

Chapter 23

Classification Methods for Detecting and Evaluating Changes in Desertification-Related Features in Arid and Semi-arid Environments

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Abstract Land cover, land use, soil salinisation and sand encroachment, which are desertification-indicating features, were integrated into a diachronic assessment, obtaining quantitative and qualitative information on the ecological state of the land, particularly degradation tendencies. In arid and semi-arid study areas of Algeria and Tunisia, sustainable development requires the understanding of these dynamics as it withstands the monitoring of desertification processes. Two different classification methods of salt and sand features have been set up, using historical and present Landsat imagery. Mapping of features of interest was achieved using both visual interpretation and automated classification approaches. The automated one implies a decision tree (DT) classifier and an unsupervised classification applied to the principal components (PC) extracted from Knepper ratios composite. Integrating results

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with ancillary spatial data, we could identify driving forces and estimate the metrics of desertification processes. In the Biskra area (Algeria), it emerged that the expansion of irrigated farmland in the past three decades has been contributing to an ongoing secondary salinisation of soils, with an increase of over 75%. In the Oum Zessar area (Tunisia), there has been a substantial change in several landscape components in the last decades, related to increased anthropic pressure and settlement, agricultural policies and national development strategies. One of the concerning aspects is the expansion of sand encroached areas over the last three decades of around 27%. This work is partly supported and developed within the WADIS-MAR Demonstration Project, funded by the EU Commission through the SWIM Programme (www.wadismar.eu).

Keywords Arid and semi-arid areas · Desertification · Salinisation · Sand encroachment · Land cover/use mapping · Change detection · Decision tree classification · Knepper ratios · Principal component analysis · Landsat series

Background

Salinity built-up is a concerning and increasing problem that has rendered impracticable extensive agricultural land, whereas soil salinisation is present to different extents in more than 50% of the irrigated drylands (Elnaggar and Noller 2010; Fares and Philip 2008; Masoud and Koike 2006). The two arid and semi-arid sites of the Maghreb region that are discussed in this chapter are affected by two major land degradation processes: soil salinisation and sand encroachment. Natural and anthropologic factors have a strong impact on the ecological state and quality of soils, especially in such drylands where agricultural and animal husbandry practices are intensive, being the main branches of the local economy. Desertification phenomena and land degradation processes threaten the sustainability and reliability of economic growth, hence monitoring is an indispensable requirement for reviewing and improving resource management.

The present work proposes a versatile workflow for the qualitative and quantitative estimation of spatio-temporal variations of desertification phenomena in roughly accessible drylands. It comprises auxiliary, ground truth data and remote sensing methods. The current research was undertaken in the framework of the WADIS-MAR Demonstration Project, funded through the Sustainable Water Integrated Management (SWIM) Programme, by the European Commission (www.wadismar.eu). It aims at the endorsement of an integrated, sustainable management of agriculture and water harvesting in the Biskra region of Algeria and the Dahar-Jeffara area (Oum Zessar study area) of central-eastern Tunisia (Ghiglieri et al. 2014).

Considering the main forms of land degradation that are specific to drylands, soil salinity and especially secondary salinisation represent the main threat to sustainable agriculture in the Biskra region. The economy of the Biskra area is

agricultural-based, and it represents one of the most important date palm producer and exporter at national and also international scale. In order to cope with increasing production demand and population needs, agricultural activities intensified, over-soliciting already fragile soils. Moreover, the climatic setting predisposes the concentration of salts in ephemeral surficial and slow-flowing underground waters that eventually are brought to surface through seepage due to excessive evapotranspiration, thus favouring salt crust formation (Fares and Philip 2008). In the Oum Zessar study site in Tunisia, on the other hand, sand encroachment represents the main threat for the agro-pastoral activities, which represent the base of the regional economy (Ouerchefani et al. 2013; Ouessar 2007). However, even if salinisation is present to a much lesser extent, the issue of salinisation must not be overlooked.

Remote sensing and the employment of geospatial tools have been confirmed as valid instruments and methods for diachronic analyses through the assessment of desertification indicators in order to support decision-makers (Abbas et al. 2013; Allbed and Kumar 2013; Vogiatzakis and Melis 2015; Zewdie 2015; Vacca et al. 2014; Melis et al. 2013b; Fichera 2012). The employment of change detection analysis offers the possibility to quantitatively and qualitatively estimate change rates and, therefore, argue driving factors (Afrasinei 2016).

Common and acknowledged digital image classification methods, such as supervised, unsupervised or spectral mixture, have been widely applied for the delineation of salt features, but no agreed-upon and replicable technique has been acknowledged to be optimal. The state-of-the-art reports problems regarding misclassification and spectral mix-up with other land cover types, especially impermeable features, bare land and areas that have a high content of carbonate minerals (Elnaggar and Noller 2010; Fares and Philip 2008; Khan et al. 2001).

In the Oum Zessar study area, in Tunisia, the main desertification issues are of anthropic origin, as pressure increased in recent years due to changes in socio-economic policies (Afrasinei et al. 2015a; Ouessar 2007, 2010; Sghaier et al. 2010; Schiettecatte et al. 2005).

Sand encroachment is one of the most serious environmental problems in South Tunisia, and previous research shows that several unwary human activities have contributed to the intensification of this process, namely overgrazing, change in land use, from pasture to agriculture and other disturbances coming from inappropriate agricultural practices (Ouerchefani et al. 2013). The studies conducted in the arid and semi-arid Tunisia that approach the sand encroachment and salinisation issues (Lorenz et al. 2013; Ouerchefani 2012; Essifi et al. 2009; Dalel Ouerchefani 2008) are limited to either local test sites or regional scale, and results on driving forces and trends need more insight. The contributing factors are reported as being mainly of anthropogenic nature and not of natural, windborne one, with the Grand Oriental Erg is the source area. In this sense, studies argue that the aeolian sand transport in Southern Tunisia is influenced by the predominant active winds ($u > 3 \text{ m}^{-1}$), coming from the east, south-east and north. This implies a movement towards Sahara and not the opposite (Khatelli and Gabriels 1998, 2000), but the results need further validation.

Considering (1) vast spatial and temporal coverage required for monitoring, (2) limited or no access to ground verification, and (3) the need to correctly delineate features of interest (land cover types, salty and sandy areas), we propose a customised methodological workflow involving remote sensing techniques and mapping land cover and land use (LCLU) through both visual interpretation and automated image classification methods.

Salt and sandy features can be delineated and characterised spectrally based on the high content of main minerals when mapping using multi- or hyperspectral satellite imagery. Band ratios are simple but highly efficient band operations that have been used also by the geological remote sensing community to identify hydrothermally altered minerals, hydrated sulphates and carbonates and other types of land features as described by Langford (2015) (Mia and Fujimitsu 2012). Specific red-green-blue (RGB) composites have been defined through the combination of various ratios, such as the Knepper ratios (Langford 2015). Up-to-date literature shows that Knepper ratios have been used only in geological remote sensing until now (Afrasinei et al. 2017; Langford 2015; Afrasinei et al. 2015a, b). In this study, we propose its employment for salt and sand features extraction (Afrasinei et al. 2015a, b).

The two automated classifications that are developed in this work comprise either supervised multi-stage decision tree classifier (DT) (Matthew 2012; Srimani and Prasad 2012; Elnaggar and Noller 2010), or unsupervised Iterative Self-Organizing Data classification applied to principal components (PC) of Knepper ratios.

For what the Tunisian study area is concerned, the classification methods, either visual or automatic, are supported by a thorough, systematic ground truth (GT) campaign. In the case of the Biskra site, a large and complex set of auxiliary data were employed in the different stages of the analysis, as field survey was difficult to acquire due to the current political and social context.

The scope of this study was not only to map the land cover and soil conditions for a certain point in time but also to construct a customised and replicable methodology in order to repeat this investigation in different moments in time in similar environmentally sensitive areas and minimise previously reported issues of misclassification (Li 2014; Nutini et al. 2013; Ceccarelli 2013).

Study Sites

Wadi Biskra Study Area, Algeria

This study site, of approx. 5000 km², is located in the Biskra Wilayat, in the north-eastern sector of the Northern Sahara. Representing a vast piedmont area, it is delimited by the Aures mountainous domain in the North and by the Sahara plain in the South (Fig. 23.1a). The area is also known as the *Zibans* (meaning *oasis* in

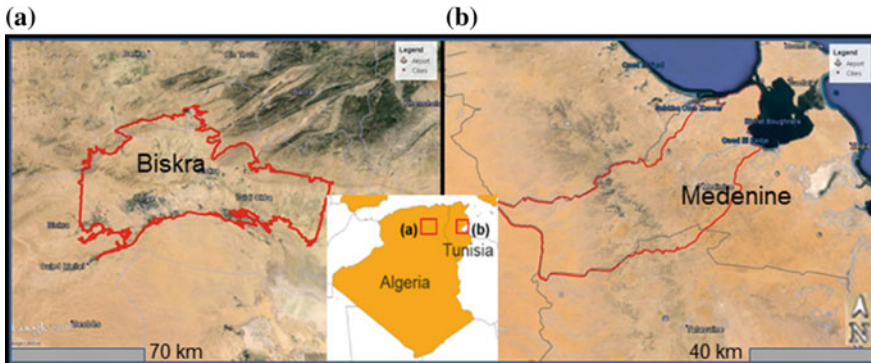


Fig. 23.1 Study areas: Biskra, Algeria (a) and Oum Zessar, Tunisia (b)

berbere language), being possible to distinguish two agricultural sub-zones: (1) the *Occidental Zab* or the *Zibans palmeraie* (meaning palm groves), based on date palm plantations and (2) the *Oriental Zab* based on open field and industrial cultures. These latter cultures do not require a shallow aquifer (unlike phoeniculture), and this favoured their expansion in the past 30 years, but, instead, they require deep pumping of groundwater that has a higher salinity than the shallow acquirers of the Occidental Zab (Bougherara and Lacaze 2009).

In the Occidental Zab, the highly productive and superficial aquifers (average salinity of 2–4 g/l) provide the conditions for a high production of high-quality dates (Ghiglieri et al. 2014). The irrigated area of around 70,000 ha has been reported to require the drawing of more than 600 million m³ per year (NRD 2011).

Various studies have focused on obtaining qualitative and quantitative parameters of these aquifers, some of which have employed up-to-date approaches of three-dimensional (3D) modelling, bringing to the attention of end users their limited and fragile features (Arras et al. 2016; Arras et al. 2015; Pelo et al. 2015; Arras et al. 2014a, b; Buttau et al. 2013; Buttau and Funedda 2008; Buttau et al. 2007).

From the geological point of view, the Biskra area is located in the eastern part of the Saharan Atlas (Aures), between the folded Atlas domain in the northern part of the area and the Saharan desert and flat domain in the South. Its main lithological characteristics are given by the presence of Quaternary and Mio-Pliocene sands and clays, Mid-Eocene gypsum clays and evaporitic deposits, Lower Eocene limestone, gypsum clays and halite, Turonian dolomitic limestone and dolomites and Cenomanian clay, marlstone and gypsum (Buttau et al. 2013; Algerienne 1980).

The climatic regime of this area is hot and dry, with an average annual temperature of about 22 °C, with a total annual rainfall average of approx. 150 mm. However, the average rainfall within a year is less than 20 mm. The minimum rainfall is almost null in the months of July and August, and the maximum occurs in March and November.

Oum Zessar Study Area, Tunisia

The area of about 3000 km² mainly overlaps the Médenine Governorate and stretches from the Great Oriental Erg in the West and crosses the Dahar Plateau and Jeffara plain, reaching the Mediterranean Sea to the East (Fig. 23.1b).

It is denominated generically ‘Oum Zessar’ because it comprises the whole Oum Zessar watershed (of about 35 000 ha), and it bares its name due to its importance for optimal characteristics for water supply in the surrounding area. The land use types are: extended rangelands, extended olive groves (mainly in the Jeffara plain), local scale arboriculture, episodic cereals and small-farming irrigated agriculture. Crop sites, mainly arboriculture, are mainly found within torrential bodies behind water harvesting structures: *jessour* and *tabias*. (Ouessar 2011) which are favoured by the geomorphological context of the area, such as a high presence of alluvial landforms and paleo-valleys (Marini et al. 2008; Waele and Melis 2008).

The geological setting is given by (1) Mesozoic deposits outcropping mainly in the Dahar domain, underlining the importance of the Cretaceous carbonate deposits with gypsum intercalations for the current study and the (2) Mio-Pliocene continental deposits and (3) Quaternary alluvial and aeolian deposits found mainly in the Jeffara plain (Arras et al. 2015).

The shallow aquifers of the Mio-Plio-Quaternary deposits and the Turonian dolomitic limestone are exploited for the domestic use, with a salinity that ranges from 0, 6 to 5 g/l. The water table ranges from 30 to 2–3 metres near the coastal plain. The area receives between 150 and 240 mm of total annual rainfall and is defined by mild to cold winters and warm to very hot summers (up to 48 °C), with almost null rainfall from June to August.

Methodology and Data Analysis

The methodological approach was tailored considering several criteria based on the objectives of this work and the issues aimed to solve. It was approached from both the theoretical and empirical perspective, explained as follows. The theoretical one refers to the existing environmental problem of salinity and sand encroachment, and the approach that the state-of-the-art literature advises to be adopted when attempting to define current state, driving forces and the trends of these phenomena. The empirical perspective refers to the chosen schema of methods, considering the availability of ancillary data, coping with the difficulty or impossibility to acquire ground data and misclassification issues. This latter one refers to the spectral confusion that is very common among desert features, as they are very reflective.

The mapping methods scheme refers to the employment of two different classification approaches: mapping through on-screen visual interpretation and digital image automatic classification. The first phase of this research consisted of the comprehensive knowledge of the areas and the generation of the LCLU maps used

as support and base map for the following analysis phases. Since base cartographic data were limited or outdated in these areas (dating from the 60s, in the case of Biskra area) as well as not of full spatial coverage, this first phase was necessary in order to update pre-existing maps or even create new ones, being indispensable for the holistic knowledge and acquaintance with the study area.

Secondly, two different automated classifiers were assessed, designed and applied: (1) a decision tree classifier (DT) and (2) a customised unsupervised classification method. These methods were chosen in accordance with reported limitations of variously experimented classification methods in similar case study contexts by the scientific community (Elnaggar and Noller 2010; Pal and Mather 2003). The DT contains five new indices (Afrasinei et al. 2017; Afrasinei et al. 2015b) tailored for this particular type of study, that were constructed manually through thorough spectral analysis, band transformation techniques, image statistics and expert knowledge (Rao et al. 2006; Elnaggar and Noller 2010; Matthew 2012; Srimani and Prasad 2012). The IsoDATA classification was applied to the PC extracted from the Knepper ratios (Langford 2015), as described in Section ‘[Principal Component Analysis of the Knepper Composite](#)’. Given the political and social context in Algeria, the ground survey was not possible to undertake personally, therefore it was acquired in collaboration with the Algerian WADIS-MAR partners. Being difficult to acquire it in the proper amount required by such studies, multi-source ancillary data were employed throughout the study phases.

Thirdly, the IsoDATA-Knepper-PC resulting maps are compared with the DTA results and with the visually interpreted LCLU maps and assessed for error assessment through the application of the confusion matrix. Change detection is applied in both cases, and the results are discussed through correlation to social and economic ancillary data. The ESRI ArcGIS (version 10.2) software was employed for geoprocessing and spatial data analysis and ENVI ITT VIS Exelis version 5.2 for digital image management (pre-treatment, processing and post-classification). A schematic flowchart is illustrated in Fig. 23.2.

Dataset

A comprehensive database of various data types (containing either spatial data or non-spatial) was put together within the WADIS-MAR project, having homogeneous geometries and projections. For easiness of interrogation, manipulation, overlay and geoprocessing, hard copy information was digitalised and stored within a database in a GIS environment, comprising agricultural calendars, pedological surveys and well reports, as well as topographical, geological maps and aerial photographs. These consisted the support data used for the first phase of analysis and LCLU mapping through visual interpretation.

Most of the data were made available by the WADIS-MAR local partners such as the National Agency of Hydraulic Resources of Algeria (ANRH), the Technical Institute of Development of the Sahara Agronomy (ITDAS), Arid regions Institute

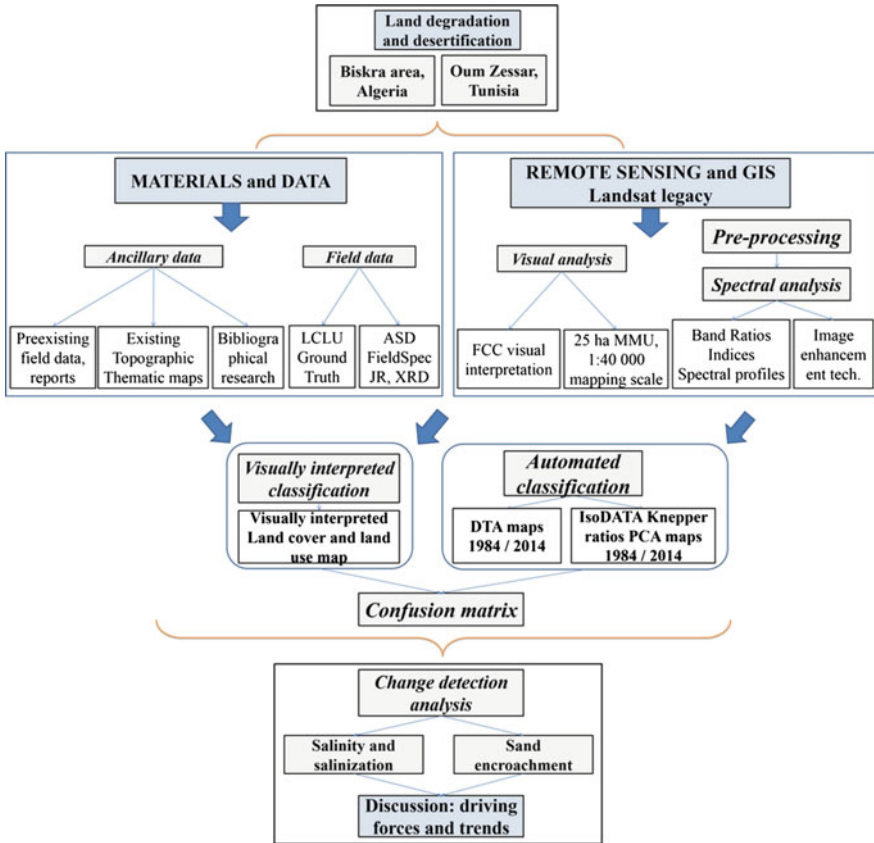


Fig. 23.2 Methodological flowchart

(IRA) and *Observatoire du Sahara et du Sahel* (OSS). Google Earth and its community-based ground truth data were also used as ancillary information.

In addition to this, field data was acquired in the Oum Zessar area from April to June 2014, according to a stepwise methodology. These observations served as ground truth data for the adjustment of the previously interpreted LCLU maps and as field data on salt-affected areas and sand encroachment areas.

The results consist in a ready-to-use geodatabase of 400 observation points with attached geotagged photographs and attributes obtained partly from land cover sheets and attributes recorded onsite in ArcPAD GIS software on Mobile Mapper GPS. A part of these points was also used as training data for further supervised classification and, the other part, for validation.

The Landsat satellite imagery (courtesy of USGS, <http://earthexplorer.usgs.gov>) was downloaded and selected discarding exceptional humid years and considering only the scenes with less than 10% cloud coverage. Climate data was taken into consideration when choosing the imagery acquired during the dry season or at the

Table 23.1 Landsat scenes used for Biskra area and climate data. Climatic data legend: T—average temperature (°C); TM—maximum temperature (°C); Tm—minimum temperature (°C); SLP—atmospheric pressure at sea level (hPa); H—average relative humidity (%); PP—total rainfall and/or snowmelt (mm); VV—average visibility (km); V—mean wind speed (km/h); VM—maximum sustained wind speed (km/h) (Tutiempo Network)

Landsat	WRS path	WRS row	Year	Date	T	TM	Tm	SLP	H	PP	VV	V	VM
LT5	194	36	1984	2 Sept	29.6	36.2	23.4	1017.2	29	0	13.7	10.2	25.9
LC8	194	36	2015	7 Aug	35.8	43	29	1010.2	28	0	11.6	9.6	22.2

end of it, as it has been reported to be the most suitable period of the year for remote sensing salinity mapping (Elnaggar and Noller 2010). Scenes starting from 1984 to 2015 were employed in the analysis of the two study areas (Tables 23.1 and 23.2). It must be mentioned that in the case of Oum Zessar area, two scenes were needed for the full coverage of the study area, so the closest dates as possible were chosen for the mosaic construction of each year.

Visual Interpretation

Visual interpretation is still one of the most widely used methods for identifying and classifying spatial features in a digital image. In this study, the visual interpretation and construction of the LCLU maps served as support for the following phases of the study. Their quality and validity (Elnaggar and Noller 2010) are confirmed through to the use of acknowledged methodology (ETC/LC and Agency 1999; Feranec and Otahel 2000; Büttner et al. 2000; Jaffrain and EEA 2011), a large set of ancillary data, a mapping scale of 1:40,000 and a minimum mapping unit of 25 hectares (MMU). This phase was also supported by ground truth data in the Tunisian study area (Elnaggar and Noller 2010).

Integrating also a geomorphological study (Marini et al. 2008), we managed to delineate and define classes using objective criteria of a set of seven variables (precision of contours, colour/hue, size, texture, structure, spatial distribution and location (ETC/LC and Agency 1999) and keys of interpretation. This procedure allowed us to define and describe the identified classes in detail and define a customised LCLU nomenclature to the local context with a detail up to the fourth level of (according to CORINE (ETC/LC and Agency 1999), CORINE outside Europe (ESA and FAO) and AFRICOVER 2000). In the Biskra area, the interpretation of the June 2011 Landsat scene resulted in 37 feature classes, employing the data described in the previous sections, given the difficulty to undertake ground verification. For the Oum Zessar area, the 36 classes were delineated based on the visual interpretation of Landsat 8 images of 17 May 2013, path 190, row 37 and 24 May 2013, path 191, row 37, combined with ancillary data and the ground truth data described in the previous *Dataset* section.

Table 23.2 Landsat scenes used for Oum Zessar area and climate data. Climatic data legend: T—average temperature (°C); TM—maximum temperature (°C); Tm—minimum temperature (°C); SLP—atmospheric pressure at sea level (hPa); H—average relative humidity (%); PP—total rainfall and/or snowmelt (mm); VV—average visibility (km); V—mean wind speed (km/h); VM—maximum sustained wind speed (km/h) (Tutiempo Network)

Landsat	WRS path	WRS row	Year	Date	T	TM	Tm	SLP	H	PP	VV	V	VM
LT5	190	037	1984	18 Jun	28.3	34.5	17.7	1017.3	37	0	8	15.6	25.9
LT5	191	037	1984	25 Jun	29	34.4	21.3	1015.1	49	0	8	19.3	25.9
LC8	190	037	2014	21 Jun	28.6	32.8	21.6	1013	68	0	23	11.9	18.3
LC8	191	037	2014	28 Jun	30.6	36	20.8	1017.7	47	0	24.9	9.6	14.8

Image Processing and Classification Methods

For both areas, level LIT products were radiometrically calibrated to obtain top of atmosphere reflectance and atmospherically corrected by applying Dark Object Subtraction, thus obtaining surface reflectance. The information contained in the metadata of each scene was used to understand the level of product pre-processing undergone by the provider. Since these products were LIT level, meaning that their provider pre-processing employed ground control points and relief models, geometric correction was not performed (Hamid Reza and Majid Shadman 2012). The relevance of applying topographic correction was determined through an assessment of its effects when applied in arid regions such as our study areas, where land features are very reflective, and the thresholds for their separation are very sensitive. Thus this type of correction was not performed since the state-of-the-art literature reported that topographic correction in desert areas is prone to over-correct values in plain areas and lose valuable information (Vanonckelen et al. 2013).

Decision Tree Classifier Design

A complex spectral analysis was undergone in order to determine optimal data for each decision node. Several vegetation, water and mineral indices were reviewed and applied, choosing the relevant ones reported as successful saline (Allbed and Kumar 2013; Mulder et al. 2011; Hamid Reza and Majid Shadman 2012; Khan et al. 2005; Elnaggar and Noller 2010) and sandy areas delineation (Ouerchefani et al. 2013; Essifi et al. 2009), respectively, in similar environmental and biogeographical areas. The outcomes of these tests showed discrepancies regarding correct delineation of features and accuracy of class assignment. Therefore, in order to construct the decision tree, the best band ratios or indices constructed through compound band mathematical operations were determined for the discrimination of features of interest, with the highest possible accuracy. The choice of optimal band ratios and spectral indices was done through a complex spectral analysis for all scenes of both areas. This involved 2D scatter plots, vertical and horizontal spectral profiles

assessment, band transformation techniques with emphasis on image spectral enhancement, among the other types (spatial and radiometric). Image statistics were used to calculate each node's threshold.

In order to delineate each feature of interest, regions of interest (ROIs) were created either from 2D scatter plots or through direct delineation on images and consequently, statistics were extracted from each band. The bands that were highly uncorrelated (had the highest covariance), were used for band operations as they provided less redundant data and the maximum information content. This retrieval of information is obtained from the combination of bands that have higher covariance among them, and the higher the standard deviation is, the more information content is derived from composite bands (Afrasinei et al. 2015b).

Out of a total of eleven indices, five new ones proposed by (Afrasinei et al. 2015b), were employed in the DTA for Biskra area (Table 23.3), which were constructed through relatively complex mathematical band operations.

Two new indices are proposed within this study and they were employed in the DT used for Oum Zessar area, as presented in Table 23.4. All the indices were constructed differently for each area, depending on the spectral and biophysical-geographic particularities of each area, but also on the basis of the features of interest to be extracted: in Biskra area, salt-affected areas had priority, followed by the main land cover types, whereas in Oum Zessar area, the sandy ones, followed by the saline ones and eventually land cover.

Principal Component Analysis of the Knepper Composite

The principal components were extracted from Knepper composites (Langford 2015). This gave us the input for understanding to what degree Knepper PC can

Table 23.3 Decision tree classification nodes and thresholds—Biskra study site, Algeria (decision nodes)

Decision nodes	Node expressions	Band operations
NDVI (Allbed and Kumar 2013)	b1 GE 0.240	$(NIR-R)/(NIR + R)$
NDWI (SEOS 2014)	b2 GE 0.010	$(NIR-SWIR1)/(NIR + SWIR1)$
NDWI USGS (McFeeters 1996; Khan et al. 2005)	b3 GE -0.390	$(R-NIR)/(R + NIR)$
WR [derived from (van der Meer et al. 2012)]	b4 GE 1.01	R/NIR
SMI*	b5 GE 0.740	$\sqrt{((B^2) + (G^2) + (R^2))}/SWIR2)$
MI*	b6 GE 0.0280	$(B * G * R) / NIR$
IRI_SWIR1*	b7 GE 0.880	$\sqrt{((NIR^2) + (SWIR2^2))}/SWIR1)$
IRI_NIR*	b8 GE 1.70	$\sqrt{((SWIR1^2) + (SWIR2^2))}/(NIR^2))$
S2 (Allbed and Kumar 2013)	b9 LE -0.320	$(B-R)/(B + R)$
HIS*	b10 GE 1.740	$(B + G+R)/SWIR2$
1/5 (Melis et al. 2013a)	b11 GE 0.220	B/SWIR1

*Indices proposed by (Afrasinei et al. 2017)

Table 23.4 Decision tree classification nodes and thresholds, Oum Zessar area, Tunisia (decision nodes)

Decision nodes	Node expressions	Band operations
NDVI	b1 GT 0.1450	$(\text{NIR}-\text{R})/(\text{NIR} + \text{R})$
Ratio 5/2	b3 GT 4.20	(NIR/B)
Diff 5-2	b5 GT 0.370	$(\text{NIR}-\text{B})$
Ratio 6/3	b7 GT 3.10	$(\text{SWIR1}-\text{G})$
Diff NDVI-NDWI	b8 GT 0.260	$((\text{NIR}-\text{R})/(\text{NIR} + \text{R})) - ((\text{NIR}-\text{SWIR1})/(\text{NIR} + \text{SWIR1}))$
MMI*	b4 GT 0.60	$(\sqrt{\text{R}*\text{R}} + (\text{SWIR1}*\text{SWIR1}))$
Modif SI*	b6 GT 0.450	$(\sqrt{\text{B}*B} + (\text{NIR}*\text{NIR}))$
NDWI	b2 GT -0.050	$(\text{NIR}-\text{SWIR1})/(\text{NIR} + \text{SWIR1})$

*Indices proposed in this study

spectrally distinguish the features of interest, namely the mineral components and vegetation types. Moreover, this phase aimed to assess its prospective as a simple user-independent approach of fast classification, an auxiliary to decision tree classifier, since this latter one is highly dependent on how thresholds are calculated and requires much computational labour for the determination of rules. The obtained images were classified using IsoDATA unsupervised classifier for both areas.

Results and Discussions

DT Classifier

The normalised vegetation index, two water indices, existing and new salinity indices, as well as simple band ratios were employed in the DT classifier, and the final map was obtained. The choice of the indices or band operations that were derived through the previous spectral analysis has proven to give optimal results (Melis et al. 2013a). Considering mean values and standard deviation, the threshold values of the decision nodes were derived from each index image statistics. The DT classifier was applied to the 1984 and 2015 images in the case of Biskra area and to the 1984 and 2014 images for the Oum Zessar area. The example of Biskra area is presented in Figs. 23.3 and 23.4, where classes are defined according to (Afrasinei et al. 2017; Afrasinei et al. 2015b) and the Oum Zessar one, in Figs. 23.5 and 23.6.

The DT components and class description were tailored for each study site considering their particular biophysical characteristics, bearing in mind especially their specific lithology and the main types of vegetation cover that can be spectrally distinguished among themselves, respectively.

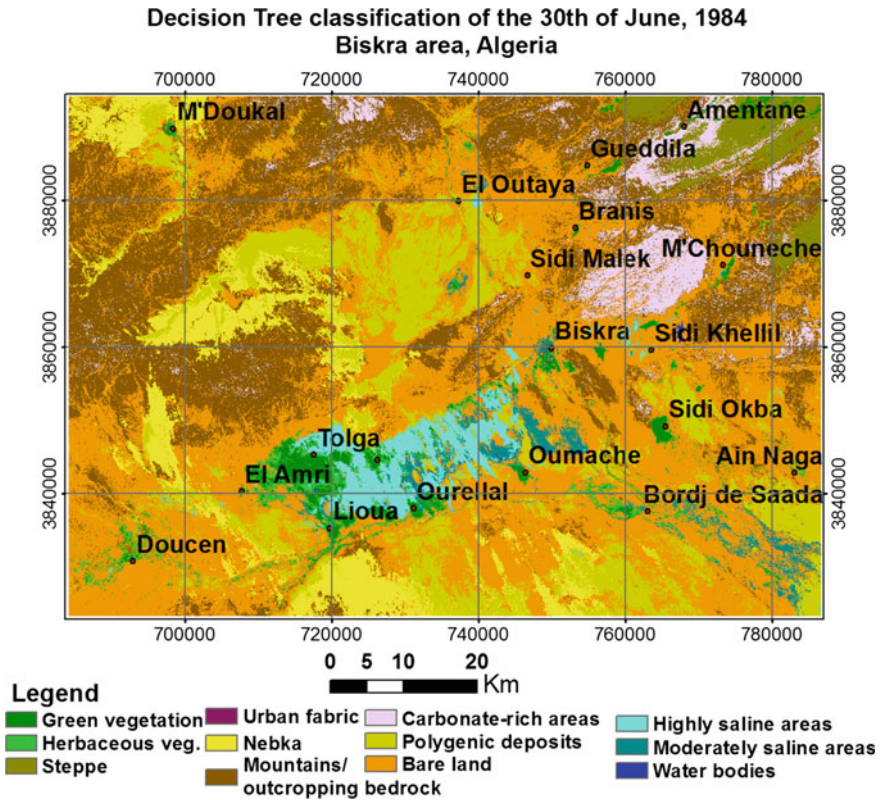


Fig. 23.3 Customised decision tree classification applied to the 1984 Landsat scene, Biskra area, Algeria

IsoDATA Classifier of Knepper-ratios composite Principal Components

The principal components analysis indicated that the information regarding the abundant salt minerals were found within the third component in both years' images in the case of Biskra area. The highest amount of irredundant data of the three input images (namely the Knepper ratios) was related to sand minerals, emphasised by the first principal component. The second component emphasised clay minerals, usually overlying alluvial fans areas where sandy, loamy or clayey soils are usually present.

Consequently, the resulting PC bands were further classified using unsupervised classification, IsoDATA in ENVI 5.2. ITT VIS Exelis Boulder, CO, applied with 100 iterations and a 2% threshold to obtain a clear delineation of saline areas and sandy areas. The seven major classes were not delineated correctly using IsoDATA classification since it presented misclassification issues in both areas and it gave an overall accuracy inferior to 60%. Therefore, only the 'saline soil' and 'moderately

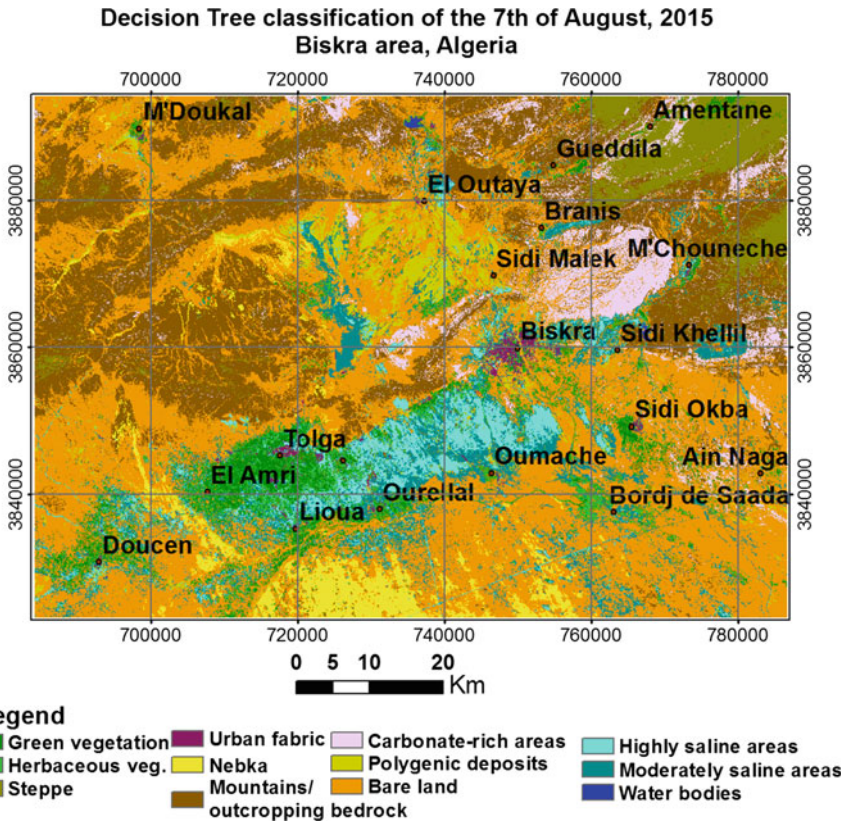


Fig. 23.4 Customised decision tree classification applied to the 2015 Landsat scene, Biskra area, Algeria

saline areas’ classes were employed for the confusion matrix analysis for change detection. In the Oum Zessar area, the third principal component contained the sandy areas information, and good results were also obtained on the spectral distinction between the aeolian sand West of Dahar and the inner-plain one. IsoDATA was applied on the three resulting components, but with several issues of misclassification.

Discussion

The observations that were made on the Biskra satellite images during the pre-classification phase related to the analysis of the features of interest from the spectral point of view revealed that the main elements that influence the reflectance of salty soils are the content and mineralogical typology of salts. In addition, the

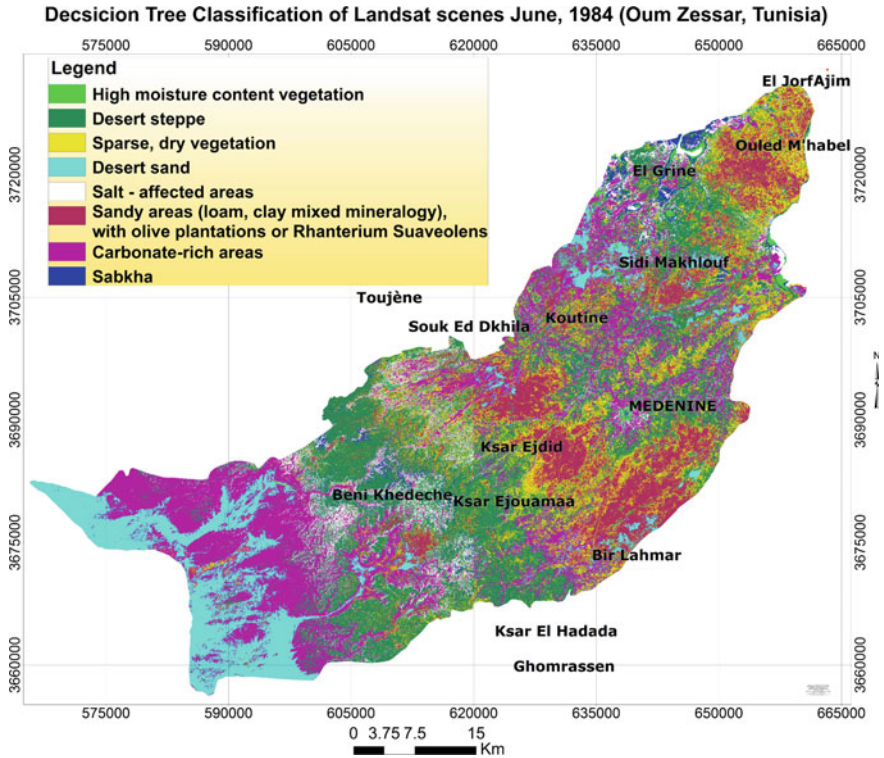


Fig. 23.5 Customised decision tree classification of the 1984 Landsat mosaic image, Oum Zessar area, Tunisia

physical properties are also important, such as moisture content, surface roughness, impurities or colour.

The spectral signature is influenced by the mineralogy of the chloride, carbonate or sulphate salts, hence elementary anion groups (carbonate, sulphate, hydroxyl and hydroxide) that trigger the behaviour of tones, either exciting them or favouring combinations, which are related to the internal vibration modes translated into the presence/absence of absorption features (Metternicht and Zinck 2008). Given this premise, we can explain why we encountered difficulties in correctly identifying the saline features, even though it must be mentioned that the *highly saline areas* class have presented the highest degree of misclassification because of spectral similarity to areas that have a strong carbonate component and implicitly outcropping limestone. Various tests were conducted on the images applying salinity indices indicated by the literature (Masoud 2014; Allbed and Kumar 2013; Khan et al. 2005), but no substantial outcomes were achieved. This is argued by the fact clayey soils, silty soils, impervious surfaces, bare rock and land, as well as carbonate-rich areas presented high similarity to saline areas so as to be classified altogether in one unique class.

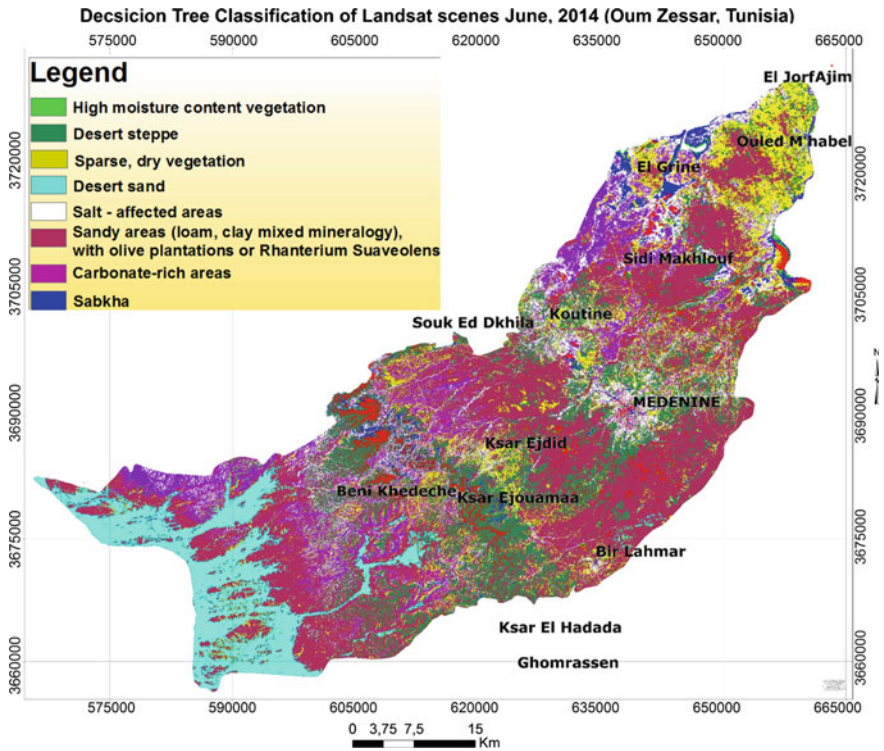


Fig. 23.6 Customised decision tree classification of the 2014 Landsat mosaic image, Oum Zessar area, Tunisia

We managed to minimise these issues, and both classifiers showed agreeable results and an overall accuracy of over 80%.

However, it must be mentioned, as an overall observation, that from both spectral analysis and classification phases, we can determine that common drylands features that are highly reflective may present high levels of similarity to those of areas with high salt concentration. Such typical drylands features are braided stream beds, eroded surfaces with skeletal soils and non-saline silt-rich structural crusts, as previously stated in literature (Metternicht and Zinck 2008).

Change detection statistics of the 1984 and 2015 years showed an increase of approx. 76% of the surface of salt-affected areas, including ‘moderately saline areas’ class, mainly in the disfavour of steppe vegetation (18%), orthents (2%), green vegetation (around 16%) and other small percentages of other classes.

In the Oum Zessar area, the *aeolian sand* class presented an increase of 10, 13% and the desert one, of 10, 44%, between 1984 and 2014. However, the PCA of the Knepper composites, between the same years has shown an increase of 21% of the *aeolian sand* class and 19% of the *desert sand* class, as resulted from the change detection statistics. The *desert sand* class had presented problems of spectral

confusion with another feature (possibly saline areas in the western extremity of the image), as shown from comparison to IsoDATA of Knepper PCA and ground truth data. Thus, the index employed to extract it needs further revision. The class was identified but it was overestimated. Thus, we reached our goal of separating the *desert sand* class from the inner plain aeolian sand, but we cannot fully appreciate the change between the two dates, as it needs further revision. It is also important to specify that the sparse vegetation on sand encroached areas, mainly *psammophyte* species have decreased by 40% which can be argued by the fact that in the past decades the rainfed agriculture and especially olive plantations overlay mostly to the sandy areas of the plain.

The most important aspect obtained from this analysis was the net separation between inner plain aeolian sandy areas and the desert ones along paleo-valleys that converge towards the Great Oriental Erg. Both classification methods have shown good separability between the two classes, for both years in discussion.

Conclusions

Based on a vast bibliography, this work combines and proposes a specifically tailored workflow for thematic mapping, indices construction, classification built-up and change detection analysis. The customised decision tree classifier was proven to be more flexible and adequate for the extraction of highly and moderately saline areas, and major land cover types, as it allows multi-source information and higher user control, yielding an overall accuracy of more than 85%.

The results showed that the secondary salinisation of soils is an ongoing process in the Biskra area of Algeria. The main driving factors are related to human activities, namely the intensification of agriculture, through the enlargement of date palm plantation and market gardening fields in the Occidental Zab, and the expansion of open field and large-scale industrial agriculture practices in the Oriental Zab. In the last three decades, the salinized areas have increased by 76%.

In the Oum Zessar study area, in Tunisia, the analyses show a substantial change in several components of the environment since the 80s, related to increased anthropic pressure, settlement and agricultural policies and national development strategies. One of the concerning aspects that emerged from this study is that the Jeffara plain, is more affected by sand encroachment over the last decade, namely by around 27%, also adding changes in several other classes of land cover.

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