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EVOLUTION OF LAND COVER IN THE TRARAS MTS. REGION BETWEEN 1984 AND 2020 BY REMOTE SENSING AND GIS (NORTHWEST ALGERIA)

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Abstract

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In Algeria, the mountainous zones represent 11% of agricultural land of the country and are home to 25% of the population. The economic development and the associated urbanization have led to environmental degradation in the Traras Mountains, which are part of the Atlas Mountains. With the aim to evaluate the degradation consequences of this region, we focused on the evolution of land use and land cover over 36 years (1984–2020). Accordingly, we used Landsat and Google Earth Pro images, topographic and ecological inventory maps, as well terrain truth; our analysis tools were mainly based on ArcGIS, Global Mapper, and ENVI software. The diachronic analysis showed that the Traras Mountains lost 8,100 ha of agricultural and forestland between 1984 and 2020. Relating to this, we point out the destruction of 9,200 ha of forested area by the fire. The urbanization also contributed to the loss of agricultural and forested areas (6,300 ha), of which 27% are located in the coastal zone. The built-up situation led to an increase of soil impermeability which causes flooding during heavy rainfall.

Key words: Algeria; GIS; land use; remote sensing; Traras Mountains.

Introduction

Nowadays, environmental change is considered as a global threat, which impacts different regions, especially mountainous zones, as they are environmentally vulnerable areas. Their high sensitivity is due to climatic changes between hot and dry summer against heavy rainfall during cold periods; accidental forest fires, land clearing, and urbanization are also significant anthropogenic factors that contribute to environmental degradation. In fact, these factors reduce the vegetation cover, increasing the vulnerability of the soil to erosion. In 2009, due to natural evolution, the average air temperature increase recorded in French Alps was twice higher than the national average air temperature registered in France (EEA, 2009). Therefore, mountainous regions respond rapidly and extremely to climate change, affecting ecosystems and the well-being of the population (Ametys, 2021). In this context, summer period with high temperature leads to an intensification of rock falls at high altitudes, destabilization of glaciers and block glaciers, torrential rain, and forest fires. More gradual changes are also perceptible according to seasonality or location of the events, such as shifting of the peaks of snow melt and glacial floods, which increase the proportion of wet snow avalanches, and increase in altitude of the zones where debris flows start (Einhorn et al., 2015). Mountains are, therefore, considered as indicators or natural laboratories for observation of climate change and its effects (Richard et al., 2010). The degradation of soil and loss of biodiversity can also be an indicator of climate change (Skole, 1994). The results obtained in our present study show that erosion, forest fires, and anthropogenic behavior have caused a consequent change in land use and cover in the Traras Mountains (NW Algeria). These causal factors have been poorly perceived for a long time by the local society. Thanks to the diachronic study conducted between 1984 and 2020, we were able to generate a spatial mapping of identification, location, and quantification of the natural and anthropogenic effects that impacted soils. During the period 1992–2020, 210 fires, that is, seven fires/year representing 15% of the total fires declared in the district of Tlemcen, affected 9,200 ha. In the east of the country, the region of Tizi Ouzou recorded 145 major fires that destroyed 47,942 ha of forest (48.45%). Analysis of annual reports shows that Algeria records an annual average of 1,500 fires covering a total area of 35,000 ha (Sahar et al., 2020). In the Mediterranean basin, an average of 600,000 ha of forest are affected by fire yearly.

The impact of the effect of fire on the soil is heavy. Soils on slopes, after fire, are more rapidly depleted in organic matter and become more vulnerable to erosion and drying (Morsli et al., 2013a). In addition, drought episodes weaken soil's resistance to erosion (Boughalem, 2013). Under its natural effects, the surface

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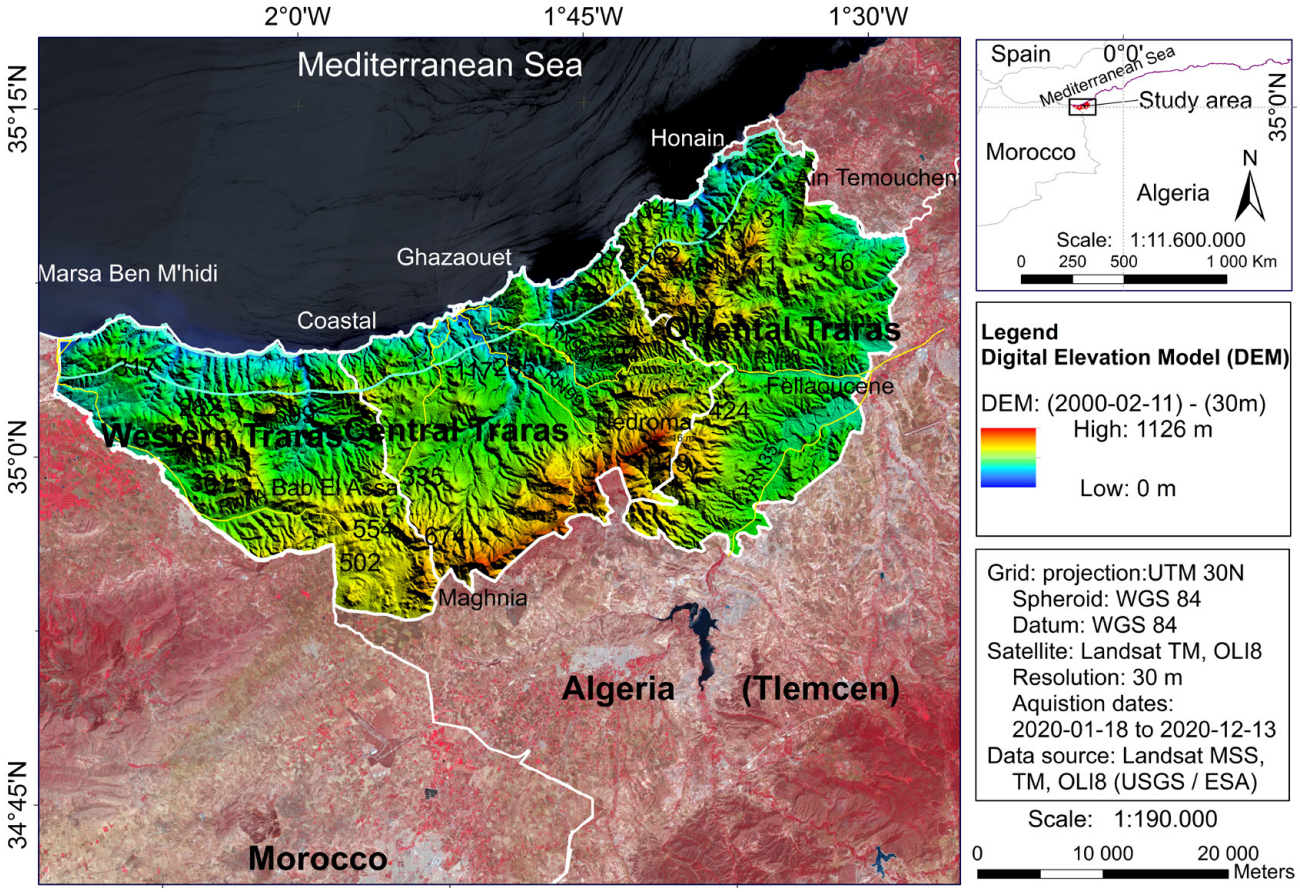


Fig. 1. Topographical configuration of Traras mountains.

of the eroded soils in the Traras Mountains has increased by 1,800 ha in 36 years (1984–2020), that is, an increase of 50 ha/year. Of the 13 hill water reservoirs in the area, only two are operational due to soil degradation. Western Algeria is the most eroded region of the country, with 47% of its land affected by erosion (Morsli et al., 2013b). With an average annual specific erosion of 2,000–4,000 t/km²/year (Demmak, 1982), Algeria is classified as one of the most erodible countries in the world (Touaibia, 2010).

Between 1984 and 2020 (36 years), urbanization consumed 4,500 ha (125 ha/year) of agricultural land, 1,500 ha (41 ha/year) of forest, and 300 ha (83 ha/year) of bare soil. In Oran (Northwest Algeria), the annual growth of the cluster of three communes in central Oran was estimated at 3% in 12 years (1991–2003: 152 ha/year) (Bendraoua et al., 2011). In the east of the country, between 1961 and 2014 (53 years), the urbanization rate of the city of Batna was estimated at 50 ha/year (Benyahia, Dridi, 2017). Between 1990 and 2006, the total surface area of European urban areas increased from 17,620,000 ha in 1990 to 19,120,000 ha in 2006, which corresponds to an increase of 9% (93,750 ha/year). In French, the surface area of French urban space increased by 19% in a decade (Elmi, 2016). Between 2012 and 2014, the French land classified as artificial land increased by 4% (Bechet et al., 2017). In Belgium, urbanization is progressing at a rate of 2 m²/s, that is, the surface area of two football pitches, in 1 h (Brück, Mérenne-Schoumaker, 2002). The objectives of our work were to provide the local authorities, territory planners, and decision-makers with a diachronic digital map of identification and localization of the changes that occurred in the Traras Mountains between 1984 and 2020. This measure would contribute to the development and protection plans for the Traras Mountains.

Material and methods

Study area

The study area is located between latitudes 35°23´ and 34°88´N and longitudes 2°21´ and 1°46´W; it covers 129,500 ha. According to the analysis of the Digital Elevation Model (DEM) 30-m resolution (Fig. 1), it presents a high relief, mainly formed by mountains. Analysis of topographic indices shows that 57% of the total area of the Traras Mountains is located on slopes between 9 and 76%, which are consequently exposed to erosion (Kazi-Tani, Gaouar, 2015). An important and well-developed hydrographic network crosses the lands that are located in the western (33%), central (38%), and eastern (33%) pars of the Traras Mountains. Marl, sandstone, limestone, and alluvium build the lithology of the study area. The presence of gullies formed by water action, especially on marl terrain, shows the vulnerability of marl or marl–sandstone to erosion (Kazi-Tani, Gaouar, 2015). The geological map of Alge-

ria established in 1952 (1:500,000) shows that limestone and marl substrates cover 56 and 41% of the entire area, respectively. The Traras Mountains are subject to a warm semi-arid Mediterranean climate with a long summer drought (Quézel, 2000). The average annual values for precipitation and temperature are 306.80 mm and 18.59 °C, respectively (Medjahdi, 2010). In 2020, agricultural land (59%) and forest (28%) occupied 87% of the total study area. Cereals (10 q/ha), arboriculture (10–15 q/ha), viticulture, and livestock represent the main agricultural activities. Yields of wheat and arboriculture have been reduced due to irregularity, low annual rainfall, and poor cultivation practices (Khemies, 2013). The forests are mainly composed of Aleppo pine, thyua, eucalyptus, cork oak, and undergrowth constituted by *Pistacia lentiscus, Quercus coccifera, Juniperus phoenicea, Olea europea*, and so on. The degradation of the plant structures is due to a combined action of man and climate. In the study area live 177,971 (2008) inhabitants, who represent 28% of the population of Tlemcen district. The average population density is 143 inhabitants/km^2 (ANAT, 2010).

Image processing

To detect and quantify land cover change between 1984 and 2020, we applied remote sensing methods because it has the potential to provide accurate land cover information (Olofsson et al., 2013). Accordingly, we performed a diachronic analysis, applying processing methods of 50 seasonal, annual, and temporal optical images acquired from the Landsat satellite "MultiSpectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager8 (OLI8)" (USGS) for the period from 07-03-1984 to 12-13-2020 in order to refine the date of the change event (Olofsson et al., 2014). Diachronic analysis of the images allows for the detection of natural or anthropogenic changes in an area (ESA, 2018).

Classification of units of land use

Geometric and radiometric correction, segmentation, and supervised object-oriented classification were carried out using GEOclassifier-1.2.3-win32, which has been developed by the European Space Agency. The GEOclassifier was implemented on ArcGIS software, whose tools are adapted to Mediterranean thematic categories (Beltrame et al., 2015). Among the tools, we used segmentation and supervised classification. The object-oriented method aimed to group similar pixels into objects that are classified based on spectral, textural, shape, and neighborhood criteria for characterization of major vegetation types (Sellin et al., 2013) and other thematic categories. This supervised classification method, applied in land use and land cover studies, has shown that land use is meaningful and responds better to the interpretation of ground truth data (Achbun et al., 2011). This method requires the use of several exogenous data such as topographic maps (INCT, 2004), National Forest Inventory (NFI), archive images from Google Earth Pro, Microsoft Bing, satellite images, and images of the spectral index (*Normalized Difference Vegetation Index (NDVI), Normalized Differencial Water Index (NDWI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Built-up Index (NDBI) and Normalized Burn Ratio (NBR*). The external data makes it possible to provide additional discriminatory elements (Ducrot, 2005) and to refine the identification and interpretation of the thematic classes sampled on the satellite images. Field observations in the study area, conducted in 2020, validated the remote sensing data. A Garmin global positioning system (GPS) and processing software such as ArcGIS, QGIS, Global Mapper, ENVI, Excel, and Paint were used. In addition, the Corine Land Cover (CLC) typology was used to map land use and land cover. This typology is useful since the characterizations of the Mediterranean thematic classes are similar. In this context, the typology combines two semantic fields of land cover (Sparfel, 2011), which are a geographic database derived from satellite image interpretation (ONCEA, 2014) and the classification method (CLC) applied to the thematic classes present in the Mediterranean basin (Beltrame et al., 2015). It is one of the initiatives of land use mapping worldwide (García-Álvarez et al., 2022). The application of typology in our present work consists of identifying, codifying, and editing the thematic classes observed in the field into classes up to level two (2) of land cover as defined by the European Directive INSPIRE (2007/2/EC) (García-Álvarez et al., 2022), and this is in order to characterize the main land use classes of the area and avoid mapping too much detail (Table 1).

Table 1. Land cover classes in the study area.

CLC classes	Description
CLC11	Urban fabric
CLC24	Heterogeneous agricultural areas
CLC31	Forests
CLC33	Open spaces with little or no vegetation

Note: CLC – Corine Land Cover.

To estimate the accuracy of the classification, we compared the classes in the classified image with those observed in the field (Sparfel, 2011) using the simple random sampling method. This enabled us to estimate the classification accuracy and thematic class area (Foody, 2002). We sampled 490 points on the classified image (2020) and 330 on the image (1984). We chose five random and simple samples in each stratified segment. The samples were located in the field with a GPS, observed, described, and registered. For the reference image (1984), we used external data of high quality (Landsat, Google Earth Pro, image archive, cartographic documents of topography, management, and forest inventory) (Olofsson et al., 2014). To assess the quality of the image classification with the aim to validate the land use and cover maps, we applied a scoring protocol used by the Tour du Valat Research Institute (French) for the observation of Mediterranean wetlands. Furthermore, we scored the observed classes in the field from 1 to 5 as the Certainty Level (CL) and from 0 to 8 as the Reference Score (RS), and then divided the total of the CL column by that of the RS. The statistical analysis shows that the accuracy is about 93% (CL: 1380/RS: 1484) for the reference year 1984 and 97% (CL: 2240/RS: 2310) for 2020. The rates show that the satellite images have been well classified and the remotely sensed data are fairly close to reality. The results can, therefore, be integrated into a Geographic Information System (GIS) environment (Thomlinson et al., 1999).

Results

We have produced three digital maps by remote sensing and GIS methods, a map of land use, and land cover for the years 1984

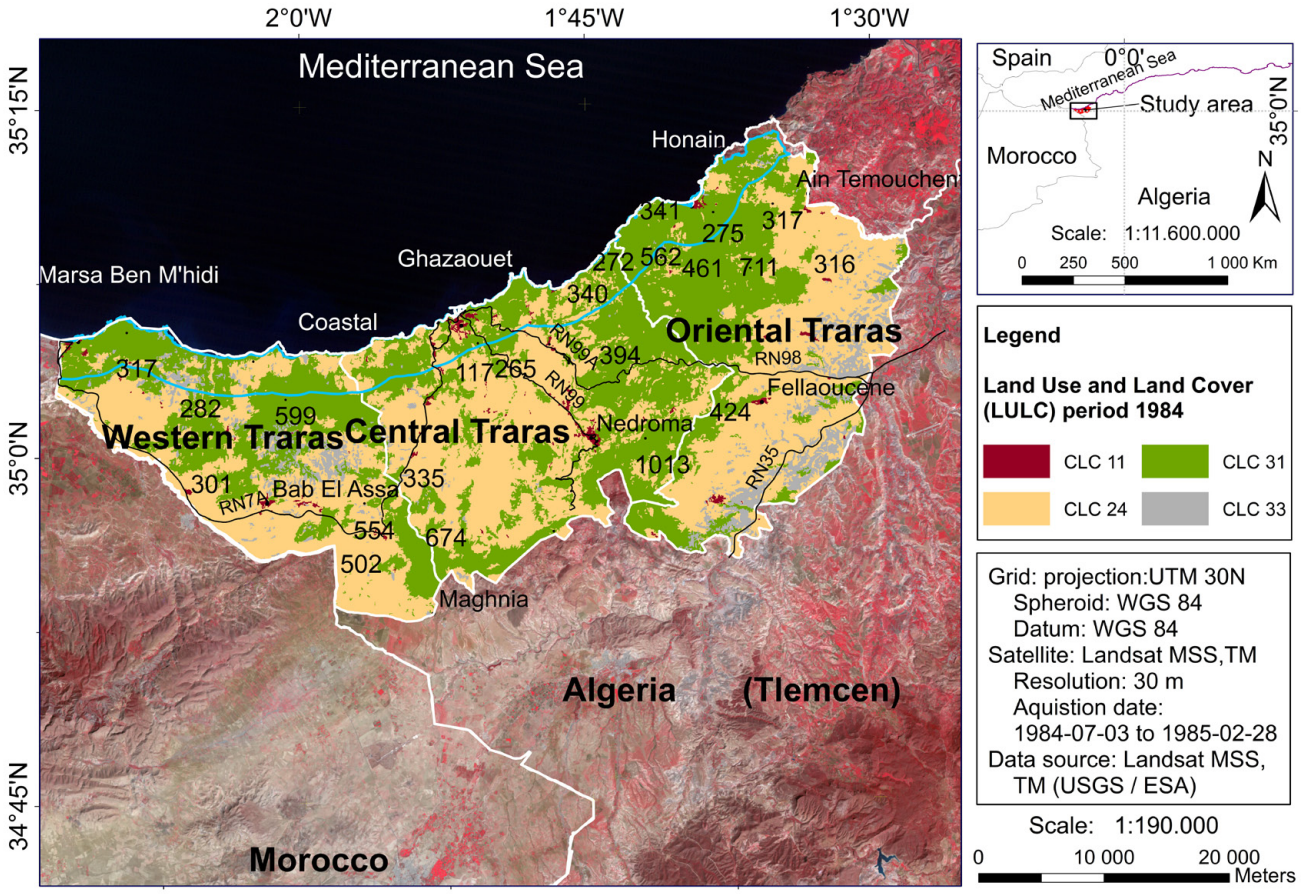


Fig. 2. LULC of Traras Mountains (period 1984).
Note: LULC = land use and land cover.

Table 2. CLC classes of land use (period 1984).

CLC classes	Area (ha)	Proportion of total area (%)
Urban fabric (CLC11)	1,100	0.85
Heterogeneous agricultural areas (CLC24)	65,200	50.35
Forests (CLC31)	56,000	43.24
Open spaces with little or no vegetation (CLC33)	7,200	5.56

Note: CLC – Corine Land Cover.

Table 3. CLC classes of land use (2020).

CLC classes	Area (ha)	Proportion of total area (%)
Urban fabric (CLC11)	7,400	5.71
Heterogeneous agricultural areas (CLC24)	77,100	59.54
Forests (CLC31)	36,000	27.80
Open spaces with little or no vegetation (CLC33)	9,000	6.95

Note: CLC – Corine Land Cover.

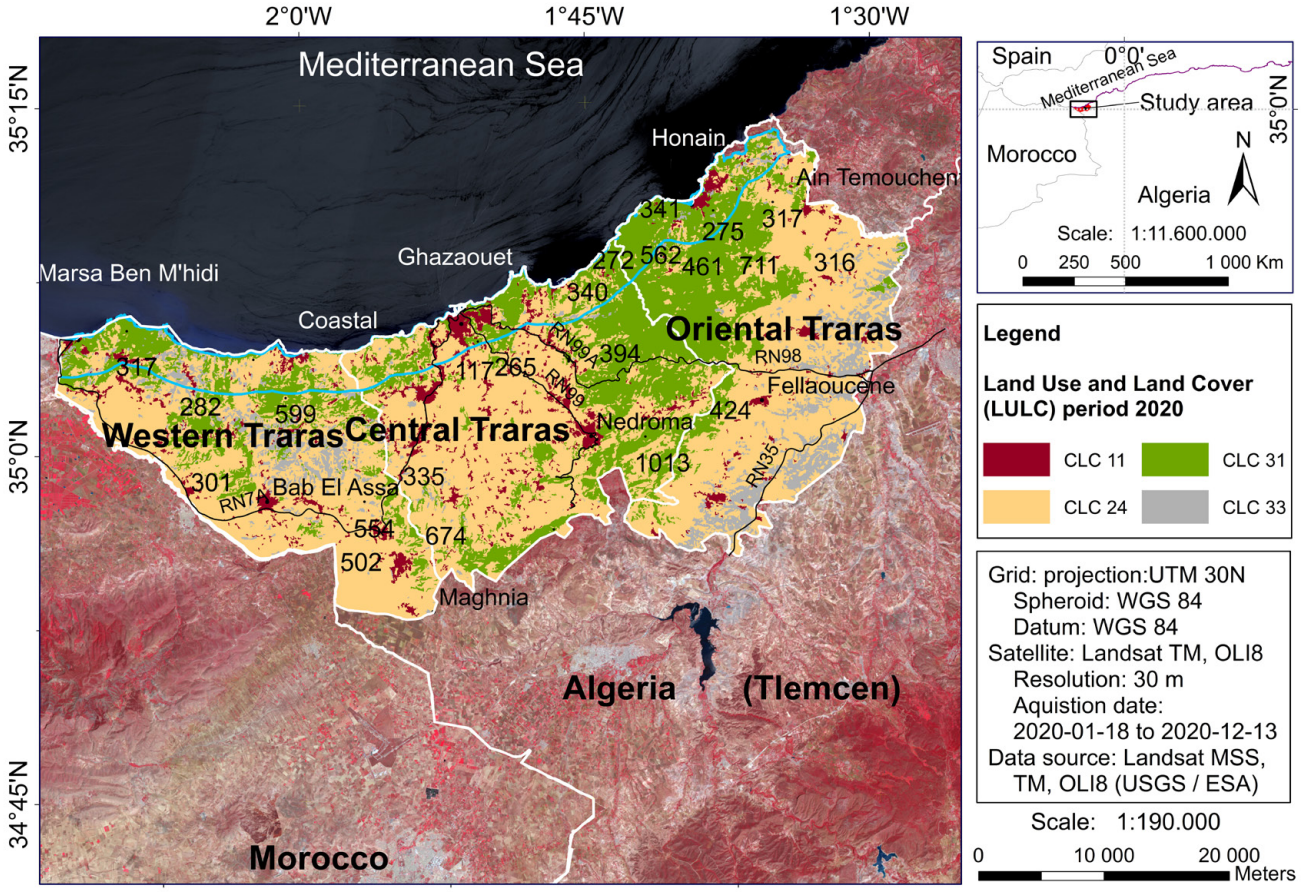


Fig. 3. LULC of Traras Mountains (period 2020).
Note: LULC = land use and land cover.

(Fig. 2), 2020 (Fig. 3) and land use and land cover change between 1984 and 2020 (Fig. 4). According to the map analysis, the agricultural land and forest of the Traras Mountains (CLC 24 and 31) occupied 93% of the total study area in 1984 (Fig. 2, Table 2) and 87% in 2020 (Fig. 3, Table 3). This confirms that the vegetal surface experienced a regression of 6% (Fig. 4, Table 4).

Open spaces with little or no vegetation (CLC33) increased from 7,200 ha in 1984 (Fig. 2) to 9,000 ha in 2020 (Fig. 3) as a result of erosion. This change in land cover corresponds to an extension of 1,800 ha in 36 years, that is, 50 ha/year. Regarding forest fires, 210 outbreaks occurred over 9,200 ha, which corresponds to an annual average surface loss of 328 ha. The areas converted by urbanization increased from 1,100 ha in 1984 (Fig. 2) to 7,400 ha in 2020 (Fig. 3); these values correspond to an urban extension of 6,300 ha, that is, an annual increase of 175 ha.

Fig. 4 highlights that 20,100 ha of forest were substituted by agricultural land (16,700 ha), urbanization (1,500 ha), and bare land (1,900 ha), which corresponds to a decrease of 36% of the total original woodland (1984).

The results were well verified by means of field observations, and in addition, by using management documents from the local administration; the Google Earth image archives were photo interpreted according to Card (1982) and Olofsson et al. (2014).

Discussion

The results show that it is possible to register land use change and monitor its spatiotemporal dynamics by means of remotely sensed data. According to Congalton (1991) and Girard and Girard (1999), the accuracy of the produced maps is about 80%, which confirms the classification precision and its acceptance (Beltrame et al., 2015). Kouassi (2014) also confirmed in this way the cartographic accuracy in their work on the Ivory Coast. The comparative study shows that our results come closer to reality, which enables integration of the cartographic data into a GIS environment and its interpretation, as reported by Thomlinson et al. (1999).

The realization of built-up projects caused the destruction of agricultural land (4,500 ha) and forests (1,500 ha) (Fig. 5, Table 4). Consequently, the surface of agricultural land and forests decreased from 121,200 ha in 1984 to 113,100 ha in 2020, which corresponds to a decline of 8,100 ha, that is, 7% of the total area in 36 years (225 ha/year) (Figs 2, 3, Tables 2–4).

Urbanization as an obvious cause of the loss of agricultural areas and forests

Between 1984 and 2020, urbanized areas in the Traras Mountains increased from 1,100 ha in 1984 (Fig. 2, Table 2) to 7,400 ha in

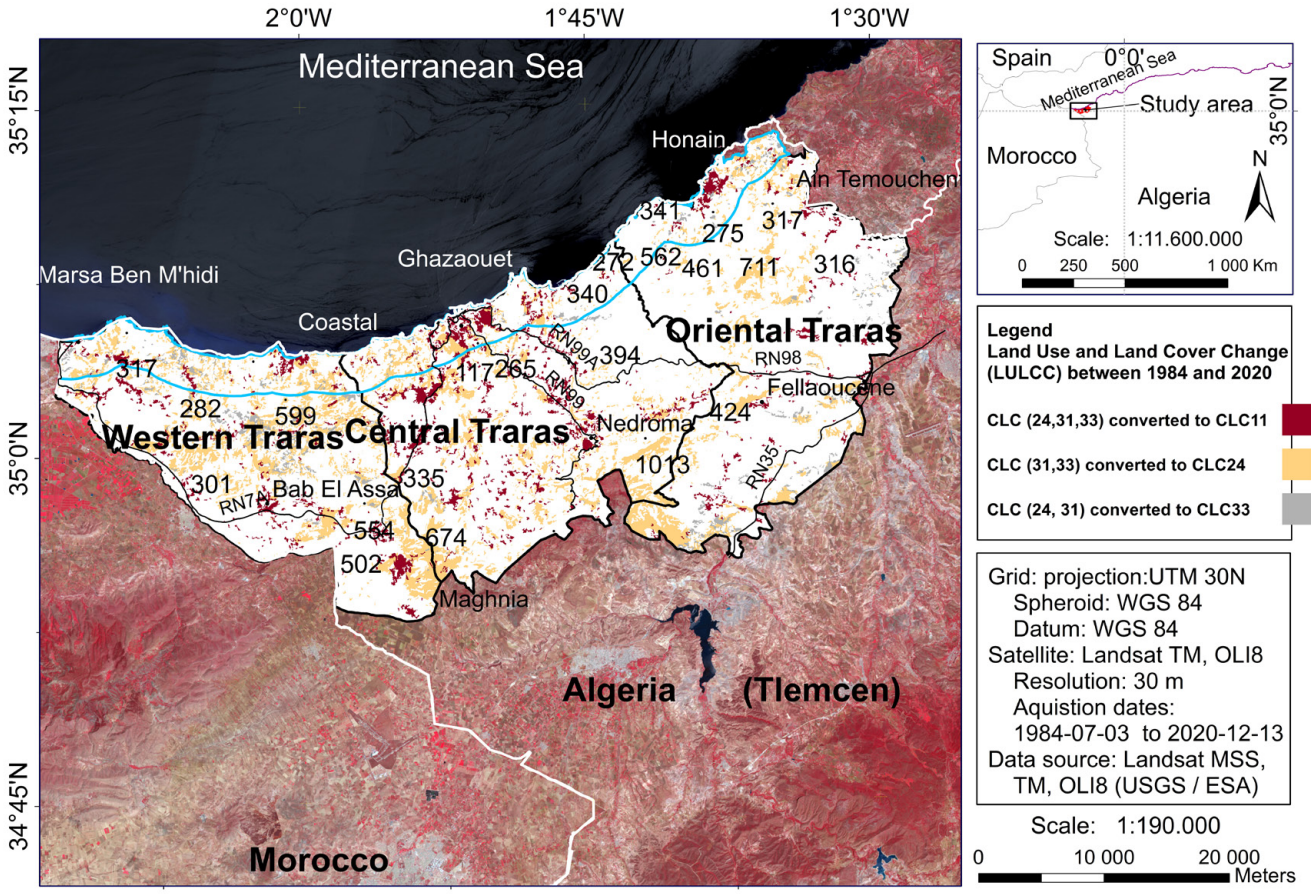


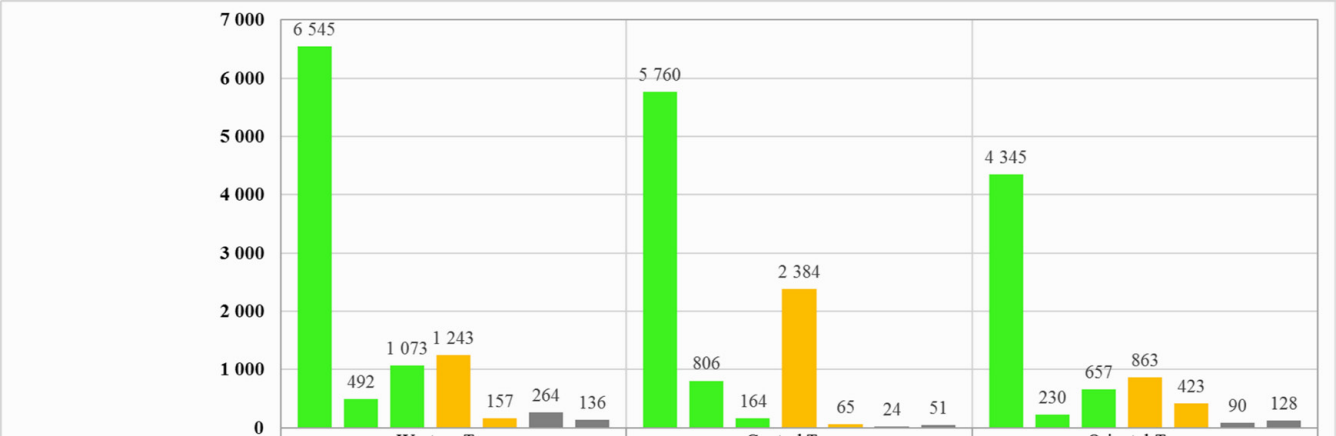
Fig. 4. LULCC of Traras Mountains from 1984 to 2020.
Note: LULCC = land use and land cover change.

Table 4. Evolution of units of land use between 1984 and 2020 in the study area.

LULCC from 1984 to 2020	Western Traras		Central Traras		Oriental Traras		Total (ha)
	Area (ha)	Rate (%)	Area (ha)	Rate (%)	Area (ha)	Rate (%)	
Forests converted to heterogeneous agricultural areas	6,545	12	5,760	26	4,345	13	16,700
Forests converted to urban fabric	492	5	806	8	230	3	1,500
Heterogeneous agricultural areas converted to urban fabric	1,243	1	2,384	0.5	863	2	4,500
Open spaces with little or no vegetation converted to urban fabric	136	66	51	62	128	65	300
Open spaces with little or no vegetation converted to heterogeneous agricultural areas	264	11	24	2	90	10	400
Forests converted to open spaces with little or no vegetation	1,073	2	164	1	657	6	1,900
Heterogeneous agricultural areas converted to open spaces with little or no vegetation	157	3	65	0.5	423	1	600
Total	**9,910**	**100**	**9,254**	**100**	**6,736**	**100**	**25,900**

Note: LULCC = land use and land cover change.

2020 (Figs 3–5, Tables 3, 4), which corresponds to an increase of 6,300 ha in 36 years (175 ha/year). Urbanization has caused a loss of 4,500 ha of agricultural land, 1,500 ha of forest, and 300 ha of bare soil. Our results remain comparable with other results obtained using geomatic tools at the local and regional levels. In Algeria, between 1960 and 2006 (46 years), the built-up area increased by 5,400 ha/year, destroying 250,000 ha of agricultural land (Official journal, October 21, 2010, cited by Boukort,



	Western Traras	Central Traras	Oriental Traras
CLC 31 converted to CLC 24	6 545	5 760	4 345
CLC 31 converted to CLC 11	492	806	230
CLC 31 converted to CLC 33	1 073	164	657
CLC 24 converted to CLC 11	1 243	2 384	863
CLC 24 converted to CLC 33	157	65	423
CLC 33 converted to CLC 24	264	24	90
CLC 33 converted to CLC 11	136	51	128

Fig. 5. LULCC dynamics of Traras Mountains between 1984 and 2020.
Note: LULCC = land use and land cover change.

Mekhaled, 2016). Between 1960 and 1970, the Algerian Useful Agricultural Area (UAA) decreased from 1 ha/capita to 0.52 ha/capita. Between 1985 and 2008, urbanization led to the loss of UAA (0.34–0.24 ha/inhabitant) (Boukort, Mekhaled, 2016). Since the late 1970s, Algerian cities have undergone dynamic expansion, multiplying their surface area by 5 in 30 years (Boukort, Mekhaled, 2016). In Oran (Northwest Algeria), annual urban growth was estimated at 3% over the period 1991–2003 (152 ha/year) (Bendraoua et al., 2011). In the east of the country, the city of Batna recorded an expansion rate of 50 ha/year between 1961 and 2014 (Benyahia, Dridi, 2017). Urban areas around the world are growing at twice the rate of their population (Angel et al., 2011). Our results show that more than half of the urbanized land (51.4%) is located in the central area of the Traras Mountains. This means that the population growth in the wilaya of Tlemcen, which increased from 78.9 inhabitants/km^2 in 1987 to 104.7 inhabitants/km^2 in 2008, corresponds to an increase of 25.8 inhabitants/km^2 (ONS, 2008), and their need for urban infrastructure is behind this phenomenon of land artificiality. Europe is one of the most urbanized continents in the world due to its intense urbanization, which has a direct impact on its ability to produce food. New urban areas are historically built on fertile soils located especially around large cities and coastal areas (Gardi et al., 2015). Our results show that 26% of the total urbanized area is located in the littoral zone of the Traras Mountains. This urbanization progressed on land at low altitudes (0–400 m), located on slopes between 0 and 9%, oriented to the north, northeast, and northwest, and in the vicinity of local access roads. This shows that the rate of urbanization of urban, peri-urban, and rural land in the Traras Mountains has been confronted with the configuration of the land. Between 1990 and 2006, the rate of land artificiality increased by almost 9% (Prokop et al., 2011) with an average annual growth of 0.5% (Guerois, Pumain, 2017). Soil sealing could pose a significant threat to food security in the European Union (European Commission, 2012).

Littoralization and coastal erosion

The built-up surface located in the coastal zone increased in the study area from 360 ha in 1984 (Fig. 2) to 2,000 ha in 2020 (Fig. 3). This corresponds to an urban growth of 1,640 ha (45.5 ha/year), which is low compared to that observed on the coastal zones close to big cities. During the period 1962–1998 (36 years), the urbanization rate of the north-central coast of Algiers increased from 26 to 59.4% (Kacemi, 2011). With these urbanization rates, Algiers and Blida, cities located in the north-central part of Algeria and 50 km distant, may form within 20 years a single build-up area (Rabehi et al., 2020). The phenomenon of littoralization in Algeria follows the same built-up dynamics as observed in North Africa, where urbanization caused considerable damage in the shores (Ghodbani et al., 2015).

Increase in forest areas destroyed by fire

Between 1992 and 2020 (28 years), 210 fires (seven fires/year) occurred in the Aleppo pine and cedar forests of the study area. They covered 9,200 ha of forest, which corresponds to 328 ha/year. At the scale of the wilaya of Tlemcen, 1,500 fires/year have destroyed 60,000 ha of forest in 35 years (1980–2015) (Mortada, 2017). The analysis of fire reports shows that most of the fires in forests in the region are due to human negligence observed during the exploitation of woods, grazing, and clearing activities (Ghezlaoui, Benabadji, 2018). Other activities such as beekeeping, urbanization, and tourism increase susceptibility to forest

fires, especially in coastal and mountainous areas (Meddour-Sahar, Derridj, 2012). Our results show that more than half (55%) of the total area burned was in the coastal forest communes of Marsa Ben Mhidi, Dar Yaghmourassen, and Honaine and in the mountains of Nedroma and Ain Kebira. Studies showed that the highest number of heat waves was recorded in Oran (Northwest Algeria) in 1994 and 2004, with five waves per year (Matari, 2016). Our results show that burning of almost half (49%) of the total area occurred between 2004 and 2020 (16 years). In the east of the country, between 1987 and 2017 (30 years), the wilaya of Tizi Ouzou recorded 145 expanded fires that destroyed 47,942 ha of forest, which corresponds to 48.45% of the total forest of the wilaya. Analysis of annual reports shows that Algeria records 1,500 fires/year, destroying a total area of 35,000 ha (Meddour-Sahar et al., 2020). Between 1985 and 2010 (25 years), 1,702 fires/year covered a total area of 910,640 ha. Annual assessments in 1993, 1994, 2000, and 2007 highlighted that forest loss by fire was catastrophic in Algeria (Meddour-Sahar et al., 2008). The economic loss between 1985 and 2006 (21 years) reached 11 billion DA (1.11 billion Euros), which shows that vulnerable Algerian forests need protection because their destruction is increasing due to repeated forest fires (Meddour-Sahar et al., 2008). Our results show that the repeated fires between 2014 and 2020 caused a loss in total area of 2,390 ha in the forest commune of Honaine, 1,244 ha in Beni Khaled, and 209 ha in Beni-Ouarsous. Compared to neighboring regions, Morocco loses 30,000 ha of forest area due to fires (Bijaber, 2005). Le Houérou (1987) estimates that Mediterranean forests are losing 600,000 ha of forest annually, almost double of that recorded in the 1970s. It shows that the annual cost of fire prevention and control plans is estimated at more than 1 billion dollars (US). French recorded in 2018 and 2019 an annual average of 3,600 fires and 3,000 fires, respectively (Borne, 2020). Studies conducted on different watersheds around the world have indicated a significant increase in soil loss after wildfire. As a result, soil susceptibility to surface erosion remains high for 1–2 years and then decreases rapidly as vegetation reclaims the land (Vennetier et al., 2013). Our results show that forests recover very slowly after fire due to drought, erosion, and grazing.

Significant loss of agricultural areas and forests

Between 1984 and 2020, the area of open space with little or no vegetation (CLC33) in the Traras Mountains increased due to erosion from 7,200 ha in 1984 (Fig. 2, Table 1) to 9,000 ha in 2020 (Fig. 3, Table 2), which corresponds to an average annual increase of 50 ha. The impacted soils in the eastern, western, and central zones cover 5,400 ha (60%), 3,200 ha (35%), and 400 ha (5%), respectively. In the western part, badlands cover more than 64% of the total area (Medjahdi, 2010). In this western area, our results show that the surface of bare soil occupies 1,326 ha in the commune of Souk Tleta, 628 ha in Msirda Fouaga, 627 ha in Bab El Assa, and 476 ha in Marsa Ben Mhidi, which correspond to 97% of the total eroded surface in the western area. The analysis of the results shows that among the 13 hill water reservoirs located in the Traras Mountains region, only two are operational, which is due to erosion and siltation. The average specific degradation of soils in the Isser watershed located east of the study area is estimated at 150 t/km^2/year (Sogreah, 1967). The communes of Beni-Ouarsous, Fillaoucene, and Ain-Fettah located to the east of the study area are an integral part of the northwestern part of this watershed. Our results show that the surface of bare soil covers 2,113 ha in Beni-Ouarsous, 1,419 ha in Fillaoucene, 1,381 ha in Ain-Fettah, 337 ha in Beni Rached, and 108 ha in Honaine. This situation of soil degradation prompted the administration of forests to carry out 30,800 m^3 of torrential correction, 200 ha of bank repair, 50 ha of bank fixation, and 455 ha of forestry and fruit plantations (Medjahdi, 2010) in the coastal communes of Dar Yaghmourcène and Honaine in 2011. The resulting soil degradation is due to the heavy runoff caused by the heavy and violent downpours that occur in the region during fall and winter. The effects of runoff and erosion are very much aggravated in agricultural areas due to ploughing and in forest areas due to overgrazing and forest fires (Bleu, Antipolis, 2003). Our results show that the eroded soils were occupied by forests and agriculture. Steep slopes also accelerate runoff; therefore, soil vulnerability to erosion increases (Chikhaoui et al., 2010) and post-fire soils are rapidly depleted of organic matter and become more vulnerable to erosion and desiccation (Morsli et al., 2013a). Drought events have also led to soil erosion (Boughalem, 2013). Added to this are the geology, the nature of the soil, and the protection of the soil by vegetation cover (Toumi et al., 2013). These factors increase the sensitivity of soils to erosion (Bouanani, 2006). Our results show that more than half of the total area is located on marl and limestone soils (64%), on slopes between 9% and 76% (57%) and oriented to the west (40%), and on soil with low vegetation cover (22%). Western Algeria is the most eroded region of the country, with 47% of the land affected by erosion (Morsli et al., 2013b). Specific soil erosion at the country level varies between 2,000 and 4,000 t/km^2/year (Demmak, 1982), causing the loss of 45% of the fertile land in Algeria (Gataâ, 2016). Under the erosive effect, Algeria loses 45–50 million m^3 of water each year (Abdelli, Zaggane, 2007). These volumes of soil loss have ranked Algeria among the countries with the most erodible soils in the world (Touaibia, 2010). In North Africa, rainfall causes significant water erosion in watersheds and contributes to siltation of dam reservoirs (Touahir et al., 2018). In the Mediterranean region, the period of greatest erosion risk is about 1 month after the onset of fire (Fox et al., 2006), particularly during the first autumn rains (Prieto-Fernandez et al., 1998). In this context, destruction of the vegetation cover has, therefore, led to a considerable increase in soil loss and erosion. However, the impact may be greater and more persistent in the case of repeated fires or fires affecting steeply sloping terrain or subject to heavy post-fire rainfall. The more intense and severe a fire is, the more the vegetation will be altered and the more the landscape will be transformed, whether at a local or regional scale. The results are identical in the case of repeated fires (Jacquet, Cheylan, 2008). Our results show that the repeated fires that occurred between 2014 and 2020 (7 years) in forests in the eastern zone caused a loss in total area of 3,383 ha in the eastern zone, which corresponds to an average of 483 ha/year in 7 years. Studies show that in one century, the forest area in Algeria has decreased from 7 to 2.5 million ha (Heddadj, 1997). In 2011, the Algerian Ministry of Agriculture and Rural Development and Fisheries estimated that about 14 million hectares of mountainous areas in the north of the country were degraded by water erosion (Touahir et al., 2018). Studies show that the triggering of erosive phenomena is linked to fire, a corollary of human activity (Lavabre, Martin, 1997). Our results show that more than

half (51%) of the total number of fires occurred in forests of the attractive coastal tourism communes (Marsa Ben Mhidi, Msirda Fouaga, Ghazouet, Dar Yaghmorassene, Honaine, and Beni Rached). In these communes, the total area of fire, eroded soils, and urbanization represents 48% (4419 ha), 20% (1817 ha), and 38% (2806 ha), respectively, of the total area of each impact.

Conclusion

This work shows the cartographic and thematic results obtained by the application of remote sensing and GIS in the diachronic study of the evolution of land occupation and use in the Traras Mountains. The study area is located in Northwest Algeria, characterized by a semi-arid climate. During the period 1984–2020 (36 years), the bibliographic synthesis shows that the area had attracted the attention of several authors. Since 1840, 26 botanists visited the region; among them was Doctor Krémer, who most explored the Traras Mountains between 1852 and 1855 (Medjahdi, 2010). Other authors concentered their exploration on the vegetation of the Traras (Hadjadj, 1996; Medjahdi, 2010; Nichane et al., 2013; Medjahdi, Letreuch-Belarouci, 2017). Kazi-Tani and Gaouar (2015) sketched a 200,000th-scale soil mapping in the eastern part of Traras. These facts show that the Traras required an extensive study to understand the land cover and land use dynamics as a coupled human–environmental system.

The methodology applied showed that the soils in the study area were affected by the influence of man and climate. An extensive forest area was converted into agricultural land and bare land and used for urbanization (20,100 ha). The urbanization increased by 6,300 ha in 36 years, which corresponds to an average increase of 175 ha/year. The area of open space, with or without vegetation (CLC33), increased by 1,800 ha in 36 years, which corresponds to an average loss of 50 ha/year of the vegetation cover. Eroded areas increased by 900 ha in the eastern part and 800 ha in the western part compared to the baseline data (1984). Compared to the rate of spatial–temporal change, the average annual urbanized land in 36 years corresponds to 3.5 times the area of eroded land. This result shows the magnitude of urbanization in the Traras Mountains.

It is a diagnosis made for the area using geomatic tools, thanks to which it was possible to know the area of the Traras Mountains in its spatial, physical, biotic, abiotic, and dynamic aspects. This work has demonstrated the importance and contribution of GIS and remote sensing in the identification, understanding, and analysis (topographic and thematic) of the study area. This approach has contributed to updating the existing data.

The realized spatial maps for the Traras Mountains provide a useful geographic and alphanumeric database for decision-makers, enabling them to be aware of environmental issues related to urbanization, loss of agricultural or forest land, and coastal degradation. The availability of such a database to managers and local administration would provide additional information on awareness, planning, sustainable management, and decision-making.

To fight against land erosion in the Traras Mountains, it is necessary to protect and restore bare land with mechanical (bench and gabion systems) and biological (plantation of agaves, opuntia, and fruit trees) processes. To act against forest fires, compatible prescriptive management should be applied to help the forest toward «self-protection.» In the urbanized areas, it would be necessary to create green spaces with the aim to reduce pollution and slow down floods. This study needs to be continued in the future to investigate further the details of change that still require sensor data of improved spatial and spectral resolution. These means would allow us to model land use and land cover changes to understand the trend of change in relation to socioeconomic conditions and to predict the best policy objectives that we seek.

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