Long-term monitoring of transformation from pastoral to agricultural land use using time-series Landsat data in the Feija Basin (Southeast Morocco)

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Abstract

The expansion of agricultural land at the cost of pastoral land is the common cause of land degradation in the arid areas of developing countries, especially in Morocco. This study aims to assess and monitor the transformation of pastoral land to agricultural land in the arid environment of the Feija Basin (Southeast of Morocco) and to find the key drivers and the issues resulting from this transformation. Spectral mixture analysis was applied to multi-temporal (1975–2017) and multi-sensor (i.e. Multi-spectral Scanner, Thematic Mapper, and Operational Land Imager) Landsat satellite images, from which land use classifications were derived. The remote sensing data in combination with ground reference data (household level), groundwater and climate statistics were used to validate and explain the derived land use change maps. The results of the spatiotemporal changes in agricultural lands show two pattens of changes, a middle expansion from 1975-2007, and a rapid expansion from 2008 to 2017. In addition, the overall accuracy demonstrated a high accuracy of 94.4%. In 1975 and 1984, the agricultural lands in Feija covered 0.17 km² and 1.32 km², respectively, compared with 20.10 km² in 2017. Since the adoption of the Green Morocco Plan in 2008, the number of watermelon farms and wells has increased rapidly in the study area, which induced a piezometric level drawdown. The results show that spectral mixture analysis yields high accuracies for agricultural lands extraction in arid dry lands and accounts for mixed pixels issues. Results of this study can be used by local administrators to prepare an effective environmental management plan of these fragile drylands. The proposed method can be replicated in other regions to analyse land transformation in similar arid conditions.

Keywords: Land use monitoring; Landsat images; Linear-Mixture Analysis; GIS; Remote sensing; Morocco

1. Introduction

The population of the world has been growing rapidly in recent years, especially in Asian and African countries (FAO, 2017). In most developing countries, the changes in land use are mainly due to the intense population pressure and changes in the socioeconomic situation of the population. Human activities can change the structure and the biological capacity of ecosystems over a period of time (Long et al., 2010). Accordingly, the effect of anthropogenic impact on the biological ecosystems can be found through the identification and monitoring of the land cover alterations (Teixido et al., 2010). These man-made changes are one of the major causes of environmental degradation in any landscape (Ait Lamqadem et al., 2018).

The expansion of cultivated areas can mitigate the increasing demand for food, especially in developing countries. Therefore, agricultural lands are most vulnerable to changes under climate variabilities, political strategies and human pressures (Hamad et al., 2018). However, some adverse effects of this rapid expansion emerge, especially in arid areas (Foley et al., 2011). One of the major effects on the environment is the groundwater drawdown (Tilman and Clark, 2015). However, in the arid regions of Morocco and due to heavy government subsidies (under the Green Morocco Plan since 2008), agricultural lands have been expanded on former pastoral lands in recent years (Faysse, 2015).

Pastoral land use has been considered one of the traditional economic activities in arid regions. The Feija Basin, Central-South-Eastern Morocco, presents an example of pastoral land use. Nevertheless, this arid pastoral communal land underwent several environmental transformations, such as the expansion of agricultural lands instead of the traditional pastoral activities.

In the last four decades, remote sensing data inherit the potential to map and monitor these environmental changes on various spatial and temporal scales (Ait Lamqadem et al., 2017; Allbed et al., 2014; Tang et al., 2017; Xie et al., 2017). Changes in the land use/land cover can be monitored and assessed using the historical data from the Landsat program using a multispectral scanner (MSS) which started in 1972 until the current operational land imager (OLI) in 2017 (Medjani et al., 2017; Zhu, 2017). Derived thematic maps can provide spatial information on historical data, thereby serving as a valuable source, for example in the land use and degradation monitoring of ecosystems (Xofis and Poirazidis, 2018; Zhang et al., 2018). Remote sensing data can be used to monitor the land use changes, specifically transformations from pastoral to agricultural uses (Kartya et al., 2005; McPeak and Little, 2018). Comparing satellite imagery from different Landsat sensors can be a challenge due to varying sensor types. A Spectral Mixture Analysis (SMA) technique was applied to overcome this problem (Schmidt et al., 2003). Several studies have proved that SMA can monitor land-cover/land-use changes in arid and semi-arid environments (Adams et al., 1995; Dawelbait et al., 2017; Salih et al., 2017). SMA, as a subpixel classification, produces fractions or abundances of the different features of surfaces (Scarth et al., 2010). Endmembers are required as inputs to the unmixed different components of the surface.

However, only a few studies on the arid areas of South-Eastern Morocco to detect the effects and the drivers of the specific types of land use changes are available. Consequently, an urgent need to monitor and assess the land use dynamics emerges. Therefore, this study aims to assess and monitor the land use changes and analyse the possible change-driving forces and the impact of the transition from pastoral land use to an agricultural land use. Accordingly, multispectral and multitemporal Landsat satellite data (i.e. MSS, thematic mapper (TM) and OLI) from 1975 to 2017 were used. SMA was used to extract the extent of agricultural land use in the Feija Basin at the time of the study.

2. Study Area

The sub-basin of Feija is part of the Middle Draa Valley (MDV). The MDV is located in the central-southern part of Morocco, middle of the 06° west meridian and below the 30° north parallel. The basin of Draa has an area of approximately 14380 km² and a width of 1200 km, crossed by Draa Wadi (typical ephemeral river), the longest wadi in Morocco. The basin is fed by the Mansour Eddahbi Dam upstream MDV, constructed in 1972. The Draa river forms a chain of six successive oases, varying from 100 m to 10 km in width (Mezguita, Tinzouline, Ternata, Fezouata, Ktaoua and M'Hamid) (**Fig. 1**).

Geographically, the Feija Basin (2270 km²) is located in the southern foot slopes of the high Atlas Mountains in South Morocco. It stretches approximately 80 km from west to east and 8 to 12 km from north to south. Feija is part of the Fezouata Basin and situated at the west of the River Draa near Zagora Town (**Fig. 1**). The sector of the study is characterized by arid climate with an average of 70 mm of annual precipitation equivalent to 15 days of rain. The potential evapotranspiration is high, reaching 2500 mm/year (Schmidt et al., 2003). Temperatures can reach more than 48 °C in the summer and varies between –1 and 7 °C in the winter (Ait Lamqadem et al., 2018). The hydrological system depends on the extent of water runoff in the central Anti-Atlas. In traditional oases (Mezguita to M'Hamid), the agricultural system usually consists of three production levels, namely, date palm trees (*Phoenix dactylifera*), fruit trees and surface-level vegetables (i.e. tomatoes, maize, alfalfa and henna) (Ait Lamqadem et al., 2019). Outside of the palm oases, the surface-level system is the main agricultural system (henna, wheat and watermelon). Furthermore, the extensive mobile pastoralism on collective land is the traditional form of land use in the Feija area (Schmidt et al., 2003). This is the rationale behind selecting this basin as a study area.

Over centuries and decades, pastoralism in arid areas has been considered a crucial economic activity and a method of land exploitation (Zainabi, 1989). Goats, sheep and dromedaries are the main livestock in the study site.

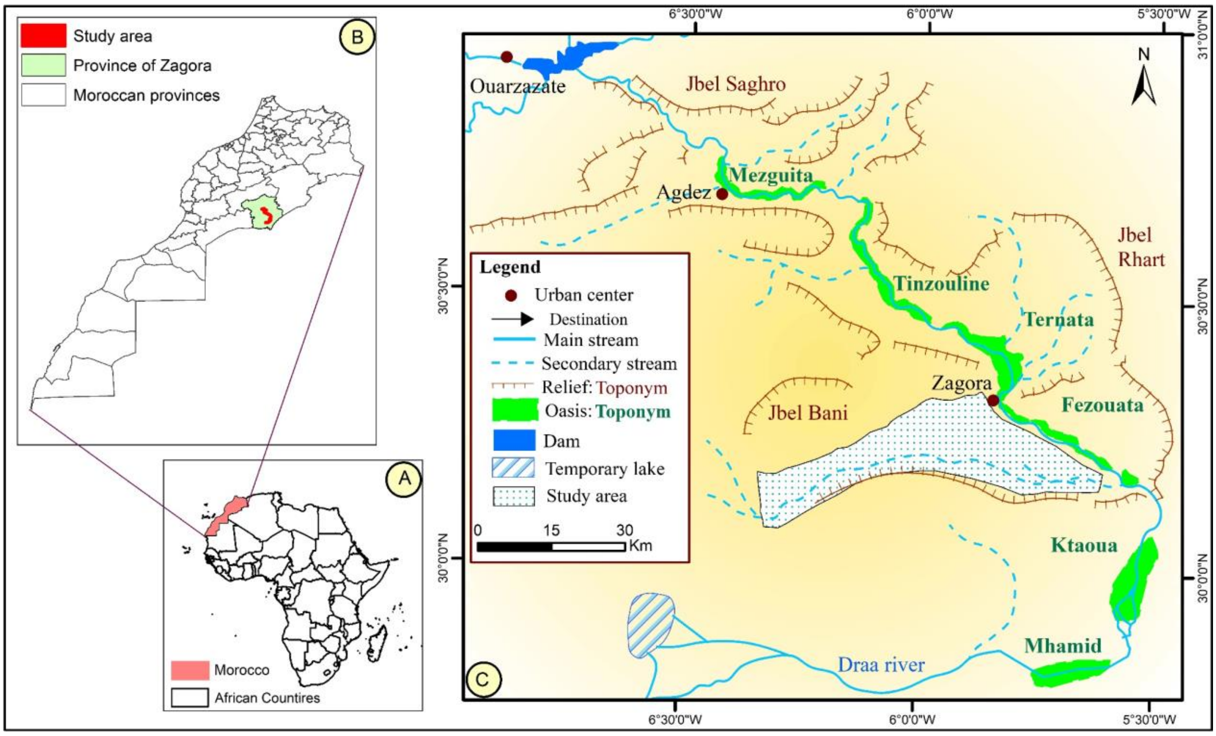

Fig. 1. Location map of study area: (A) Morocco in Africa; (B) study area in Zagora Province; and (C) study area.

Water for agricultural purposes is directly pumped from private wells. The productivity of the groundwater is between 1 and 5 l/s with some exceptional zones where it reaches 40 l/s. In addition, traditional and drip irrigation systems are adopted in the Feija Basin. The soil consists of the lacustrine sediments that show fine textures and low skeleton contents, favouring water holding properties and the possibility of mechanical treatment (Klose, 2009).

Historically, the sedentarisation in the Feija Basin (settling of a nomadic population) started in 1970 because of the advances in well technologies. Livestock and agriculture are the main socioeconomic activities in the Feija.

The figure 2 shows the main land cover/land use in the study area.

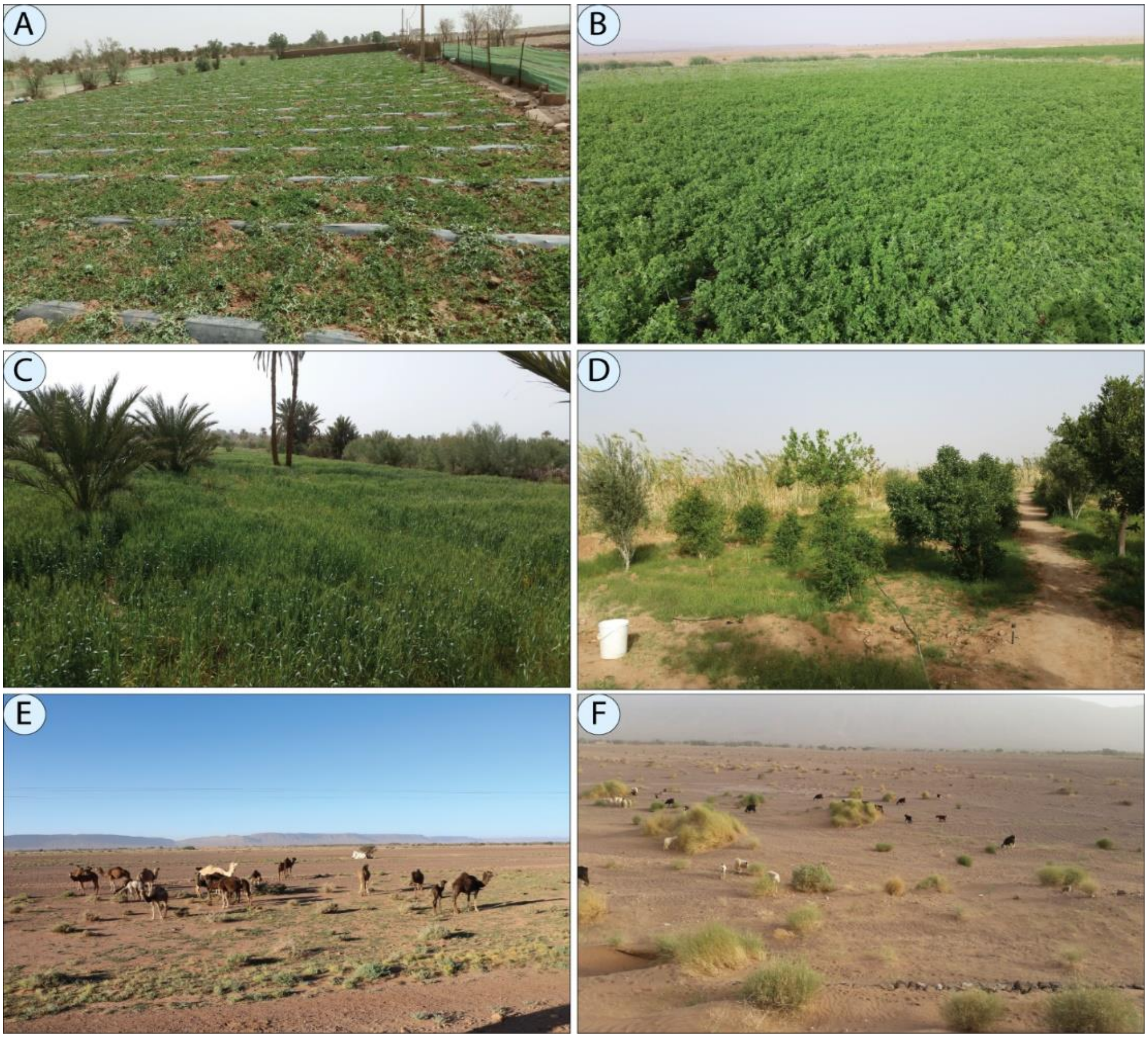

Figure2. (A) Watermelon fields; (B): Alfalfa fields; (C) Wheat fields; (D) Fields with fruit trees; (E) and (F): Pastoral lands.

3. Data

The data used in this study include the remote sensing images, factional vegetation field measurements and ancillary data.

3.1. Remote sensing data

Three multispectral image sets from Landsat Multispectral Scanner (MSS), Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational land Imager (OLI) were collected. Georectification Level 1 Precision Terrain (L1TP) Landsat from 1975 to 2017 images with less than 10% cloud coverage were downloaded freely online from the U.S. Geological Survey platform (https://earthexplorer.usgs.gov/). The radiometric resolutions for the Landsat MSS and TM sensors were 8 bits, while the radiometric resolution of Landsat OLI sensor was 16 bits. Table 1 describes the main characteristics of the used images**.** The linear spatial resolution of MSS image is 79 by 79 meters. For Landsat 5 TM and Landsat 8 OLI images, the native resolution is 30 m. The selected period is from May to June (except 1975), which coincides best with a full ground cover of watermelon, cropped from January to June. This period was also chosen to avoid confusion and interference with the annual vegetation and agricultural cycles. Landsat images represent the only source of global, calibrated and moderate spatial resolution measurements of the Earth's surface with the longest lifespan among Earth Observation Systems that are preserved in a national archive and freely available to the public (https://landsat.usgs.gov/landsat-8-l8-data-users-handbook-section-1). Furthermore, the L1TP products made available by the provider allow the user to have immediate access to ready-to-use high quality products suitable for pixel-level time series analysis without further pre-processing.

Table 1. Description of the used Landsat data.

Satellite	Sensor	Spatial resolution (m)	Acquired date	Cloud cover (%)	Path	Raw
Landsat 1	MSS	79	03-July-1975	0.00	216	39
		30	14-May-1984	0.00	200	39
Landsat 5	TM		03-May-2000	0.00	200	39
			30-May-2007	0.00	200	39
			10-Juin-2011	0.00	200	39
Landsat 8		30	30-May-2013	0.00	200	39
			02-June-2014	0.00	200	39
	OLI		20-May-2015	0.08	200	39
			22-May-2016	0.07	200	39
			25-May-2017	0.00	200	39

3.2. Field data collection

Fieldwork was conducted in the Feija Basin between April and May 2017. Preliminary topographic map and high-resolution images from Google Earth were used to identify the candidate areas to be surveyed, and the appropriate paths. In addition, agricultural lands, rocks, pastoral lands, sand, partial vegetation coverage and water plots were identified during fieldwork.

An economical, efficient and high-speed method to estimate the vegetation fraction coverage is the use of a digital camera (Han and Han, 2015). In total, 38 plots were collected in the field using the vertical photography method, with an altitude of one meter. The chosen elementary size of sample plots matched with the spatial resolution of the Landsat images perfectly (30m × 30 m). An area size of 1 m² quadrant was selected and the photos were taken vertically using a Nikon D90 digital camera. Every plot was registered using a Gramin eTrex GPS, with 2 meters of precision, to allow integration with the other spatial data in the GIS and image processing systems. The vegetation percentage of each image was extracted after geometric correction, enhancement processing, colour space transformation and classification (Li et al., 2015), which used the ISODATA-unsupervised classification algorithm in ENVI Exelis Harris Geospatial Solutions Software. In addition, 14 subclasses were determined to classify each photograph, and then the subclasses were combined to derive the bare land, nonphotosynthetic and photosynthetic vegetation. This method was previously validated and applied to extract the fractional vegetation coverage (Li et al., 2015; White et al., 2000; Zhang et al., 2013). The samples were randomly collected in the field. The data were collected in different land cover types in the study area (agricultural land, palm grove, sparse vegetation, and bare land). A portion of the collected samples was used to assess the accuracy of the fractional vegetation coverage extracted by the SMA subpixel model and the land use classification (agricultural vs. nonagricultural) and the remaining portion for the validation of the results.

Field data also consisted of semi-structured interviews with the pastoralists. The interviews focused on the mains motivations of the process of sedentisarisation from a pastoral to an agricultural land use. The semi-structured interview is a method of qualitative study based on the performance of the individual or collective interviews during which the facilitator dictates only the different topics to be addressed without asking specific questions (Ait Lamqadem et al., 2019).

3.3.Ancillary data

The ancillary data were used to analyse the driving forces of the vegetation changes. The climatic and socioeconomic data were provided from different administrations. The climatic data were acquired from the Office Régional de Mise en Valeur Agricole de Ouarzazate (ORMVAO). The household level data were provided through interviews with local residents and government administrators.

Water samples were also collected during the field survey in the Feija Area with the aim to measure the salinity of the water. The water well was collected in different bottles and then the salinity was measured. Water salinity was measured through electrical conductivity. The electrical conductivity (mS cm^{-1}) of the water samples was measured using a conductometer at 25 °C (Yıldırım and Öner, 2015).

4. Methodology

The adopted methodology in this study is divided into three main stages (**Fig. 3)**. Firstly, the collection and pre-processing of Landsat images include co-registration check and atmospheric correction to assure the spatial and spectral consistency of multi-date images. Secondly, this stage includes the application of spectral mixture analysis and then the extraction of agricultural land use. Lastly, this stage includes the exploitation of ancillary data to evaluate the effects of the agricultural land use evolution and to discuss the driving forces of changes.

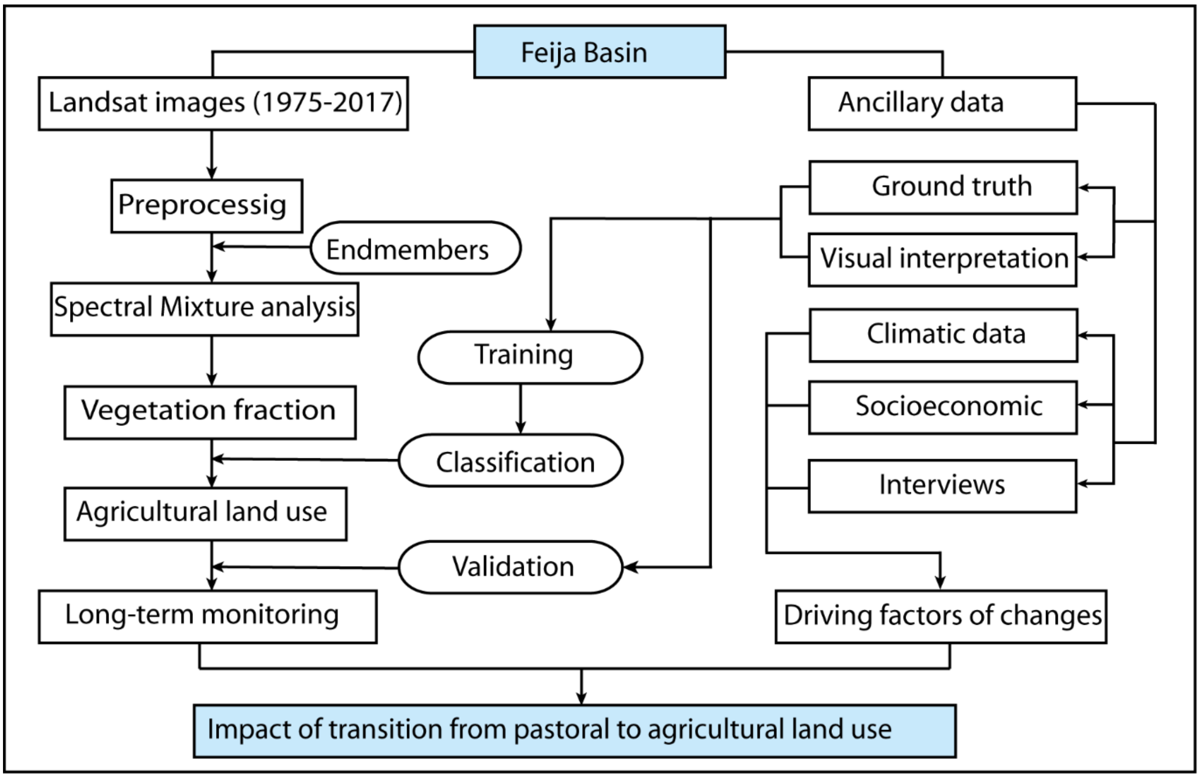

Fig. 3. Methodological flowchart.

4.1. Landsat images and pre-processing

The downloaded images contain high-quality L1TP. The images selected in this research were radiometrically normalized to obtain the top of atmosphere reflectance by the USGS (Guo et al., 2017; Mihi et al., 2017). Subsequently, dark object subtraction (Mantinfar et al., 2012; Pons et al., 2014) was applied for atmospheric correction, thereby obtaining surface reflectance. Landsat images were converted from digital numbers to surface reflectance through rescaling in accordance with the instructions of the provider (Afrasinei et al., 2018). Given the characteristics of the study area, no topographic correction was applied because L1TP was orthorectified using ground control points and a digital elevation model to correct the relief displacement (Afrasinei et al., 2018). Therefore, the geometric correction was unnecessary for L1TP (Roy et al., 2014). Landsat MSS image was resampled to the native resolution of Landsat OLI using the nearest neighbourhood algorithm (Ait Lamqadem et al., 2018).

4.2. Spectral mixture analysis

SMA has been widely used as one of the most efficient models to assess and monitor vegetation coverage in arid and semiarid environments (Masoud, 2014; Meusburger et al., 2010; Smith et al., 1990). In comparison with the other classification techniques, such as support vector machine or artificial neural network, which offer high accuracy, SMA is more effective for subpixel classification, especially for the differentiation of vegetation and soil (Wang et al., 2010). Further, the ranges of the spectral bands are different, as with the case of the sensors of the Landsat program (MSS, TM, and OLI). Furthermore, their ratios (NDVI and SAVI), as most vegetation indices, are also not directly comparable. The most common approach in SMA is to apply post-classification change detection (Schmidt et al., 2003).

In the satellite images of arid and semi-arid areas, the pixels usually contain mixed spectral reflectance due to the variability in the distribution of different feature components on the surface. SMA is based on the presumption that the spectral reflectance of each pixel is a function of the weighted average of the objects within it (Dawelbait et al., 2017).

SMA uses endmembers to transform the radiance or reflectance of the image into abundances or fractions (Elmore et al., 2000). The resulting image of the SMA is an image, with each band representing an endmember abundance (Adams et al., 1986; Smith et al., 1985).

To perform SMA involves the evaluation of specific features in the image to extract the endmembers (pure pixels) and the selection of physical features. Lastly, the step allows the determination of fraction for each selected endmember.

SMA was adopted due to its ability to compare the data acquired from different sensors, i.e. MSS, TM and OLI. SMA was performed with ENVI (ITT Exelis, USA) with the sum to unity constraints, which means that the sum of the endmember fraction for each pixel equals to one. The values of each fraction vary between 0 (0% of the material) and 1 (100% of the material).

4.3. Endmembers extraction

The selection of endmembers (pure pixels) is one of the most crucial stages in performing SMA (Lu, 2006). Endmember collection can be approached from the field or library, also known as the library endmember (Smith et al., 1990), or the selection of spectra directly from the image (image endmember). In this study, the image-based method was performed to extract endmembers. The image endmember is easier to perform compared with the library endmember, which needs calibration between selected endmembers and the spectra measured in the field or laboratory (Lu, 2006).

For the extraction of endmembers and the development of high-quality fraction images, different image transformations can be used, such as principal components and minimum noise fraction (MNF). Several automated methods commonly used to extract endmembers (geometric perspective and pixel purity index [PPI]) employ PCA or MNF to reduce the dimensionality of data and image noise (Fernández-Manso, 2015). We determined the candidate endmembers by analysing the PPI. This algorithm has been widely used in hyperspectral image analysis for endmember extraction. The MNF was applied to each Landsat image, and then we connect the MNF transformation with the PPI using an n-dimensional visualization tool to apply n-dimensional visualization analysis and extract the spectral information of all the components (Han and Han, 2015). The four endmembers defined in the study are vegetation, sand, clay and rock.

4.4. Agricultural land selection

Agricultural class use was derived by thresholding the vegetation fraction by the same amount in every image after performing SMA. Each vegetation fraction was classified by the binary decision rule. The pixels that were more than the fixed threshold will be classified as agricultural land; otherwise, they will be classified as non-agricultural (water, sand, rocks and clay). The threshold was defined on the basis of the collected fractional vegetation coverage in the field, visual interpretation and the exploitation of the high-resolution Google Earth images to affine the binary classification.

4.5. Accuracy assessment

Evaluating vegetation fraction estimates can be challenging due to the difficulty of obtaining reference data, especially for historical datasets. The land cover historical maps can be used to assess the accuracy when the ground points of verification are absent. Unfortunately, after a long research, we did not find the historical maps of Feija. Given the lack of high-quality reference images from the 1980s, an accuracy assessment was only possible for 2017 using Landsat OLI. We consider that the classification of the vegetation fraction from 1975 to 2016 would have acceptable accuracy if the vegetation fraction image in 2017 was reasonably accurate.

For the accurate comparison of the differences between the estimated and the measured fractional vegetation coverage, the coefficient of determination R^2 was used. Furthermore, the accuracy of the binary classification was assessed using confusion matrix validation. A part of the collected points was used in the initial phase of the SMA accuracy assessment, training and binary classification of the vegetation (20 points). The other part was used for the confusion matrix validation (18 points). The confusion matrix was estimated with reference to ground reference data for producers, users and overall accuracy.

4.6. Driving forces of changes

This part discusses the extent to which the main factors contribute to the agricultural lands' evolution. We conducted interviews with the local residents and stakeholders. The interviews were consistent with the triggering events in the water harvesting management, economic demand, agricultural policy changes and incentives. Several visits were made to the local administrators. The interviews focused on agriculture policy change. For this purpose, 16 nomadic and 16 mainly sedentary households installed on communal pastoral land in the Feija area were selected and visited in 2017.

5. Results

5.1. Results of endmembers and SMA

The application of PPI for each Landsat image allowed us to select four endmembers, which are vegetation, clay, rock and sand. Given the analysis of the four spectral indices of the pure pixels, rock, clay and sand had a similar spectral signature. Furthermore, the vegetation spectral response was characterised by a pick between red and NIR bands (**Fig. 4**). This result implies that the extraction of vegetated coverage can be easily distinguished from other features in the Feija Area. The result of the SMA was an image with four abundances and a band of RMS error. For each period, the RMS error was low (less than 0.02), indicating the pixel unmixing results performed with high accuracies.

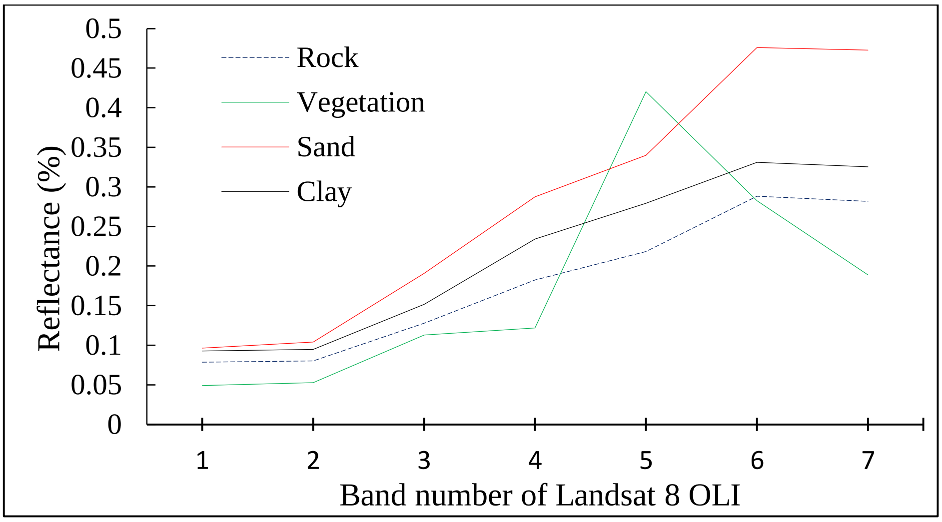

Fig. 4. Endmembers spectra of the Landsat OLI image.

After performing the SMA, we extracted the estimated coverage corresponding to each spatial position of field survey samples. Linear regression analysis was conducted between the measured and the estimated fractional vegetation for 20 points. The scatter plot of the accuracy assessment result presents a significant correlation (R^2=0.90) (**Fig. 5)**.

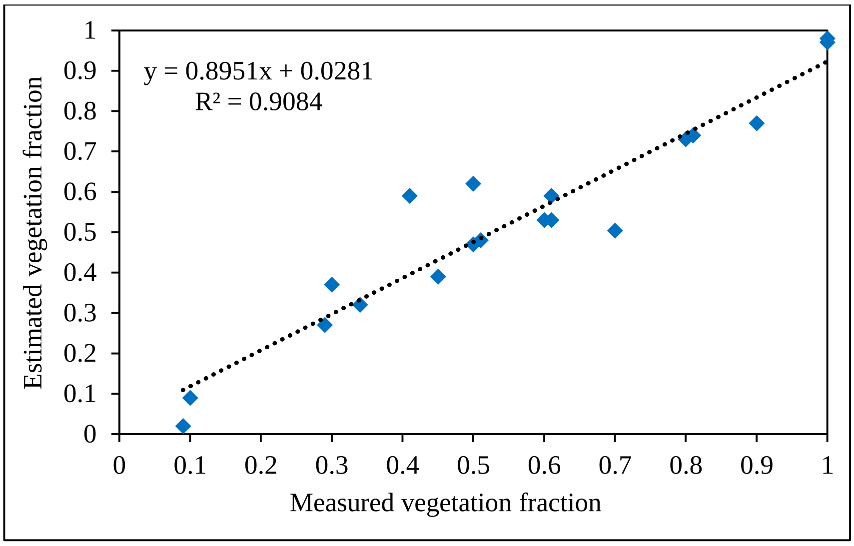

Fig. 5. Relationship between field survey data and estimated fractional vegetation.

5.2. Spatiotemporal evolution of agricultural land in the Feija Basin

On the basis of the collected field vegetation coverage and Google Earth images, a threshold was terminated to separate the agricultural class with the other surface features, i.e. rangeland vegetation and barren lands. The class of agricultural land includes alfalfa, wheat, watermelon and date palm. A total of 30% of the vegetation was affirmed to have an accurate threshold that separates agricultural from the other land cover types. The classification accuracies are remarkably high due to the binary rule of a clear distinguishable feature.

The overall accuracy was calculated for the map of agricultural land of the Feija Area in 2017. The error matrix shows an overall accuracy of 94.4% (**Table 2)**. No misclassification of nonagricultural samples into the agricultural class on the resulting map emerges. This illustrates that no commission error emerges in the agricultural class. However, an omission error in agricultural bounds emerges (only one pixel has been mapped as non-agricultural).

Table 2. Overall accuracy matrix for the agricultural land use map of the Feija Area in 2017.

		Reference data			
		Agriculture	**Non-agriculture**	**Total**	**User accuracy**
Map data	Agriculture	**10**	00	10	100.0 %
	Non-agriculture	01	**07**	08	87.5 %
	Total	11	07	18	–
Producer accuracy		90.9%	100.0%	–	**94.4%**

The evolution of agricultural area on the pastoral lands of Feija from 1975 to 2017, as a result of the binary classification tree, was presented in **Fig. 6**. The results demonstrate a rapid expansion over the time of the study. The total agricultural areas were 0.17 km² and 1.32 km² for 1975 and 1984, respectively, compared with 28.10 km² in June 2017. Ground observations revealed that these areas represent new farms within the former rangelands. The highest value of the agricultural land use surface was recorded in 2015 (30.25 km²).

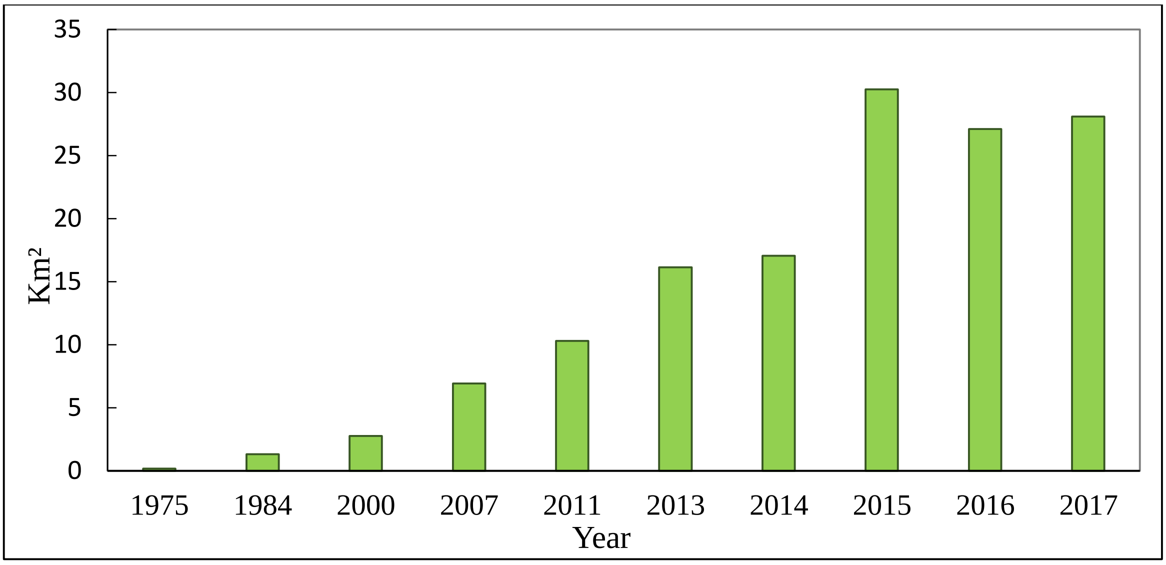

Fig. 6. Evolution of the agricultural land use area (Km²) from 1975 to 2017.

The agricultural class is displayed in the time steps 1984, 2007 and 2017. Figure.7 displays the spatial distribution of the agricultural land for 1984, 2007 and 2017. Spots with abundant vegetation occurred since 1984. These areas were totally non-existent in 1975. These spots appeared and increased remarkably in 2011. Ground observations revealed that these areas represent newly founded farms within the former rangelands.

The maps showed a rapid increase of farms in the north-east part of the study area, in Mgheder. Generally, the nearness to Zagora City was one of the reasons for the increasing farms in this region. New farmers prefer the areas near roads and cities for ease in selling products.

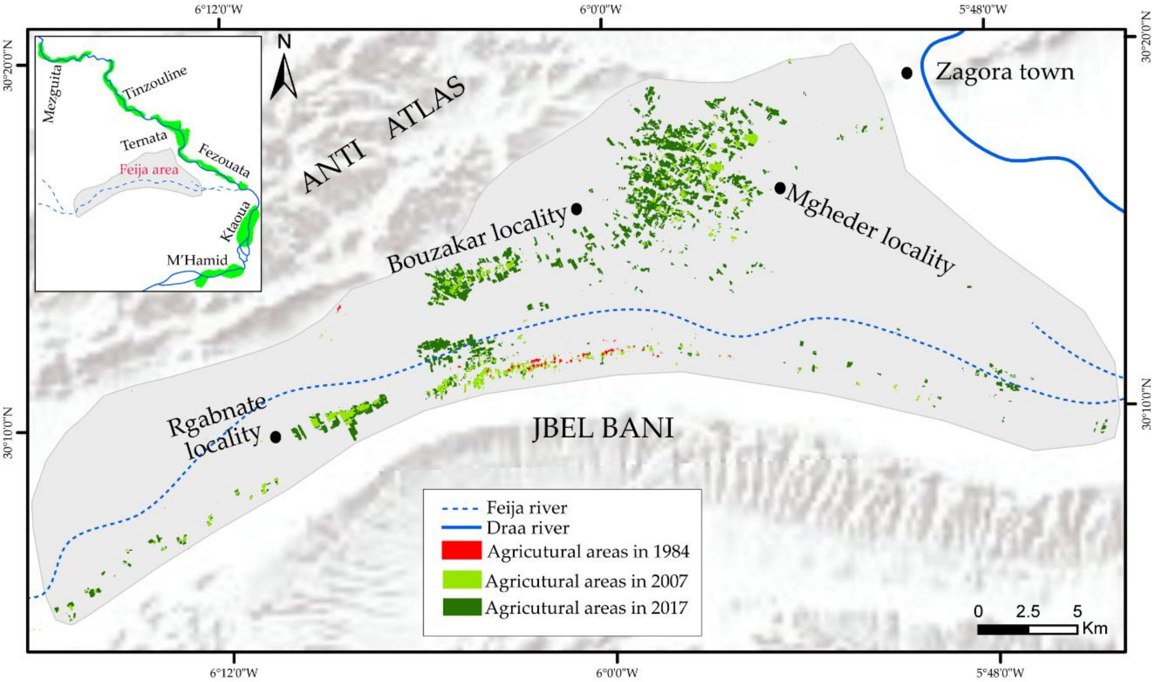

Fig. 7. Spatial distribution of the agricultural land use evolution in the Feija Area for 1984, 2007, and 2017.

6. Discussion

6.1. SMA and agricultural land use extraction in an arid context

The conditions in this arid pastoral area are suitable for the application of the SMA model due to the clear separability of the agriculture class from the other surface features and pastoral vegetation as expressed in the example of the four endmembers. This approach fits well when used to discriminate only green biomass, but it cannot be expected to fit other purposes, such as distinguishing among different soil types. However, SMA was proven to yield good performance, which is consistent with the other studies that have compared SMA with other fractional vegetation cover extraction models (Jia et al., 2017). It also provides a remarkable result for the mapping of agricultural lands (Peddle and Smith, 2005).

Previous studies analysed the oasis vegetation changes using spectral indices (NDVI) and Landsat images belonging from the previous sensors (Ait Lamqadem et al., 2017). In fact, applying the same threshold to separate vegetation and non-vegetation for the images from the different sensors is impossible. Given that during the last four decades the Landsat program employed different sensors and spectral band characteristics, SMA has proved to overcome the limitations of spectral indices.

6.2. Spatial and temporal evolution of the agricultural land use

The expansion was the main change trend exhibited by the agriculture class in the Feija Area over the last 42 years. This situation is similar to the other arid pastoral areas across the world, such as the cases of Kyrgyzstan and Kazakhstan (Rahimon, 2012), in the communal rangeland grabbing in Sudan (Sulieman, 2018) and in China (Li et al., 2018). Generally, two stages can be distinguished in this study. Firstly, the stage of 1975–2007 was characterized by a moderate expansion in Feija. Secondly, the stage of 2007–2017 was characterized by a rapid expansion, especially in the areas near the main road and Zagora City.

6.3. Driving forces of changes

The extracted extent of the irrigation lands shows a rapid expansion during the last two decades. The number of inhabitants in the Feija Basin has increased rapidly during this period. The number of population jumped from 20 inhabitants to 1572 from 1972 to 2014, respectively (HCP, 2018). The sedentarisation of the pastoralists in this area can be explained by the existence of water in the Feija River, pastoral land and a groundwater characterized by its quality comparable with that of the oases in MDV. Furthermore, 78 new farms were managed and created in the collective lands of the Feija Basin between 1971 and 1985, and 169 news units were created from 1986 to 1997 (Proludra, 1998). However, an updated census does not exist.

Several reasons can explain the sedentarisation in the study area. The pastoralists were coming from the nearby regions of Feija within the 1000 km buffer zones, after each rainy period, by vehicles. The results of the interviews prior to 2003 informed that the overgrazing in this area increased the land degradation in the Feija Plain. Consequently, mobile pastoral can no longer sustain grazing. Taking this into consideration plus the high cost of transportation, the transformation of these pastoral lands into an irrigation areas deemed the only solution.

Regarding the climatic conditions, several drought episodes occurred in 1979–1984, 1987 and 1993–1995. This climatic factor accelerated the sedentarisation of mobile pastoralists (Ait Lamqadem et al., 2018).

Pastoralists started the cultivation of henna as a secondary source of income before 2008 using groundwater. However, this new form of farming does not solve overgrazing. Grazing was continued in the neighbouring settlements because of their reduced of mobility. Farmers reported scarcity of irrigation water, which had some negative effects. For some years, several farmers had to deepen their wells from 2 to 5 m/year. In years of drought, cultivation in some cases was no longer possible and farms had to be abandoned.

Starting 2008, Morocco launched the Moroccan Green Plan that gives subsidies to farmers in Morocco to support agricultural activities. Figure **8** illustrates the consequences of overgrazing and irrigation.

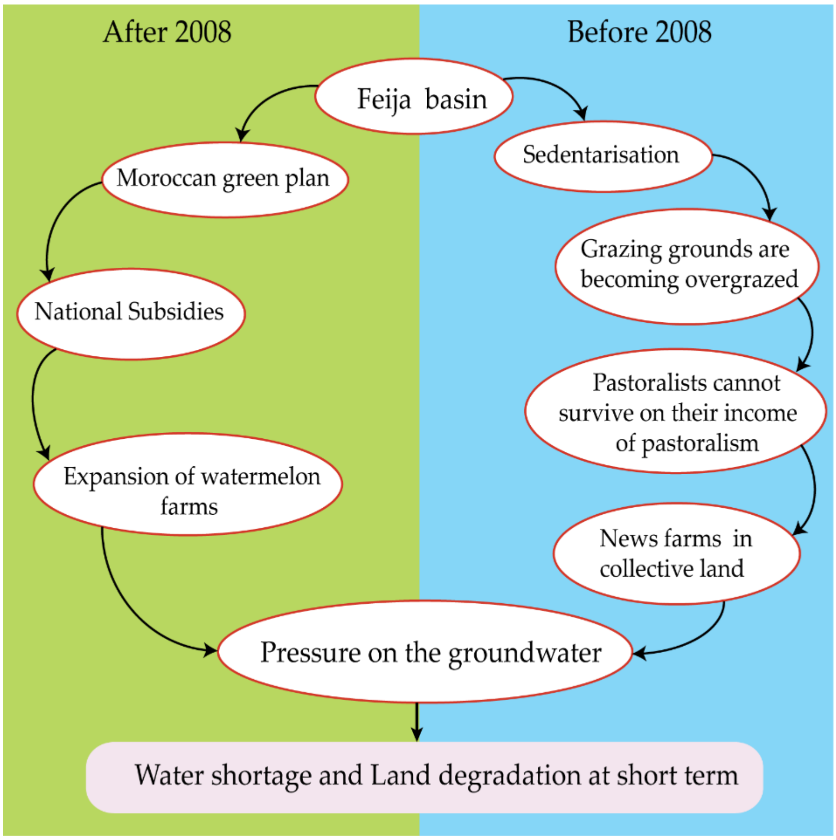

Fig. 8. Vicious circle deriving from farming on collective pastoral land

6.4. State policies and agricultural land use expansion

The number of farmers growing watermelon rapidly increased especially after 2010 as shown in Figure 8 because of the development of new materials for drilling wells, motor-pumps and the subsidies given to farmers under the Green Morocco Plan, which began in 2008. It was introduced by the Ministry of Agriculture and Fisheries (Sedra, 2015; Sraïri, 2017). The Plan's two pillars are for intensive farms and small subsistence farms or solidary agriculture. According to the ORMVAO, the farmers in Feija benefited from the installation of dripping irrigation and drilling wells. The Moroccan Green Plan gives subsidies to farmers to equip the farms. Those subsidies can go up to 90%.

Since 2008, the cultivation of watermelon has spread in the southeast of Morocco to the provinces of Ouarzazate and Zagora (where the Feija is located). Indeed, the favourable climatic conditions increased the quality and yield of crops, guaranteeing a high selling price (MAPM, 2013). The results of the expansion of irrigation areas correlate with the official statistics of Morocco. According to the Ministry of Agriculture and Fisheries, the cultivated area of watermelon was increased from less than 100 ha in 2008 in the Zagora Province to 1100 ha in 2013 (MAPM, 2013).

Furthermore, the climatic and edaphic characteristics in the Feija Area favoured the cultivation of watermelon. In fact, watermelon (*Citrullus vulgaris*) is endemic in arid zones. Watermelons prefer an arid to a semiarid climate with average daily temperatures of 22 to 30 °C. The maximum and minimum temperatures required for their development are approximately 20 to 35 °C (FAO, 1980), with sandy loam soil, which was found in the study area. Watermelons in arid regions have a high content of sugar (FAO, 1980).

6.5.Towards a good environmental management in Feija and in the MDV

The watermelon farms can mobilise the local economy of the region because of the crops' added value, which has created job opportunities for the younger generations. The use of groundwater has two benefits for the locals, irrigation and drinking water supply for Zagora. The quality of this water is good (low concentration of salinity) compared with the water in the groundwater of the Ternata Oasis. In addition, the water in the Feija Basin is fresher than those of the other oases and compared with the other groundwater at the MDV. On the basis of the analysis of the collected water samples, the average water salinity in Feija was 1.09 g/l, against 2.51 g/l and 5.56 g/l for the Ternata and M'Hamid oases, respectively. The expansion of the irrigated areas exerted pressure in the groundwater, thereby causing water scarcity in the area. The increasing number of wells and motor pumps resulted in a negative groundwater balance estimated at –1.3Mm³/a in 2006 (Klose and Reichert, 2006) and more than 5 Mm³/a in 2014 (ABHSM, 2014). Between 1980 and 2014, the piezometric level showed a drawdown from 1 to 21 m, the high values registered in the localities of Lamghadre and Bouzkar (ABHSM, 2014). During the field visits and our interviews with locals, they affirmed that watermelons do not have any effect on the environment. However, date palm trees planted in the areas of the quaternary water table (rechargeable) must be taken into consideration, against the Feija Plain that is located in an area with a deep water table (ABHSM, 1997).

In sum, damaging human practices were affirmed to be the dominant factor driving water scarcity in the Feija Area in the past decades, characterized by the integration of new cultivations that require large quantities of water, which leads to water scarcity. Water scarcity in Zagora City was manifested by the shortage of drinking water in October 2017. This finding is similar in to those in other countries, e.g. north of China (Wang et al., 2016), Jordan (Abu-Allaban et al., 2015), West Africa (Klose and Reichert, 2006) and Egypt (Ouda, 2016; Zohry and Ouda, 2016) with arid and Saharan climate, where water scarcity occurred due to the expansion of irrigated areas and the overuse of groundwater.

In recent years, the cultural areas in the Feija basin has rapidly expanded, and the influence of the damaging agricultural practices have accelerated, which will cause serious environmental problems, such as groundwater recession, drinking water scarcity, land degradation by using chemicals fertilizers (Badraoui, 2006) and wind erosion after each cropping season. Furthermore, Morocco is severely affected by climate change (Brahim et al., 2017; Pascual et al., 2017) with the consequences evident in the rising temperatures and decreasing precipitations. The situation is getting aggravated in these arid areas. The government should pay considerable attention to the fragile ecosystem, and we propose in this research to stop cultivating watermelons in the Feija Basin and to adopt other cultivation with less water consumption and with high added value in the market, e.g. medicinal and aromatic plants, regeneration of old date palm in the oases and conversion of watermelon farmers to modern palm date palm farms equipped with the drip irrigation system and a sustainable rangeland governance for the remaining pastoral lands. To support this proposal, we compared the water requirement to irrigate watermelon and palm tree cultivations. The irrigation of 1 ha of watermelons requires 50,000 m^3 of water, which is equivalent to 5 ha of date palm trees (ABHSM, 2014). This estimate covers the period of 2017–2022. We then estimated the required water for irrigation in two scenarios. The first scenario is if we continue cultivating watermelons and the second is if we adopt the cultivation of palm trees. For the first scenario, the expected agricultural land areas will reach 4758.77 ha in 2022, which needs 237.93M m^3 to irrigate. If we adopt palm trees instead of watermelon crops for the same area, then the needed amount of water for irrigation is only 47.58M m^3 (**Fig. 9**).

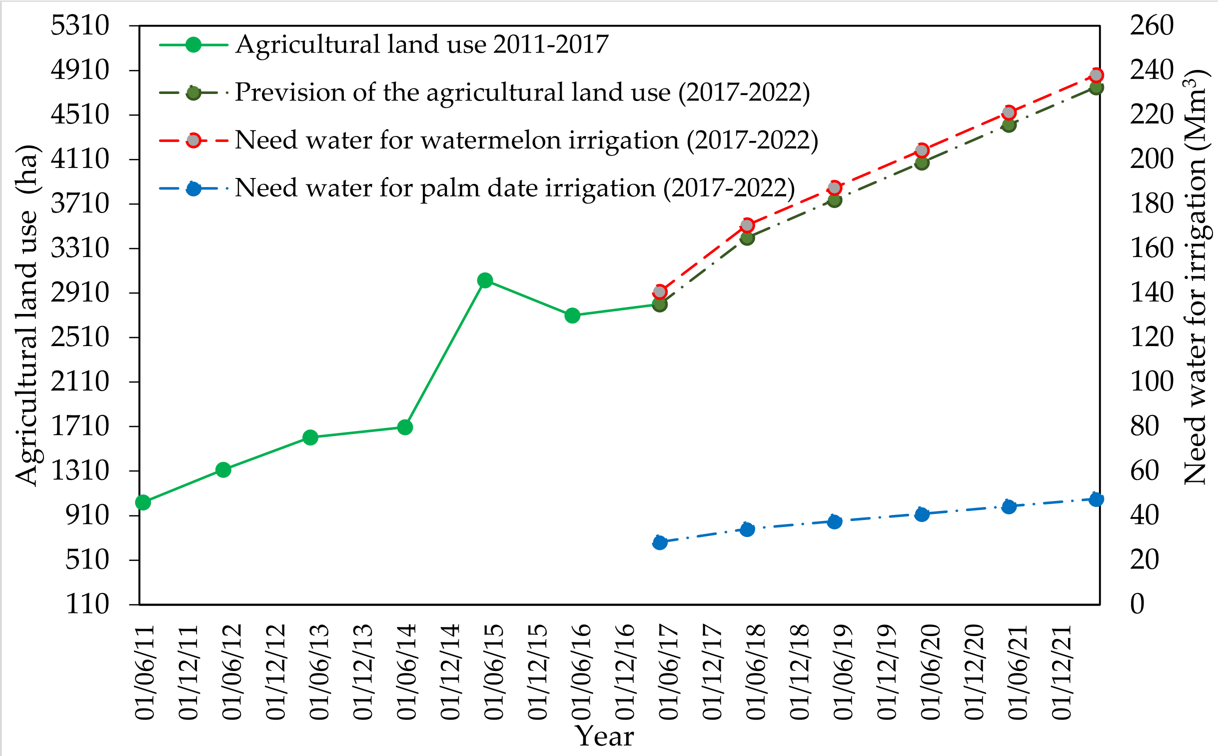

Fig. 9. Prevision of the agricultural land use for the period 2017–2022 and estimation of the needed water for irrigation for the cultivation of watermelon and palm date scenarios.

Furthermore, increasing the awareness of the local population to adopt good practices through research like ours can provide a solution for reducing the negative effect damaging agricultural practices in these fragile lands.

7. Conclusion

Historical remote sensing data from multi-sensors and geospatial tools were used to reconstruct the past and present conditions in the Feija Area and the driving forces of the changes and their effects to the environment over the last three decades. The use of SMA was useful to detect the changes between 1975 and 2017 in the land use in Feija. This long-term monitoring shows not only the pattern of changes but also the extent and degree of the impact of damaging practices on the environment, specifically in an arid area. This study reveals that rapid expansion was the dominant change in the last 33 years. This area has seen a transition from mobile pastoral to agricultural land use. The results corroborated that, in the long term, the inhabitants suffer from uncontrolled changes in the land use. People are forced to change their way of living to survive. The vegetation area increased rapidly during the last three decades in Feija from 1.23 km^2 in 1984 to 30.03 km^2 in June 2017. The expansion caused several environmental problems, such as water scarcity of the population of Zagora City and groundwater drawdown due to the intensity of irrigation. The socioeconomic situations of population, policy and economic interests were the driving forces of these changes in this area. The Feija Area and the arid areas of Morocco need considerable attention and studies to protect and adopt good practices, which are suitable for arid climatic conditions while considering the effects of climate change. The limitations of the study lies in the lack of the historical image of land use/ land cover, and accurate socio-economic data (precipitation, temperature, inhabitations number). In addition, to improve the results of the fraction vegetation extraction in the arid areas, the new remote sensing data of Sentienel-2 satellite could be a good alternative.

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