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# Land cover changes mapping of the west-Algerian territory: a multiscale data analysis for the estimation of the sustainable goal 15.3.1

Nadjla Bentekhici<sup>1</sup> · Walid Rabehi<sup>1</sup> · Mohammed Amine Bouhlala<sup>1</sup> · Farah Benharrats<sup>1</sup> · Moussa Sofiane Karoui<sup>1</sup> · Fethi Benhamouda<sup>2</sup> · Ahmed Zegrar<sup>1</sup>

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## Abstract

At the heart of the 2030 Agenda, 17 Sustainable Development Goals (SDGs) have been adopted by the United Nations. SDG 15 aims to implement sustainable management of terrestrial ecosystems by preserving biodiversity and soils and limiting the long-term impacts of disasters. SDG 15.3.1 (proportion of degraded land over a total area) is based on the fight against desertification, the restoration of degraded land and soil, in particular land affected by desertification, it thus remains a major priority for states taking of the UNCCD convention. Land degradation is a large-scale phenomenon, of anthropogenic or natural origin, its measurement via the calculation of indicator 15.3.1 is an effective solution for sustainable management at the planet level. In this contribution, we assessed the change in land cover between 2007 and 2018, one of the sub-indicator of SDG 15.3.1, for the north–west and south–west region of Algeria which occupies 43% of the national territory and includes 15 wilayas while adopting the axes of the methodology proposed by the UNCCD with adaptations to the local geography. The methodology proposed in this work is based on a multi-source/multi-sensor approach while respecting the class nomenclature standardized by the UNCCD. This is a multi-date (2007–2018) supervised classification specific to Algeria known for its significant geographical and bioclimatic diversity, optimized through a multi-scale hierarchical approach based on MODIS images and a hierarchy under a tree multi-sources (NDVI–slope–altitude–land cover from ESA CCI and MODIS MODQ13C1). The output results compared with Trend-Earth data and evaluated via very high and medium resolution spatial data (Alsat 2 “2.5 m” and Landsat “30 m”). This document thus presents a model methodological approach for the production of quality small-scale occupancy maps in semi-arid zones. According to the results obtained, 7905 km<sup>2</sup> or 0.9% of the territory studied suffered degradation and 14,738 km<sup>2</sup> or 1.64% were improved during 2007 to 2018. To achieve neutrality by 2030, developments and monitoring must be undertaken in these areas. Responsive and implement effective and sustainable management practices. Policy makers must strike a balance between development and environmental protection to restore degraded lands.

**Keywords** Land cover changes · SDG indicator 15.3.1 · MODIS images · Hierarchical approach · Land degradation · Geospatial data

## Introduction

Land degradation is characterized by the reduction and loss of the biological and economic capacity of land to produce. It is a global phenomenon that has an often immediate negative impact on the local level. Land degradation is often caused by human activities, and exacerbated by natural processes such as climate change. About 25% of the world’s arable land area is considered degraded; every year, about 12 million hectares are added to the total area of degraded land. The economic costs of land degradation are estimated

✉ Nadjla Bentekhici  
nbentekhici@cts.asal.dz; bentekhicinani@gmail.com

<sup>1</sup> Space Techniques Center (CTS), Earth Observation Department, Algerian Space Agency (ASAL), BP13 Arzew, 31200 Oran, Algeria

<sup>2</sup> Algerian Space Agency (ASAL), Algiers, Algeria

at 490 billion dollars per year, or 3–6% of the gross domestic product of agriculture worldwide according to FAO in 2015.

Desertification, land degradation and drought (DLDD) are major environmental and development problems worldwide. In this context, the United Nations Convention to Combat Desertification (UNCCD) was created in 1994 and has been ratified by 195 United Nations member states, including Algeria. The main mission of the Convention is “to provide a comprehensive framework to support the development and implementation of policies, programs and measures at national and regional level which aim to prevent, control and reverse desertification/degradation of land and mitigate the effects of drought through scientific and technological expertise, public awareness, standard setting, resource mobilization strategy, thus contributing to poverty reduction”.

Following the declaration of the United Nations decade for deserts and the fight against desertification (2010–2020) and the adoption, in September 2015, of the Sustainable Development Goals (SDGs), the international community approved, “The Agenda 2030 for Sustainable Development” comprising 17 goals (SDGs) and 169 targets (United Nations 2015). Indeed, one of the most important indicators is indicator 15 “life on land”, which urges countries to protect, restore and promote the sustainable use of terrestrial ecosystems, to implement sustainable forest management, to combat against desertification, and to halt and reverse land degradation and halt biodiversity loss. Target 15.3.1 aims to “combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a world without land degradation” by 2030. The land cover changes sub-indicator represents the essential issue to be addressed in this document. Technically, this sub-indicator is perceptible through a multi-temporal map of land cover.

Monitoring the changes in land cover is a theme that solves the problem of natural resource management, environmental assessment, monitoring and land use planning. This monitoring requires frequently updated information on land cover and its condition over large areas.

Land cover mapping techniques have made significant progress linked to the improvement of the quality of sensors (Lussem et al. 2016), their diversity (optics, Radar, lidar, etc.) (Congalton et al. 2014), or in relation to image classification approaches (pixel approaches) (Outukei and Blaschke 2010), object-oriented approaches (Doronova et al. 2011; Gaetano et al. 2009) or emerging machine learning/neural network techniques (Rukhovich et al. 2021).

These techniques, often effective at small geographical scales (local/regional), are often less effective in the case of larger scales (national level), given the high variability of the geographical landscapes concerned. Several international projects for the implementation of large-scale

mapping has taken place to provide exploitable products in terms of land cover, in this case by the USGS (MODIS MODQ13C1, 250 m) (Broxton et al. 2014), or the ESA CCI (200 m then 20 m very recently) (UCL-ESA 2016), or Tend Earth (Owuor 2021) these classifications are nevertheless subject to major radiometric confusion (especially in North Africa), mainly on plant classes, or learning is not adapted to the ecogeographical regional specificity.

The UNCCD, carrier of SDG 15 and in particular the sub-indicator related to land cover change, and in a quest for generalization of approaches (for better uniformity of quantitative methods), proposes a methodology based on massive sampling (classification approach) using an open-access tool such as Open Forise and collect Earth (Zonn et al. 2017), for the rapid mapping, especially for developing countries (Csiro UNCCD 2017). This approach also has certain limits (confusion), the countries involved are nevertheless free to set up approaches that are more specific to their territory, and it is with this in mind that this contribution proposes a multisource/multisensor classification approach for the Algerian territory while respecting the class nomenclature standardized by the UNCCD (Csiro UNCCD 2017).

It is thus in this contribution to set up a multirate land cover classification (2007–2018) specific to the Algerian territory through a multi-scale hierarchical approach, starting from MODIS base imagery (supervised massive sampling) by traversing various levels of a multisource tree (Xu et al. 2005) or at each scale the classification is improved based on a source of thematic information (Altitude, NDVI vegetation index, slope, external class, etc.), and this to provide a classification most adapted to the Algerian territory and its bioclimatic stages (humid, semi-arid, arid and hyper-arid) (Zegrar 2015).

This research presents a considerable response to the needs of international institutions (FAO/UNCCD), supported by the Algerian authorities (the focal point is the General Office of Forestry and the Ministry of Agriculture), in collaboration with the Algerian Space Agency and its operational unit (Space Techniques Center), or the remote sensing expertise of ASAL/CTS combined with the territorial expertise of the DGF/MADRP have made it possible to set up this present contribution.

## Study area

Algeria is the largest country on the African continent and the Arab world, it covers 2,381,000 km<sup>2</sup>, it is in the middle position in the Maghreb (Ministry of Agriculture, Rural Development and Fisheries 2015). Bordered in its western part of Morocco, Western Sahara and Mauritania, in its eastern part of Tunisia and Libya, and finally in its southern part of the sub-Saharan countries (Mali and

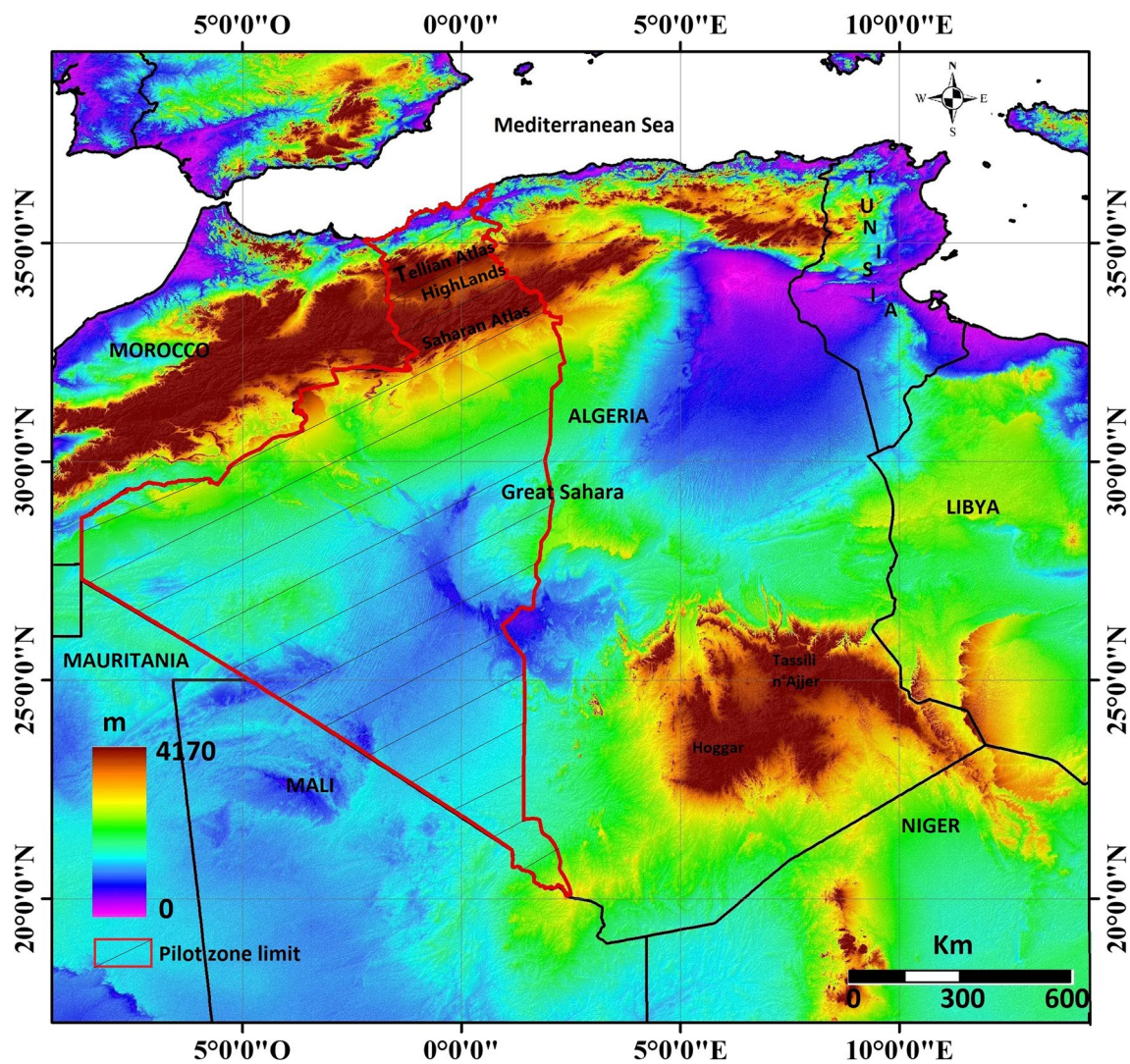


Fig. 1 Location and relief map of Algeria (MNT: GMTED2010, <https://earthexplorer.usgs.gov/>)

Niger) (Fig. 1). At the level of this vast natural expanse, the choice was made on the western part of the country as the first area of application of this methodology, with an area of approximately 894,700 km<sup>2</sup> (i.e., 43% of the territory). It includes 15 wilayas from the north (Mediterranean Shores) to the south and the Sahara (bordering the Sahel), namely: Tlemcen, Ain Témouchent, Oran, Mostaganem, Sidi Bel Abbes, Mascara, Saida, Naama, El Bayadh, Bechar, Beni Abbes, Tindouf, Adrar, Timimoun and Bordj Badji Moukhtar.

This territory presents a variety of relief, in the North, along the Mediterranean Coast, there is a strip called “the Tell” over about 480 km and 80–190 km wide, composed of mountain ranges and Tellian coastal plains which shelter most of the fertile agricultural land (Augustin and Émile 1902; Ministry of Agriculture, Rural Development and Fisheries 2015).

Between the Tell Atlas and the Saharan Atlas, two parallel mountain ranges oriented south–west/north–east between which are interspersed a set of plains and high plateaus (Augustin and Émile 1902; Ministry of Agriculture Rural Development and Fisheries 2015) dug by salt water bodies and chotts (Fig. 1).

Going from North to South, is the Saharan Atlas, which extends the Moroccan High Atlas, in particular through the Ksour Mountains in the west to the Hodna Mountains in the east. To the south of this chain is the Saharan part which covers about 86% of the territory of the pilot zone, i.e. about 773,300 km<sup>2</sup>, it is an immense desert composed of plains (regs and ergs) as well as depressions (sebkhas and guel-tas) (Augustin and Emile 1902). It is a vast region of sands “the great Western Erg”, separated by rocky plateaus, these immense seas of sand are marked by the presence of certain scattered oases (Adrar, Timimoun, etc.).

Climatically, from an establishment of isohyet maps of annual mean precipitation for the period 2004–2019 established by calculating the Emberger index (1932) (Fig. 2), the area of interest (northwestern and southwestern part) of Algeria has three types of climates. The Mediterranean coast of the country has a humid Mediterranean climate (Köppen classification Csa) (Hufty 2001; Benhamrouche et al. 2015) with hot, dry summers and mild, rainy winters, it receives, in general, more than 400 mm of precipitation, particularly at the level of the mountainous whole of northern Algeria (Mounts of Tlemcen) known by a significant forest cover.

The semi-arid to arid climatic domain (Köppen classification BSk and BSh) (Hufty 2001) occupies vast expanses of the Algerian High Plains and high plateaus, covering approximately 7.8% of the surface of Algeria. It is an area with rarefied and more irregular rainfall, ranging from 100

to 400 mm. It is characterized by low and medium vegetation cover.

The rest of the territory of interest presents mostly a desert climate (Köppen classification BWh and BWk) (Hufty 2001), where the climate is hyper arid (Hufty 2001), it includes the Sahara beyond the Saharan Atlas. This area receives less than 100 mm/year. However, the desert domain is not completely devoid of vegetation, the beds of wadis and the spreading areas of the foothills can harbor water tables (Besbes and All 2003), they can carry discontinuous thickets of bushes or shrubs, or are completely characterized by the presence of oases (palm groves) (Senoussi et al. 2012). This part occupies the largest area, i.e. 86% of the total area studied.

The geographical position and the bioclimatic stages that characterize the studied region make this territory an important reservoir of bioecological resources (Mihi et al. 2022).

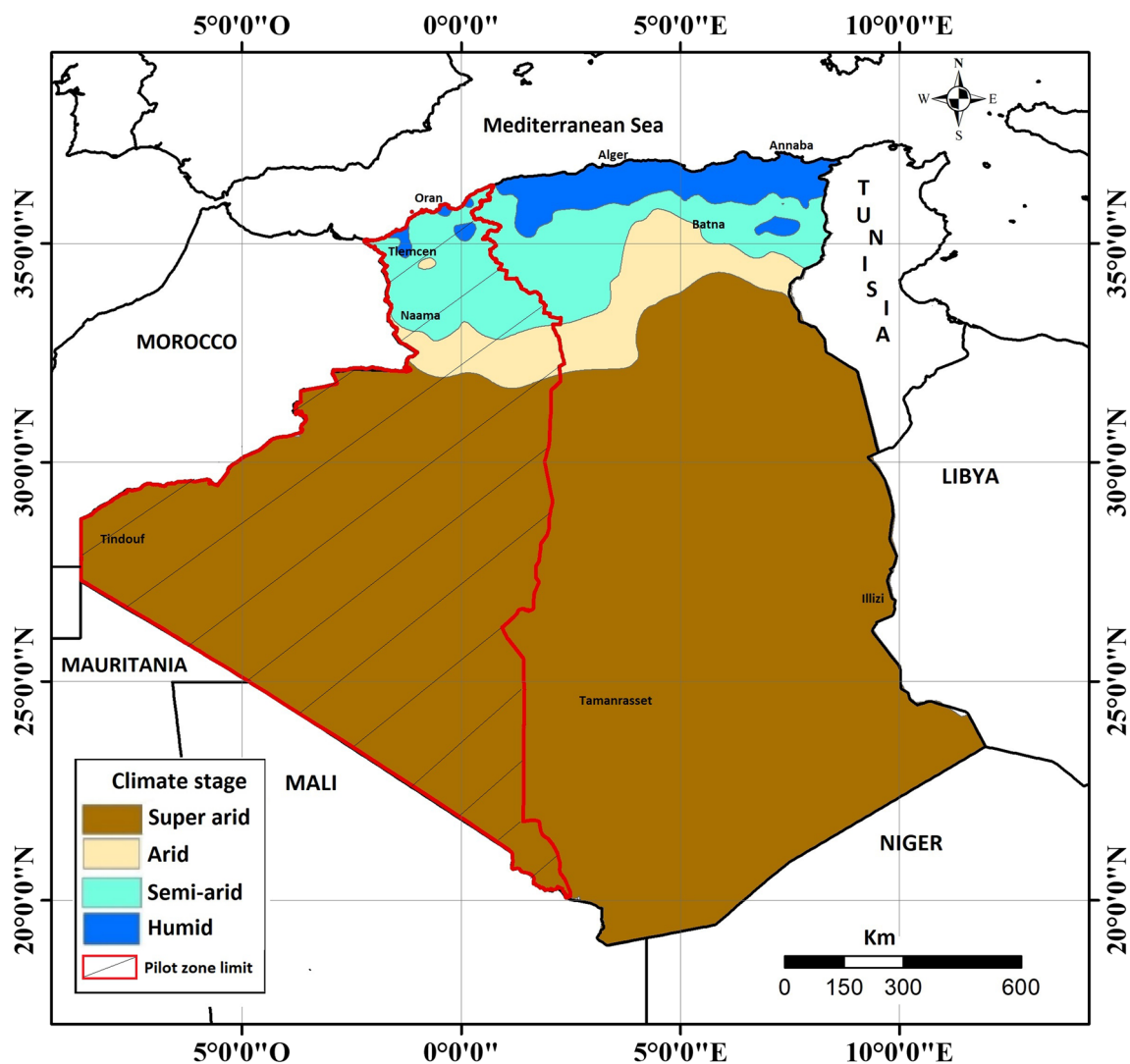


Fig. 2 Map of bioclimatic stages in Algeria (rainy period: 2004–2019)

### Methodology of work

Land cover (LC) is the observed physical and biological cover of the land surface (Congalton et al. 2014; Nedd et al. 2021). This sub-indicator of SDG 15.3.1 is estimated as the area of km<sup>2</sup> of land that has been classified according to the spectral signature of its physical cover using remote sensing techniques.

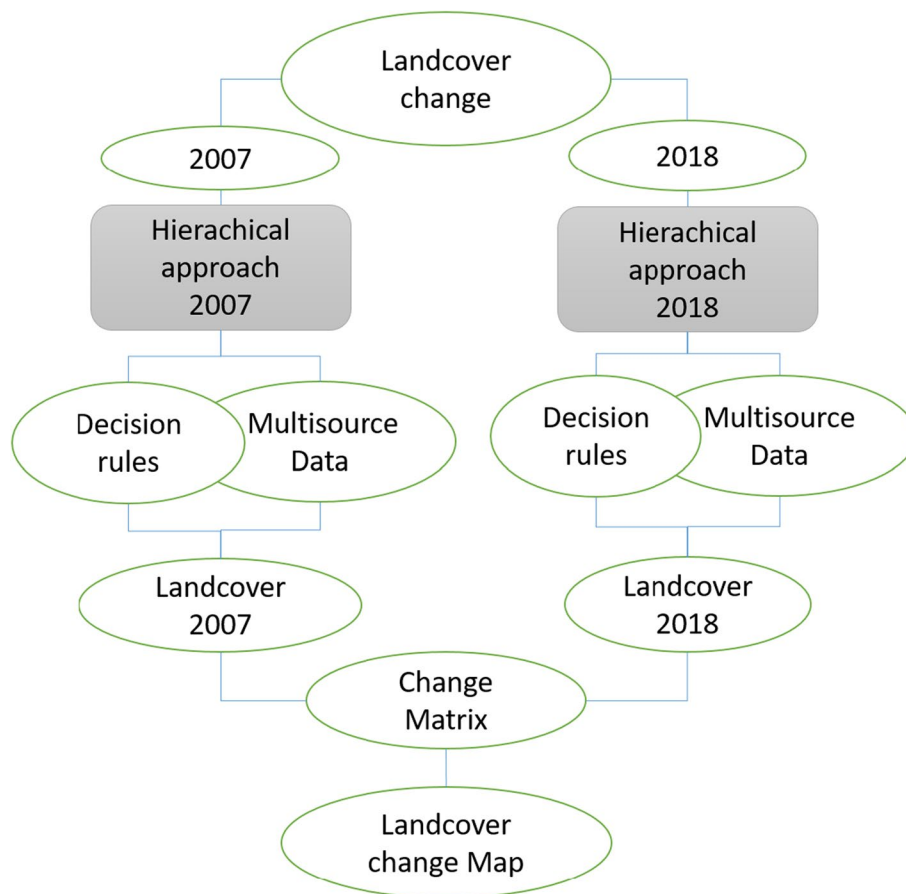
A Methodological Guide is provided by the FAO on the standards and generic rules for the preparation of UNCCD reports in 2017–2018 of the United Nations (Matina et al. 2018) specifying the land cover classes to be produced and the terminology to remember, this report also recommends developing countries simplistic approaches for the production of maps (Collection Earth/Open Foris tool) based in this case on the massive sampling (time-consuming approach but without the need for high skills) (Chandra et al. 2005), nevertheless it leaves the methodological freedom to the country having technical competence for the implementation of specific approach.

It is, therefore, a question, in this present contribution, of setting up for the mapping of land cover change, a specific methodology for the Algerian territory and its

geographical complexity based on the multisource hierarchical approach (Fig. 3).

Given the large scale of the territory, the assessment of land cover changes in Algeria was based on MODIS satellite data (MOD13Q1 with 250 m resolution) allowing the extraction of land cover classes required by FAO/UNCCD (Csiro UNCCD 2017). Its advantage is to be able to cover the Algerian territory with only 4 scenes (size 1.4 Go in total). Two dates are, respectively, chosen, 15/05/2007 and 16/05/2018. The chosen period “end of spring” allows an optimal view of the plant cover and meteorological stability. In addition, for the selection of the learning samples of the year 2018, we based on the data of the satellite images of the Landsat 8 sensor with a resolution of 30 m and the ALSAT-2 data with a resolution of 2.5 times. In 2018 with field verifications carried out at the end of the same year. Thus, for the samples for the year 2007, we used image data from the IRS sensor with a resolution of 60 m and images from the Landsat 7 sensor with a spatial resolution of 30 m as well as field trips carried out in 2009 in the framework of the study of the collaboration between the Algerian Space Agency (ASAL) and the Ministry of Agriculture and Rural Development (General Directorate of Forests) on the production of the national map of sensitivity to desertification in 2010.

**Fig. 3** The Flowchart of the methodological approach followed



Indeed, seven (7) categories of land cover are required by the UNCCD, namely “forests”, “grasslands”, “cropland”, “wetlands”, “settlement”, “bareland” and “water” (Table 1) as well as underclass changes between May 2007 and May 2018.

As part of the production of multi-date land cover maps (2007 and 2018), the classic approach (single-image radiometric) displays a lot of spectral confusion for various reasons:

- The high spectral variability of soils in Algeria between “Steppe, South, Highlands, Tell” (Hirche et al. 2011).
- The large expanse of the country of Algeria, with various climatic zones (different plant species, varied agriculture from East to West, variety of waterways, etc.) (Zegrar 2015).
- The limits of the geometric resolutions of the MODIS image (250 m), which simplifies several classes into a single pixel, complicating the photo-interpretation/classification (Didan et al. 2015).

In this case, the methodology followed therefore requires a hybrid approach combining not only the supervised classification of the two scenes (2007/2018) based on precise sampling (maximum likelihood algorithm) (Carmagnac et al. 2004), but also other external sources of information (Fig. 3), namely:

- Vegetation index “NDVI” (2007 and 2018) to limit confusion between the classes “bareland /grassland/cropland/forest”.
- A mosaic of the digital terrain model SRTM (Shuttle Radar Topography Mission; source: NASA/USGS/JPL-Caltech) of Algeria for the extraction of the wetland, it allowed, for example, the differentiation of the soils bordering the lakes (to be classified as wetlands) and which by their color (whitish dry bare soil, or saline soil) are very similar, their relatively low morphology (–5 to 5 m) makes it possible to classify them in the decision tree and avoid any spectral discrimination, and use its “slope” derivative to also eliminates confusions “forest/cropland” (Fig. 4a, b).
- A classification of the European Space Agency (ESA) for the year 2016 (<http://2016africallandcover20m.esrin.esa.int/> (accessed Aug. 27, 2020)) (20 m resolution) (Fig. 4c), the “settlement” class is, however, well-differentiated; it is also retained to support the mapping of the year 2018. A USGS classification (MODIS –LPDAAC 2007), produced on the basis of an automatic algorithm from which we have corrected it geometrically. However the “settlement” class is well-differentiated, it is also retained to support the cartography of the year 2007.

A selection of learning samples of seven occupation classes was established; this step was made on the basis of the interpretation of MODIS images (2007 and 2018) and confirmed by a set of Alsat2, Landsat 7 and 8 and IRS as well as the field reconnaissance cited above.

An evaluation of the separability between the learning classes has also been set up; the values of this separability vary between 1.8 and 1.99, so it is a good separability between the classes.

Once the classifications have been produced, the photo-interpretation has made it possible to find several anomalies in relation to the reality of the terrain, given the spatial resolution of the MODIS images (250 m). To improve this classification, a second step was necessary based on various sources of thematic information (relief, vegetation index, slope, etc.) through a hierarchical decision tree.

This approach is based on the “specification–generalization” course, of the different multi-resolution data one of the advantages of this approach is to be able to pivot on the scales (request a class at 30 m and then a class of 2.5 m resolutions (Lusser et al. 2016; Pohl and Van Genderen 1998) then again, switch back to a less fine scale class (20 m for example) for generalization purposes. This approach even if it is called “hierarchical” (Gaetano et al. 2009) in the sense of the “Mother–daughter” classes, does not exclude the use of coarse scale layers after use of a finer scale layer if the contribution is obviously beneficial, hence the interest of this “specification–generalization” game of scale.

**Table 1** Aggregated land covers legend for Algeria: European Space Agency Climate Change Initiative on Land Cover UNCCD

Occupancy class (UNCCD)	Number	Occupancy subclasses
Forest	1	Forest and bush
Grassland	2	Herbaceous cover, tree and shrub
		Brush
		Grassland
		Sparse natural vegetation
		Sparse grass cover
		Fallow
Cropland	3	Cultivated land
		Arboriculture
		Irrigated cropland or post-flood
Wetlands	4	Aquatic vegetation cover or regularly flooded
		Sebkha and Schott
Settlement	5	Urban area
Barland	6	Bare ground
		Rock outcrop
		Sandy buildup
		Dunes
Water	7	Water

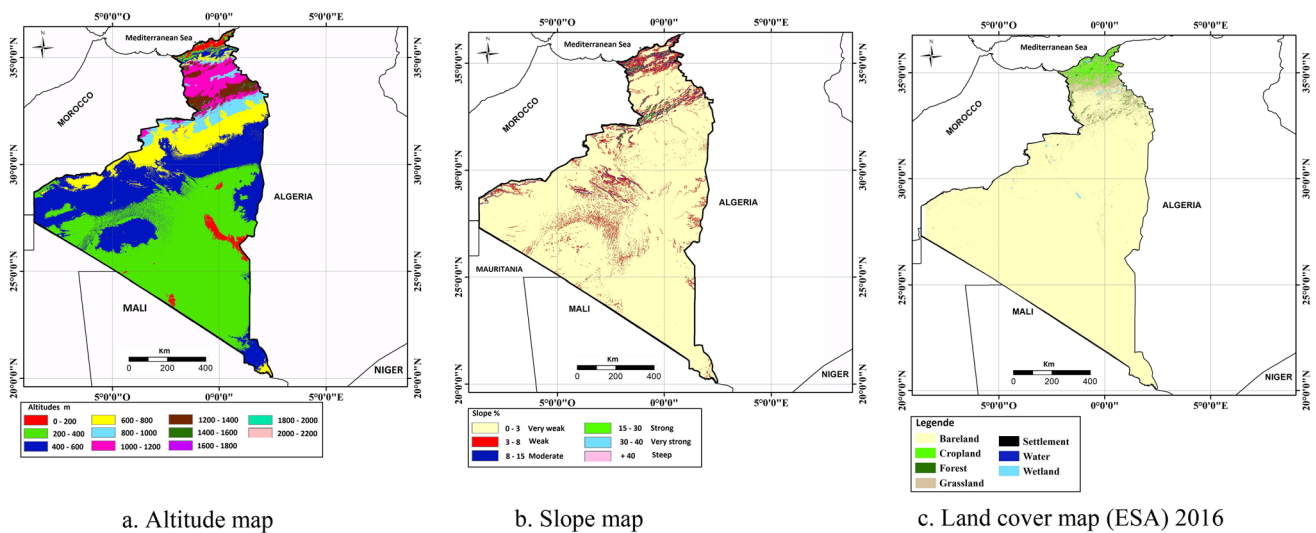


Fig. 4 a, b, c External sources of information integrated into the hybrid approach

All these layers of multi-resolution information make it possible to extract useful information from each layer of information (among those mentioned above) and deploy it for the digitalization of a class at a given scale via a binary/empirical approach as demonstrated on the decision tree below (Fig. 5).

Once the criteria and thresholds have been acquired (user expertise), the creation of classes and the allocation of discretion criteria take place via the specific language of

the decision tree “under ENVI 5.6 software” (Fig. 6). This tree makes it possible, in fact, to combine various layers of information having the same geographical extent, while overcoming the differences in radiometric resolution and the classic concerns of the different characteristics of the images (coding/format, etc.) in a multi-binary logic (Xu et al. 2005), digitalization can be done either via a single criterion ( $X = 1, X > 1, 5 > X > 1...$ ) or via the concatenation of several variables at the same time ( $X = a \text{ AND } Y < b \text{ OR } Z > c...$ ).

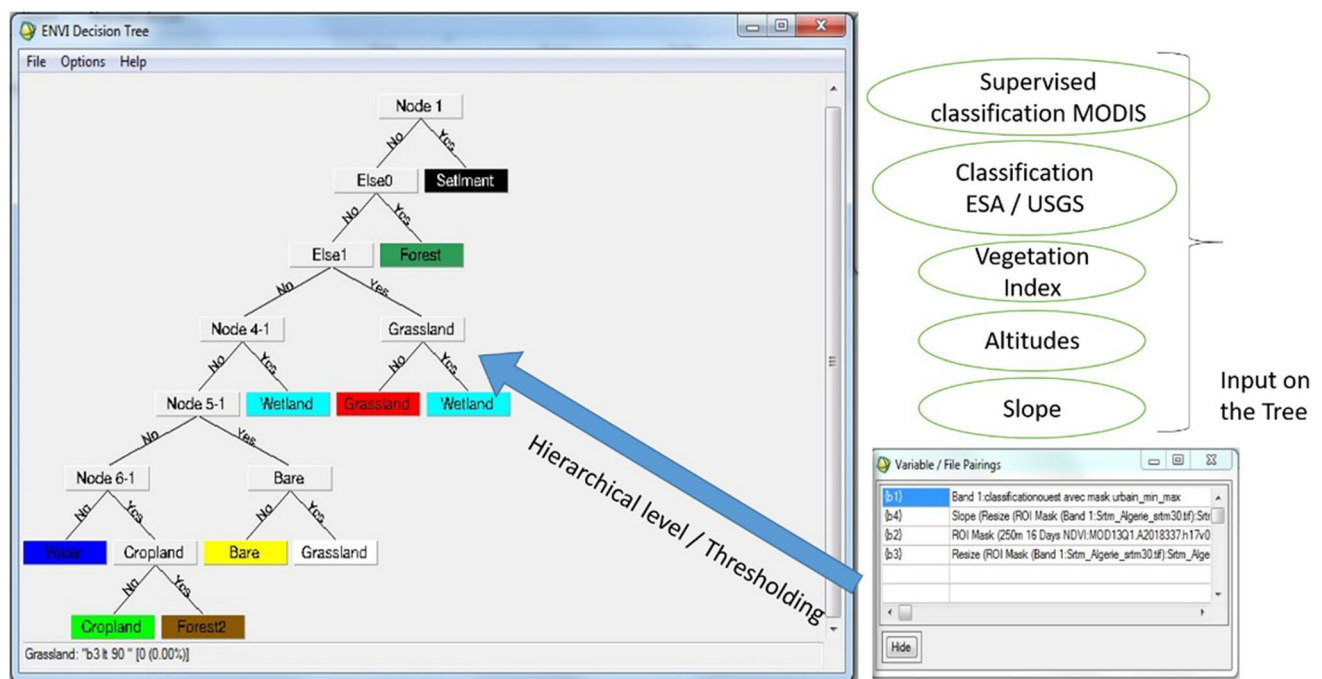


Fig. 5 Example of the decision tree used for the multi-source approach – 2018 classification

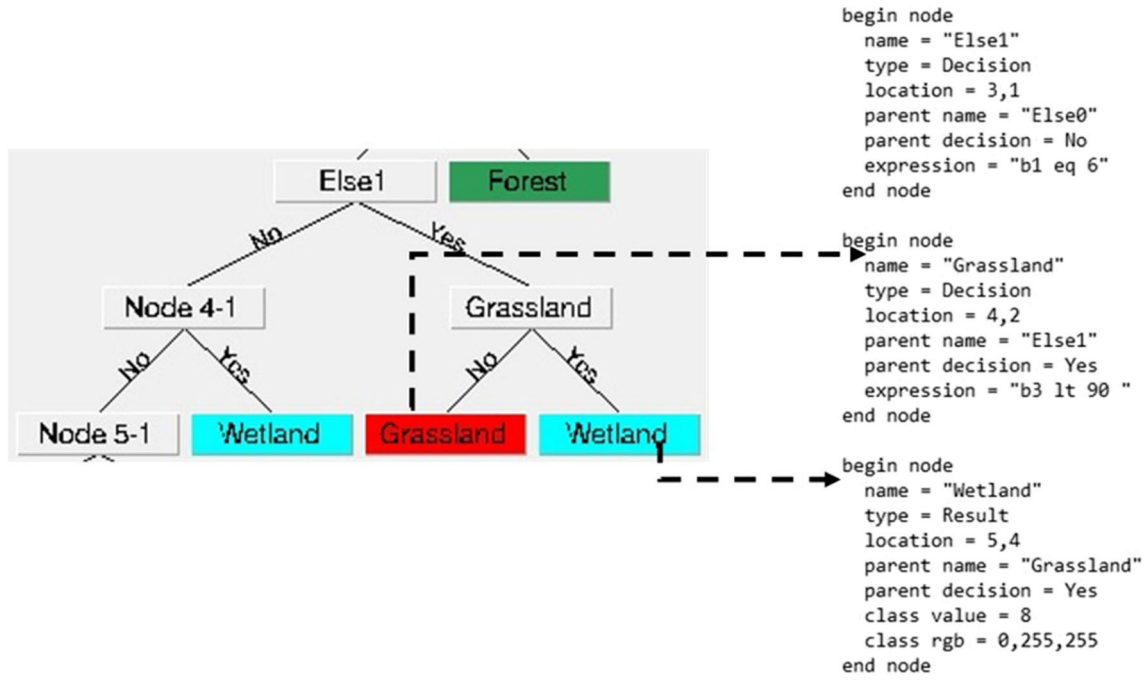


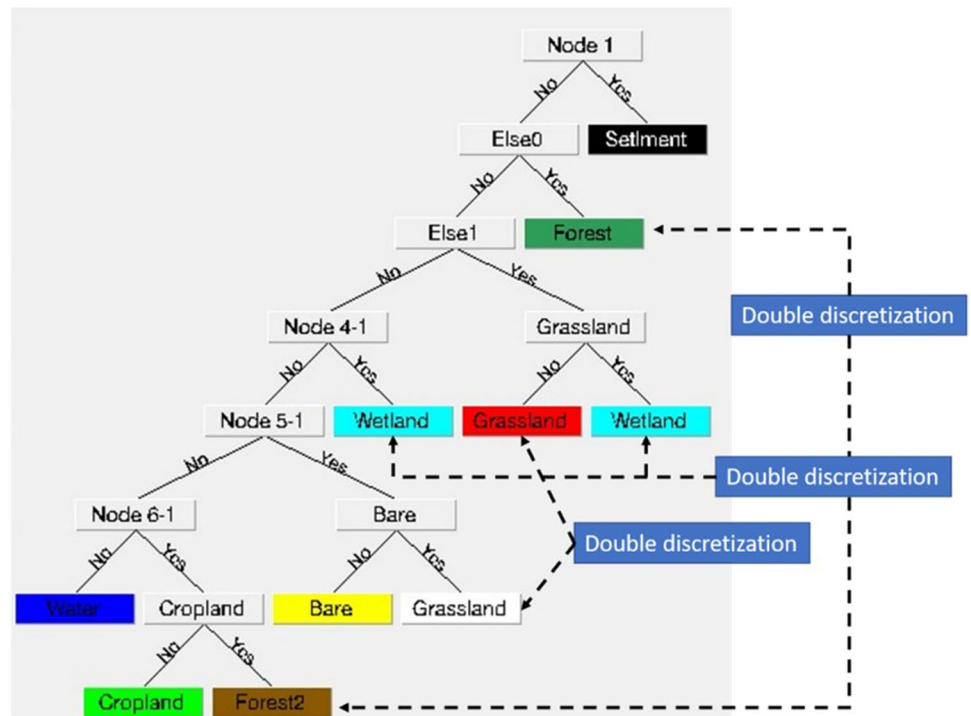
Fig. 6 Creating rules/nodes in the tree

The “binary” elimination into two logical classes (Yes–No) can sometimes eliminate useful information, this information can be recovered later (Fig. 7) by creating a second “recovery” class (Wetland 1, Wetland 2,

Grassland1, Grassland 2) of the classes that will be merged in post classification.

The last step of the study (once the two land cover maps 2007 and 2018 have been produced) is the identification of the nature of the change “improvement”, “degradation” or

Fig. 7 Scale game and recovery of lost information



“stability”, in this context, a matrix which was provided by the UNCCD has been complied with (Sims et al. 2021; Mattina et al. 2018). Changes that correspond to degradation must be: “deforestation, urban expansion, loss of vegetation, flooding, drainage of wetlands or decline in agriculture”, changes that correspond to an improvement in land cover is all: “reforestation, agricultural expansion, introduction of vegetation and creation of wetlands”. Thus, changes in land cover (LC) represent the losses and gains of natural land resulting from the processes of change from one category of LC to another, and help to identify the state of land degradation and to define what changes are considered degrading or ameliorating. The process of assigning variations to a CT change type is a subjective assessment. For example, a change from treed area to cropland could be considered “deforestation” (loss of treed areas) or “agricultural expansion” (gain of cropland), while a change from grassland to wetlands could be considered as “flooding” (wetland gain)

or “vegetation loss” (Mattina et al. 2018; Sims et al. 2021). This step of the process was carried out using a change algorithm respecting the UNCCD change matrix (Fig. 8).

For the validation of the land cover maps of the two dates, we produced via a data set satellites images from the Algerian Alsat-2 sensor for the year 2018 and images taken from the Landsat7 and IRS sensor for the year 2007 (Fig. 9a).

A confusion matrix was calculated for the validation of the 2007 classification. In this case, we used a mosaic of the IRS sensor images and the 6 scenes of the Landsat 7 images taken in 2007 (Fig. 9a) by selecting samples validation of the seven occupancy classes.

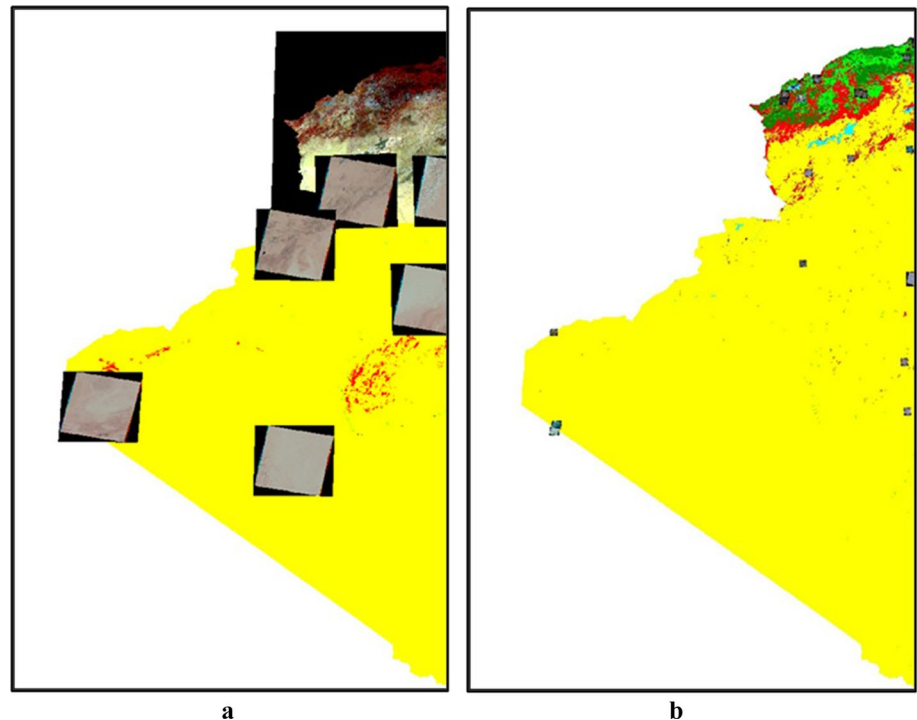
We thus used 17 scenes of merged ALSAT-2 images with a resolution of 2.5 m taken in 2018 (Fig. 9b). We have established the implementation of the sampling process of the seven occupation classes on several ALSAT-2 images that cover the north, the steppe and scenes that cover the capitals of the wilayas of the Sahara (Fig. 9b).

```

1  clearvars;
2  clear global;
3  clc;
4  NBL=8062;NBC=8318;NBB=1;
5  I1=multibandread('2007raster4.dat',[NBL NBC NBB],'uchar',0,'bsq','n');
6  I2=multibandread('2018raster3.dat',[NBL NBC NBB],'uchar',0,'bsq','n');
7  R=zeros(NBL,NBC);
8  % Classe 1 = stable
9  % Classe 2 = négatif
10 % Classe 3 = positif
11 for i=1:NBL
12     for j=1:NBC
13         v1=I1(i,j,1);
14         v2=I2(i,j,1);
15         if v1==v2
16             R(i,j)=1;
17         if v1==5 && v2==2
18             R(i,j)=2; ←
19     end
20     if v1==5 && v2==3
21         R(i,j)=2; ←
22     end
23     if v1==5 && v2==4
24         R(i,j)=2; ←
25     end
26     if v1==7 && v2==4
27         R(i,j)=3; ←
28     end
29     if v1==7 && v2==5
30         R(i,j)=3;
31     end
32     if v1==7 && v2==6
33         R(i,j)=1; ←
34     end
35     end
36 end
37 multibandwrite(uint8(R),'Changement','bsq');
    
```

Fig. 8 Change algorithm (according to UNCCD change Matrix)

**Fig. 9** **a, b** Aperçu des scènes de validation « images Landsat et IRS» (**a**) et « images Alsat2» (**b**)



A confusion matrix (overall accuracy) (Akoguhi et al. 2022) was calculated to assess the statistical quality of the learning areas developed; the objective is to quantify the number of pixels of a reference class that are found in the same assignment class (= well-classified pixels), as well as the Kappa coefficient errors of surpluses and deficits (Caloz and Collet 2001).

## Results and discussion

The first part of the analysis, in this case, the multi-date supervised classification (2007–2018), was carried out using the maximum likelihood algorithm (Pony et al. 2000), while performing a specific sampling at the 4 MODIS scenes used (East West and the two SOUTHERN scenes simultaneously), indeed bioclimatic and ecological differences require careful and separate sampling.

One of the most answered concerns in this type of approach (Maximum Likelihood Algorithm), is the confusion between bareland and urban areas, this was avoided by applying a mask to the urbanized areas on the optical image before establishing the sampling, in particular via the ESACCI-LC\_S2 land cover map of Africa/ 2016 (20 m resolution), as well as the USGS land cover map (MODIS-LPDAAC 2007).

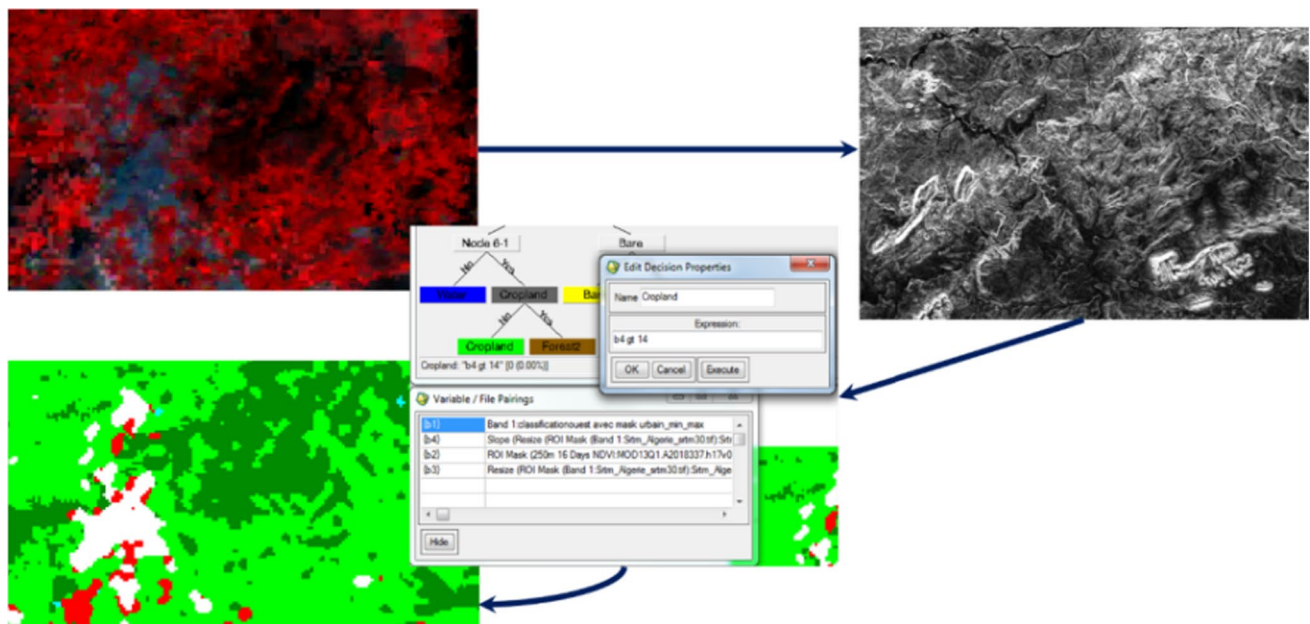
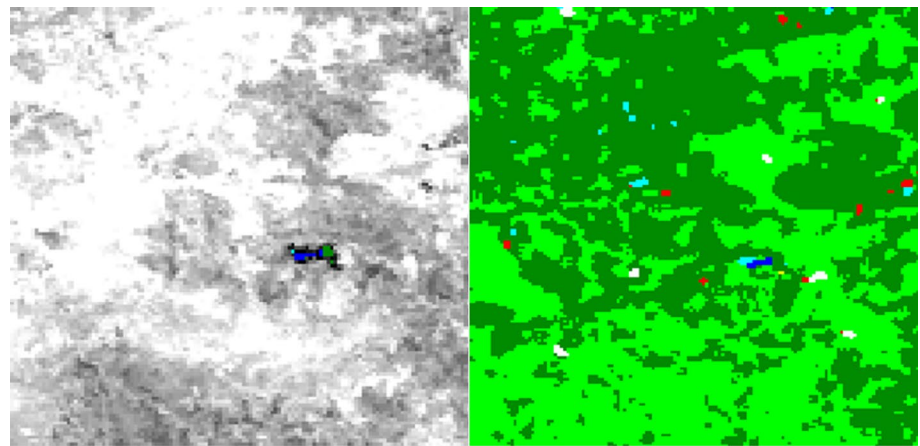
Only the “settlement” class was retained from these two layers of information (ESACCI-LC\_S2 land cover map of Africa/2016 and USGS land cover map

(MODIS-LPDAAC 2007)), the rest of the classes (in particular the classes “grassland, cropland, forests, wetlands, etc.”), are very confused due to the lack of the specific sampling in Algeria, and the rigidity of the automatic classifiers used, the confusion is very pronounced in the steppe/high plateau zone. This is the reason why we have established the specific approach to our study region to produce low land use maps that reflect the reality of the land in Algeria.

Since supervised sampling does not allow a clear differentiation between classes, in particular with the use of low resolution MODIS images (Razagui and Bachari 2014), therefore, the normalized vegetation index “NDVI” MODIS has been used on several occasions to better differentiate the vegetation cover through a thresholding of intensities (in particular between the grassland type and bareland), or on the contrary (via the insensitivity of the near-infrared band) to better distinguish streams (weak signal, see negative) (Fig. 10).

Some plant classes are very similar, even with the use of previous layers, it is above all a clear confusion between cropland (massive arboriculture) and certain forest areas, in this case and through an analysis of several samples (to using better resolution images, in particular Landsat (30 m)/ Alsat(2.5 m)), Algerian sensors), it appeared that the majority of these lands are located in territories with slopes of less than 25%, the “slope” layer derived from a SRTM DEM has, therefore, been used to further refine the agriculture class (Fig. 11).

**Fig. 10** Normalized vegetation index “NDVI” in support of spectral classifications



**Fig. 11** “Slope” variable to correct the “forest—agriculture” confusion

The cartographic improvement stage based on field knowledge and very high and medium spatial resolution images was followed to avoid any confusion found. Thus, after this multisource refinement step and cartographic improvement, land cover maps were established for the study area in 2007 and 2018 (Figs. 12 and 13) which show the seven categories of land cover taken into account by the UNCCD, namely, “forests”, “grasslands”, “cropland”, “wetlands”, “settlement”, “bareland” and “water”.

In 2007, the study area included a large area of bare land, i.e., 96%, these lands being present mainly by the Sahara, represented by vast expanses of sand and dunes/hmada (Sekoum et al. 2012). In second position (surface) come the grasslands which occupy 1.91% of the space studied (Table 2), generally located in the steppe zone between the

Tell Atlas and the Saharan Atlas characterized by a semi-arid climate (Nedjraoui and Bédrani 2008). The wooded areas (dense forest, open forest and bush) cover approximately 1.13% of the total surface. These areas are mostly located in the Monts of Tlemcen and Trara (Nichane et al. 2013). The cropland occupying small areas, about 0.37% of the study area, are generally located in the coastal plains of Ain Temouchent and M’letta as well as the interior plains, such as those of Tlemcen, Saïda, Sidi Bel Abbas. The wetlands occupying 0.27% of the surface are the sebkhas and the schotts of western Algeria, such as the sebkha of Oran and Schott Chergui (Brahim et al. 2013; Hachemi et al. 2020; Benkesmia et al. 2023).

In 2018, we noticed a significant regression of bareland, i.e., “–5513.07 km<sup>2</sup>” (Tab. 2), they cover approximately

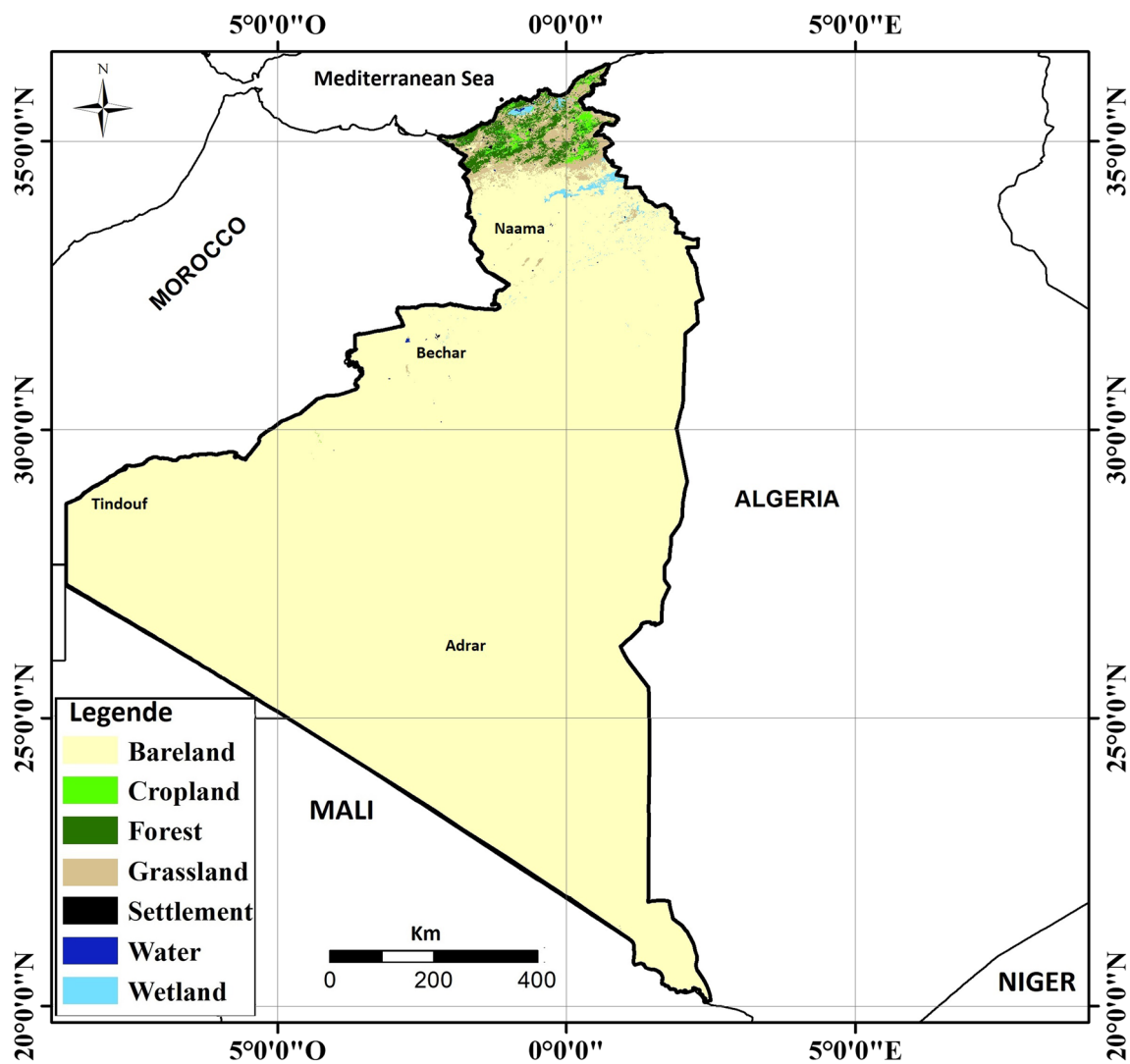


Fig. 12 Land cover map in 2007

95%, lost spaces are transformed into grassland and cropland. During this year, wetlands also experienced significant filling following favorable rainfall.

From a general point of view, the year 2018 presents a relatively rainy year, where the grassland (+2300 km<sup>2</sup>) and the cropland (+3074 km<sup>2</sup>) have experienced a significant increase compared to 2007.

We also distinguish a significant urban sprawl between 2007 and 2018, i.e., 12.48 km<sup>2</sup>, in particular in large cities, such as Oran, Ain Témouchent, Tlemcen and Sidi Bel Abbes, reflecting the strong demographic growth experienced by the country (ONS 2013; Belguidoum 2021), particularly in the strip coastal (the most attractive to the population), where the majority of the country's economic centers are located (industrial basins) (Ammi 2019).

The classifications of MODIS images of the years 2007 and 2018 made it possible to carry out an analysis of the

trajectory of the land cover to identify the pixels (land cover) which remained stable and those which mutated, in particular based on the matrix land cover changes recommended by the UNCCD (Table 3), as well as the expertise of the country's territorial dynamics by our teams.

Land cover changes (LC) represent the losses and gains of natural land resulting from processes of change from one LC category to another, and help to identify the state of land degradation and to define what changes are considered degrading (Fig. 14). The process of assigning variations to a CT change type is a subjective assessment. For example, a change from forest to cropland could be considered "deforestation" (loss of forest) or "agricultural expansion" (gain of cropland), while a change from grassland to wetlands could be considered as "flooding" (wetland gain) or "vegetation loss" (Mattina et al. 2018). The resulting

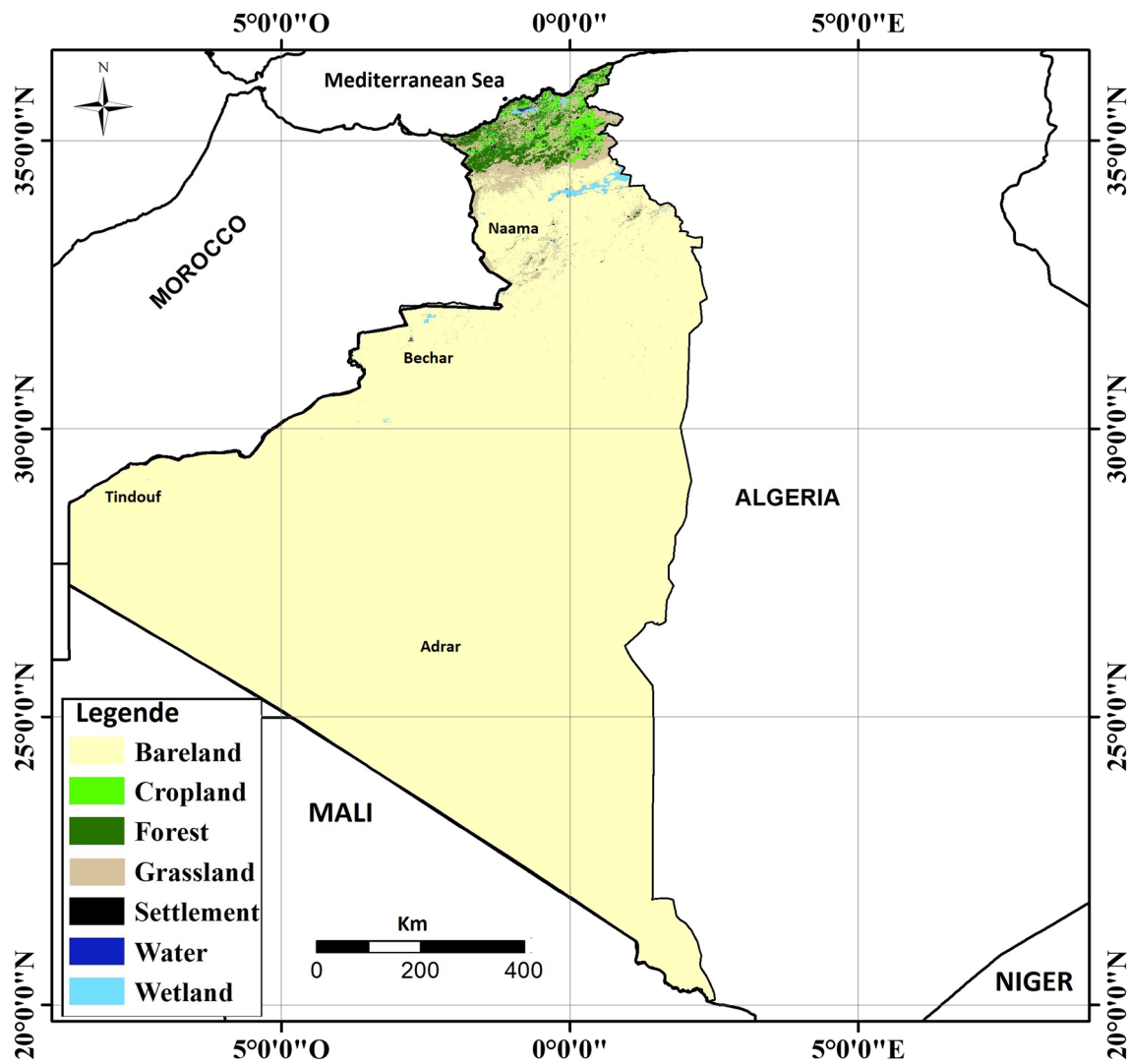


Fig. 13 Land cover map in 2018

Table 2 Land covers area in the study area in 2007 and 2018

Type of occupation	Area 2007 Km <sup>2</sup>	Area 2018 Km <sup>2</sup>	Changes Km <sup>2</sup>
Water	128.86	168.708	39.848
Settlement	587.33	599.81	12.48
Grassland	17,145.14	19,336.38	2302.43
Cropland	3312.96	6387.6	3074.64
Forests	10,148.78	10,224.86	76.08
Wetland	2484.22	2603.01	118.79
Bareland	860,806.27	855,293.2	- 5513.07
Total	894,613.56	894,613.56	

land covers change map between 2007 and 2018 over the area of interest is shown below (Fig. 14).

During the 2007–2018 periods, some LC dynamics were observed at the scale of the pilot area. It is noted that the region experienced a low overall degradation factor of 0.9% compared to the improvement which experienced approximately 1.64% of the surface studied; the rest of the territory (97%) remained stable.

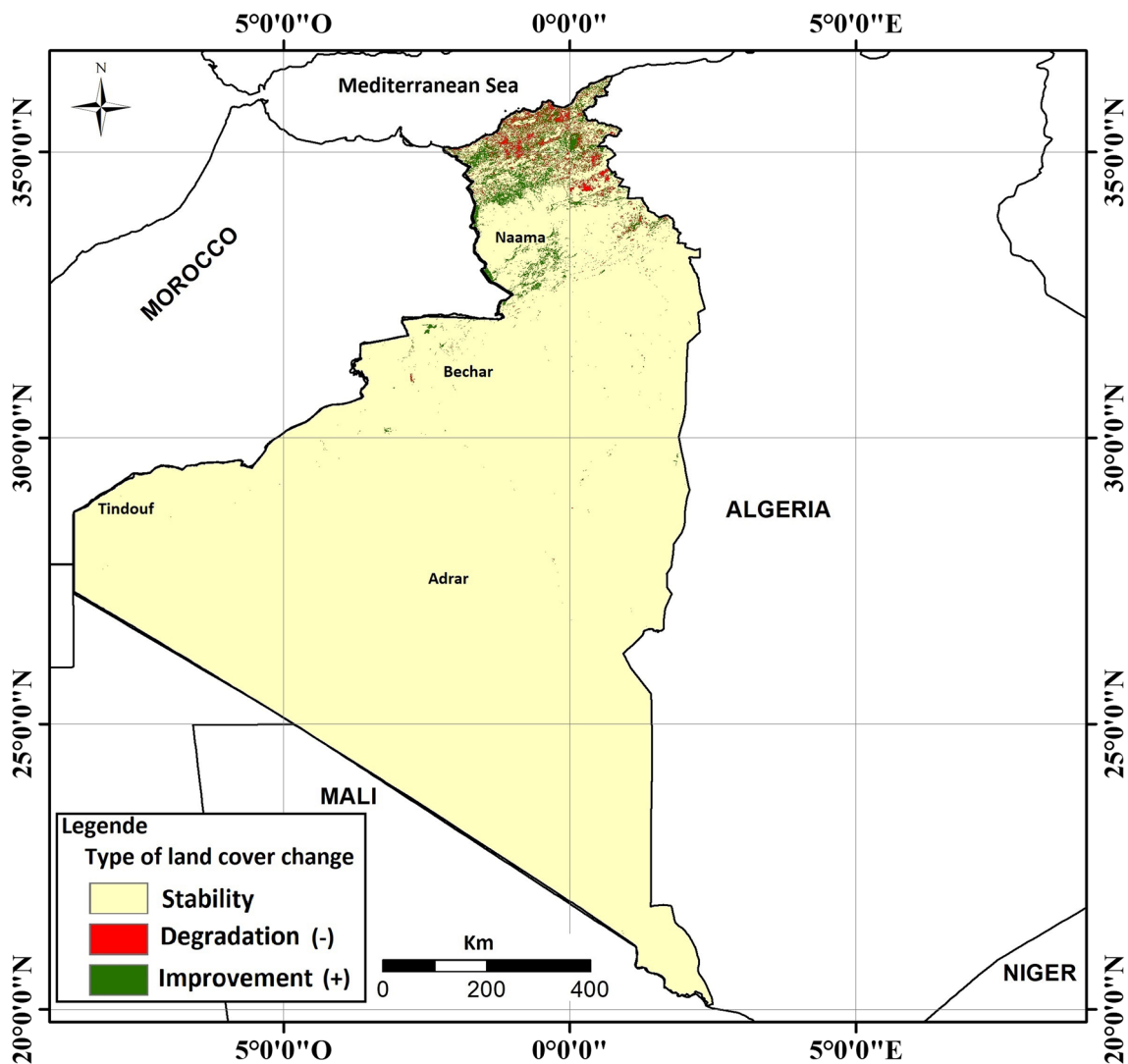
Table 4 and the map of land cover changes in Algeria between 2007 and 2018 (Fig. 14) show the following territorial dynamics:

- Urban sprawl corresponds to an area of 12.48 km<sup>2</sup>, it presents as being a type of degradation of the land cover, and because this expansion is either “a sprawl of agricultural land, deforestation or it is drainage of wetlands”. The strong demographic growth has led to this accelerated

**Table 3** Summary of land cover/land use change matrix for the six land cover classes (UNCCD)

	Forest	Grassland	Cropland	Wetland	Settlement	Other lands
Forest	<i>Stable</i>	<b><u>Loss of vegetation</u></b>	<b><u>Deforestation</u></b>	<b><u>Flood</u></b>	<b><u>Deforestation</u></b>	<b><u>Loss of vegetation</u></b>
Grassland	<i>Afforestation</i>	<i>Stable</i>	<i>Agricultural expansion</i>	<b><u>Flood</u></b>	<b><u>Urban expansion</u></b>	<b><u>Loss of vegetation</u></b>
Cropland	<i>Afforestation</i>	<b><u>Agricultural decline</u></b>	<i>Stable</i>	<b><u>Flood</u></b>	<b><u>Urban expansion</u></b>	<b><u>Loss of vegetation</u></b>
Wetland	<b><u>Undergrowth</u></b>	<b><u>Wetland drainage</u></b>	<b><u>Wetland drainage</u></b>	<i>Stable</i>	<b><u>Wetland drainage</u></b>	<b><u>Wetland drainage</u></b>
Settlement	<i>Afforestation</i>	<i>Vegetation establishment</i>	<i>Agricultural expansion</i>	<i>Creation of wetlands</i>	<i>Stable</i>	<i>Decline of human settlements</i>
Other lands	<i>Afforestation</i>	<i>Vegetation establishment</i>	<i>Agricultural expansion</i>	<i>Creation of wetlands</i>	<b><u>Urban expansion</u></b>	<i>Stable</i>

Bold underline—degradation (-), Bold italic—improvement (+), Italic—stability



**Fig. 14** Map of land cover changes between 2007 and 2018 in the study area

**Table 4** Area of land covers change in the pilot area (2007–2018)

Type of change (2007–2018)	Area km <sup>2</sup>	Area %
Degradation	7905.31	0.9
Improvement	14,738.31	1.64
Stability	871 723.25	97.44

urbanization and to the development of collective facilities on land for agricultural purposes, as in the case of the Oran conurbation, and the cities of Tlemcen, Sidi Bel Abbes and Ain Témouchent (Belguidoum 2021).

- We note a progression of the raised zones is a surface of 76.08 Km<sup>2</sup>, often represented through important reforestation processes corresponding to a positive change (improvement). However, according to the map of changes, there are some smaller forest areas where negative changes (degradation –) are perceptible, following deforestation due to forest fires or anthropogenic clearing (Bentekhici et al. 2020). This is the most worrying phenomenon that affects the forest massifs, in this case fires and random clearing. The forests of the northwestern Algerian region are heterogeneous and unevenly distributed according to the distribution of meso-climates and anthropic action (Benderradj et al. 2006). The physical components of the region attribute these forest massifs a character of fragility and vulnerability.
- The grasslands in the pilot area have experienced some significant increases (2302.43 km<sup>2</sup>) on bare land that distinguishes an establishment of vegetation in 2018; this is therefore a positive improvement of the territory. We nevertheless note some croplands which have mutated into grassland reflecting an increase in vegetation; however it presents an aspect of negative degradation of the territory.
- Cropland increased between 2007 and 2018, with an area of (3074.64 km<sup>2</sup>), it is a form of agricultural expansion due to the influence of the climatic factor (rainy year) and the contribution human activities following the development and restoration of cropland, in particular, if their origin (initial class) is bareland (past cropland). In addition, cropland that has thus experienced constant degradation is the result of unsuitable farming practices, overgrazing, land clearing and the impact of water and wind erosion, particularly in the steppe region (Arabi 2021).
- Climatic conditions are increasingly complex, tending towards drought (Medejerab and Henia 2011). The desert, arid and semi-arid zones correspond to the steppe and Saharan areas have experienced prolonged periods of aridity having a dramatic effect on the water level of the soils and, therefore, on the availability of water. This instills in these regions a more or less intense stress lead-

ing to severe degradation of vegetation (Bied-Charreton 2017). During this decade; a significant increase in wetlands was recorded. It can be perceived as a positive improvement if it is a creation of wetlands (bareland transformed into wetlands), in particular that the year 2018 presents a rainy year, the following weather stations recorded an annual precipitation ranging from 117 mm/year to 535 mm/year (Tlemcen 379 mm/year; Sidi Bel Abbes 457.9 mm/year; Oran 534 mm/year; Ain Témouchent 414 mm/year; Mostaganem 407 mm/year; Mascara 496 mm/year; Saida 454 mm/year; Naama 362 mm/year; El Bayadh 518 mm/year; Bechar 117 mm/year) (source: <https://www.infoclimat.fr/climatologie/annee/2018>). Therefore, this situation is mainly due to the influence of the climatic factor (favorable rainfall). If this progression is transformed into a “water” class, often linked to flooding of bodies of water or the drainage of wetlands, it will nevertheless be qualified as degradation of the territory.

- The catastrophic loss scenario: when the LC has changed from a vegetation type/class (forest or grasslands) to a non-vegetation type “bareland”, which must reflect both catastrophic degradation and water and wind erosion consequence of surface soils. This is the consequence of socio-economic development that does not take into account the environmental aspect (Benderradj et al. 2006). Noting the acceleration of desertification and the phenomenon of the advancement of sand in the steppe areas, in particular the wilayas of Naama and El Bayadh. At the level of these two wilayas, the desertification sensitivity map produced by the Algerian Space Agency in 2010 shows that nearly 283,548.82 ha of land in steppe zones are in the process of total desertification, 3,460,416.23 ha very sensitive zones and 4,921,164.24 ha sensitive areas (ASAL 2023).
- Overall in the study area, bareland experienced a significant regression in 2018; this can be reflected in the forms of temporary vegetation regeneration during this year. In particular of it represents a year more and less rainy.

The change assessment revealed that settlements, cropland, forest and water increased between 2007 and 2018, leading to a substantial reduction in bare land. The increase in water was insignificant following favorable rainfall in the year 2018. However, the transformation of cultivated land into settlement has caused varied and widespread environmental degradation in the study area, the main negative results of which associated with rapid urban sprawl and the growth of slums. This urban expansion is mainly due to population growth and economic development in the study area.

The results obtained showed an improvement of 1.64% represented in the form of an important establishment of

the vegetation between 2007 and 2018 and an important agricultural expansion due to the influence of the climatic factor of the year 2018, a restoration of the cultivated land and agricultural action plans followed by local authorities.

The percentage of degradation of 0.9% in the pilot area shows a land use that changes from a type/class of plants (treed areas or grasslands) to a type of non-vegetation "bare land" or even urban sprawl on cultivated land.

In light of this context of natural transformation that this region of Algeria is undergoing, the resulting land cover change sub-indicator of the sustainable development indicator created by the FAO (SDG15.3.1) is cartographic information that helps to the establishment of land management strategies aimed at the environmental, social and economic sustainability of the region.

## Validation of land covers results

A confusion matrix was produced to see the reliability of the results obtained for the year 2018 (Table 5). The latter clearly shows the acceptable confusion rate between occupation classes in majority exceeds 86.5%. Suitable given the vastness of the space studied (894,700 km<sup>2</sup>), the geomorphological variety (coastal zone, Tell zone, interior plains, steppe zone, Saharan zone) the ecological variety (forest massif of the Tell Atlas and the Saharan Atlas, steppe and Saharan, littoral vegetation, lowland agriculture (irrigation cultivation), steppe and Saharan agriculture (oasis), variety of wetlands (sabkha, schott, lake)) resulting from the large spectral varieties.

The overall accuracy which is the ratio of the number of well-classified pixels to the total number of pixels gave 77.89% (701.779/901) for the classification of the year 2018 and a Kappa Coefficient equal to 0.76 expresses the reduction proportional to the error obtained by a classification  $Kappa = -1 = >$  the concordance is zero  $Kappa \pm 0 = >$  the concordance is insignificant  $Kappa = +1 = >$  the concordance is very strong, a Kappa of 76% of correct classifications.

In the case of the classification of MODIS 2007 images, the overall accuracy is equal to 84.88% (56,337/66,369) and the Kappa Coefficient gives 0.8033, which means that 80%

of good classifications. Acceptable level of confusion in relation to the territory studied.

To see the reliability of our results extracted from the processing of MODIS satellite images and to better assess the land cover maps of Algeria in 2007 and 2018; we compared these maps with land cover maps 2016 ESA CCI-LC downloaded from Trend-Earth compared to Landsat satellite images for the year 2016 (Fig. 15).

The comparison of the land cover map in 2016 from Trend-Earth shows the following points:

The only well-classified categories are "bareland", "settlement" and "water", on the other hand, great confusion has been found concerning forests, cropland of which we will find large forest areas (forest massif of Tlemcen of Sidi Bel Abbes and Oran) were classified as cropland and grassland. Some areas of bareland in the Naama steppe zone have been represented in the Trend-Earth land cover map as "wetlands".

The overall accuracy of the 2016 Trend-Earth classification of the CCI-LC of the ESA equals (75/146) which is 54.9315%. A very low precision which indicates that the classification of CCI-LC of the ESA is misclassified, it does not reflect the reality on the ground of Algeria. The Kappa Coefficient = 0.49, means that 49% of the correct classifications of this land cover map.

To this end, the comparison between the results obtained by the classification of MODIS images following the methods of the hierarchical decision tree (combination with other multi-source data and cartographic improvements) with the occupancy map of the CCI -LC of the ESA in 2016, makes it possible to affirm that the results obtained are more coherent and better represent the reality of the territory of Algeria.

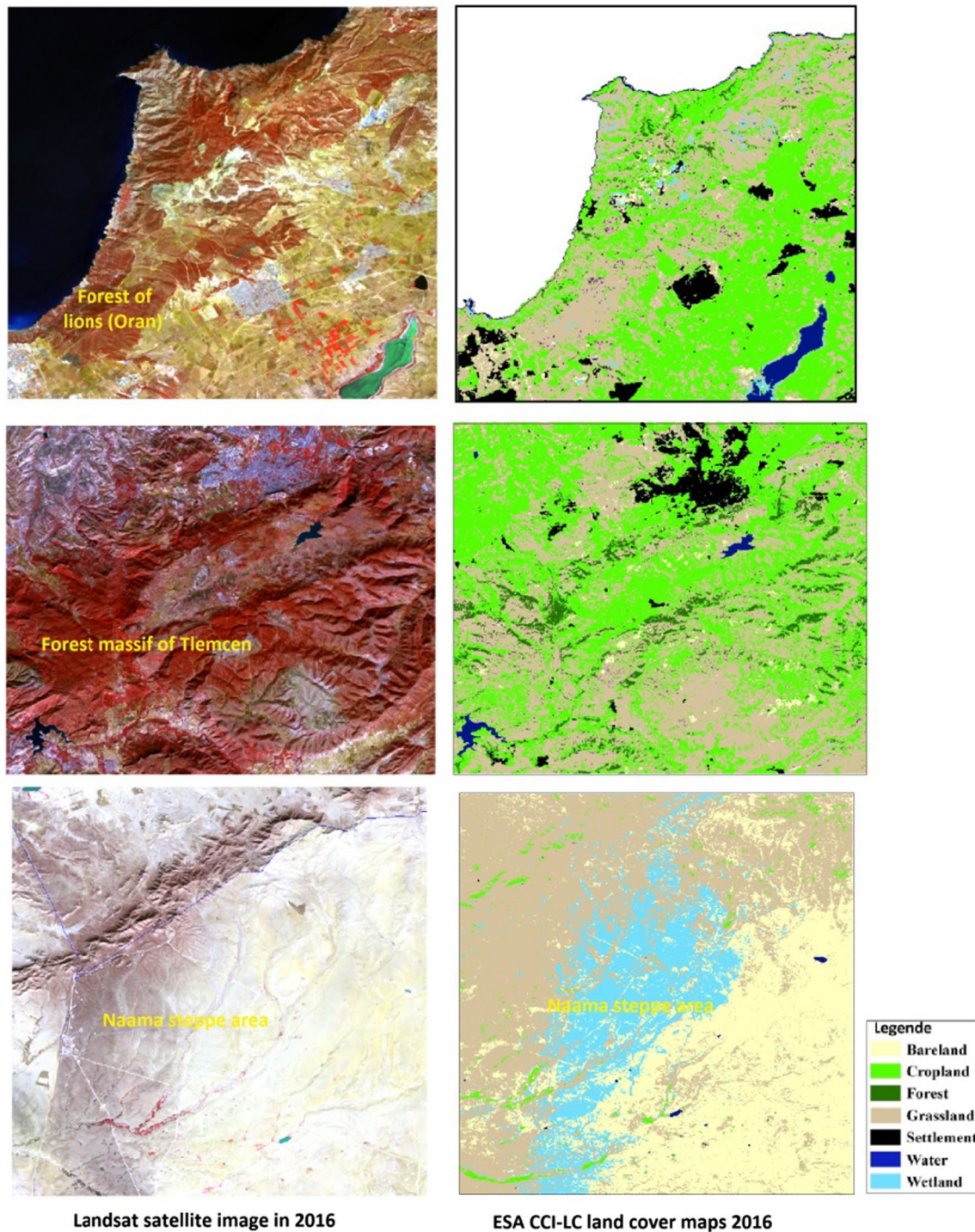
## Conclusion

Mapping approaches on a large geographical scale are a problem of major interest and the techniques around their realization remain topical and constantly evolving.

Indeed, the international demand from institutions for quantitative statistics on the resource (in particular land cover), has made it possible to mobilize various scientific

**Table 5** La matrice de confusion de la classification du 2018

	Bareland	Settlement	Cropland	Forest	Water	Wetland	Grassland
Bareland	96.30	4.41	0	0	0	9.67	0
Settlement	0	92.64	0	0	0	0	0
Cropland	0	2.94	86.51	0	0	0	0
Forest	0	0	5.61	100	0	0	0
Water	0	0	0	0	100	0	1.4
Wetland	1.31	0	0	0	0	87.09	0
Grassland	2.37	0	7.86	0	0	3.22	98.59



**Fig. 15** Comparison of 2016 ESA CCI-LC occupancy maps with 2016 Landsat satellite images of the Tlemcen and Oran region

projects with a view to stimulating scientific research around its axes, in particular the map of land use and the resulting methods, ranging from simplistic methods (mass sampling such as Collect Earth), to automate classifier methods (Trend Earth) for developing countries, to personalize methods (adapted to the specificity of each country), for the

voluntary country proposing their own approach, such as this contribution.

This methodology has made it possible to inject certain characteristics specific to the Algerian territory, such as the use of the slope factor for the discrimination between certain forests and certain shrub crops, an aspect reflecting

in particular the steep slopes of the forests of the Atlas Mountains Algerian.

Other external information has also been implemented, in particular the relief aspect characteristic of the interior Sebkhass of the country (located below sea level), making it possible to categorize the class “wetland” a very heterogeneous class morphologically and whose definition is typically based on user expertise.

The vegetation indices also made it possible to better discern the limits between the three classes “grassland”, “cropland” and “Bare land”, with a view to supporting the initial supervised classifications.

The classification thus offers a distinct added value to international classifications (ESA/MODIS), particularly in physically “heterogeneous” areas such as wetlands, these approaches are also very little adapted to the specificity of North Africa, compensated in our approach by the expertise of the local actor through the first initial classification.

It should nevertheless be noted that this classification only offers for the moment a national scale of 1/500,000, certainly compatible with the requirement of the FAO/UNCCD, but with a very generalizing aspect due to geographical detail (due to the coarse resolution of the MODIS 250 m base image), an improvement in the resolution is planned in perspective (Landsat- 30 m/Sentinel 2–10 m) via the Google Earth Engine platform, making it possible to overcome the hardware concerns (processing power, and the size of the data), while automating our approach, in view of its multi-temporal reproducibility.

In the future, this land cover changes sub-indicator map can be combined with other sub-indicators (degradation of vegetation productivity and change in soil organic carbon stock) to obtain the final result that represents the SDG15.3.1 indicator of the study area. We thus recommend the production of annual and permanent maps of the Algerian land cover to quantify the geographical dynamics at all times. Thus the approach of the decision tree, which was made in this work, could be grouped together in a single automatic program using a specific language.

**Author contributions** NB and WR wrote the main text of the manuscript, NB, WR prepared Figs. 1 to 16, MAB and FB prepared Figs. 12, 13, 14. All authors reviewed the manuscript.

## Declarations

**Conflict of interest** This document is based on materials and data from the Algerian Space Agency, Center of Space Techniques. The interpretations, conclusions and recommendations in this document are made by the authors. The authors have no conflicts of interest to declare.

## References

- Akoguhi PN, Dibi HN, Godo MH, Adja GM, Kouamé FK (2022) Évaluation des méthodes de classifications dirigées (spectrale et orientée objet) sur les images satellitaires à THRS. *Vertigo* - la revue électronique en sciences de l'environnement, Volume 22 numéro 3, Décembre 2022. <http://journals.openedition.org/vertigo/36548>; <https://doi.org/10.4000/vertigo.3654>
- Ammi H (2019) Villes et développement économique en Algérie. Thèse de Doctorat en Sciences Economiques, Sociologie. Université de Toulon, 2019. <https://theses.hal.science/tel-02894853>
- Arabi M (2021) La lutte contre l'érosion en Algérie: De la défense et restauration des sols (DRS) à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols (GCES). *Rev Mar Sci Agron Vét* 9(4):657–665
- ASAL (2023) [https://asal.dz/?page\\_id=1219](https://asal.dz/?page_id=1219)
- Augustin B, Émile F (1902) Les régions naturelles de l'Algérie. *Annales de Géographie* 11(57): 221–246. <https://doi.org/10.3406/geo.1902.18171>; [https://www.persee.fr/doc/geo\\_00034010\\_1902\\_num\\_11\\_57\\_18171](https://www.persee.fr/doc/geo_00034010_1902_num_11_57_18171)
- Belguidoum S (2021) Transition urbaine et nouvelles urbanités : la ville algérienne dans tous ses états. *Moyen-Orient*, 2021. <https://shs.hal.science/halshs-02090578>
- Benderradji MEH, Alatou D, Arfa AMT, Benachour K (2006) Problèmes de dégradation de l'environnement par la désertification et la déforestation Impact du phénomène en Algérie. *New Medit* n° 4/2006: 15–22. [https://newmedit.iamb.it/share/img\\_new\\_medit\\_articoli/80\\_15benderradji.pdf](https://newmedit.iamb.it/share/img_new_medit_articoli/80_15benderradji.pdf)
- Benhamrouche A, Bouchérf D, Hamadache R, Bendahmane L, Martin-Vide J, Teixeira Nery J (2015) Spatial distribution of the daily precipitation concentration index in Algeria. *Nat Hazards Earth Syst Sci* 15:617–625. <https://doi.org/10.5194/nhess-15-617-2015>
- Benkesmia Y, Hassani MI, Kessar C (2023) Variation of surface water extent in the great Sebkhia of Oran (NW of Algeria), using Landsat data 1987–2019: interaction of natural factors and anthropogenic impacts. *Remote Sens Appl*. <https://doi.org/10.1016/j.rsase.2023.100953>
- Bentekhici N, Bellal SA, Zegrar A (2020) A Contribution of remote sensing and GIS to mapping the fire risk of Mediterranean forest case of the forest massif of Tlemcen (North-West Algeria). *Nat Hazards* 104:811–831. <https://doi.org/10.1007/s11069-020-04191-6>
- Besbes M, Abdous B, Abidi B, Ayed A, Bachtta M, Babasy M, Ben Baccar B, El Batti D, Ben Salah Y, BietCharreton M, Biout F, Douma A, Fezzani C, Gadhi M, Horriche F, Kadri S, Khadraoui A, Khanfir R, Kinzelbach W, Larbes A, Latrech D, Margat J, De Marsily G, Mamou A, El Mejerbi M, Mekrazi A, Mhiri A, Moumni L, Nanni M, Pallas P, Pizzi G, Salem A, Salem OM, Taibi R, Zammouri M (2003) Système Aquifère du Sahara septentrional Gestion commune d'un bassin transfrontière. *La Houille Blanche* 89(5):128–133. <https://doi.org/10.1051/lhb/2003102>
- Bied-Charreton M, Makkaoui R, Petit O, Requier-Desjardins M (2006) La gouvernance des ressources en eau dans les pays en développement: enjeux nationaux et globaux. *Mondes en développement* 3: 39–62. <https://doi.org/10.3917/med.135.0039>; <https://www.cairn.info/revue-mondes-en-developpement-2006-3-page-39.htm...>
- Brahim H, Meddi M, Boucefiane A (2013) Analyse fréquentielle des pluies journalières maximales Cas du Bassin Chott-Chergui. *Revue « Nature & Technologie »*. C- Sciences de l'Environnement, n° 08/Janvier 2013 : 41–48
- Broxton P. D., Zeng X, Sulla-Menashe D, Troch P. A (2014) A global land cover climatology using MODIS data. *J Appl Meteorol Climatol* 53(6):1593–1605. <https://doi.org/10.1175/JAMC-D-13-0270.1>; <https://journals.ametsoc.org/downloadpdf/journals/apme/53/6/jamc-d-13-0270.1.pdf>

- Caloz R, Collet C (2001) Traitement numérique d'images de télédétection. Presse De L'université Du Québec, Précis De Télédétection 3:1–398
- Carmagnac F, Héroux P, Trupin E (2004) Classification supervisée d'images de document et contraintes industrielles, Actes du Huitième Colloque International Francophone sur l'Écrit et le Document CIFED'04, 2004. [https://archivesic.ccsd.cnrs.fr/sic\\_00001207/document](https://archivesic.ccsd.cnrs.fr/sic_00001207/document)
- Chandra G, Zhiliang Z, Bradley R (2005) A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets. *Remote Sens Environ* 94(1):123–132. <https://doi.org/10.1016/j.rse.2004.09.005>
- Congalton RG, Gu J, Yadav K, Thenkabail P, Ozdogan M (2014) Global land cover mapping: a review and uncertainty analysis. *Remote Sens* 6(12):12070–12093. <https://doi.org/10.3390/rs61212070>
- CSIRO-UNCCD (2017) Good Practice Guidance SDG Indicator 15.3.1, Proportion of land that is degraded over total land area Version 1.0, September 2017: 1–115 [https://catalogue.unccd.int/1531\\_Good\\_Practice\\_Guidance\\_SDG\\_Indicator\\_15.3.1\\_Versi on\\_1.0.pdf](https://catalogue.unccd.int/1531_Good_Practice_Guidance_SDG_Indicator_15.3.1_Versi on_1.0.pdf)
- Didan K, Barreto Munoz A, Solano R, Huete A (2015) MODIS Vegetation Index User's Guide (MOD13 Series), Version 3.00, June 2015 (Collection 6): 1–35 [https://vip.arizona.edu/documents/MODIS/MODIS\\_VI\\_UsersGuide\\_June\\_2015\\_C6.pdf](https://vip.arizona.edu/documents/MODIS/MODIS_VI_UsersGuide_June_2015_C6.pdf)
- Dronova I, Gong P, Wang L (2011) Object based analysis and change detection of major wetland cover types and their classification uncertainty during the low water period at Poyang Lake, China. *Remote Sens Environ* 115(12):3320–3326. <https://doi.org/10.1016/j.rse.2011.07.006>
- Gaetano R, Scarpa G, Poggi G (2009) Hierarchical texture-based segmentation of multiresolution remote-sensing images. *IEEE Trans Geosci Remote Sens* 47(7):2129–2141. <https://doi.org/10.1109/TGRS.2008.2010708>; <https://ieeexplore.ieee.org/abstract/document/4804737>
- Ghazi A (2009) Desertification in Algeria: policies and measures for the protection of natural resources. In: Facing Global Environmental Change. Hexagon Series on Human and Environmental Security and Peace, vol 4. [https://doi.org/10.1007/978-3-540-68488-6\\_10](https://doi.org/10.1007/978-3-540-68488-6_10)
- Hachemi K, Amrouni Y, Daoudi M, Bamoussa AO (2020) Diachronic study of the great Sebkhia of Oran (western Algeria) based on SAR radar images (1992–2011). *J Taibah Univ Sci* 14(1):1433–1446. <https://doi.org/10.1080/108016583655.2020.1825183>
- Haouchine A, Haouchine FZ, Labadi A (2015) Changements climatiques et activités anthropiques: impacts sur les aquifères côtiers en Algérie. *Larhyss J* 24:227–241
- Hirche A, Salamani M, Abdellaoui A et al (2011) Landscape changes of desertification in arid areas: the case of south-west Algeria. *Environ Monitor Assess* 179(1–4):403–420. <https://doi.org/10.1007/s10661-010-1744-5>
- Huft A (2001) Introduction à la climatologie, Les presses de l'Université de Laval, De Böeck Université: 545
- Lussem U, Hütt C, Waldhoff G (2016) Combined analysis of Sentinel-1 and Rapideye data for improved crop type classification: an early season approach for rapeseed and cereals, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B8, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague: 959–963. <https://doi.org/10.5194/isprsarchives-XLI-B8-959-2016>; <https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XLI-B8/959/2016/isprs-archives-XLI-B8-959-2016.pdf>
- Mattina D, Erdogan H.E, Wheeler I, Crossman ND, Cumani R, Minelli S (2018) Default data: methods and interpretation. A guidance document for the 2018 UNCCD reporting. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany: 1–53. [https://prais.unccd.int/sites/default/files/helper\\_documents/3-DD\\_guidance\\_EN.pdf](https://prais.unccd.int/sites/default/files/helper_documents/3-DD_guidance_EN.pdf)
- Medejerab A, Henia L (2011) variation spatio-temporelles de la sécheresse climatique en Algérie Nord-occidentale, *cour. Savoir* 11:71–79
- Mihi A, Ghazela R, Wissal D (2022) Mapping potential desertification-prone areas in North-Eastern Algeria using logistic regression model, GIS, and remote sensing techniques. *Environ Earth Sci* 81(385):2022. <https://doi.org/10.1007/s12665-022-10513-7>
- Ministère de l'Agriculture, du Développement Rural et de la Pêche (2015) Rapport national sur la Neutralité dans la Dégradation des Terres: 31. [https://knowledge.unccd.int/sites/default/files/ldn\\_targets/algeria-ldn-country-report-final-draft.pdf](https://knowledge.unccd.int/sites/default/files/ldn_targets/algeria-ldn-country-report-final-draft.pdf)
- Nedd R, Light K, Owens M, James N, Elijah J, Anandhi A (2021) A synthesis of land use/land cover studies: definitions classification systems, meta-studies, challenges and knowledge gaps on a global landscape. *Land* 10(9):994. <https://doi.org/10.3390/land10090994>
- Nedjraoui D, Bédrani S (2008) La désertification dans les steppes algériennes: causes, impacts et actions de lutte, *Vertigo - la revue électronique en sciences de l'environnement* [En ligne], Volume 8 Numéro 1, avril 2008, <http://journals.openedition.org/vertigo/5375>; <https://doi.org/10.4000/vertigo.5375>
- Nichane M, Bouchikhi Tani Z, Khelil MA (2013) Biodiversité et approche bioécologique de la faune des Monts des Traras Occidentaux (Nord-Ouest Algérien) *Afrique Science* 09(2):101–109. <https://www.ajol.info/index.php/afsci/article/view/112076>
- Office National des Statistiques (ONS) (2008) L'armature urbaine RGP 2008, Les principaux résultats de l'exploitation exhaustive, Coll. Statist., n° 163: Série S : 1–240 [https://www.ons.dz/IMG/pdf/armature\\_urbaine\\_2008.pdf](https://www.ons.dz/IMG/pdf/armature_urbaine_2008.pdf)
- Otukei J, Blaschke T (2010) Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *Int J Appl Earth Observ Geoinf* 12(Suppl. 1):27–31. <https://doi.org/10.1016/j.jag.2009.11.002>
- Owuor GO (2021) Monitoring land degradation neutrality using geospatial techniques in support of sustainable land management: a case study of Narok County, Master of Science in Geographic Information Systems, Department of Geospatial and Space Technology, University of Nairobi School of Engineering: 1–57 <http://erepository.uonbi.ac.ke/handle/11295/155802>
- Pohl C, Van Genderen JL (1998) Review article Multisensor image fusion in remote sensing: concepts, methods and applications. *Int J Remote Sens* 19(5):823–854. <https://doi.org/10.1080/014311698215748>
- Pony O, Descombes X, Zerubia J (2000) Classification d'images satellitaires hyperspectrales en zone rurale et périurbaine. Rapport de recherche n 4008, Projet Ariana, Institut national de recherche en informatique et en automatique, Sep 2000, 0–64
- Razagui A, Bachari NEI (2014) Analyse spatio-temporelle de l'indice de végétation NDVI calculé à partir des images satellites NOAA et MSG. *Revue Des Energies Renouvelables* 17(3):497–506
- Rukhovich DI, Koroleva PV, Rukhovich DD, Kalinina NV (2021) The use of deep machine learning for the automated selection of remote sensing data for the determination of areas of arable land degradation processes distribution. *Remote Sens* 13(1):155. <https://doi.org/10.3390/rs13010155>. (1–28)
- Sekkoum K, Talhi M.F, Cheriti A, Bourmita Y, Belboukhari N, Boulenouar N, Taleb S (2012) Water in Algerian Sahara: environmental and health impact, advancing desalination advancing desalination edition: InTech Open Chapter 10: Water in Algerian Sahara: environmental and health impact, July 2012. <https://doi.org/10.5772/50319>
- Senoussi A, Khene B, Hannachi S (2012) Lecture de l'espace oasien en Algérie: décadence ou renouveau? Cas du pays de Ouargla et de la vallée du M'zab. *Journal Algérien des Régions Arides* n° 09/10/11-2012: 81–93. <https://www.crstra.dz/telechargement/>

[journals/jara-9-10-11-2012/pdf/journal-algerien-des-regions-arides-n-9-10-11-2012.pdf](#)

- Sims NC, Newnham GJ, England JR, Guerschman J, Cox SJD, Roxburgh SH, Viscarra Rossel RA, Fritz S, Wheeler I (2021) Good practice guidance. SDG Indicator 15.3.1, Proportion of land that is degraded over total land area. Version 2.0. United Nations Convention to Combat Desertification, Bonn, Germany
- UCL-ESA (2016) Land cover CCI product user guide, Version 2. 4: 1–84 [https://www.esa-landcover-cci.org/?q=webfm\\_send/84](https://www.esa-landcover-cci.org/?q=webfm_send/84)
- Xu M, Watanachaturaporn P, Varshney PK, Arora MK (2005) Decision tree regression for soft classification of remote sensing data. *Remote Sens Environ* 97(3):322–336. <https://doi.org/10.1016/j.rse.2005.05.008>
- Zegrar A (2015) Determination and analysis of desertification process with satellite data Alsat-1 and Landsat in the Algerian Steppe. *Eng*

*Geol Soc Territory* 2:1847–1852. [https://doi.org/10.1007/978-3-319-09057-3\\_327](https://doi.org/10.1007/978-3-319-09057-3_327). (Springer)

- Zonn IS, Kust GS, Andreeva OV (2017) Desertification paradigm: 40 years of development and global efforts. *Arid Ecosyst* 7:131–141. <https://doi.org/10.1134/S2079096117030118>

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