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Original article

Land use and land cover change analysis using geospatial techniques a case study of the Dayet Aoua Watershed, Middle Atlas, Morocco

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ABSTRACT

The Imouzzer Kandar plateau, located in the Middle Atlas of Morocco, has experienced significant land use changes over the past decades, characterized by the expansion of agricultural lands and the regression of forests and wetlands. This study aimed to detect these changes and assess their impact on the wetlands of the Imouzzer Kandar plateau. To achieve this, three Landsat satellite images from 1984, 1998, and 2018 were analyzed using the diachronic method, employing a supervised classification with the Nearest Neighbour Classifier within a Geographic Information System (GIS) framework. The classification accuracy for the three dates reached 92%, providing reliable and actionable insights. Over the 34-year period, approximately 44% of the study area, equivalent to 32,097 hectares, underwent land use changes. The confusion matrix revealed a substantial increase in agricultural and rangeland areas, coupled with a decrease in forest cover and lake area within the Dayet Aoua watershed. Most wetlands, approximately 152.37 hectares, have been converted into rangeland. The analysis further highlighted the irreversible expansion of agricultural land at the expense of areas of wetlands, with 33.34% of this expansion, about 88.20 hectares, being replaced by water-intensive agriculture.

KEY WORDS: change detecting, diachronic approach, land use, land cover, Dayet Aoua watershed

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1. Introduction

Land cover is defined as the physical and biological cover of the earth's surface, while land use refers to activities on physical things such as agriculture, forestry, construction, and water, which tend to modify natural phenomena (Timilsina et al., 2023). Global land cover has undergone continuous change, mainly due to the interaction of socioeconomic, demographic, ecological, and geophysical factors (Wu et al., 2008). In recent decades, the process of land use change has expanded considerably due to population growth (FAO, 2020). The most widespread changes are the progression of agricultural land and built-up areas to the detriment of forests (Chrif El Idrissi & Saber, 2020). The shift from natural ecosystems to agricultural or urban land hampers their sustainability and reduces their ability to provide ecosystem services (Wu & Tiessen, 2002; Beroho et al., 2023).

In recent decades, spatial remote sensing and geographic information systems (GIS) have become relevant techniques for quantifying and detecting spatio-temporal changes in land cover and use and in natural resource management (LU ET AL., 2004; PANIGRAHI ET AL., 2017). The pixel is the main unit of analysis in satellite image classification procedures (MAVUNDA ET AL., 2022). Several classification methods have been developed, such as supervised classification (decision tree, support vector machine, maximum likelihood classification, etc.), unsupervised (K-means and ISODATA), and hybrid (semi-supervised and mixture of supervised and unsupervised) classification (LU ET AL., 2004; ALAJLAN ET AL., 2012). Many studies have used these techniques to detect changes in land use (ABERA ET AL., 2019; MAVUNDA ET AL., 2022; BEROHO ET AL., 2023). These studies have all shown that these changes affect natural ecosystems, including wetlands. With the use of these techniques, researchers have been able to analyze the environmental impacts of land use changes, including soil erosion, as we demonstrate in our research from the Mediterranean Basin.

Geospatial technologies, particularly remote sensing and GIS, are crucial for analyzing land use changes in the Mediterranean Basin. In Morocco, significant transformations in land use have been observed in the Sebou Estuary and the Ziz Oases, driven by rapid urbanization, agricultural intensification, and climate variability. Similarly, in Algeria and Tunisia, extensive land degradation, increasing surface temperatures, and notable alterations in land cover have resulted from unregulated urban expansion and agricultural encroachment, highlighting the vulnerability of local ecosystems (PARK ET AL., 2011; EL ADNANI ET AL., 2019; BARDADI ET AL., 2021; KARMAOUI ET AL., 2023; SELKA ET AL., 2024). In southern Europe, Spain and Greece have experienced parallel trends, with studies indicating a decline in forest cover in Castelló and significant impacts on surface runoff in mountainous areas, attributed to human activities and climate change (DELGADO-ARTÉS ET AL., 2022; PSILOVIKOS ET AL., 2021). This collective body of research underscores the pivotal role of geospatial technologies in understanding and managing land use changes and their environmental impacts across the Mediterranean region.

This research assesses the evolution of land use and its impact on the natural lakes of Imouzzer Kandar, based on a 34-year diachronic study using geospatial data and Geographic Information Systems (GIS).

2. Materials and methods

2.1. Study area

The Imouzzer Kandar lakes are in the Middle Atlas Causses at an altitude of between 1400 m and 1700 m. The Dayet Aoua watershed that covers these lakes extends over 183 km^2 and lies between latitudes 33°30 and 33°50 N and longitudes 4°50 and 5° W and is part of the Sebou watershed (Fig. 1). Its topography is relatively rugged. The north-western part is made up of linear ridges, while in the western part (Jbel El Haloukh) and southern part (Jbel Erraggada and Timdikine), the boundary is discreet due to its rugged topography. The prevailing climate is Mediterranean, with an average annual rainfall of 700 mm. The wet season extends from October to May, while the dry season lasts from June to September. The geological context is marked by the dominance of Lower and Middle Lias calcareous-dolomitic formations, with the presence of numerous faults allowing the circulation of large quantities of water within the aquifers (SAYAD & CHAKIRI, 2019). Administratively, it is part of the Fès-Meknès region and mainly covers the northern part of Ifrane province and the southwestern part of Sefrou province.

2.2. Methodology

The chosen method is a diachronic comparison of classifications using an object-oriented approach based on pseudo-spectral bands. This method aims to analyze the dynamics and changes in land occupation and use in the Dayet Aoua watershed, where we have traced the spatio-temporal evolution over 34 years (1984–2018). Image analysis comprises the main stages shown in Figure 2 these include: satellite data acquisition, image pre-processing, supervised image classification, classification validation and evaluation, and change detection between 1984 and 2018.

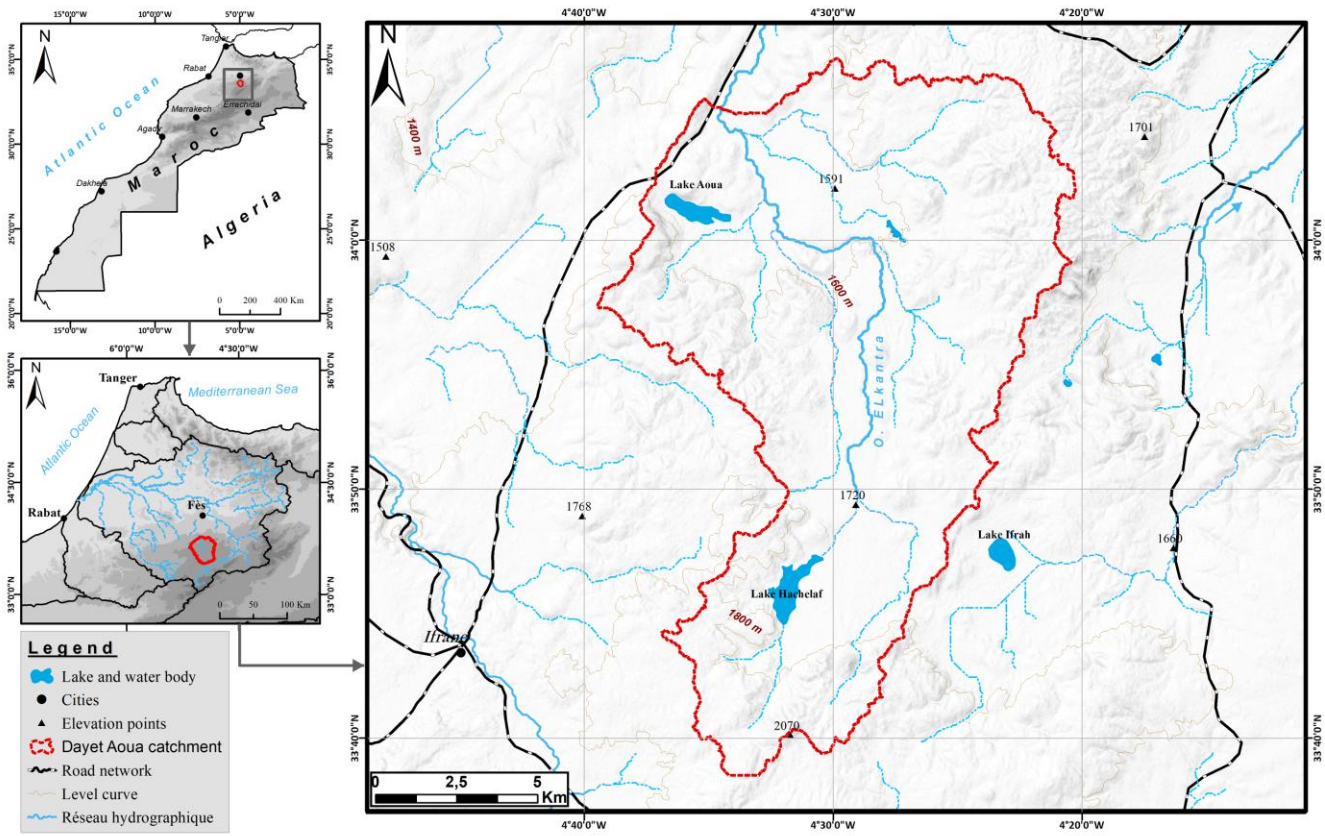

Fig. 1. Geographical location of Dayet Aoua watershed

2.3. Remote sensing data acquisition and processing

The Landsat satellites were launched by NASA to observe and monitor the Earth's environment and its spatio-temporal assessment. The choice of Landsat multispectral TM (Thematic Mapper), Landsat-7 ETM+ (Enhanced Thematic Mapper Plus), and OLI (Operational Land Imager) satellite images was based mainly on their free availability on the USGS website (http://landsat.gsfc.nasa.gov), their temporal repeatability (16 to 18 days), and their availability over a long period (over 40 years). Indeed, these advantages have helped to enrich mapping and monitoring studies of land use change in the Moroccan context (El-Jazouli et al., 2019). The Table 1 below gives a detailed summary of the characteristics of the Landsat image time series used for the study.

The basis of our work is a set of multi-spectral, multi-date Landsat satellite images, forming a time series of satellite images (STIS) of three scenes, acquired in 1984 (Landsat 5 TM), 1999 (Landsat-7 ETM+) and the last in 2018 (Landsat-8 OLI). For both modes (TM and ETM+), all channels represent a spatial resolution of 30 m*30 m except channel 6 (thermal infrared), which has a resolution of 120 m*120 m for Landsat 5 TM and 60 m for Landsat-7 ETM+. The Landsat 8 OLI image, on the other hand, consists of nine spectral bands (1 to 7 and 9) with a spatial resolution of 30 meters. However, panchromatic channel 8 has a resolution of 15 m. This band is useful for improving the resolution of spectral bands from 30 to 15 meters.

2.4. Justification for the choice of Landsat image dates

Satellite sensors are usually subject to atmospheric effects (clouds, dust) that make it difficult to view and interpret images. In this respect, the dates on which the images were taken were chosen in the dry season (summer) of each year, to avoid confusion between cultivated areas and herbaceous areas (annual species). During this season (the period of maximum differentiation of land use elements), crops and especially Rosaceous plants at the site are still chlorophyll active and can be clearly distinguished spectrally from dry herbaceous plants. These dates also consider the agricultural calendar of our region, so that we can follow their evolution over time and space. Satellite images are also well exposed in July and September, when the atmosphere remains relatively clear, allowing the sensor to capture a clean image that doesn't require too much atmospheric correction to view.

2.5. Satellite image pre-processing

Image preprocessing aims to increase data readability, facilitate interpretation, and improve the extraction of spatial information. These preprocessing operations include radiometric, atmospheric, and geometric enhancements. Radiomtric correction converts raw pixel values to reflectance. This process must precede radiometric calibration. Calibration consists of normalizing the signal intensity for multi-temporal analysis and image comparison. This allows a dimension less quantity called the backscatter coefficient to be calculated from the backscattered signal.

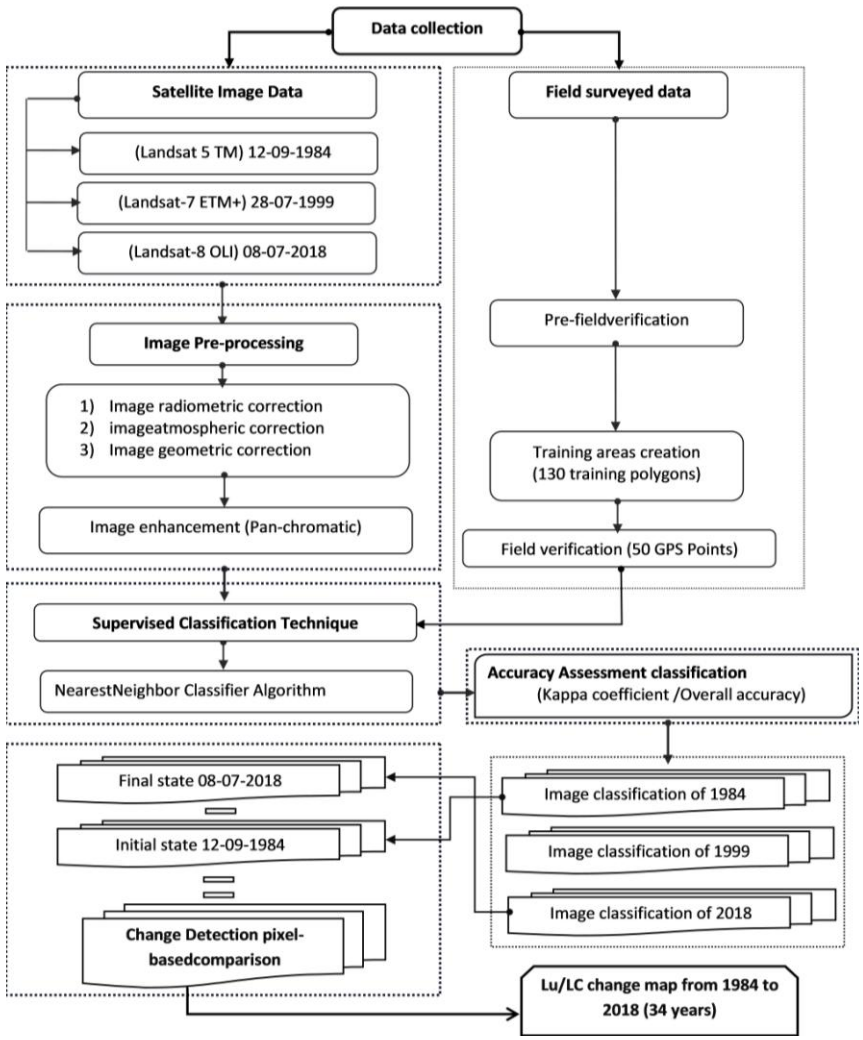

Fig. 2. Methodological approach

Table 1. Characteristics of the Landsat images used

Image characteristics			
Sensors	Landsat 4-5 TM	Landsat-7 ETM+	Landsat-8 OLI
Acquisition date	12/09/1984	28/07/1999	08/07/2018
Number of bands	9	9	11
Spatial resolution	30*30	30*30	30*30

Atmospheric corrections aim to extract information that is independent of the effects of the atmosphere, which vary in time and space (EUROPEAN SPACE AGENCY, 2017; CONGEDO, 2021). The principle of this correction is to convert the numerical values (in grayscale) of the scene into luminance values and then extract the atmospheric noise effects, which provide a physical measure of the reflectance of the target surface (GRAMOND ET AL., 2016). Most researchers in this field agree that the DOS (Dark Object Subtraction) method is the best expression of the two variables (luminance and reflectance) and the most accurate compared to other atmospheric correction methods. Using ENVI 5.1 software, we converted the digital values of our images to luminance values and then calibrated them to reflectance.

Geometric Correction is used to correct geometric distortions in the image due to variations in sensor parameters (altitude, speed) and relief (topographic effects), as well as the curvature and rotation of the Earth (CALOZ & COLLET, 2001). In change detection, geometric correction is a very important step, where the accuracy of the geometric correction will affect the accuracy of the change, especially in the analysis of the comparison of classifications (SONG ET AL., 2015). The three Landsat images have been geometrically corrected. The first-degree polynomial global transformation method with nearest neighbour resampling was chosen. Of the images used, the 2018 image has already been corrected to the UTM (WGS 84) projection system, and this was used to correct the 1984 and 1999 images, with 41 support points over the entire image. The root mean square (RMS) error is 0.44/0.38. We have also made improvements using the panchromatic band (band 8) with higher spatial resolution, i.e. 15m for Landsat-7 ETM+ and Lansat-8 OLI. The new spatial resolution allows resolution fusion, combining the advantages of both image types in a single image.

2.6. Supervised image classification

A colour composition was maintained from three channels where we obtained a synthetic image enriched with the specific contribution of each of the three spectral bands. The directed classification approach was chosen, in which the spectral space is divided into different classes using sample objects (training sites) and a description of the properties of each class. We relied on data collected in the field to characterize and classify the Dayet Aoua basin into different landscape classes. This operation was carried out using the software ENVI 5.1, (EXELIS VISUAL INFORMATION SOLUTIONS, 2014) under the function (classification workflow). The training areas were selected based on the objects identified in the field and by visual interpretation of the colour composition. We distinguished four classes in the basin (Table 2). We have chosen to use the Nearest Neighbour method because of its widespread use in remote sensing. The advantage of this approach is that the spectral and spatial characteristics of the pixel and its neighbourhood are considered in the classification process. For each of the four land cover classes, we selected training locations on the segmented images. These were chosen from very homogeneous areas where ambiguities associated with mixed pixels were negligible. We created 130 training polygons distributed across all thematic classes and the study area (30 for forest, 30 for wetland, 30 for wasteland/rangeland, and 40 polygons for agricultural land). The training sites were validated by the field contractor.

Table 2. Descriptions of LULC classes used

LU/LC classes	Description
Agricultural area	This is land planted with fruit trees (roses, etc.) mixed with vegetables and cereals.
Uncultivated land or pasture	Includes uncultivated land and bare ground; this class includes all uncultivated land and bare ground (rock outcrops, scattered habitats, and roads)
Forest area	Includes climax plant formations, mainly holm oak, Aleppo pine, cedar, and degraded formations (matorral)
Wetlands	Includes the natural lakes in the basin: Dayet Hechelaf and Dayet Aoua, the artificial lake of Sidi Mimoun, the marshy area of Oued El-Kantra, and all other flooded areas (rivers, basins), etc.

2.7. Classification validation and accuracy assessment

A field sampling campaign was conducted on August 7th and 8th, 2018 to verify the composition of certain plots used as training areas. To create a field reference to validate the classification, we surveyed 50 GPS points containing exact information on the sampled sites (coordinates, landscape types). A detailed description of these sites is given in Appendix 1. These were projected onto the classified image. To evaluate the performance of our classifications, we created confusion matrices, which show the percentage of well-classified pixels compared to the reality on the ground. Based on these matrices, we used two precision estimators: the overall precision and the Kappa coefficient (K).

The overall accuracy index (CONGALTON, 1991) was calculated by dividing all correctly identified pixels by the total number of pixels in the matrix (Equation 1). The kappa coefficient measures the degree of agreement between two maps when all elements of the error matrix are considered (Equation 2).

$$\text{Overall accuracy} = \frac{\text{Sum of the diagonal elements}}{\text{Total number of accuracy Site s (pixels)}} \times 100 \qquad \text{(Eq. 1)}$$

$$\text{Kappa coefficient} = \frac{\text{Obs} - \text{exp}}{1 - \text{exp}} \qquad \text{(Eq. 2)}$$

where: Obs is the accuracy reported in the error matrix (overall accuracy) and Exp is the correct classification.

2.8. Spatio-temporal land use land cover change detection

Object-oriented classification results from 1984 and 2018 were compared on a class-by-class and pixel-by-pixel basis. The post-classification technique was used to detect changes in UTC (YANG ET AL., 2012). The TCU change matrix was created to show the overall change in TCU between 1984 and 2018. The columns of the matrix represent the area of each class in the most recent year (2018 final state), while the rows represent that of the previous year (1984 initial state). The changed area and the extent of change were examined by creating the change map to determine the extent of change in terms of land use change (YARED & SISAY, 2019).

3. Results

3.1. Land use classification and dynamics

The overall accuracy obtained varied from around 88% to 94% between 1999 and 2018. The Kappa coefficient varies from 0.84 for 1999 to 0.90 for 2018 (Table. 3). These values are above 80%, indicating that these classifications are reliable and usable (PONTIUS, 2000), and represent a strong association between the result of the classification algorithm and the reference (MAVUNDA ET AL., 2022).

Four land-use classes were distinguished and spatialized on the maps for the dates 1984, 1999, and 2018, these were forests, wetlands, farmland, and rangeland. The current state of land use is characterized by the dominance of the forest zone (50.12%), followed by uncultivated land and rangelands (30.38%). Agricultural land covers 18.86%, while wetlands occupy a small proportion (0.19%).

Table 3. Overall accuracy and Kappa coefficient

	Classification			
Year	1984	1999	2018	Average
Overall accuracy (%)	93,14	88,67	94,50	92,10
Kappa index	0,88	0,84	0,90	0,87

Spatial patterns of land use change in the Dayet Aoua watershed are presented in Figure 3, and statistics of area and the individual class changes for the three years 1984, 1999, and 2018 are shown in Figure 4. These figures clearly show that there has been a considerable change in land use over the study period (34 years). The main characteristics of these changes are a sizeable increase in agricultural land of about 18% between 1984 and 2018. Forest, on the other hand, underwent a moderate regression of 3.47%. Uncultivated land and rangelands also decreased by 13.57%. The wetlands class, which is less extensive, has also suffered a sharp decline and is tending to disappear. These dynamics give the picture of a mountainous region in continuous and accelerated transformation.

3.2. Change matrix and spatiotemporal evolution

To display changes in land use in the Imouzzer Kandar natural lakes area, we used the matrix of changes between 1984 and 2018. Information on the nature of the changes has been mapped and presented in Figure 5, and the statistics are shown in Table 4.

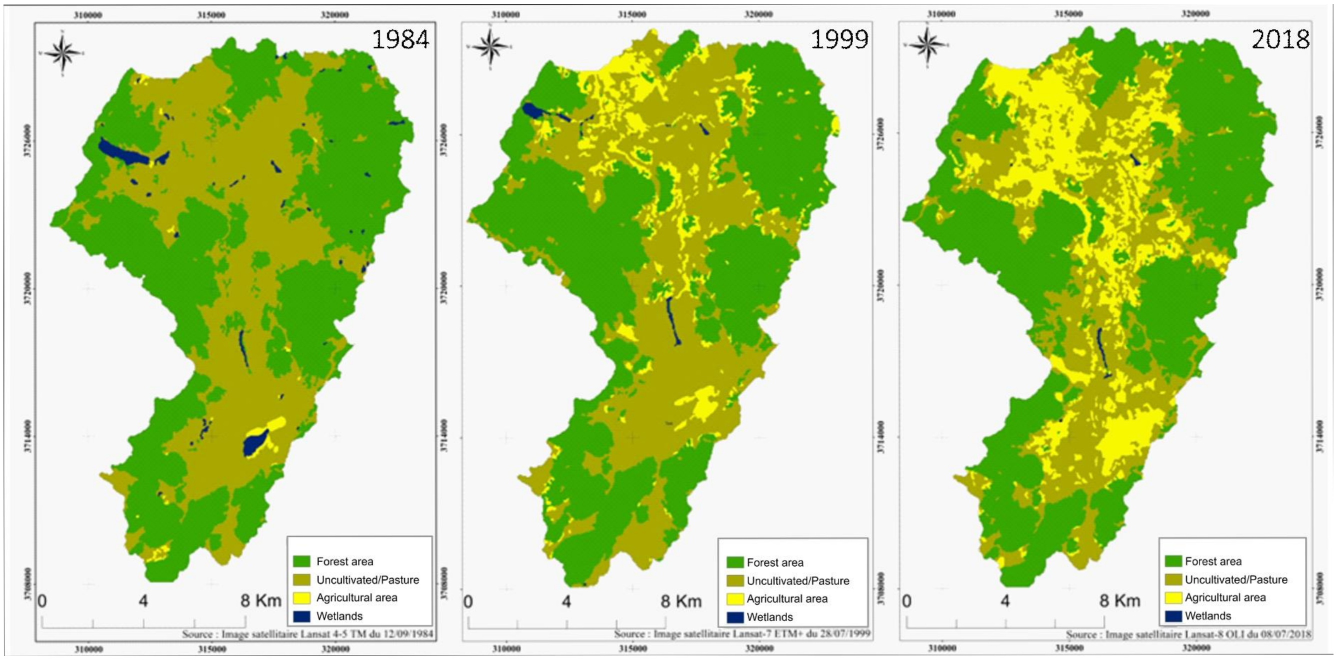

Fig. 3. Land use maps, 1984; 1999 and 2018

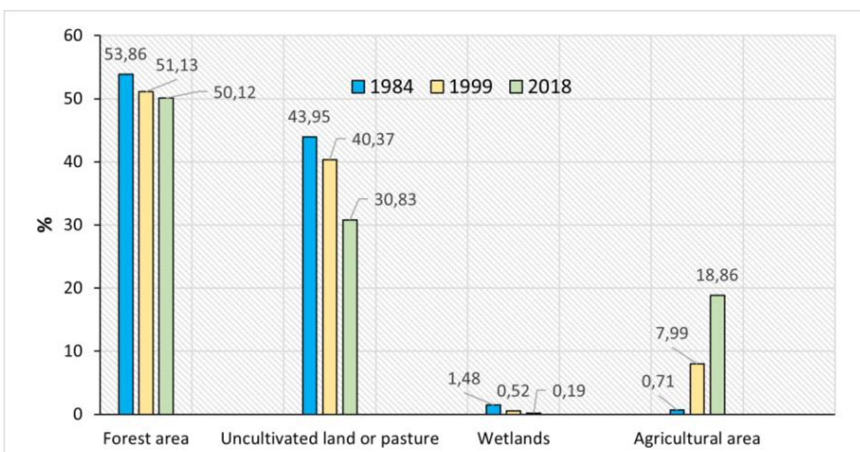

Fig. 4. Spatio-temporal evolution of land use

3.3. Forest area change

In 1984, the surface area was 9856.71 ha, representing 53.86% of the Dayet Aoua watershed; 15 years later (in 1999), this figure was 9356.22 ha or 51.13%. In 2018, it decreased by around 684.54 ha, or 3.5%. This figure is relatively moderate compared with the rate of deforestation recorded in other regions of Morocco. Several studies have found similar results in the region. Indeed, GUEJJOUD (2019) concluded that the forest in Haut Sebou had undergone severe regression, particularly because of its conversion to farmland. Thus, EL-BOUHALI ET AL., (2021) found that irrigated crops (Rosaceous) recorded a strong progression to the detriment of forests and uncultivated land in the Middle Atlas. This decrease was to the benefit of rangeland (645.66 ha) and agricultural land (311.04 ha). The area's forests are under heavy human pressure.

Significant population growth in forest and peri-forest areas, combined with social vulnerability, has led to heavy pressure on the forest ecosystem. Clearing, logging, and intensive grazing are the main forms of forest degradation in this region (BENABID, 2000*).* The expansion of agricultural land to the detriment of forests often takes place at the latter's boundaries. Fires are also a scourge that threatens the sustainability of the forest (SERBOUTI ET AL., 2022). During the period 2010–2018, fires ravaged 520 ha in the Dayet Aoua watershed (CHRIF EL IDRISSI & SABER, 2020).

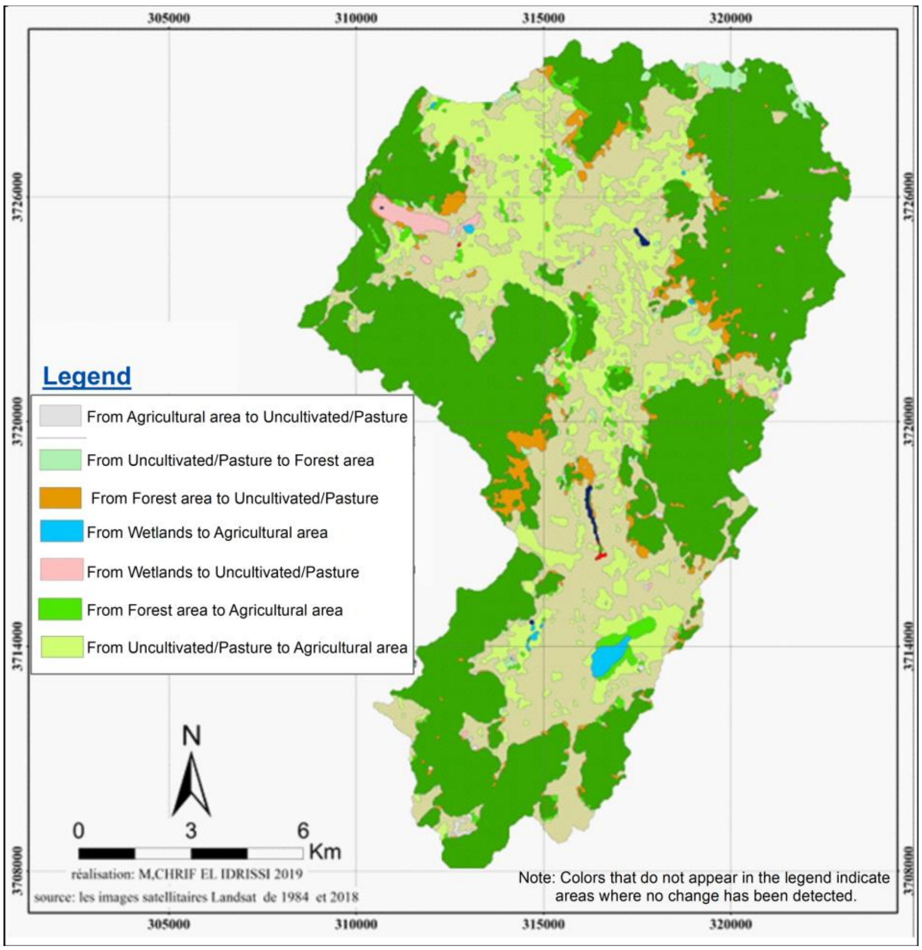

Fig. 5. Map of land use change between 1984 and 2018

Table 4. Land use change matrix from 1984 to 2018

	Land use in 1984 (ha)					
Land use in 2018 (ha)	Class	Forest area	Uncultivated land/pasture	Agricultural area	Wetlands	Total
	Forest area	8895,60	256,14	0,00	0,00	9151,74
	Uncultivated land/pasture	645,66	4798,53	38,07	152,37	5634,63
	Agricultural area	311,04	2979,27	90,99	88,20	3458,88
	Wetlands	0,00	5,76	0,00	23,31	39,69
	Total	9856,71	8039,70	129,06	263,88	18289,35

3.4. Agricultural land change

This class has seen a remarkable increase in surface area between 1984 and 2018. This relatively intensive expansion began between 1984 and 1999. Its surface area increased from 130.05 ha in 1984 to 1462.05 ha in 1999 and to 3451.05 ha in 2018, an overall increase of 252.2%. This evolution is taking place at the expense of rangelands, forests, and wetlands. This expansion can be explained by the rapid population growth since the 1980s (CHRIF EL IDRISSI & SABER, 2020), and also by the hydro-agricultural development projects that have been implemented since the 2000s, the most important of which is the Green Morocco Plan. These interventions were aimed at improving the living conditions of the population and safeguarding natural resources. To achieve this, these projects encouraged private investors to plant fruit crops, particularly Rosaceous plants, on uncultivated land (CHRIF EL IDRISSI & SABER, 2020).

3.5. Area change of wetlands

The surface area of wetlands in 1984 was 270.97 ha, and this had fallen to 94.55 ha by 1999, a regression of 176.42 ha, and represented just 34.86 ha in 2018 (Fig. 5). Much of this area has been converted to farmland and pasture. If this pace continues and no conservation measures are taken, these areas could disappear completely in the coming years. The reduction in the surface area of natural lakes (Dayet Aoua, Hachelaf) is linked to rainfall fluctuations. Indeed, the succession of drought periods accompanied by rising temperatures since the 1980s has led to the weakening of this natural environment. During this period, Dayet Aoua dried up three times (Fig. 6) due to low rainfall (SAYAD & CHAKIRI, 2019). In addition, agricultural pressure on underground and surface water resources in the Imouzzer Kandar has contributed to this decline.

3.6. Uncultivated and pastoralland area

Between 1984 and 1999, there was a relatively remarkable change in the regression of included lands and rangelands of around 655.92 ha, or 3.58%. However, the period between 1999 and 2018 saw a significant decrease of 1,744.95 ha, especially in the basins and depressions where people began to show more interest in arboriculture with the advent of more vigorous cultivation techniques (BADIDI,1999). This class was transformed mainly into an agricultural class of 2979.27 hectares, a forest area of 256.14 hectares, and wetlands of 5.76 hectares. The creation of a small artificial lake as a result of building a dike to collect all the water flowing from the Sidi Mimoun springs explains this increase in wetland area.

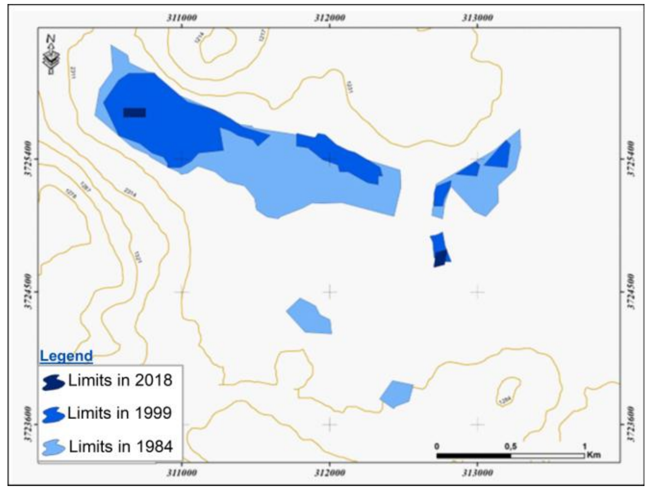

Fig. 6. Spatio-temporal evolution of Dayet Aoua

4. Discussion

One of the existing methods for detecting land cover changes was applied to the context of a mountain basin in the Moroccan Middle Atlas. Many obvious points emerged from this research, and the method of comparing classifications showed some usefulness and weaknesses. Regarding the image classification method, previous studies conducted in the Moroccan Middle Atlas (GUEJJOUD, 2019; EL-BOUHALI., 2021; ICHEN ET AL., 2021;) obtained less accurate results than the present research. A significant improvement in results was obtained compared to the use of traditional classification methods. The overall accuracies obtained were 93.14% (1984), 88.67% (1999), and 94.5% (2018). In addition, the classification comparison method demonstrated the usefulness of a simple approach to detecting land cover change and the ease of producing change maps. This method provided 32 combinations of changed occupations "from - to" based on 4 thematic classes. This information is very useful in the context of integrated natural resource management in a mountain basin.

Thanks to the improved segmentation using pseudo-spectral bands, we were able to separate objects well, separating types of crops (fruit trees, vegetables), roads and buildings. However, in a region where land use is complex and mixed, images with coarse spatial resolution (30*30 m) have some limitations. At this spatial resolution, some objects are not well distinguished, so confusion is inevitable. High-resolution images are also useful for obtaining detailed information (buildings, industrial areas, isolated dwellings, etc.). In this respect, the Sentinel2 images provided free of charge by the European Space Agency offer a better discrimination of small-scale objects. However, the problem is that these high-resolution images (10*10m) have only been available since 2015.

This study Found that there has been a significant spatial expansion of the agricultural environment. There has also been a significant reduction in grazing lands and wetlands, including the Ramsar lakes (Dayet Aoua and Hechelaf). Among the factors influencing land use change, anthropogenic factors are the most important. The diachronic study allowed us to assess the pressure and evolution of agricultural land over 34 years. This study showed the fluctuations in wetlands. In 1984, there was eight times more water surface area than in 2018. In fact, according to the results, 6.95 ha of water surface disappears every year. Thus, the change analysis showed that most of the wetland (152.37 ha) has become pasture. The analysis also highlighted the irreversible increase in agriculture at the expense of wetlands, where 88.20 ha of wetlands have been permanently replaced by dense, water-intensive agriculture.

The analysis highlights the regressive dynamics of the natural environment in the Dayet Aoua watershed. This degradation seems to be general and affects all natural classes, especially wetlands and forests. The evolution shows regressions for the pasture and bare land classes. This could be partly explained by the expansion of agricultural orchards following the development of arboriculture, especially apple trees, in the area (Badidi, 1999; Boukil, 2004; Chillasse & Dakki, 2004; Abba et al., 2012). This water-intensive speculation certainly has an impact on the depletion of the groundwater table and the lowering of natural lake levels. The degradation of the environment, reflected in the regression of natural formations, is essentially linked to the development of socio-economic activities, especially agropastoral activities. In a context characterized by demographic pressure, the exploitation of agropastoral resources is necessarily increasing. In this regard, Chrif El Idrissi & Saber, (2020) noted that the dynamics of land use and the increase in irrigated land in the Dayet Aoua-Dayet Hechelaf corridor has led to overexploitation of the water table through the intensification of groundwater pumping, especially since 2006.

Several authors consider that demographic growth and certain agricultural practices are responsible for the degradation of natural environments, leading to the disruption of ecological balances (Chillasse & Dakki, 2004; Ichen, 2021), especially of wetlands, most of which are highly vulnerable to climatic hazards (IPCC, 2007; ANEF, 2015). This phenomenon is particularly pronounced in sub-Saharan Africa, where high population densities and scarcity of arable land are driving populations to seek new land (Abotchi., 2002; Atta et al., 2010). To achieve this, it is essential to draw up an integrated and concerted plan for the development and management of the natural resources of the site to ensure the sustainable and effective management of the natural ecosystems of the area. This plan should focus on two main areas: the conservation of the heritage of the Ramsar site, through the programming of reforestation campaigns using species better adapted to the conditions of the area; and the organization of the use of the site by the local population, through the creation of cooperatives aimed at reducing the impact of human activities on the natural resources of Lake Dayet Aoua.

Finally, this study offers very encouraging prospects for work more oriented towards the development of automated integrated management systems and tools to better assess the impact of land use changes on the natural environment, especially on wetlands and forests in a watershed (Rousseau et al., 2000). This analysis will provide watershed managers with a picture of land use patterns and anthropogenic pressures on natural resources. It will also enable the creation, archiving and updating of a diachronic digital database.

5. Conclusion

This study focused on land-use dynamics in the Dayet Aoua watershed in the Middle Atlas using geospatial and GIS data. The object-oriented approach used in this work proved effective. Improvements to the results can be obtained and verified using other methods. The spatial resolution of Landsat images is a limitation. Confusion due to spectral signature similarities between certain thematic classes is still present. However, the change detection approach provides detailed information on changes and proved useful for assessing land use changes in the study area.

The map of changes detected between 1984 and 2018 showed a significant expansion of agricultural areas to the detriment of forest areas and uncultivated land. However, we are currently witnessing increasingly intensive agricultural use around the natural lakes of Imouzzer Kandar. This development of crops, particularly fruit trees, is among the most water-intensive. Most wetlands have been transformed into wastelands and rangelands, and this increase in agriculture has been irreversibly detrimental to wetlands. This is the consequence of demographic growth. Thus, most of the land that was uncultivated or used for grazing during the transhumance period has been transformed into fruit plantations, notably for Rosaceous plants.

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