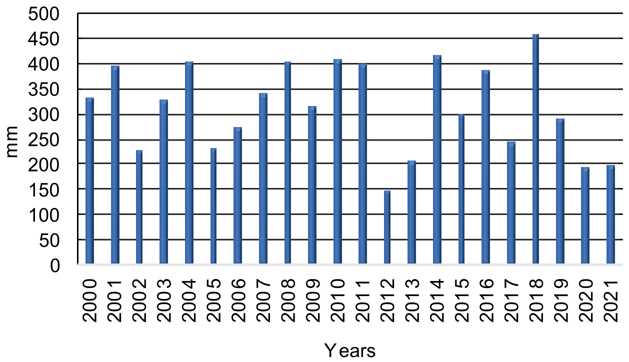

Fig. 2. Average annual precipitation of the station of Sidi Bel Abbès for the period of 2000–2021; source: own elaboration based on data of Office National Météorologique (2022)

FIELD DATA

According to Belhadi, Righi and Tayeb (2013), a field study mission has such objectives:
– to verify the results of the visual interpretation of the satellite image and to provide clarification for areas that are difficult to interpret;
– to recognise and define the different vegetation formations and all other thematic units according to their spectral responses on the colour composition;
– to characterise vegetation types according to their physiognomy and floristic composition;
– to indicate, if possible, any changes recognised from the comparison of the preliminary visual interpretation of the satellite image and the available data;
– to provide other information that cannot be extracted from the satellite images, such as the stratification of the different vegetation formations.

REMOTE SENSING DATA

To analyse the spatio-temporal evolution of land use changes in our study area, two Landsat satellite images taken in the spring (March) were used:
– from 10 March 2000: Landsat 7 ETM (Landsat scene ID: LE07_L1TP_198036_20000310_20170213_01_T1);
– from 12 March 2021: Landsat OLI 8 (Landsat scene ID: LC08_L1TP_198036_20210312_20210317_01_T1).

Another Aster global digital elevation model (GDEM) satellite image was also used to cover the study area (as a shapefile).

The choice of this type of satellite images is generally based on its availability, its quality, but also on the good spectral and spatial resolution that they offer.

For this purpose, these images were downloaded free of charge from USGS (no date) and then georeferenced according to the UTM-WGS 1984 zone 30 projection system. They have the advantage of covering the entire study area with a spatial resolution of 30 m to map its evolution.

METHODOLOGY

The method adopted to assess the dynamics of land use change combines satellite image processing techniques, field visits and observations for the validation of results. We adopted a methodology based on supervised classification after preprocessing by geometric and radiometric correction of satellite images (Fig. 3).

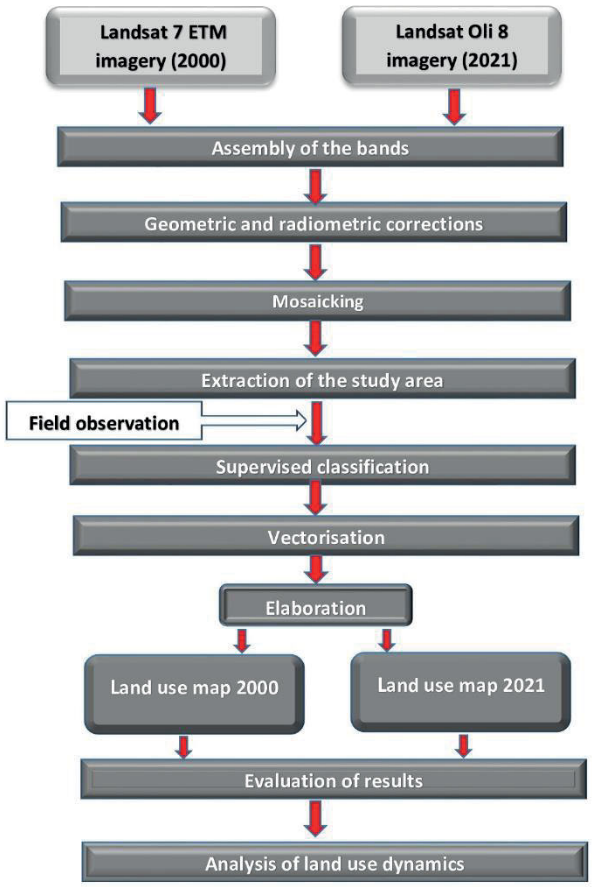

Fig. 3. Methodological protocol for the realisation of land use maps; source: own elaboration

The Figure 3 presents the main phases developed in the methodological protocol during this work.

All the digital processing is done with ArcGIS 10.3 and ENVI 5.3 (environment for visualising images). Such steps as preprocessing and supervised classification have punctuated this work.

The use of ENVI software allowed the geometric and radiometric correction of the two satellite images used.

It is then necessary to go through a finer analysis of detection based on a supervised classification, resulting from the definition of training sites corresponding to homogeneous regions, the type of plant grouping of which is known. Supervised classification is based on the maximum likelihood algorithm (Sitayeb and Benabdeli, 2008).

The supervised classification requires the intervention of the expert who must define the classes that he/she considers important and characterises the environment to be studied. The land cover in an area varies from year to year due to various changes triggered by different causes (fires, cuttings, urbanisation). It is essential to go directly to the field for verification missions of the selected training samples. Training polygons are defined on the image to calculate the statistics of spectral bands (Atte Cyrille, 2020).

KAPPA INDEX AND CONFUSION MATRIX OF THE OVERLAY CLASSIFICATION

In order to validate and definitively evaluate the performance of the classification used to establish the land use maps in this study, two indices were used.

The overall accuracy was derived from the sum of correctly classified pixelsdivided by the total number of pixels. Besides that, the accuracy for the individual class was calculatedbased on the user's accuracy and producer's accuracy approach. The user's accuracy, or reliabilityindicates that predicted correct values belong to a class for an individual category. User's accuracy wasmeasured by dividing correctly classified pixels with classified total pixels. Meanwhile, producer'saccuracy reveals the probability that a value in a given class was correctly classified. The producer'saccuracy could be obtained by dividing correctly classified pixels with reference total pixels (Ismail, Ludin and Hosni, 2020).

The Kappa index indicates how well the data to be classified matches the reference data. It is a reliable measure in the evaluation of thematic classifications because it examines all the elements of the confusion matrix and takes into account both errors of omission and errors of commission (Rosenfield and Fitzpatrick-Lins, 1986).

RESULTS

The analysis of remote sensing images has allowed us to distinguish six different classes of land use. The first class, agriculture, mainly constitutes of cereal crops, fodder and arboriculture and occupies the very fertile soils in the region of Ain Trid and Tessala. The second class is the one that dominates in quality of surface, the bare lands that are exploited by the pasture and/or reserved for market gardening. The third group is that of the water bodies formed by the hillside reservoirs, the wadis and the single dam of Sarno. The fourth class is settlements, which includes the cities of Sehala, Tessala, Ain Trid and Dlahim as well as their extensions (Fig. 4, Fig. 5). Similarly, the fifth class, the class of open forests and pastures, includes some degraded forest vegetation structures based on *Pinus halepensis*, woody matorrals and occupying sloping land such as the southern slopes of the Tessala Mountains. Finally, the sixth, dense forest class composed of *Quercus ilex* and scrub (*Calicotome spinosa* and *Chamaerops humilis*) covers the altitudes that exceed 750 m (Photo 1).

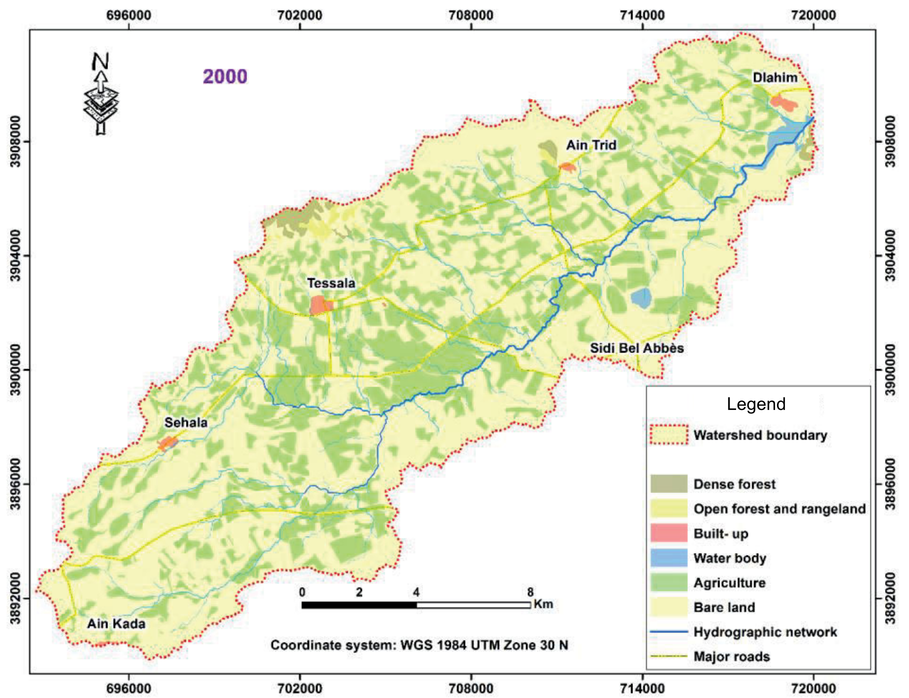

Fig. 4. Land use map of the watershed for 2000; source: own study

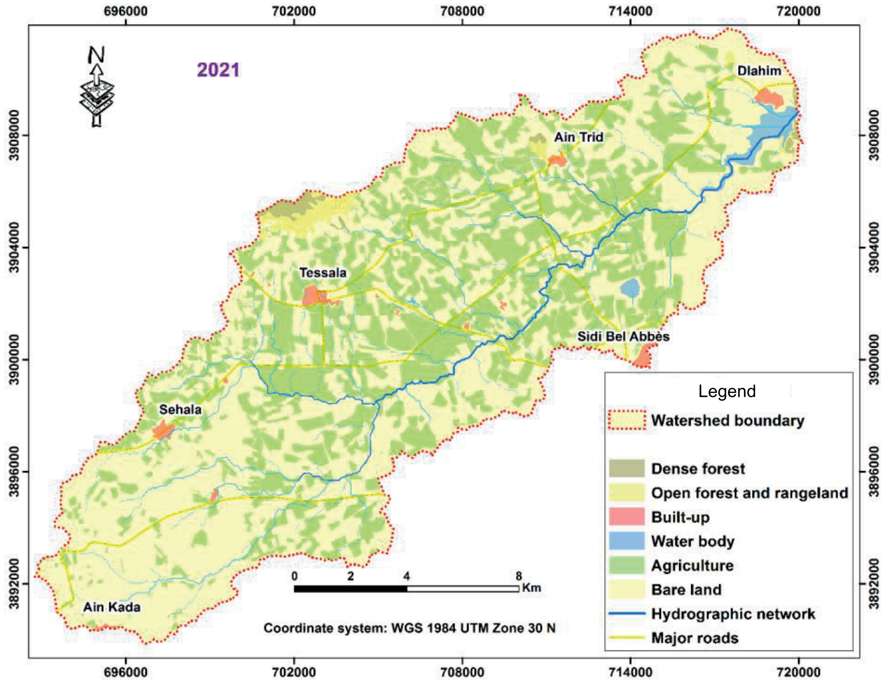

Fig. 5. Land use map of the watershed for 2021; source: own study

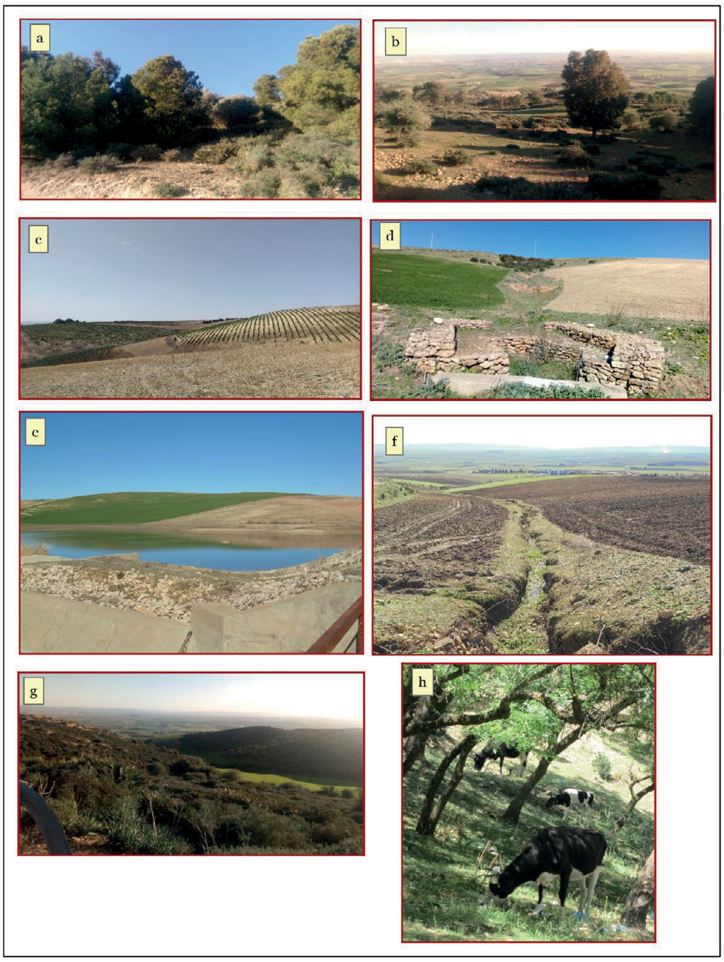

Photo 1. The landscape of the study watershed: a) dense holm oak forest, b) open forest and rangeland, c) soil fixation of slopes by the establishment of perennial crops, d) vegetation cover against the effect of soil erosion, e) Tessala reservoir, f) inadequate tillage favours erosion, g) clearing of the forest for the benefit of cereal cultivation, h) overgrazing of the Tessala forest (phot.: *A. Melalih*); source: own elaboration

To give an overview of the evolution of the structure of these classes from 2000 to 2021, Table 1 presents the changes in the area of each land use class in relation to the total watershed area of 25,461 ha. It is also useful to present the percentage change for each class considering the situation in 2000 as a reference.

Table 1. Spatial and temporal evolution of the land cover between 2000 and 2021

Class	Class area (ha)		Change in area	
	2000	2021	ha	%
Agriculture	7,506	9,153	1,647	6.47
Bare land	17,359	15,344	–2,015	–7.91
Water body	168	278	110	1.39
Built-up	123	244	121	1.53
Open forest and rangeland	104	270	166	0.65
Dense forest	201	172	–29	–0.11
Total	25,461	25,461	–	–

Source: own study.

This part of the results presents, on the one hand, the state of the land use for each year of 2000 and 2021, and on the other hand, the qualitative and quantitative analysis of the dynamics of the land uses by comparing the changes in the two-year components mentioned in the figures above.

According to the analysis of the data in Table 1 and Figures 4 and 5, it appears that from 2000 to 2021, natural formations (dense forest and bare land) have experienced a regression in their surface area, from 17,560 to 15,516 ha, i.e. a change of –8.04%. While the anthropised formations (agriculture, open forest and rangeland, built-up, water body) have experienced an increase in their area from 7,901 to 9,945 ha or 10.4% of the total area of the basin (Fig. 6).

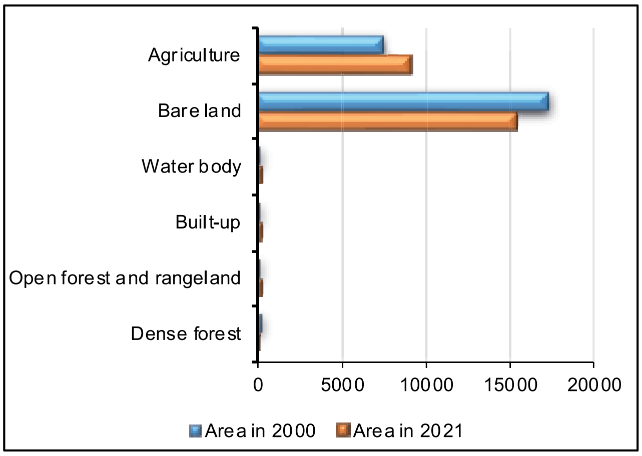

Fig. 6. Area distribution of different land use classes in 2000 and 2021; source: own study

DISCUSSION

Tessala Mountains constitute one of the regions of northern Algeria most exposed to the phenomenon of soil degradation. Indeed, its accentuated relief and a strongly degraded vegetation cover associated with semi-arid climatic conditions and interventions of human activities, make this region vulnerable to the risk of this scourge. Thus, the continuous water erosion has carried away the most fertile layer of the soil, which then contributes strongly to the silting of dams.

Analysis of satellite data validated by field missions identified six main land use classes in the Wadi Sarno watershed in 2000 and 2021 and highlights the dominance of the classes bare land and agriculture compared to other land use classes namely dense forests, open forests and rangelands, built-up area and water body.

The dominant class for both dates is bare land, which exceeds 60% in terms of land use and has undergone a regression of about 10% (from 17,359 ha in 2000 to 15,344 ha in 2021). That is the result of the land development by farmers and the limitation of fallow areas generally reserved for the installation of rainfed market garden crops such as melon and watermelon. It was noted that the forest massif of the Boutaleb region located in the semi-arid zone (Setif), as in our case, has experienced a remarkable dynamic from 2010 to 2021. Indeed, the analysis of the results revealed degradation of the cover to the detriment of bare soil. Translated by the loss of 6,171.77 ha of forest on 28,427 ha, there was a regression of more than 21% over the same period (Bouchelouche, Hani and Lebazda, 2022).

During this period, the area occupied by forests underwent a reduction of more or less dense forests to the benefit of open forests and rangelands. This loss of forest cover is estimated at about –0.11% and is largely related to the considerable extension of rangelands, which leads to a considerable reduction in the rate of soil cover and hinders the natural regeneration of the flora while depleting the available resources. The clearing of land before ploughing destroys perennial plants, often leads to the disappearance of the best pastures (reduction of plant biodiversity) and promotes erosion. And this confirms the results of the work by Zerey, Gael and Zerey-Belaskri (2017), where it is considered that there are two types of causes at the origin which are likely to lead to the degradation of 10% of forest cover. Direct causes are related to human activities such as deforestation, cropping systems, overgrazing and land clearing. Indirect causes are related to socio-economic needs in four categories (population growth, poverty, land tenure, and inequitable distribution of resources). Currently, the mountain population, mostly private landowners, continues to plough in the various forest floors in order to benefit from the development of a few cereal perimeters whose yields remain insignificant (Photo 1g).

The factor of fires can be also added, which is formidable and very frequent during the summer period, especially the two months of July and August, when the temperature reaches its maximum. According to the conservation of forests of Sidi Bel Abbès, our study area experienced several fires in 2004, 2005 and 2011, the burned areas of which are 30, 6 and 3 ha, respectively.

The open forests cover an area of 104 ha in 2000 which will almost triple by 2021 (270 ha) to the benefit of dense forests. They are located to the north of the study area in difficult-to-access sectors where the slope is relatively steep and the land is exposed to water erosion. These are therefore forestry lands that are bare and not suitable for permanent vegetation and have been completely abandoned in favour of rangeland (Photo 1b).

Agriculture at the level of the studied watershed concerns cereal growing, especially durum wheat and arboriculture, which occupies an area that has undergone an increase from 7,506 ha or

29.48% in 2000 to 9,153 ha or 35.95% in 2021. According to El Zerey (2014), this situation in the region is the result of a support policy by the Ministry of Agriculture through the implementation of many development programs in the sector. These programs include the National Agricultural Development Plan (Fr.: Plan national de développement agricole – PNDA), the National Agricultural and Rural Development Plan (Fr.: Plan national de développement rural et agricole – PNDRA), the Agricultural and Rural Renewal Program (Fr.: Programme de renouveau agricole et rural – PRAR), and Elttahadi and Refig since 2000. Emphasis is placed, among other things, on the development of land in concession, which is an area of transformation based on the right of enjoyment in concession under the law No. 10/03 of August 15, 2010 (La loi, 2010). This law sets the conditions and terms of exploitation of agricultural land in the private domain of the state. The best cultivation lands are reserved for cereals, for which irrigation is necessary, especially in critical moments, and those that are less fertile are occupied by fruit crops, especially vines (Photo 1c).

The areas occupied by water bodies, lake, reservoir and dam, have undergone a significant evolution, almost doubling the occupancy rate from 0.66% to 1.10%. This is reflected in the number of impoundments installed in our study area since 2004 and also by the increase in the volume of water at the dam of Sarno compared to the Sidi M'hamed Benali Lake (Photo 1e). Not only by the amount of rainfall recorded in recent years (in 2014, 2016 and 2018 recorded 415, 386 and 458 mm, respectively, the latter being the rainiest of the series) but also by the phenomenon of siltation that leads to a decrease in the water storage capacity of these water bodies.

Finally, demographic pressure leads to significant degradation of resources, particularly agricultural land adjacent to the urban fabric, due to the expansion of cities on the most fertile land. In fact, we see that the area occupied by the urban area has been increasing continuously from 2000 to 2021. This increase in surface area is estimated at 1.53% or a gain of more than 121 ha. This is explained by the relative growth rate of the population, in the city of Tessala, for example, there were 6,711 inhabitants in 1987 which increased to 7,499 inhabitants in 2008 and then reached 10,150 inhabitants in 2014 according to the statistics of the Directorate of Planning and Development of the Territory (Fr.: Direction de la planification et aménagement du territoir – D.P.A.T) of the wilaya of Sidi Bel Abbès and also the results of the work of Bouiadjra, Zerey and Benabdeli (2011) who estimate the population density of the Tessala Mountains to 61 inhabitants per km^2.

The results of this study are granted by the work done by Zerey, Gael and Zerey-Belaskri (2017), on the southern region of Sidi Bel Abbès where they showed that from the climatic and socio-economic data of the region, it can be concluded that the main factor of soil degradation is the anarchic and abusive use of natural resources by the local population.

The results are given in the form of a confusion matrix which includes two indices that will be used for the final validation and to evaluate the performance of this classification. Tables 2 and 3 show the confusion matrix and classification Kappa index of the two images used in this study.

From the analysis of the results of these confusion matrices as well as their verification in the field, we note that for the year 2000, water bodies are the themes that were mapped with producer and user accuracies of 99.31 and 100% respectively (Tab. 2). For bare land, which is one of the classes of interest in this study, it is mapped with an accuracy greater than 98% (99.18% for producer accuracy and 98.31% for user accuracy). This confusion is due to the selection of some training segments that were omitted and erroneously classified in the agriculture class but contain parcels periodically occupied by tilled fallow during the crop year. Dense forest, open forest and rangeland have a lower classification accuracy than the other classes (95.85%) with confusion with these on the one hand, and bare land (due to grazing) on the other.

For the year 2021, all classes were mapped with producer and user accuracies exceeding 99% and even 100% for water bodies and the built-up area with the exception of some insignificant confusions that occurred between the bare land class and the open forest and rangeland class.

When the Kappa index exceeds 0.8 (80%), the classification is conventionally considered relevant (Landis and Koch, 1977).

Table 2. Confusion matrix and the Kappa index of Landsat 7 ETM image classification (2000)

Spectral signature	Thematic class						Total	User's accuracy
	Agr	Bl	Wb	Bup	Ofr	Df		
Agr	5,376	56	0	0	9	0	5,441	98.80
Bl	114	10,234	0	19	43	0	10,410	98.31
Wb	0	0	287	0	0	0	287	100
Bup	0	0	2	431	0	0	433	99.54
Ofr	14	29	0	0	5,043	154	5,240	96.24
Df	22	0	0	0	74	3,554	3,650	97.37
Total	5,526	10,319	289	450	5,169	3,708	25,461	–
Producer's accuracy	97.28	99.18	99.31	95.78	97.56	95.85	–	–
Overall accuracy = 0.979				**Kappa index = 0.972**				

Explanations: Ag = agriculture, Bl = bare land, Wb = water body, Bup = built-up, Ofr = open forest and rangeland, Df = dense forest.
Source: own study.

Table 3. Confusion matrix and Kappa index of the Landsat OLI 8 image classification (2021)

Spectral signature	Thematic class						Total	User's accuracy
	Agr	Bl	Wb	Bup	Ofr	Df		
Agr	6,125	2	0	0	0	0	6,127	99.97
Bl	1	9,356	0	5	19	0	9,381	99.73
Wb	0	0	378	0	0	0	378	100
Bup	0	0	0	624	0	0	624	100
Ofr	3	29	0	0	4,721	13	4,766	99.05
Df	1	0	0	0	11	4,173	4,185	99.71
Total	6130	9387	378	629	4751	4186	25,461	–
Producer's accuracy	99.92	99.67	100	99.20	99.37	99.67	–	–
Overall accuracy = 0.997			**Kappa index = 0.996**					–

Explanations: Ag, Bl, Wb, Bup, Ofr, Df as in Tab. 2.
Source: own study.

In our case and for the two unsupervised classifications of satellite images (from 2000 and 2021), we find that these coefficients had exceeded 0.8 (image from 2000 – 0.972; image from 2021 – 0.996). This led us to affirm and validate our classification results.

CONCLUSIONS

The present study based on the use of remote sensing tool and GIS has provided a vision of the current state of land use in the watershed of Wadi Sarno, in which the spatiotemporal dynamics is generated by a series of natural factors including climatic (prolonged drought, water erosion) and other socio-economic factors manifested mainly by the intensity of anthropogenic impact (overgrazing, land clearing, ploughing in the direction of the slopes). Between 2000 and 2021, the analysis and comparison of land use maps show that the study area has undergone significant changes. These changes concern the mutations of the landscape units, and it appears that some of them have evolved considerably, which is the case of the anthropised occupation classes (agriculture, agglomerations, water bodies) the surface of which has increased from 7,901 ha to 9,945 ha (10.4% of the total surface of the basin). While the natural occupation classes such as dense forests and bare land are in regression, there is a change of –8.04% in favour of open forests and pastures. In fact, agro-pastoral activity is the main cause of the degradation of the territory's natural heritage and resources.

This requires a program of vigilance agreed upon by the Algerian state and well-studied by associated researchers, whose remote sensing has proven its effectiveness as a tool that can easily, and more or less objectively, meet the concern of acquiring information on the dynamics of land use. And this with the associationof a participatory approach that integrates the local population to rationalise the use of existing natural resources and preserve them for future generations.

To cope with this situation, it is necessary to develop the bare land and classify the degraded areas by priority of intervention, restoring the soil, giving priority to perennial crops to fix the soil in place and benefiting from a complementary income for farmers in the region. And this can be done by the installation of hardy species such as olive, fig, almond, carob, etc. These species have proven their effectiveness and their adaptation to local soil and climate conditions.

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CONFLICT OF INTERESTS

The author declares that he or she has no known competing financial interests or personal relationships that might have appeared to influence the work reported in this article.

REFERENCES

AbdelRahman, M.A.E. *et al.* (2018) "GIS spatial model based for determining actual land degradation status in Kafr El-Sheikh Governorate, North Nile Delta," *Modeling Earth Systems and Environment*, 4, pp. 359–372. Available at: https://doi.org/10.1007/s40808-017-0403-z.

Afifi, A.M. and Semary, M.A.E. (2018) "The impact of long term cropping and land use change on the degradation of heavy clay soils in the Nile Delta, Egypt," *Modeling Earth Systems and Environment*, 4, pp. 805–814. Available at: https://doi.org/10.1007/s40808-018-0459-4.

Atte Cyrille, T.B. (2020) *Apport de la télédétection et des SIG pour le suivi spatio-temporel de l'occupation du sol et la cartographie de la sensibilité à l'érosion hydrique dans la région montagneuse du Tonkpi (Ouest de la Cote d'Ivoire) [Contribution of remote sensing and GIS for spatio-temporal monitoring of land use and mapping* *of sensitivity to water erosion in the mountainous region of Tonkpi (Western Cote d'Ivoire)]*. PhD Thesis. Yamoussoukro: Institut National Polytechnique Félix Houphouët-Boigny.

Baraka, D. (2008) *Inventaire des plantes médicinales dans les monts du Tessala [Inventory of medicinal plants in the Tessala Mountains]*. Master's Memory. Université de Tlemcen.

Belhadi, A., Righi, S. and Tayeb, T.S. (2013) "Utilisation de la télédétection pour la cartographie de l'occupation du sol : Cas des monts de Beni-Chougrane (Mascara-Algerie Nord Occidentale) [Use of remote sensing for land use mapping: Case of the Beni-Chougrane Mountains (Mascara-Northwestern Algeria)]," *Mediterránea: Serie De Estudios Biológicos*, (24), pp. 60–75. Available at: https://doi.org/10.14198/mdtrra2013.24.02.

Bouchelouche, A., Hani, M. and Lebazda, R. (2022) "Dynamique spatio-temporelle du couvert végétal en zone semi-aride: forêt de Djebel Boutaleb (Algerie) [Spatio-temporal dynamics of the vegetation cover in semi-arid zone: Djebel Boutaleb forest (Algeria)]," *Algerian Journal of Arid Environment*, 12(1), pp. 15–27.

Bouiadjra, S.E.B., Zerey, W.E. and Benabdeli, K. (2011) "Étude diachronique des changements du couvert végétal dans un écosystème montagneux par télédétection spatiale : Cas des monts du Tessala (Algérie occidentale) [Diachronic study of vegetation cover changes in a mountainous ecosystem by spatial remote sensing: Case of the Tessala Mountains (Western Algeria)]," *Physio-Géo*, 5, pp. 211–225. Available at: https://doi.org/10.4000/physio-geo.2048.

Bouzidi, M.A. *et al.* (2009) "Caractérisation des matorrals et des garrigues à *Urginea pancration* Phil. dans le Djebel Tessala (Algérie occidentale) [Characterisation of matorrals and garrigues with *Urginea pancration* Phil. in the Djebel Tessala (western Algeria)]," *Physio-Géo*, 3, pp. 131–149. Available at: https://doi.org/10.4000/physio-geo.892.

Cherifi, K. *et al.* (2017) "Floristic composition of the mountainous massif of Tessala (Algerian West): Biodiversity and regressive dynamics of the forest ecosystem," *Journal of Materials and Environmental Sciences*, 8(9), 3184–3191. Available at: https://www.jmaterenvironsci.com/Document/vol8/vol8_N9/337-JMES-1881-Cherifi.pdf (Accessed: January 7, 2023).

Chihab, M. (2019) *Biologie de la conservation de quelques géophytes de la région de Sidi Bel-Abbés [Conservation biology of some geophytes from the region of Sidi Bel-Abbés]*. PhD Thesis. Université El Djillali Sidi Bel Abbés. Available at: http://rdoc.univ-sba.dz/bitstream/123456789/2573/1/These%20Chihab.pdf (Accessed: January 6, 2023).

El Zerey, W. (2014) "Etude diachronique de la régression du couvert forestier de la plaine de Telagh (Algérie) : Approche par télédétection et SIG [Diachronic study of forest cover regression in the Telagh plain (Algeria): Remote sensing and GIS approach]," *Bulletin De L'Institut Scientifique, Rabat, Section Sciences De La Vie*, 36, pp. 25–31. Available at: http://www.israbat.ac.ma/wp-content/uploads/2016/01/4-%20El%20Zerey%20(25-31).pdf (Accessed: January 6, 2023).

FAO and ITPS (2015) *Status of the World's Soil Resources – Main Report*. Rome: Food and Agriculture Organization of the United Nations, Intergovernmental Technical Panel on Soils. Available at: https://www.fao.org/3/i5199e/i5199e.pdf (Accessed: January 9, 2023).

Faraoun, F. *et al.* (2016) "Caractérisation des formations végétales à *Ampelodesmos mauritanicus* (Poir.) D. & S. sur Djebel Tessala, Algérie occidentale [Characterisation of *Ampelodesmos mauritanicus* (Poir.) D. & S. plant formations on Djebel Tessala, western Algeria]," *Afrique Science*, 12(5), pp. 326–335.

Ferka Zazou, N. (2006) *Impact de l'occupation spatio-temporelle des espaces sur la conservation de l'écosystème forestier : Cas de la commune de Tessala, wilaya de Sidi-Bel-Abbès [Impact of the spatio-temporal occupation of spaces on the conservation of the forest ecosystem: Case of the commune of Tessala, wilaya of Sidi-Bel-Abbès]*. Master's Memory. Université de Tlemcen.

Ismail, M.A., Ludin, A.N.M., and Hosni, N. (2020) "Comparative assessment of the unsupervised land use classification by using proprietary GIS and open source software," *In IOP Conference Series: Earth and Environmental Science*, 540, 1, 012020. Available at: https://doi.org/10.1088/1755-1315/540/1/012020.

Jamali, A. (2021) "Land use land cover modeling using optimized machine learning classifiers: A case study of Shiraz, Iran," *Modeling Earth Systems and Environment*, 7, pp. 1539–1550. Available at: https://doi.org/10.1007/s40808-020-00859-x.

Kumar, B.P. *et al.* (2020) "Identification of land degradation hotspots in semiarid region of Anantapur district, Southern India, using geospatial modeling approaches," *Modeling Earth Systems and Environment*, 6, pp. 1841–1852. Available at: https://doi.org/10.1007/s40808-020-00794-x.

La loi (2010) "La loi n°10–03 du 15 août 2010 fixant les conditions et les modalités d'exploitation des terres agricoles du domaine privé de l'état [Law No. 10–03 of August 15, 2010 setting the conditions and modalities for the exploitation of agricultural land in the private domain of the state]," *Journal Officiel de La Republique Algerienne Democratique et Populaire*, No. 46, pp. 4–7. Available at: https://gazettes.africa/archive/dz/2010/dz-government-gazette-dated-2010-08-18-no-46.pdf (Accessed: September 17, 2022).

Landis, J.R. and Koch, G.G. (1977) "The measurement of observer agreement for categorical data," *Biometrics*, 33(1), pp. 159–174. Available at: https://doi.org/10.2307/2529310.

Meddi, M. (2015) "Contribution à l'étude du transport solide en Algérie du nord [Contribution to the study of solid transport in northern Algeria]," *LARHYSS Journal*, 24, pp. 315–336.

Melalih, A. and Mazour, M. (2021) "Using RUSLE and GIS for the soil loss assessment in arid regions: The case of the Ain Sefra catchment in the Ksour Mountains, Algeria," *Journal of Water and Land Development*, 48, pp. 205–214. Available at: https://doi.org/10.24425/jwld.2021.136163.

Ministry of Agriculture and Rural Development (2015) *Country Summary Report outline: Towards achieving Land Degradation Neutrality: Turning the concept into practice*.

Mostephaoui, T. *et al.* (2013) "Cartographie des risques d'érosion hydrique par application de l'équation universelle de pertes en sol à l'aide d'un système d'information géographique dans le bassin versant d'El Hamel (Boussaada) Algérie [Mapping of water erosion risks by application of the universal soil loss equation using a geographic information system in the El Hamel watershed (Boussaada) Algeria]," *Journal Algérien Des Régions Arides*, 12(1), pp. 131–147. Available at: https://www.asjp.cerist.dz/en/article/76912 (Accessed: January 11, 2023).

Office National Météorologique (2022) *Données climatiques de la région de Sidi Bel Abbès [Climatic data for the region of Sidi Bel Abbès]*, Wilaya of Sidi Bel Abbes.

Omran, E-S.E. (2016) "Early warning information system for land degradation hazards in New Suez Canal region, Egypt," *Modeling Earth Systems and Environment*, 2, 103. Available at: https://doi.org/10.1007/s40808-016-0148-0.

Otmane, A. *et al.* (2018) "Mise en évidence de la sécheresse par l'étude de la variabilité climatique dans le bassin versant de l'oued Mekerra (Nord-Ouest algérien) [Evidence of drought through the study of climatic variability in the watershed of the Mekerra

Wadi (Northwest Algeria)]," *Techniques Sciences Méthodes*, (9), pp. 23–37. Available at: https://doi.org/10.1051/tsm/201809023.

Rosenfield, G.H. and Fitzpatrick-Lins, K. (1986) "A coefficient of agreement as a measure of thematic classification accuracy," *Photogrammetric Engineering and Remote Sensing*, 52(2), pp. 223–227. Available at: https://pubs.er.usgs.gov/publication/70014667 (Accessed: January 11, 2023).

Sitayeb, T. and Benabdeli, K. (2008) "Contribution à l'étude de la dynamique de l'occupation des sols de la plaine de la Macta (Algérie) à l'aide de la télédétection et des systèmes d'information géographique [Contribution to the study of the land use dynamics of the Macta plain (Algeria) using remote sensing and geographic information systems]," *Comptes Rendus Biologies*, 331(6), pp. 466–474. Available at: https://doi.org/10.1016/j.crvi.2008.03.010.

USGS (no date) *EarthExplorer*. Available at: https://earthexplorer.usgs.gov/ (Accessed: February 9, 2023).

Woldemariam, G.W. *et al.* (2018) "Spatial modeling of soil erosion risk and its implication for conservation planning: The case of the Gobele Watershed, East Hararghe Zone, Ethiopia," *Land*, 7(1). Available at: https://doi.org/10.3390/land7010025.

Wubie, M.A. and Assen, M. (2020) "Effects of land cover changes and slope gradient on soil quality in the Gumara watershed, Lake Tana basin of North–West Ethiopia," *Modeling Earth Systems and Environment*, 6, pp. 85–97. Available at: https://doi.org/10.1007/s40808-019-00660-5.

Zerey, W.E., Gael, M. and Zerey-Belaskri, A.E. (2017) "Monitoring land use change and vegetation dynamics by remote sensing in the steppe region of Sidi Bel Abbes (Northwest, Algeria)," *International Journal of Environment*, 6(3), pp. 71–81. Available at: https://doi.org/10.3126/ije.v6i3.18098.