The role of cannabis (*Cannabis sativa*) cultivation growth as a driving force in land use and cover change (LUCC) in the upstream part of the Laou river catchment area (Northern Morocco)*

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Abstract

The population of the Rif mountains in Morocco depends mainly on the cultivation of cannabis for its livelihood. This study shows the role played by such cultivation in landscape changes in the upstream part of the Laou river catchment area between 1985 and 2019. The analysis was developed using Landsat data. The results indicate that cannabis cultivation has contributed to accelerating the process of LUCC, given that most types of forests were largely transformed to cultivated areas. The increasing pressure on agricultural land, especially after agricultural innovations and the culture of new cannabis hybrids, has had serious consequences on the environment, economy and society. This has been demonstrated in the intensive exploitation of water, and as a result several areas are now denied access to drinking and irrigation water. To reduce the harm of these transformations, diversified and sustainable agricultural practices must be restored to their previous state.

Keywords: *Cannabis sativa*; LUCC; Landscape; Laou river catchment; Rif Mountains; GIS

* We are thankful to the United States Geological Survey (USGS) for providing Landsat images.

Resum. *El paper de l'increment del conreu de cànnabis (*Cannabis sativa*) com a força motriu dels canvis d'usos i cobertes del sòl (LUCC) a la capçalera de la vall del riu Laou (nord del Marroc)*

La població de les muntanyes del Rif al Marroc depèn majoritàriament del conreu del cànnabis per al seu sosteniment. Aquest estudi presenta el paper que ha tingut aquest conreu en els canvis en el paisatge a la capçalera de la conca del riu Laou durant el període 1985-2019. L'anàlisi s'ha desenvolupat utilitzant dades Landsat. Els resultats indiquen que el conreu de cànnabis ha contribuït a l'acceleració del procés de LUCC i ha provocat que la majoria dels boscos s'hagin transformat en zones de conreu. L'increment de la pressió de les terres agrícoles, especialment després de les innovacions en l'agricultura i el conreu de noves varietats híbrides de cànnabis, ha tingut severes conseqüències per al medi ambient, l'economia i la societat. Això s'ha posat en relleu en una explotació intensiva de l'aigua i, com a resultat, diverses àrees no disposen d'accés a l'aigua per al consum humà o per al regadiu. Així doncs, per reduir els riscos derivats d'aquest tipus de transformacions, cal recuperar la pràctica d'una agricultura diversificada i sostenible, tal com prèviament havia estat.

Paraules clau: *Cannabis sativa*; LUCC; paisatge; conca del riu Laou; muntanyes del Rif; SIG

Resumen. *El papel del incremento del cultivo de cánnabis (*Cannabis sativa*) como fuerza motriz de los cambios de usos y cubiertas del suelo (LUCC) en el alto valle del río Laou (norte de Marruecos)*

La población de las montañas del Rif en Marruecos depende mayoritariamente del cultivo del cánnabis para su sustento. Este estudio presenta el papel de este cultivo en los cambios en el paisaje en la cuenca alta del río Laou durante el periodo 1985-2019. El análisis se ha desarrollado usando datos Landsat. Los resultados indican que el cultivo de cánnabis ha contribuido a acelerar el proceso de LUCC y ha provocado que la mayoría de bosques hayan sido significativamente transformados en zonas de cultivo. El incremento de la presión de las tierras agrícolas, especialmente después de las innovaciones en la agricultura y el cultivo de nuevas variedades híbridas de cánnabis, ha tenido serias consecuencias en el medio ambiente, la economía y la sociedad. Esto se ha puesto de relieve en una explotación intensiva del agua y, como resultado, diversas áreas en la actualidad no disponen de acceso al agua para el consumo humano o el regadío. Así pues, para reducir los riesgos derivados de este tipo de transformaciones, la práctica de una agricultura diversificada y sostenible debe ser recuperada tal como había sido previamente.

Palabras clave: *Cannabis sativa*; LUCC; paisaje; cuenca del río Laou; montañas del Rif; SIG

Résumé. *Le rôle de l'expansion de la culture du Cannabis (*Cannabis sativa*) comme force motrice des changements de l'utilisation et la couverture des sols (LUCC) dans la partie en amont du bassin versant de Laou (Nord du Maroc)*

La population des montagnes du Rif au Maroc dépend principalement de la culture du Cannabis pour assurer sa subsistance. L'article présente le rôle de cette culture dans la transformation du paysage dans la partie en amont du bassin versant de l'Oued Laou durant la période allant de 1985 à 2019. L'analyse a été développée en utilisant des données Landsat. Les résultats confirment que la culture du Cannabis a contribué à accélérer le processus de LUCC, étant donné que la plupart des types de forêts sont grandement converties en terres agricoles. La pression exercée sur les terres agricoles, surtout après les innovations dans l'agriculture et l'introduction de nouvelles variétés hybrides de Cannabis, a des conséquences graves sur l'environnement, l'économie et la société. Cette réalité a été clairement démontrée par l'exploitation intensive des ressources en eau. De ce fait, plusieurs zones n'ont pas accès à l'eau potable ni à l'irrigation. À cet égard, pour réduire les répercussions néfastes de ces transformations, il faut maintenir les pratiques agricoles diversifiées et durables comme elles l'avaient été auparavant.

Mots-clés : *Cannabis Sativa* ; LUCC ; paysage ; bassin versant de Laou ; montagnes du Rif ; SIG

Summary

1. Introduction

Cannabis cultivation has been practiced since ancient times. Hemp (*Cannabis sativa*) originated in Central Asia and has been grown in China since Neolithic times, around 6,000 years ago (Li, 1974). It then spread to other ancient civilizations, such as Egypt from the 16th century BC, Assyria, Israel, Prehistoric Europe and Scythia, Ancient Greece and Rome, Persia, Arabia and South America (Wills, 1998). Other studies have shown that the oldest records of cannabis date from the late-glacial period in central Italy (Mercuri et al., 2002: 263). Generally speaking, there are three main species of cannabis: *Cannabis indica*, *Cannabis sativa* and *Cannabis ruderalis* (Anderson, 1974; Anderson, 1980; Emboden, 1974; Schultes et al., 1974). The plant has many uses: as foodstuff, fuel or medicine; for phenolic compounds and antioxidant extraction; as non-conventional oil for the cosmetic and agro-industries (Russo, 2007; Bouarfa et al., 2020; Damej et al., 2020; Touiti et al., 2020; Taaifi et al., 2021; Aazza, 2021; Mokhtari et al., 2021); or as fibres for green plaster-based building materials (Charai et al., 2021). However, its most common use is still non-medical (Sedrati et al., 2022).

In Morocco, the first appearance of cannabis, in particular *Cannabis sativa* (Aboulaich et al., 2013), or *Kif* as it is called locally, dates back to between the 7th and 15th centuries, during the Islamic conquest of North Africa (Blickman, 2017). Its cultivation "started to develop from the 16th century in an area of the Rif region covering some 40km^2 in Ketama in the province of Al Hoceima, and to some extent at Bab Berred in the province of Chefchaouen" (Afsahi, 2011). Since the 18th century, the Rif Mountains of northern Morocco have been the largest producer of cannabis (Belakhdar, 1997). According to testimonies collected by Auguste Mouliéras, the plant was cultivated by three tribes: the Beni Bou Nsar, the Beni Seddate, and the Ketama (Mouliéras, 1895). Towards the end of the 19th century, Sultan Moulay Al Hassan (1873-1894) officially authorized the cultivation of cannabis for local consumption in five *douars* (villages) of the tribes cited above (Labrousse and Romero, 2001).

The proliferation of cannabis continued during the French and Spanish protectorate periods. However, following independence in 1956, Moroccan authorities prohibited cannabis cultivation except where it had traditionally taken place: the Ketama region (Chouvy, 2008).

Despite this prohibition, cannabis cultivation extended to other regions of the Rif. This was principally the result of poverty, which in turn was due to two factors: the first is principally ecological, as there is an extreme shortage of natural resources, particularly water and fertile soil; the second is political and linked to insufficient government attention to rural development (Joseph, 1973). Thus the area under cannabis cultivation in Morocco grew from 5,000 to 10,000 ha during the 1980s, then to 50,000 ha in 1994, 90,000 ha in 1999, and about 120,000 ha in 2001 (Labrousse and Romero, 2001). The total area under cultivation has steadily shrunk this century, from 134,000 ha in 2003 to 120,500 in 2004, and then to 72,000 in 2005 (Streel and Chinet, 2008). The Moroccan authorities succeeded in further reducing the area to 60,000 ha in 2009, 50,000 ha in 2010 and 47,500 ha in 2011. It is worth comparing these figures with the aim of the Moroccan state to reduce the cultivated area to 12,000 hectares by 2012 (Brownfield, 2011). However, following the Arab Spring in 2011, forced eradication of cannabis was less effective. As a consequence, the fight to reduce the amount of land under cannabis cultivation has stalled; thus, "during the period 2013–2017, some 47,000 ha were reported to be under cannabis cultivation by the Moroccan government in 2017" (UNODC, 2019).

Regarding trade and commerce, cannabis resin (*hashish*) has come to play a significant global geopolitical and strategic role. However, according to Chouvy (2019: 20), the data available for this trade "is most often inaccurate, unreliable and highly controversial". Drugs, including *hashish*, question the very concept of boundaries by creating a vision of boundaries that differs greatly from that of politicians. Recent decades have seen drugs play a major economic role in illegal trade, first entering via the strait of Gibraltar and the Alboran Sea into the north of the Mediterranean, and then going on to meet the demands of the major consumption markets of northern Europe (Gamella and Jiménez, 2008; Herbert and Gallien, 2020).

Despite the imposition of strict border controls, the cannabis trade from Morocco has not stopped. Drug couriers travelling from Morocco to Spain are mostly Europeans hired by traffickers because they are seen as less likely to be stopped at the border and to fall into the hands of the authorities. Large quantities of *hashish* are also seized at the port of Tangiers-Med, which highlights the city's major role in trafficking. Tangiers is an important transit point for the trafficking of drugs, whether local cannabis or imported cocaine.

From the drug trafficker's perspective, boundaries are areas of confusion and unregulated porosity which exist outside the regulatory logic of the state (Gallien, 2020). This indicates how our tangible relationships with borders only take shape when they become strategically important to the actors. This leads us to see dynamic work fields within borders.

It should be noted that since the increase in land use during the 1980s, the cultivation of cannabis in the Rif region of Morocco has played a crucial role in socio-cultural, economic and spatial transformations. This change has become increasingly visible with the appearance of new varieties of cannabis which have replaced the landrace *kif* that "could be considered a terroir product, due to its typicity, its origin and its production environment" (Chouvy, 2022). These new varieties, such as Pakistana, Jamaicana, Mexicana, Marijuana, Avocat and Trikita, are characterized by "radically different physical aspects and with much larger resin yields and much higher potency" (Chouvy and Afsahi, 2014: 2; Chouvy and Macfarlane, 2018: 86). "Traditional *kif*", which can adapt to local climatic conditions in the same way as all rain-fed agriculture, is sown in February and March and harvested in July or August. In contrast, the long growing time of new varieties, from April to October, needs large amounts of water, including in summer. This transformation has been accompanied by the emergence of an active and competitive cannabis seed market in the Rif (Afsahi, 2021). Climate change, with a general tendency towards higher average temperatures, drier conditions and greater irregularity in spatiotemporal rainfall, is a further key factor in understanding the recent conflicts over the availability of water in this new socio-economic and environmental context (Cramer et al., 2018; Salhi et al., 2019).

In the context of rapid, recent changes in northern Morocco, and following the United Nations vote on 2nd December 2020 to remove cannabis and cannabis resin from the list of the world's most dangerous drugs, the Moroccan government passed a bill on 11th March 2021 authorizing the medical, cosmetic and industrial use of cannabis (Chouvy, 2020; Rammouz and Boujraf, 2021; Mouna and Afsahi, 2020). Nevertheless, legalization may be difficult to implement in practice, for a number of complex reasons. The most important of these is the complexity of the land system in the Rif mountains. Furthermore, since recreational use is still illegal, and high demand from Europe continues, the situation seems unlikely to change in the near future. This context calls for prudence, and for measures to be put in place to minimize potential future environmental impact, since the new incentive to cultivate cannabis may lead to a high impact on the environment, with significant negative collateral effects that are often unknown or overlooked (Carah et al., 2015; Klassen and Anthony, 2022).

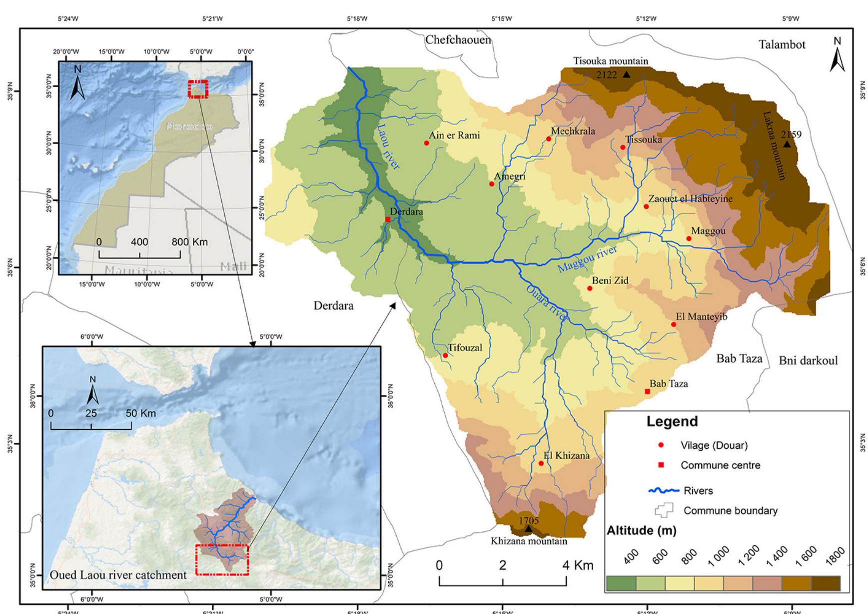
This article attempts to study the role of cannabis cultivation in landscape structure changes – in other words, land use and cover changes (LUCC) – in the Rif Mountains of Morocco, focusing on the upstream part of the Laou river catchment area. LUCC has become the subject of much research across various disciplines (geotechnical, engineering, geography, economics and sociology, among others). Several studies in Morocco have focused on land use and land cover change. Some are scientific, focused particularly on soil, surface and vegetation analysis (Maanan et al., 2014; Mohajane et al., 2018; Simonneaux et al., 2015; Sobrino and Raissouni, 2000), while others are in the field of urban studies (Barakat et al., 2019; Debolini et al., 2015; El Garouani et al., 2017). Most studies show that cannabis cultivation in the Rif Mountains has negative environmental results. It "deepens the ecological crisis of the Rif, by contributing to the destruction of land" (McNeill, 1992: 390). Research into soil shows that the ratio of pore (aggregates, fissures, biopore holes) in areas where cannabis is cultivated does not exceed 53%, compared to 63.7% in land under cereal cultivation. Furthermore, the stable infiltration rate in cannabis-tilled soil is extremely slow (32.7%/mm/h), compared to 63.7% in forested land (Sabir et al., 2004). This issue has, however, not been studied using a detailed LUCC analysis. This would show that cannabis cultivation is the driving force of environmental and socioeconomic change in the region. Therefore this study aims to understand the evolution and expansion of cannabis cultivation and its contribution to LUCC in the area of study. It is also a basic contribution to understanding the general change of LUCC in the main part of the Rif Mountains over the past 35 years, and the real impact of the new varieties of cannabis on the transformation of this region's landscape.

2. Materials and Methods

2.1. Study Area

The Laou river catchment area is located in north-western Morocco, and lies between 35°00' and 35°90' N, and 5°9' and 5°19' W. It covers an area of

Figure 1. Study area location



Source: Authors' own work based on SRTM elevation data at 90m resolution.

around 930km^2, with altitudes that vary between two metres below and 2,159 metres above sea level. The area consists of three main bioclimatic stages: humid; sub-humid; and semi-arid (Mharzi et al., 2016); and average annual rainfall ranges from 400mm per annum downstream to 1,000mm upstream (Salhi et al., 2019). The study area situated in the upstream part of the Laou river catchment area (Figure 1) covers 155km^2, or 17% of the total catchment surface area. Administratively, it forms part of the Province of Chefchaouen, and also includes two rural communities (Bab Taza and Derdara). According to the 1982 General Population and Housing Census (AGPH), 8,940 people lived in the area; by the 2014 census, the population had risen to 21,056, over 72% of whom lived in rural areas. According to the latest census, more than three quarters of the population work in agriculture, particularly cannabis cultivation, which, as in other areas in the Rif, provides a livelihood for most.

2.2. Data Preparation and Processing

For the purposes of this study we have used Landsat images from the United States Geological Survey (USGS) EarthExplorer website (<https://earthexplorer.usgs.gov/>). We used Landsat (5 and 8) Thematic Mapper-TM (1985, 1995, 2005) and Operational Land Imager-OLI (2013 and 2019), at path (206) and row (036) with under 2% cloud cover, a spatial resolution of 30m×30m, on the acquisition date during the dry season (i.e. the months of July and August) (Table 1). The choice of date was driven by two considerations: atmospheric conditions are favourable during the dry season; and, as this is when the cannabis plant species contains large quantities of chlorophyll, it makes it easy to distinguish from other crops such as cereals (Figure 2). The choice of the years 1985, 2013 and 2019 enabled us to ascertain the evolution of cannabis cultivation and LUCC. These were years of transition, as from the mid-1980s a few farmers started to cultivate cannabis, and, as mentioned above, since 2013 new varieties of cannabis have appeared following the Arab Spring.

Figure 2. False-colour composite (bands of 5-4-3 NIR, Red and Green) make Cannabis plants appear bright red because they reflect infrared light strongly (upstream of study area – rural commune of Bab Taza)

Source: Left: Landsat images, Operational Land Imager-OLI (20-07-2020) from the United States Geological Survey (USGS) earth explorer website (<https://earthexplorer.usgs.gov/>); Right: taken by authors 03-08-2020).

Table 1. Detailed data on Landsat images used in the study

Year	Satellite	Sensor	Path /Row	Resolution (m)	Acquisition Date	Cloud Cover
1985	Landsat 5	TM	206/036	30	04/07/1985	0%
1995	Landsat 5	TM	206/036	30	16/07/1995	0%
2005	Landsat 5	TM	206/036	30	27/07/2005	1% (not in the study area)
2013	Landsat 8	OLI	206/036	30	01/07/2013	1.38% (not in the study area)
2019	Landsat 8	OLI	206/036	30	03/08/2019	0.28% (not in the study area)

Source: Authors' own data.

The images are radiometrically and geometrically corrected by converting Landsat DNs to Top of Atmosphere (ToA) Reflectance, and are projected onto the Lambert Conformal Conic projection. We used the maximum-likelihood classification for the spectral classification of the Landsat images. Taking into consideration the existing knowledge of land use of the study area and spectral characteristics of the satellite images, seven types of land use and land cover (LULC) were identified: oak forest (OF), fir forest (FF), *matorral* (MT), rain-fed agriculture (RA), irrigated agriculture (IA), settlement area (SA), and bare soil/rock (BS/R) (Table 2 and Figure 4).

Given that the LULC maps were visually noisy – because of the similarities between the spectral responses of certain land cover categories such as new oak forest with irrigated agriculture and bare soil/rock with settlement areas – a post-classification refinement was applied in order to reduce classification errors (Manandhar et al., 2009; Peiman, 2011). This was based on visual interpretation and ground truth data: topographic maps (Feuille NI-30-XIX-2b: Bab Taza, 1969 and Feuille NI-30-XIX-2a: Chaouen, 1969) and

Table 2. LULC classification scheme

Class	Descriptions
Oak forest (OF)	Holm and cork oak forest (mainly: *Quercus ilex, Quecus humilis*) interspersed with different types of secondary vegetation.
Matorral (MT)	Degraded forests mainly consisting of shrubland and other Mediterranean plants.
Fir forest (FF)	Areas reforested with firs (mainly: *Pinus pinaster*) by the state in the context of reforestation programmes in different Moroccan zones.
Rain-fed agriculture (RA)	Agricultural land used for annual farming such as cereals and local cannabis; most of these lands are planted with olive trees.
Irrigated agriculture (IA)	Agricultural land used for cannabis cultivation, especially the new varieties.
Settlement area (SA)	Included residential, commercial, mixed rural/urban areas and roads.
Bare soil/rock (BS/R)	Exposed soil and bedrock.

Source: Authors' own data.

Figure 3. Examples of LULC classification in the upstream part of the Laou river catchment area. Top: Upstream of study area (Rural commune of Bab Taza); Bottom: Downstream of study area (Rural communes of Bab Taza and Derdara)

1: OF; 2: FF; 3: MT; 4: RA; 5: IA; 6: SA; 7: BS/R

Source: Taken by authors. Top: 07-10-2014; bottom: 29-06-2013.

high-resolution satellite images (Google Satellite Map Imagery downloaded using the SASplanet application). The importance of local area knowledge was also taken into account, since accurate cannabis crop mapping is complex (Sujud et al., 2021). In order to verify the quality of the results of the classified maps, we needed to use assessment accuracy methods. "Normally, classification accuracy is carried out by comparison of two datasets: one based on reference information, referred to as ground truth, and the other being the result of the analysis of remotely sensed data" (Twisa and Buchroithner, 2019: 5). Accuracy was assessed using more than 50 pixels per category, through the adoption of visual interpretation and ground truth data described above. The overall accuracy for the data was 85.71% for 1985; 86.08% for 2013; and 88.44% for 2019. The Kappa coefficient for 1985 and 2013 was 0.84, and 0.87 for 2019 (Table 3). Lastly, in order to show the spatial transformations, it was necessary to make the change detection matrix during the period examined.

Table 3. Accuracy assessment of the LULC classification upstream of the Laou river catchment area

	1985		2013		2019	
LULC	**PA**	**UA**	**PA**	**UA**	**PA**	**UA**
OF	90.28	94.20	85.71	97.06	100.00	96.92
FF	100.00	98.25	100.00	100.00	100.00	92.98
MT	81.36	78.69	91.49	79.63	82.61	71.70
RA	68.54	87.14	73.40	90.79	79.35	96.05
IA	100.00	89.04	100.00	79.10	97.06	98.51
SA	96.67	63.04	96.97	69.57	97.06	66.00
BS/R	75.00	82.35	71.43	80.36	72.06	87.50
Overall	85.71		86.08		88.44	
Kappa	0.84		0.84		0.87	

Source: Authors' own data.

All processing and post-classification steps were completed using the ArcGIS 10.7 and ENVI 5.3 software packages. The first stage was a radiometric correction, followed by the assignment of the coordinate system and of the datasets, and sub-setting the images based on the polygon of the study area. The final stage was the production of the LULC maps. The change detection matrix between the initial (1985) and final (2019) states, and the graphs, were calculated using Microsoft Office Excel 2016.

3. Results

3.1. LULC Change Direction

In recent decades, the study area has undergone significant change. Tables 4 and 5 and Figure 4 reveal the full extent of LULC change from 1985 to 2019.

Table 4. Results of the LULC classification for 1985, 2013 and 2019 images showing the area of each category and category percentages upstream of the Laou river catchment area

Year	1985		2013		2019	
LULC (Area)	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**
OF	5385.04	34.68	4018.91	25.88	3098.74	19.96
FF	375.14	2.42	258.95	1.67	119.97	0.77
MT	3660.53	23.58	2843.86	18.32	2975.47	19.16
RA	4022.51	25.91	5238.36	33.74	6186.05	39.84
IA	705.82	4.55	1573.69	10.14	1299.27	8.37
SA	198.79	1.28	307.31	1.98	310.55	2.00
BS/R	1167.00	7.52	1273.75	8.20	1524.78	9.82
Total	15526.37	100.00	15526.37	100.00	15526.37	100.00

Source: Compilation based on map database – Figure 5.

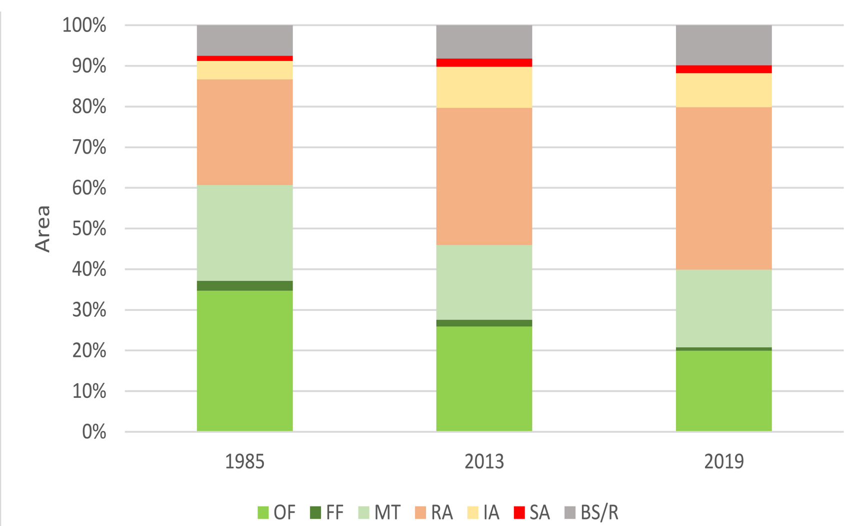
Table 5. Results of the LULC classification for 1985, 2013 and 2019 images showing the area changed and percentage upstream of the Laou river catchment area

Year	1985-2013		2013-2019		1985-2019	
LULC (Area)	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
OF	–1366.13	–8.80	–920.17	–5.93	–2286.30	–14.73
FF	–116.19	–0.75	–138.99	–0.90	–255.18	–1.64
MT	–816.67	–5.26	131.61	0.85	–685.06	–4.41
RA	1215.84	7.83	947.70	6.10	2163.54	13.93
IA	867.87	5.59	–274.42	–1.77	593.45	3.82
SA	108.52	0.70	3.25	0.02	111.76	0.72
BS/R	106.76	0.69	251.03	1.62	357.78	2.30

Source: Compilation based on map database – Figure 5.

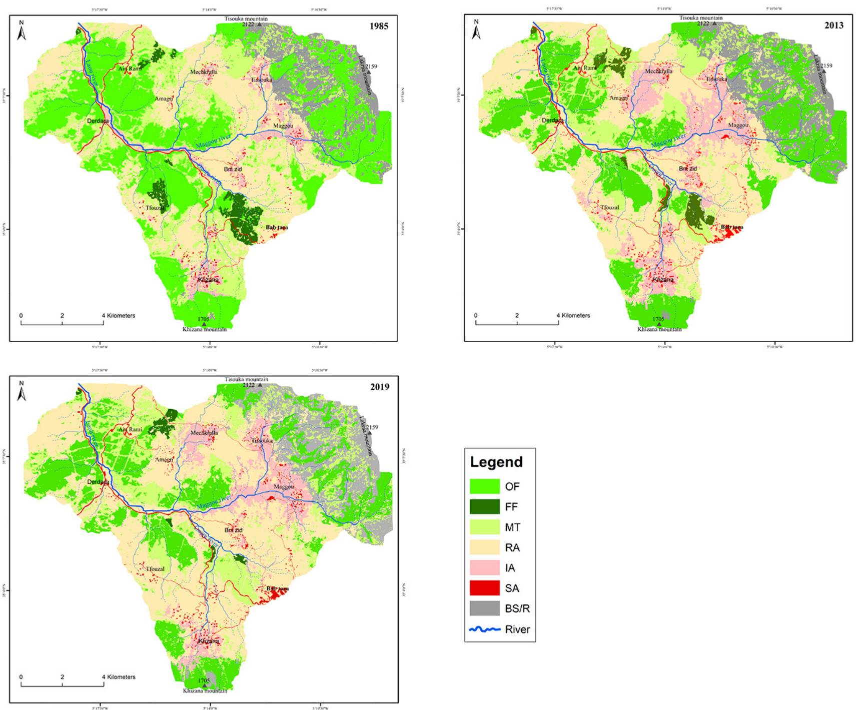
Furthermore, Figure 5 summarizes the spatial representation of LULC types over the same period. In 1985, forest areas represented 60.68% of the total area studied: 34.68% was oak forest, 23.58% *matorral*, and 2.42% fir forest. Rain-fed agriculture represented 25% of the total area studied, while the remaining categories represented only small percentages. However, over time, the situation started to change for all LULC, and the order was different in 2019. Rain-fed agriculture occupied around 40% of the total area, followed by oak forest and *matorral* (19% each), bare soil/rock at 9.82%, irrigated agricul-

Figure 4. LULC change graph for 1985, 2013 and 2019 upstream of the Laou river catchment area



Source: Compilation based on the map database – Figure 5.

Figure 5. LULC maps for 1985, 2013 and 2019 upstream of the Laou river catchment



Source: Authors' own data based on Landsat images (5 and 8) Thematic Mapper-TM (1985, 1995, 2005), and Operational Land Imager-OLI (2013 and 2019) from the United States Geological Survey (USGS) earth explorer website (<https://earthexplorer.usgs.gov/>); field survey, 2019.

ture at 8.37%, settlement areas at 2%, and fir forest (reforestation) at 0.77% (Table 4). As Table 5 shows, natural areas have decreased by 20.78%: oak forest by 14.73%, *matorral* by 4.41%, and fir forest by 1.64%. Conversely, the agricultural land base significantly expanded between 1985 and 2019 by a total of 17.76% (13.93% of rain-fed agriculture and 3.82% of irrigated agriculture).

We constructed a change detection matrix (Tables 6 and 7) to determine changed and unchanged pixels in each pixel pile (Lê et al., 2014). The change detection matrix during the period examined has been split into two: Table 6 shows the changes in land cover classes over a 28-year period (the first period, from 1985 to 2013), while table 7 shows the change over a six-year period (the second period, from 2013 to 2019). In the first period, 26.3% of oak forest had been given over to other classes by 2013: 982.87 ha became *matorral*, 320 ha were turned into agricultural areas (280.35 ha of rain-fed agriculture and 39.65 ha of irrigated agriculture), 80.09 ha became bare soil/rock, 30.37 ha was forested with firs, and 2.45 ha became settlement lands. Only 35.48% of the total area of fir forest remained in 2013, 170.31 ha had been converted

Table 6. Transition matrix showing LUCC upstream of the Laou river catchment area, 1985 to 2013

			From 1985							
	LULC	Unit	OF	FF	MT	RA	IA	SA	BS/R	Class Total
To 2013	OF	(Ha)	3969.25	47.72						4016.97
		%	73.71	12.72						
	FF	(Ha)	30.37	133.11	95.51					258.99
		%	0.56	35.48	2.61					
	MT	(Ha)	982.87	170.31	1692.63					2845.81
		%	18.25	45.40	46.24					
	RA	(Ha)	280.35	21.68	1483.78	3160.27	258.24		32.25	5236.57
		%	5.21	5.78	40.53	78.56	36.59		2.76	
	IA	(Ha)	39.65	1.35	310.35	789.02	434.20			1574.57
		%	0.74	0.36	8.48	19.62	61.52			
	SA	(Ha)	2.45	0.97	18.13	73.22	13.4	198.79	0.24	307.17
		%	0.05	0.26	0.50	1.82	1.90	100.00	0.02	
	BS/R	(Ha)	80.09		60.14				1134.51	1274.74
		%	1.49		1.64				97.22	
	Class Total	(Ha)	5385.04	375.14	3660.53	4022.51	705.82	198.79	1167.00	15514.83
		%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

Source: Compilation based on the map database – Figure 5.

to *matorral*, 47.72 ha to oak forest, 23 ha to cultivation area, and around one hectare became settlements. It is striking that deforestation most affected *matorral*, with almost half its surface area deforested for the purpose of crop growing. In contrast, only 2.61% of *matorral* was reforested over this period, 1.64% became bare soil/rock, and 0.50% settlements. The transformation of agricultural land was mainly from irrigated to rain-fed land or vice versa. Of 4,022.51 ha of rain-fed agriculture, 789.02 ha were converted to irrigated agriculture, and of 705.82 ha of the latter, 258.24 ha were converted to the former. In addition, certain areas given over to agriculture have become settlements intended for housing. It is important to note that 32.25 ha of rain-fed agriculture have taken the place of bare soil/rock, particularly at the foot of the Lakraa, Tisouka and Khizana mountains. In contrast to the other classes, no change in settlement areas was noticed, with 100% remaining intact.

Change in LULC continued over the second period (2013 to 2019). 21.44% of oak forest was converted to *matorral*, 6.38% to bare soil/rock, about 4% to agriculture, and 0.01% was reforested (0.35 ha of fir). The largest change was that of fir forest, as over half of the total area was converted to *matorral*, and 7.67% to agriculture. As in the earlier period, *matorral* is experiencing large-scale deforestation for cultivation. 15.75% has been transformed into agricultural areas (427.90 ha of rain-fed agriculture, and 19.93 ha of irrigated agriculture), and 1.88% has become bare soil/rock. In contrast, only 13.28% was reorganized and converted into oak and fir forest (348.16 ha

Table 7. Transition matrix showing LUCC upstream of the Laou river catchment area 2013–2019

			From 2013							
	LULC	**Unit**	**OF**	**FF**	**MT**	**RA**	**IA**	**SA**	**BS/R**	**Class Total**
To 2019	**OF**	(Ha)	2750.58		348.16					3098.74
		%	68.44		12.24					
	FF	(Ha)	0.35	90.13	29.49					119,97
		%	0.01	34.80	1.04					
	MT	(Ha)	861.61	148.96	1964.91					2975.47
		%	21.44	57.52	69.09					
	RA	(Ha)	128.16	18.70	427.90	4874.11	681.15		56.03	6186.05
		%	3.19	7.22	15.05	93.05	43.28		4.40	
	IA	(Ha)	21.90	1.17	19.93	361.24	892.30		2.73	1299.27
		%	0.54	0.45	0.70	6.90	56.70		0.21	
	SA	(Ha)				3.00	0.25	307.31		310.55
		%				0.06	0.02	100.00		
	BS/R	(Ha)	256.31		53.47				1214.99	1524.78
		%	6.38		1.88				95.39	
	Class Total	(Ha)	4018.91	258.95	2843.86	5238.36	1573.6	307.31	1273.75	15514.83
		%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

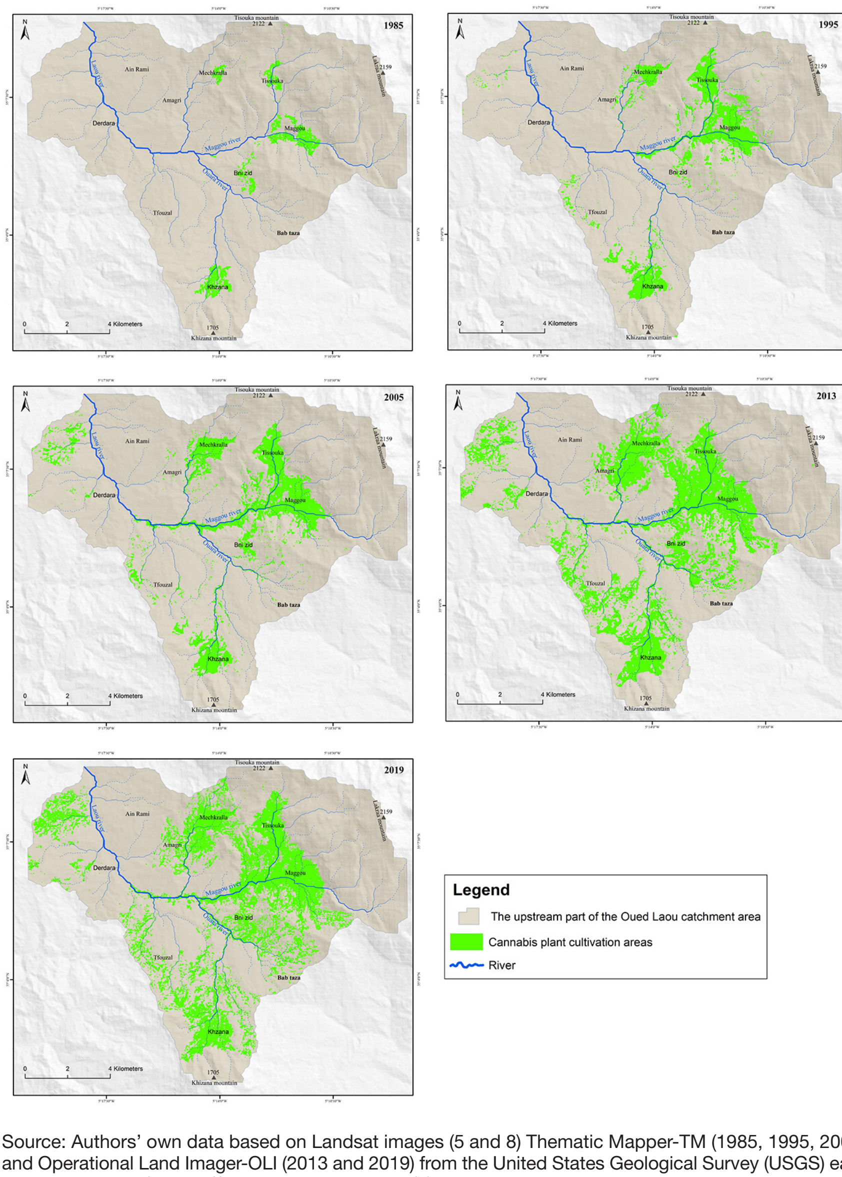
Source: Compilation based on the map database – Figure 5.

of the former, and 29.49 ha of the latter). The transformation of agricultural lands was notable at the level of irrigated agriculture, as 43% of the total area was converted to rain-fed agriculture, whereas 93.05% of the area given over to rain-fed agriculture remained unchanged, the rest being converted to irrigated agriculture (6.90%), and to settlement area (0.06%), which saw no change at all. We note that some new agricultural land was created from bare soil/rock (58.76 ha), as shown in table 7.

3.2. The spatial evolution of cannabis cultivation

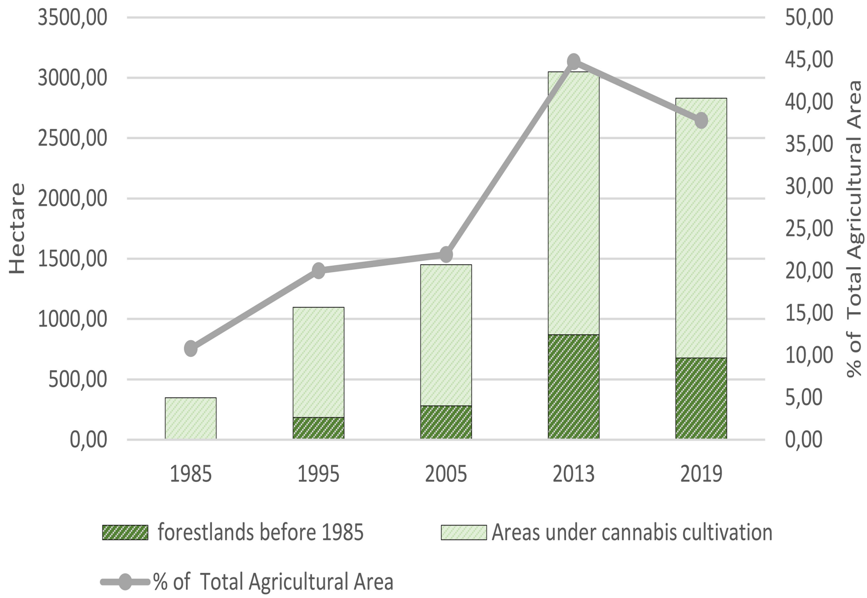
Figures 6 and 7 show the evolution of cannabis cultivation from 1985 to 2019 in the upstream part of the Laou river catchment area. Few farmers grew cannabis in the mid-1980s, mainly in fields located near the *douars*, and the total area under cannabis cultivation in 1985 was 349 ha, just 10.81% of the total agricultural land area. Ten years later, cannabis cultivation was no longer located in fields near settlements, rather it was increasingly concentrated in the distant fields adjacent to the valleys, and took place on land that had been forest. The response to the initial increase of governmental control of cannabis cultivation was to force it into remote areas, far from settlements, and in zones that had traditionally been forest. The rate of cannabis cultivation more than tripled between 1985 and 1995, as about 1,100 ha were given over to cannabis cultivation; this is equivalent to 20% of the total agricultural

Figure 6. The evolution of Cannabis cultivation upstream of the Laou river catchment area 1985-2019



Source: Authors' own data based on Landsat images (5 and 8) Thematic Mapper-TM (1985, 1995, 2005), and Operational Land Imager-OLI (2013 and 2019) from the United States Geological Survey (USGS) earth explorer website (<https://earthexplorer.usgs.gov/>); field survey, 2019.

Figure 7. Cannabis cultivation area for 1985, 1995, 2005, 2013 and 2019 upstream of the Laou river catchment area



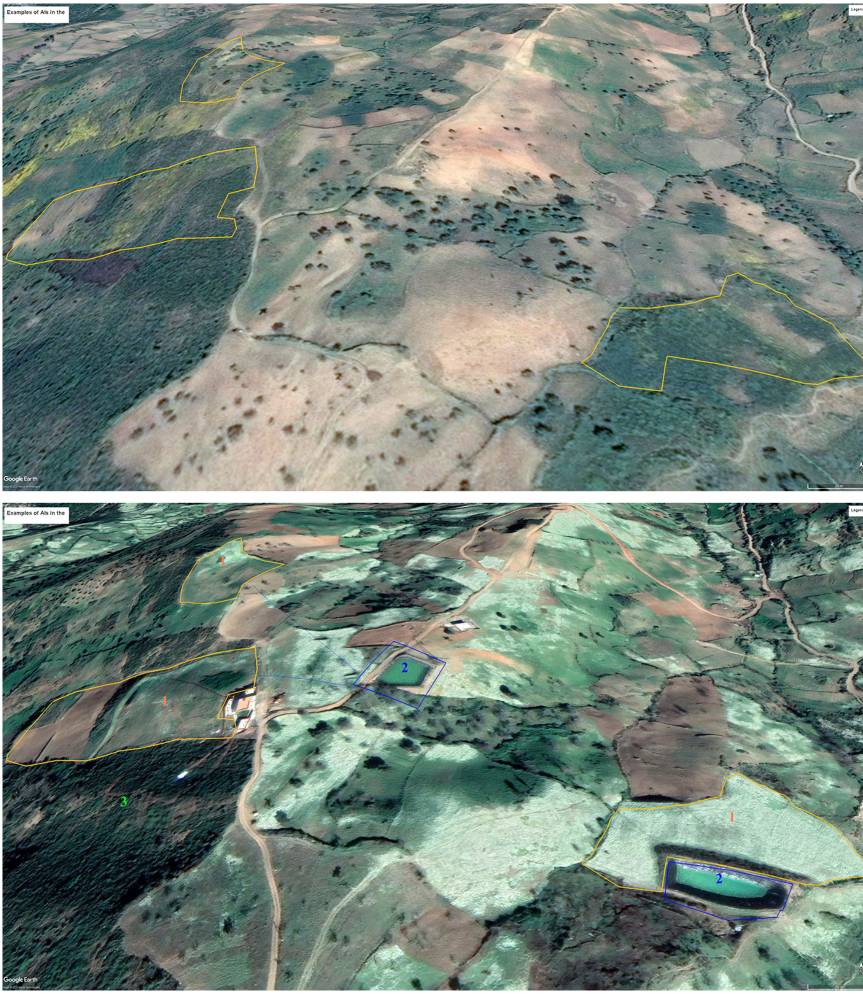
Source: Compilation based on the map database – Figure 4 and Figure 6.

land area. 17% of this area had been forest before 1985. Over the years, the increase continued, reaching 1,451 ha in 2005, representing 22% of the total agricultural land area, 19% of which had been forest two decades before. In 2013, following the Arab Spring and decreasing governmental control, the cultivation of cannabis reached its maximum land use, at 44.76% of total agricultural land area (3,051 ha), 29% of which was obtained through deforestation. We note here a recent slight fall in the area under cannabis, to 38% of total agricultural land in 2019.

4. Discussion

In the early-1990s, the study area experienced a significant transformation. This is reflected in the LUCC; and that 40% of LULC changed between 1985 and 2019. Forested area (oak, fir and *matorral*) decreased during this period by 5141 ha, equivalent to losing 151 ha of forest every year. In contrast, the agricultural land base grew significantly, increasing to 2,757 ha (2,164 ha of rain-fed agriculture, and 593 ha of irrigated agriculture). This fast-changing dynamic is linked essentially to the cultivation of cannabis, the economic benefits of which have contributed to demographic stability in this mountain area, where the population grew at an annual rate of 2.7% between 1982 and 2014.

Figure 8. Example of landscape change process in the area of study: construction of artificial impoundments and LUCC from matorral vegetation to irrigated agriculture (west of the village of Maggou, rural commune of Bab Taza)



1: Irrigated agriculture, 2: Artificial impoundments, 3: Matorral vegetation.

Source: Google Earth. Top: 23-5-2016; bottom: 28-2-2020.

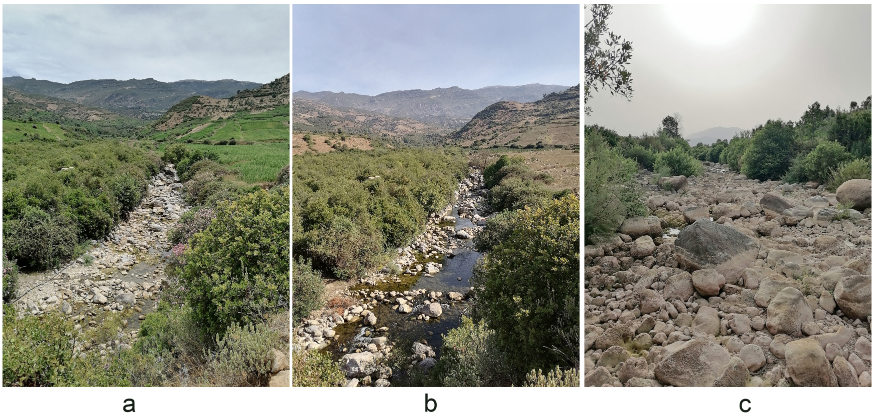
The irrigated area, characterized by the dominance of cannabis cultivation, has experienced significant changes. Evidence of this is the transformation of several hundred hectares of rain-fed to irrigated lands, and vice versa. The transformation from rain-fed to irrigated crops mainly included those areas near water sources (especially in the upstream part of the study area); as well as in some zones which have seen hydro-agricultural improvements; and in some agricultural areas surrounding the urban centre of Bab Taza taking advantage of wastewater. However, about 270 ha which had been irrigated, particularly agricultural land in the downstream area, are now no longer irrigated. Consequently, spatial justice, in levels of accessibility to irrigation water, is no longer available, which has given rise to the emergence of new conflicts between the *douars,* located upstream, and others in the downstream part of the study area.

This shift was already evident after the progressive and varied adoption of agricultural innovations at the cultivation and production stages in the early 2000s, and increased during the 2010s (Chouvy and Macfarlane, 2018: 86). This was demonstrated by the acquisition of modern irrigation equipment such as petrol and/or electric pumps, the construction of artificial impoundments (Hmamou and Bounakaya, 2020) (Figure 8), and the use of modern equipment to clear land of rocks. This has coincided with the appearance of new cannabis varieties which cannot produce a resin (*hashish*) without irrigation water. Agricultural innovations and the culture of new cannabis hybrids in the study area, as well as the other areas under cannabis cultivation in the Rif, have raised a number of concerns regarding ecological aspects (Blickman, 2017; Taïqui, 1997); environmental aspects (Afsahi, 2011; Afsahi and Darwich, 2016; Afsahi, 2017; Moore et al., 1998); and economic and social sustainability (Afsahi, 2011; El Mazi et al., 2019; El Motaki et al., 2019; López Lara et al., 2015; Meklach and Merzouki, 2021; Rahmi et al., 2021). The deterioration of the local environment has a huge impact on the global environment (Foley et al., 2005).

As is well known, water sources make a great contribution in the creation of attractive cultivated landscapes, especially during the dry season. While this was the case for the Rif in the past, this study has revealed a massive disappearance of this contribution since the end of the 1990s, which only worsened at the beginning of the 2010s. The trend, which is dominated by cannabis plant cultivation, resulted in state intervention, aided by the European Union, in these areas through a variety of development programmes, especially the Meda programme (Natorski, 2008), and the Green Morocco Plan (Faysse, 2015), as the issue of water formed a substantial part of these projects. However, the outcomes were modest in most instances, and so environmental degradation has persisted.

The greenness of the landscape in several areas of the Rif Mountains during the autumn planting season has been declining steadily from downstream to upstream, and the same decline is noted in a number of fruit trees (quince, pomegranate, plum, and cherry, among others). In other words, the water resources flowing from the Lakraa, Tisouka and Khizana mountains are no longer sufficient, apart from areas near water sources (Figure 9). This has had an adverse effect on the environment, greatly reducing the land area available for fruit trees. More importantly, it has also led to the extinction of native tree species which grew on river banks, such as *Salix alba*, Black poplar and others; it has also led to the death of fish and other aquatic organisms which had long been a source of food and leisure for many people.

Figure 9. Example of the water landscape change process due to the overexploitation of water for irrigation of cannabis (upstream of the Maggou river, rural commune of Bab Taza)



(a) and (c): During irrigation period; (b): After irrigation period

Source: Taken by authors on (a) 03-08-2020; (b) 10-10-2020; and (c) 24-07-2021.

This transformation is clearly not only the result of climate change; it is equally due to inter-related demographic-human-behavioural, technical and financial factors. The population has risen quickly, with a corresponding demand for resources. In particular, agricultural land has been, and still is, intensively exploited due to actions that fail to take into account the environmental, economic and social side effects. The availability of financial resources from cannabis production has contributed to a greater openness to modern techniques used in land use changes. The arrival of electricity in rural areas has led to the use of legal or illegal electric pumps, thus facilitating an increase in the amount of irrigated land. In addition to this, new cannabis varieties are more productive and need more water, making their environmental impact greater, and leading to social conflict regarding the use of water in a context of water shortages at a time of climate change.

5. Conclusions

This accurate spatial analysis, using and comparing the Landsat data from the last 35 years (1985 to 2019) clearly highlights the significant expansion of cannabis cultivation. The comparison of satellite images taken over the period examined gave us greater understanding of the impact of cannabis cultivation on landscape structure changes in the upstream part of the Laou river catchment area. The maps in this study revealed substantial change in the distribution of land cover and land use, especially when cannabis cultivation became the main agricultural activity for the majority of the rural population. This happened because the mountain areas are characterized by a limited amount of arable land, and because of the high financial benefits of cannabis cultivation. The cultivation of cannabis was at the expense of forests, which lost more than one third of their original area between 1985 and 2019, at an annual average rate of 94 ha per year. From 1985 to 2013, the rate was 82 ha per year, while this rose to 155 ha per year in the period from 2013 to 2019. This provides evidence of a clear process of acceleration in LUCC. This indicates that deforestation has increased with the appearance of new varieties of cannabis when compared with the earlier period of local cannabis cultivation. In addition, the new post-Arab Spring political context has led to a drastic reduction in the governmental fight against the expansion of cannabis production, and the corresponding tolerance of large-scale cultivation in the Rif. However, it must be noted that in 2019 the area under cannabis cultivation fell slightly, due to the renewed efforts of the state to crack down on cultivation, especially along main roads in rural areas, and increased attention on new varieties of cannabis that need the presence of water sources to grow. Faced with this situation, farmers will have no choice but to cultivate irrigated areas. The difficulty in exporting cannabis resin abroad is a further reason for this fall, as is the cultivation of imported foreign cannabis, which not only caused significant degradation of forests and soils, but was also a fundamental source of conflict over access to irrigation water. Such studies may therefore be considered as a basis for strategic planning. In order to halt, or at least reduce, the damage of these transformations, we must restore diversification and sustainable agricultural practices to their previous state. We need to reconsider current agricultural practices, as it has become apparent that their economic benefits are not lasting, and in reality they are a major cause for the socio-economic and environmental crises in the Rif Mountains, both now and in the near future.

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