Pesquisas em Geociências

v. 53, nº 1 (2026)
doi.org/10.22456/1807-9806.153402

Research article

Multi-decadal Land Use and Land Cover Change Detection Using Landsat Time Series in the Wadi Rdat Basin, Morocco

Detecção de Mudanças no Uso e na Cobertura da Terra Utilizando Séries Temporais Landsat na Bacia do Wadi Rdat, Marrocos

Lamiae Belhak[1], *Taj-din Rahmani*[2], *M'hamed Nmiss*[1] & *Abdelmajid Essami*[1]

[1]Hassan II University, Department of Geography, Faculty of Arts and Humanities Mohammedia, Casablanca, Morocco. E-mail: lamiae.belhak-etu@etu.univh2c.m_, mhamed.nmiss@etu.univh2c.ma_, abdelessami@yahoo.fr

[2]Ibn Tofail University, Department of Geography, Faculty of Humanities and Social Sciences, Kenitra, Morocco. E-mail: tajdin.rahmani@uit.ac.ma

Abstract: Land use and land cover (LULC) changes represent a key indicator of environmental dynamics, particularly in semi-arid regions where natural resources are highly sensitive to anthropogenic pressure and climatic conditions. Understanding the spatio-temporal evolution of LULC is essential for sustainable land and water management. This study examines long-term LULC changes in the Wadi Rdat Basin, central Morocco, using multi-temporal Landsat satellite imagery and GIS-based techniques. A diachronic analysis was conducted over a 30-year period from 1990 to 2020, based on Landsat TM and OLI data. Supervised classification using the Maximum Likelihood algorithm was employed to generate LULC maps for four representative years. Six major LULC classes were identified: forest, agricultural land, fallow land and rangelands, built-up areas, bare land, and water bodies. The results indicate significant transformations, characterized by a continuous decline in forest cover, dynamic changes in agricultural land, a marked expansion of bare land, and gradual urban growth. These findings highlight ongoing land degradation processes and provide valuable insights for future land-use planning and environmental management in the basin.

Keywords: Land use and land cover; Spatio-temporal; GIS; Wadi Rdat Basin.

Recebido: 02/2026
Aceito: 06/2026
Publicado: 06/2026

Resumo: As mudanças no uso e na cobertura da terra (LULC) constituem um importante indicador da dinâmica ambiental, particularmente em regiões semiáridas, onde os recursos naturais são altamente sensíveis à pressão antrópica. A compreensão da evolução espaço-temporal da LULC é essencial para a gestão sustentável da terra e dos recursos hídricos. Este estudo analisa as mudanças de longo prazo da LULC na Bacia do Wadi Rdat, no centro do Marrocos, utilizando imagens multitemporais do satélite Landsat e técnicas baseadas em Sistemas de Informação Geográfica (SIG). Foi realizada uma análise diacrônica ao longo de 30 anos, entre 1990 e 2020, com base em dados de Landsat TM e OLI. A classificação supervisionada, baseada no algoritmo de máxima verossimilhança, foi aplicada para gerar mapas representativos de LULC de quatro anos. Foram identificadas seis principais classes de LULC: floresta, terras agrícolas, terras em pousio e pastagens, áreas construídas, terras nuas e corpos d’água. Os resultados indicam transformações significativas, caracterizadas por um declínio contínuo da cobertura florestal, mudanças dinâmicas nas terras agrícolas, uma expansão acentuada das terras nuas e um crescimento urbano gradual. Esses resultados evidenciam processos contínuos de degradação da terra e fornecem subsídios relevantes para o planejamento do uso da terra e para a gestão ambiental futura da bacia.
Palavras-chave: Uso e cobertura da terra; Análise espaço-temporal; SIG; Bacia do Wadi Rdat.

1. Introduction

Land use and land cover (LULC) change is widely recognized as one of the main drivers of environmental and geomorphological processes, influencing hydrological regimes, soil erosion, vegetation dynamics, and ecosystem services at different spatial and temporal scales (Foley *et al.*, 2005; Shiferaw *et al.*, 2025; El Mazi *et al.*, 2026). These changes are particularly pronounced in semi-arid and Mediterranean regions, where climatic variability and increasing anthropogenic pressure interact strongly, leading to land degradation, water scarcity, and ecosystem vulnerability (Lambin *et al.*, 2003; Hansen & Loveland, 2012; García-Ruiz *et al.*, 2013).

In recent decades, population growth, agricultural expansion, urban development, and policy-driven land management practices have accelerated LULC transformations worldwide (Ellis *et al.*, 2010; Gouveia *et al.*, 2015; Meyfroidt *et al.*, 2018; Nmiss *et al.*, 2025; Afenzar *et al.*, 2025; Benbih *et al.*, 2025). Monitoring these changes is therefore essential for understanding landscape evolution and for supporting sustainable land and water resource management (Veldkamp & Lambin, 2001). Remote sensing has proven to be an effective approach for LULC mapping and change detection due to its synoptic coverage, temporal consistency, and ability to provide objective and repeatable observations over large areas (Coppin *et al.*, 2004; Roy *et al.*, 2014; Ferreira *et al.*, 2018; Wulder *et al.*, 2019).

Among Earth observation systems, the Landsat program offers the longest continuous archive of medium-spatial-resolution satellite imagery, enabling multi-decadal assessments of land surface dynamics since the 1970s (Roy *et al.*, 2014; Kennedy *et al.*, 2014; Wulder *et al.*, 2019). Landsat data have been extensively used to analyze long-term changes in vegetation cover, agricultural systems, urban growth, and land degradation across different environmental contexts (Hansen & Loveland, 2012; Zhu & Woodcock, 2014). The availability of consistent Landsat imagery allows the investigation of LULC trajectories at regular temporal intervals, which is essential for capturing both gradual and abrupt landscape changes.

Traditional LULC change detection approaches based on two-date image comparisons may fail to adequately represent complex land-cover transitions, especially those occurring progressively over time. To overcome these limitations, multi-temporal analyses using Landsat time series have gained increasing attention, as they provide a more robust framework for assessing spatiotemporal LULC dynamics and reducing uncertainties related to seasonal effects and sensor differences (Zhu, 2017; Kennedy *et al.*, 2010; Zhu *et al.*, 2020). Selecting representative years at decadal intervals has become a common and effective strategy for evaluating long-term land-use trends.

In North Africa, and particularly in Morocco, LULC change has emerged as a major environmental concern due to the combined effects of climate variability, agricultural intensification, rangeland degradation, and expanding settlements (Assede *et al.*, 2023; Yahaya *et al.*, 2024; Chrif El Idrissi *et al.*, 2024; Alvarez & Govind., 2025). Several studies have demonstrated significant changes in vegetation cover, cropland distribution, and land degradation processes across Moroccan watersheds using remote sensing and GIS techniques (Charif El Idrissi *et al.*, 2024; Arari *et al.*, 2025; Irifi *et al.*, 2025; El Mazi *et al.*, 2026). However, despite these efforts, many river basins remain insufficiently studied at the basin scale using consistent multi-decadal datasets.

The Wadi Rdat Basin has been subjected to increasing pressure from agricultural activities and settlement expansion over recent decades, making it a valuable case study for examining long-term LULC dynamics. However, comprehensive assessments quantifying these changes over extended periods remain limited for this basin. Therefore, the objective of this study is to analyze land use and land cover changes in the Wadi Rdat Basin over a 30-year period using Landsat imagery acquired in 1990, 2000, 2010, and 2020. By applying supervised classification and post-classification change detection techniques, this research aims to quantify major LULC transitions and provide spatially explicit information to support sustainable land management and geoscientific analysis at the watershed scale.

2. Materials and Methods

2.1 Study area

The Wadi Rdat Basin is located between longitudes 5°20′ and 5°55′ W and latitudes 34°28′ and 34°49′ N. It forms part of the northern sector of the lower Sebou Basin and is bounded to the west by the Mda Basin, to the east by the Ouergha Basin, and to the north by the Loukkos Basin. Wadi Rdat is a tributary of the Sebou River and drains an area of approximately 1,165 km² (Figure 1).

The study area extends across portions of three administrative provinces: Sidi Kacem, Ouezzane, and Kenitra. The basin’s population is predominantly rural and is distributed among more than 200 villages of varying sizes.

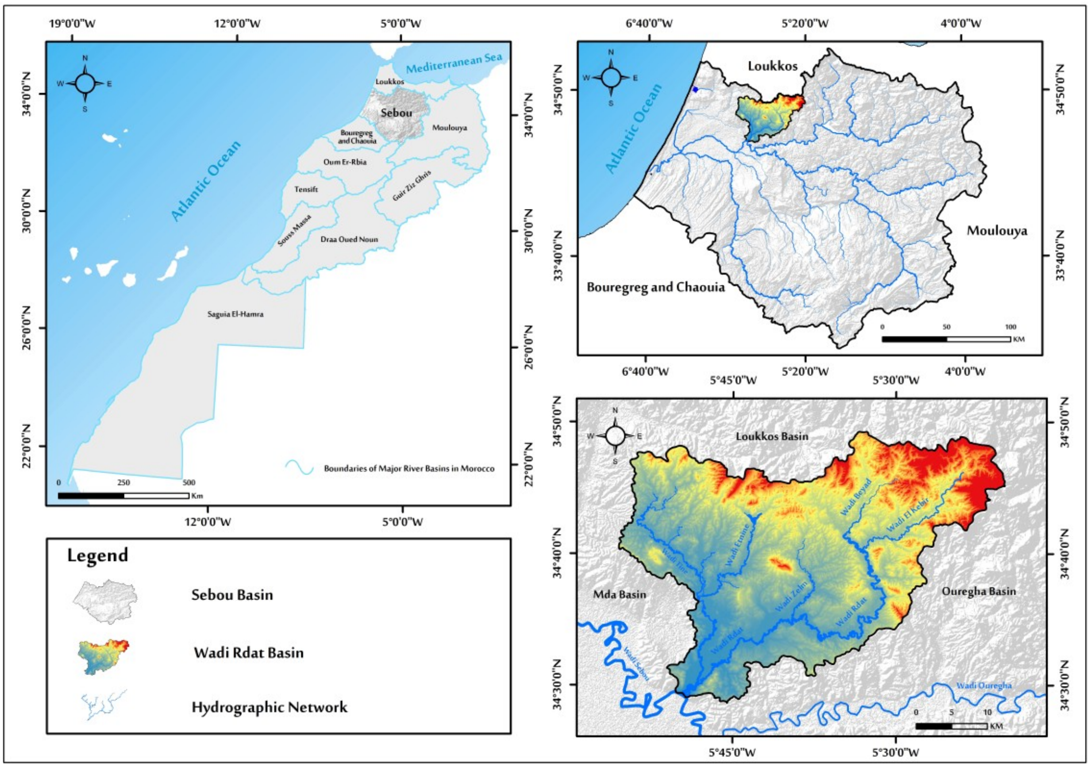

Figure 1. Location of the Wadi Rdat Basin.

Figura 1. Localização da bacia do Wadi Rdat.

2.2 Data source

This study is based on multi-temporal satellite imagery acquired from the Landsat program to investigate land use and land cover (LULC) changes in the Wadi Rdat Basin. Four representative years—1990, 2000, 2010, and 2020—were selected at decadal intervals in order to analyze long-term LULC dynamics over a 30-year period. The Landsat mission provides a continuous and reliable archive of medium-resolution satellite data, which has been widely used in regional and basin-scale LULC studies.

Landsat 5 Thematic Mapper (TM) images were used for the years 1990, 2000, and 2010, while Landsat 8 Operational Land Imager (OLI) imagery was used for 2020 due to its improved radiometric quality. All images have a spatial resolution of 30 m and were selected from the same season to minimize the effects of seasonal variability in vegetation and land surface conditions. Spectral bands in the visible, near-infrared, and shortwave infrared regions were used to ensure consistency among the different datasets.

Table 1. Description of the satellite images used in the study.

Tabela 1. Descrição das imagens de satélite utilizadas no estudo.

Satellite	Sensor	Acquisition Date	Spatial Resolution	Source
Landsat 8	Operational Land Imager (OLI)	16/10/2020	30 m	USGS
Landsat 5	Thematic Mapper (TM)	11/09/2010		
		10/11/2000		
		20/09/1990		

2.3 Methodology

2.3.1 Image Pre-processing

All Landsat images were pre-processed to ensure consistency across sensors and acquisition dates (Figure 2). Pre-processing steps included geometric correction, radiometric normalization, and atmospheric correction using surface reflectance products, following standard recommendations for long-term land cover analysis (Zhu & Woodcock, 2014). All images were projected to a common coordinate reference system and clipped to the boundary of the Wadi Rdat Basin. Cloud and shadow effects were minimized through visual inspection and quality masking where necessary (Scaramuzza *et al.*, 2012).

2.3.2 Land Use and Land Cover Classification

Land use and land cover maps were produced using a supervised classification approach, which is commonly used in LULC studies due to its ability to incorporate expert knowledge through training samples (Foody, 2002; Lu & Weng, 2007). Based on the characteristics of the study area and spectral separability, six major LULC classes were identified: forest, agricultural land, fallow land and rangelands, bare land, built-up areas, and water bodies.

Training samples for each class were selected through visual interpretation of Landsat imagery and high-resolution satellite imagery available through Google Earth Pro (imagery from 2020–2023), which was used solely as a visual reference to improve class identification, following common practices in land cover mapping (Olofsson *et al.*, 2013). The Maximum Likelihood Classification (MLC) algorithm was applied independently to each image, as it remains a robust and widely accepted method for medium-resolution LULC classification (Richards & Jia, 2006).

2.3.3 Land Use and Land Cover Change Detection

Land use and land cover changes were assessed through a post-classification comparison approach. This method is based on the independent classification of multi-temporal images from different dates in order to analyze changes in the spatial distribution and area of LULC classes over time (Singh, 1989; Lu *et al.*, 2004). Change analysis was carried out for three time intervals: 1990–2000, 2000–2010, and 2010–2020, allowing the identification of the main spatio-temporal trends in the Wadi Rdat Basin.

2.3.4 Accuracy Assessment

A quantitative accuracy assessment was performed for the 2020 LULC classification using 105 validation points. Reference classes were identified mainly from high-resolution Google Earth Pro imagery acquired close to 2020, while field observations from 2022–2024 were used only as supplementary support for stable land cover classes. Classification performance was evaluated using a confusion matrix, from which overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA), and the Kappa coefficient were calculated following standard methods (Congalton, 1991; Foody, 2002; Olofsson *et al.*, 2014). Overall accuracy was calculated as:

$$OA = \frac{\sum D}{N} \times 100$$

$$PA = \frac{D}{R} \times 100$$

$$UA = \frac{D}{C} \times 100$$

where $\sum D$ is the sum of correctly classified samples, N is the total number of validation points, D is the number of correctly classified samples for a given class, R is the total number of reference samples in that class, and C is the total number of samples classified in that class. The Kappa coefficient was also computed to assess agreement beyond chance (Cohen, 1960; Congalton, 1991). For the earlier years (1990, 2000, and 2010), quantitative validation was not possible due to the lack of reliable historical reference data; therefore, these classifications were evaluated qualitatively.

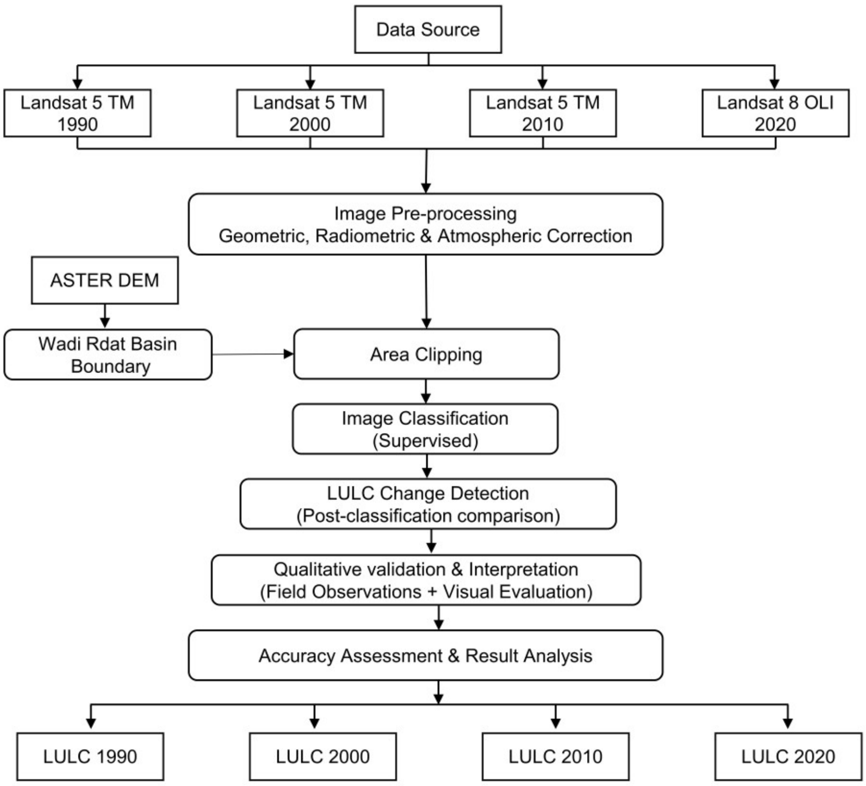

Figure 2. Methodological workflow and data analysis.

Figura 2. Fluxograma metodológico e da análise de dados.

3. Results

3.1. LULC status (1990–2020)

Multi-temporal land use and land cover (LULC) maps of the Wadi Rdat Basin for the years 1990, 2000, 2010, and 2020, classified into six major classes—forest, agricultural land, fallow land and rangelands, built-up areas, bare land, and water bodies—are presented in Figure 3. The spatial distribution and areal extent of each LULC class derived from supervised classification are summarized in Table 2.

The results from the 1990 classified map indicate that fallow land and rangelands dominated the basin, covering 42.40% (494.3 km²) of the total area, followed by agricultural land at 29.54% (344.4 km²). Forest covered 16.74% (195.1 km²), while bare land accounted for 11.00% (128.2 km²). Built-up areas and water bodies occupied very small proportions of the basin, representing 0.32 and 0.01%, respectively.

In 2000, a noticeable expansion of agricultural land was observed, reaching 36.93% (430.5 km²) compared to 29.54% in 1990. In contrast, forest cover decreased to 13.16% (153.4 km²). Fallow land and rangelands declined to 34.75% (405.1 km²), while bare land increased moderately to 14.75% (171.9 km²). Built-up areas showed a slight increase to 0.41%, whereas water bodies remained negligible.

The classified results for 2010 reveal a substantial increase in bare land, which expanded to 25.29% (294.8 km²) of the basin. During the same period, agricultural land decreased to 27.35% (318.8 km²), while fallow land and rangelands increased slightly to 37.54% (437.6 km²). Forest areas continued to decline, covering only 8.96% (104.4 km²). Built-up areas expanded to 0.87%, indicating progressive urban growth.

By 2020, fallow land and rangelands remained the dominant LULC class, occupying 39.78% (463.7 km²) of the basin. Agricultural land showed a slight recovery, covering 28.76% (335.3 km²), while bare land decreased to 22.36% (260.7 km²) compared to 2010. Forest cover reached its lowest extent, accounting for 7.73% (90.1 km²). Built-up areas continued to increase gradually, reaching 1.32% (15.4 km²), whereas water bodies remained marginal, covering less than 0.1% of the total area.

Table 2. LULC distribution in the Wadi Rdat basin.

Tabela 2. Distribuição do uso e da cobertura da terra na bacia do Wadi Rdat.

LULC Class	**1990**		**2000**		**2010**		**2020**	
	Area (km²)	**Area (%)**	**Area (km²)**	**Area (%)**	**Area (km²)**	**Area (%)**	**Area (km²)**	**Area (%)**
Forest	195.1	16.74	153.4	13.16	104.4	8.96	90.1	7.73
Agricultural land	344.4	29.54	430.5	36.93	318.8	27.35	335.3	28.76
Fallow land and rangelands	494.3	42.40	405.1	34.75	437.6	37.54	463.7	39.78
Built-up areas	3.7	0.32	4.8	0.41	10.2	0.87	15.4	1.32
Bare land	128.2	11.00	171.9	14.75	294.8	25.29	260.7	22.36
Water bodies	0.09	0.01	0.06	0.01	0.04	0.00	0.6	0.05
Total	1165.8	100	1165.8	100	1165.8	100	1165.8	100

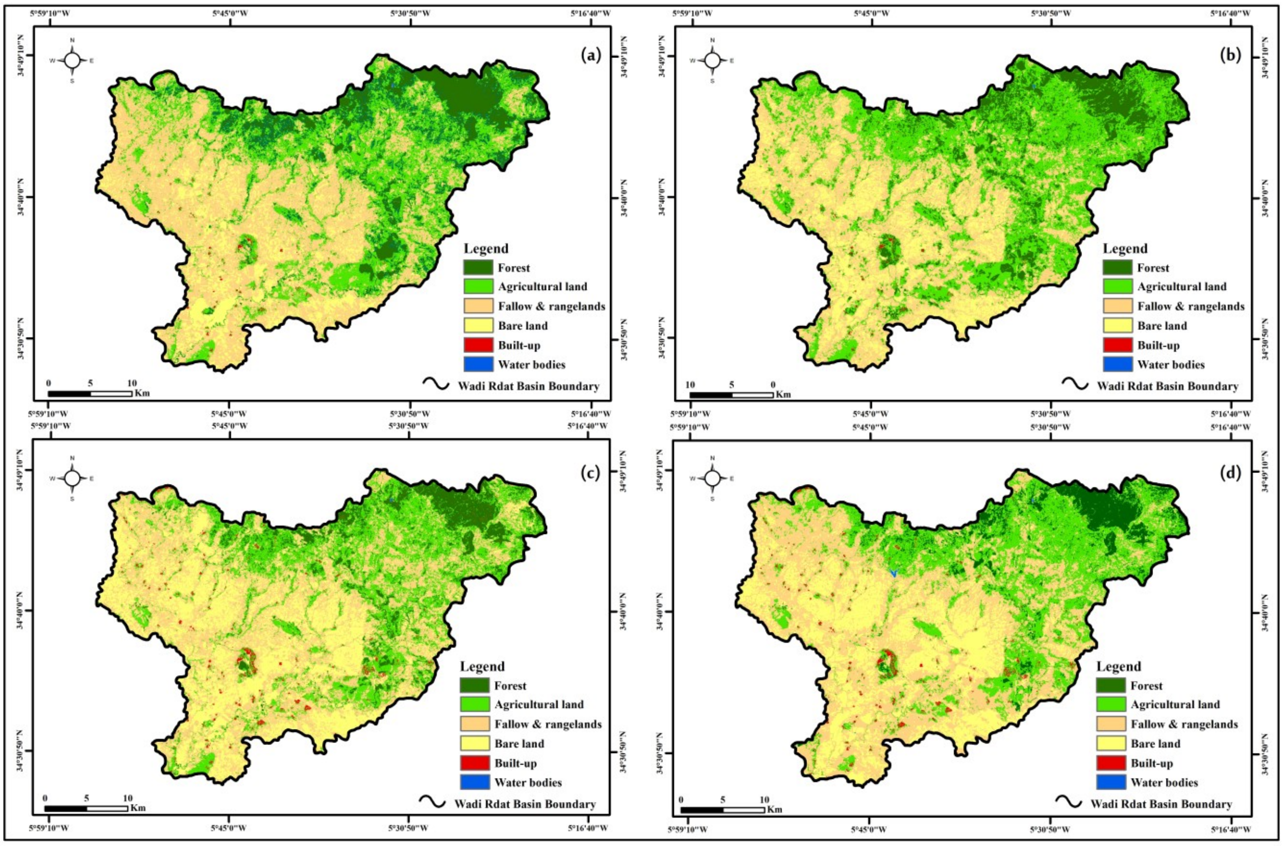

Figure 3. Spatial distribution of land use and land cover classes in the Wadi Rdat Basin in (a) 1990, (b) 2000, (c) 2010, and (d) 2020.

Figura 3. Distribuição espacial das classes de uso e cobertura da terra na bacia do Wadi Rdat em (a) 1990, (b) 2000, (c) 2010 e (d) 2020.

3.2. Spatio-temporal changes in LULC

The spatio-temporal analysis of land use and land cover (LULC) changes in the Wadi Rdat Basin between 1990 and 2020 reveals notable variations in the extent and distribution of the main land cover classes (Figure 4). During the first period (1990–2000), agricultural land showed a clear expansion, while forest areas experienced a noticeable decline. At the same time, fallow land and rangelands slightly decreased, whereas built-up areas increased marginally.

Between 2000 and 2010, the most pronounced change was the strong expansion of bare land, accompanied by a reduction in both agricultural land and forest cover. Fallow land and rangelands increased moderately during this period, indicating a shift toward less intensively used land. Built-up areas continued to grow gradually, although they still occupied a relatively small proportion of the basin.

In the most recent period (2010–2020), agricultural land showed a slight recovery, while bare land decreased compared to 2010. Fallow land and rangelands remained the dominant land cover class throughout the basin. Forest cover continued its declining trend, and built-up areas showed a steady increase, reflecting ongoing urban expansion.

Overall, the spatio-temporal LULC changes indicate a continuous decline in forest cover, significant fluctuations in agricultural land, expansion of bare land during the mid-period, and a gradual but persistent increase in built-up areas across the Wadi Rdat Basin.

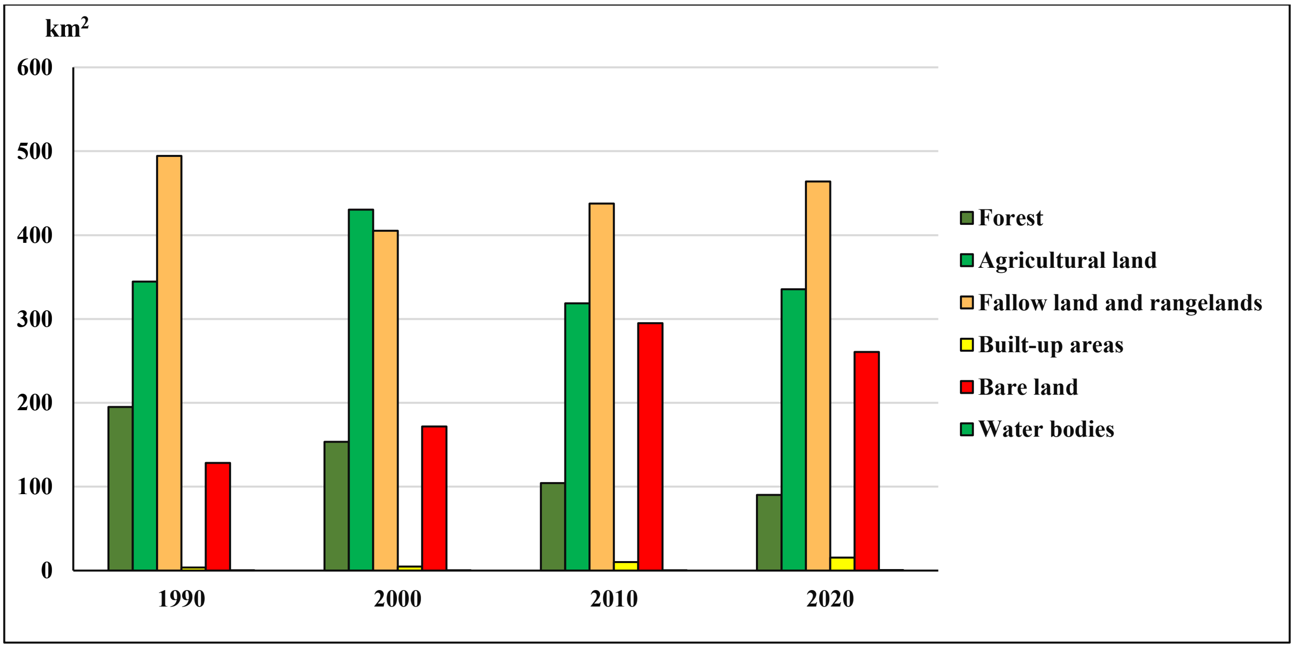

Figure 4. Spatio-temporal variation of land use and land cover classes in the Wadi Rdat Basin (1990–2020).

Figura 4. Variação espaço-temporal das classes de uso e cobertura da terra na bacia do Wadi Rdat (1990–2020).

3.3. LULC patterns during individual periods

- 1990–2000

The analysis of LULC patterns between 1990 and 2000 shows noticeable changes in the spatial distribution of land cover classes within the Wadi Rdat Basin (Figure 3). During this period, agricultural land expanded, becoming more prominent across the central and eastern parts of the basin. In contrast, forest areas declined, indicating a reduction in forest cover compared to 1990. Fallow land and rangelands slightly decreased, while bare land showed a moderate increase. Built-up areas expanded marginally, remaining limited in spatial extent, and water bodies showed no significant change.

- 2000–2010

Between 2000 and 2010, more pronounced LULC transformations were observed across the basin (Figure 3). This period is characterized by a strong expansion of bare land, especially in marginal and previously cultivated areas. At the same time, agricultural land and forest cover experienced substantial declines, indicating a contraction of these land use types. Fallow land and rangelands expanded moderately and became more widespread. Built-up areas continued to grow gradually, although they remained spatially limited, while water bodies remained negligible throughout the basin.

- 2010–2020

During the most recent period (2010–2020), LULC patterns indicate partial stabilization of some land cover classes within the Wadi Rdat Basin (Figure 3). Agricultural land showed a slight recovery, while bare land decreased compared to its peak extent in 2010. Fallow land and rangelands remained the dominant land cover type across most parts of the basin. However, forest cover continued to decline, reaching its lowest spatial extent during the study period. Built-up areas exhibited a continuous but gradual expansion, whereas water bodies showed minimal spatial variation.

3.4. Field observations (qualitative validation)

Field observations were conducted during 2022–2024 to provide qualitative support for the interpretation of land use and land cover (LULC) classes derived from satellite image classification. The field photographs illustrate representative examples of the main LULC categories identified in the study area, including forest (Figure 5a), agricultural land (Figure 5b), fallow land and rangelands (Figure 5c), and bare land (Figure 5d).

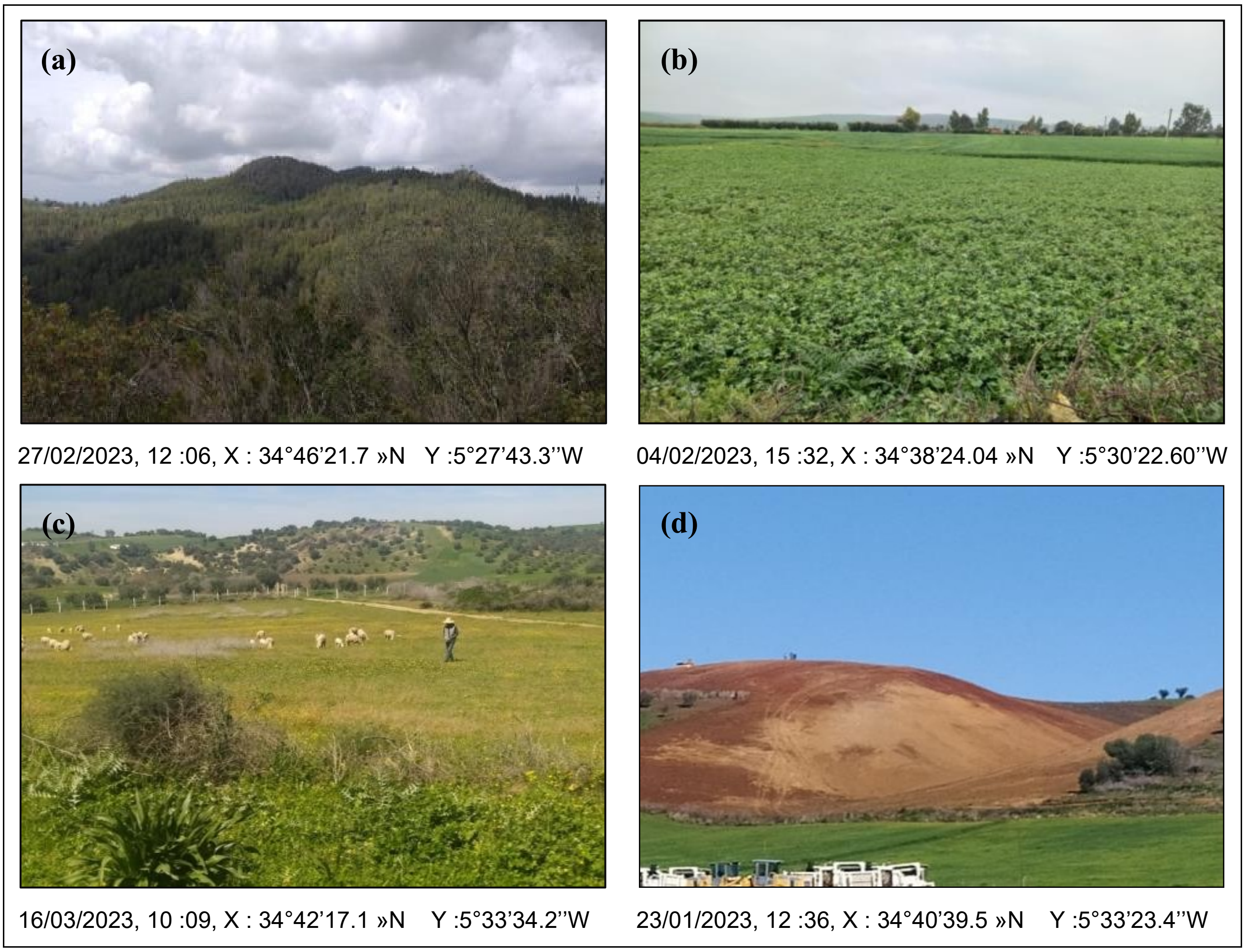

Figure 5. Field photographs illustrating major land use and land cover classes in the Wadi Rdat Basin: (a) forest, (b) agricultural land, (c) fallow land and rangelands, and (d) bare land.

Figura 5. Fotografias de campo ilustrando as principais classes de uso e cobertura da terra na bacia do Wadi Rdat: (a) floresta, (b) terra agrícola, (c) terra em pousio e pastagens e (d) terra nua.

Although these observations postdate the period analyzed, they were used exclusively as qualitative reference data to confirm the general characteristics and visual appearance of the mapped land-cover classes. The field photographs supported visual interpretation and increased confidence in the classification results, without being used for quantitative validation or area estimation.

For the earlier years (1990, 2000, and 2010), quantitative validation was not possible because reliable historical reference data were unavailable. Therefore, the classification results for these periods were qualitatively supported by field observations, visual interpretation, and temporal consistency analysis.

3.5. Accuracy Assessment of the 2020 Classification

A quantitative accuracy assessment was performed for the 2020 LULC map using 105 validation points interpreted mainly from high-resolution Google Earth Pro imagery acquired close to 2020. The confusion matrix yielded an overall accuracy of 70.48% and a Kappa coefficient of 0.641, indicating satisfactory classification performance. The highest accuracies were obtained for built-up areas and water bodies, whereas lower accuracies were observed for agricultural land, fallow land and rangelands, and bare land due to spectral similarity among these classes. Detailed class-based accuracy metrics are presented in Table 3.

Table 3. Accuracy assessment results for the 2020 LULC classification in the Wadi Rdat Basin

LULC Class	Producer Accuracy (%)	User Accuracy (%)
Forest	90.0	90.0
Agricultural land	40.0	50.0
Fallow land and rangelands	68.4	65.0
Built-up areas	100.0	80.0
Bare land	60.0	60.0
Water bodies	100.0	90.0

4. Discussion

The LULC dynamics observed in the Wadi Rdat Basin between 1990 and 2020 indicate a progressive transformation of the basin landscape under the combined influence of anthropogenic pressure and environmental constraints. Rather than reflecting isolated land cover shifts, the identified trends suggest a broader trajectory toward increasing land degradation, especially through forest decline, the expansion of bare land, and the instability of agricultural areas. Similar trajectories have been reported in Mediterranean and semi-arid regions, where land systems are highly sensitive to both climatic stress and human disturbance (Lambin *et al.*, 2001; Geist & Lambin, 2002; Debolini *et al.*, 2018).

The decline in forest cover appears to be one of the clearest indicators of ecological pressure in the basin. In semi-arid environments, forest regression is rarely caused by a single factor; rather, it usually results from the interaction of agricultural encroachment, overgrazing, wood extraction, and reduced regeneration under irregular rainfall conditions. This interpretation is consistent with previous studies carried out in Morocco and other Mediterranean environments, where forest ecosystems have shown increasing vulnerability to both human use and climatic stress (El Idrissi *et al.*, 2024; Chrif El Idrissi *et al.*, 2026). In the Wadi Rdat Basin, this decline likely reflects the cumulative effects of land conversion and ecological fragility.

Agricultural land did not follow a linear trend, but instead showed successive phases of expansion, contraction, and partial recovery. Such instability suggests that agricultural systems in the basin are highly responsive to changing socio-economic conditions and environmental constraints. The expansion recorded during the 1990s may be linked to increased cultivation pressure, while the decline observed between 2000 and 2010 may reflect reduced productivity, land abandonment, or climatic stress. The modest recovery after 2010 suggests that some cultivated lands remained adaptable, although still vulnerable. Comparable patterns have been reported in Mediterranean rural landscapes, where cropland dynamics are closely influenced by rainfall variability, land management strategies, and market or livelihood pressures (Debolini *et al.*, 2018; Ben-Said *et al.*, 2025).

The marked expansion of bare land, especially during the 2000–2010 interval, can be interpreted as a strong signal of land degradation. In semi-arid regions, the increase of bare surfaces is commonly associated with vegetation loss, soil erosion, declining biomass productivity, and prolonged drought conditions, often intensified by unsustainable agricultural and pastoral practices (Dregne, 2002; UNCCD, 2017). In the Wadi Rdat Basin, this change likely reflects both natural stress and human-induced degradation, particularly in fragile areas exposed to repeated land pressure. Although bare land decreased slightly after 2010, its persistence at a relatively high level in 2020 indicates that degradation processes remain active.

The persistence of fallow land and rangelands as the dominant land class highlights the importance of extensive grazing and mixed rural land-use systems in the basin. However, the long-term stability of these surfaces should not necessarily be interpreted as ecological equilibrium. In semi-arid contexts, rangelands may remain spatially dominant while undergoing gradual qualitative degradation due to overgrazing, reduced vegetation cover, and soil exhaustion. Their persistence, therefore, reflects not only land-use continuity but also the structural dependence of local livelihoods on low-intensity land systems.

The gradual increase in built-up areas reflects slow but continuous settlement expansion and local infrastructure development. Although the spatial extent of built-up land remains limited, its increase is consistent with broader rural transformation processes reported in Morocco and other semi-arid regions, where demographic growth and changing settlement patterns progressively convert agricultural or open land into built surfaces (Salvati *et al.*, 2012; Loulad *et al.*, 2023; Leghrib *et al.*, 2025). Even when spatially limited, this type of expansion may contribute to land fragmentation and increased pressure on surrounding natural and agricultural areas.

Overall, the LULC changes identified in the Wadi Rdat Basin appear to result from the interaction between natural factors and human drivers. Climatic irregularity, drought episodes, and the ecological fragility typical of semi-arid landscapes likely increased the sensitivity of land systems, while agricultural pressure, grazing intensity, wood extraction, and settlement growth accelerated surface transformation. The observed landscape evolution is therefore best understood as the outcome of both environmental stress and long-term human use of the basin.

This study nevertheless presents some limitations that should be considered when interpreting the results. First, the 30 m spatial resolution of Landsat imagery may reduce the precision of class discrimination, particularly for small or fragmented features such as built-up areas and narrow water bodies. Second, some LULC classes, especially agricultural land, fallow land, rangelands, and bare land, may show spectral similarity, which can affect class separability and partly explain the lower classification accuracy for these categories. Third, quantitative validation was only possible for the 2020 map because reliable historical reference data were unavailable for earlier years. Finally, the use of four representative dates provides a robust long-term overview, but does not capture short-term fluctuations that may have occurred between observation years. Despite these limitations, the multi-temporal Landsat-based approach remains suitable for identifying major LULC trends and provides useful baseline information for land management and environmental monitoring in the Wadi Rdat Basin.

5. Conclusions

This study assessed the spatio-temporal changes in land use and land cover (LULC) in the Wadi Rdat Basin, central Morocco, over a 30-year period from 1990 to 2020, using multi-temporal Landsat imagery and GIS-based analysis. The results demonstrate that the basin has undergone significant landscape transformations during the study period, reflecting the combined effects of human activities and environmental constraints in a semi-arid context.

The analysis revealed a continuous decline in forest cover, highlighting increasing pressure on natural ecosystems. Agricultural land exhibited dynamic behavior, characterized by periods of expansion, contraction, and partial recovery, while fallow land and rangelands remained the dominant land-cover types throughout the basin. A marked expansion of bare land, particularly during the mid-study period, indicates ongoing land degradation processes, whereas built-up areas showed a gradual but persistent increase, reflecting progressive urban development. Water bodies remained negligible and stable over time.

The integration of multi-temporal satellite data proved effective in monitoring long-term LULC dynamics and identifying major land-cover trends. The findings provide valuable baseline information for land use planning, environmental monitoring, and sustainable resource management in the Wadi Rdat Basin. Continuous monitoring using remote sensing and GIS is recommended to support decision-making aimed at mitigating land degradation, preserving forest resources, and promoting sustainable land-use practices in semi-arid regions.

Future research should focus on integrating higher-resolution satellite imagery, annual or seasonal time series, and additional environmental variables to improve detection of short-term land-cover dynamics and class separability. Further studies may also combine LULC analysis with climate, hydrological, and socio-economic data in order to better understand the drivers of landscape change and support more targeted watershed management strategies.

Acknowledgments: The authors sincerely thank the editorial committee and the reviewers for their relevant and constructive comments, which contributed significantly to improving the quality of this research. They also extend their heartfelt thanks to the United States Geological Survey (USGS) for providing the images used in this study.

Author contributions: LB, T.R.: Conceptualization, Methodology, Field study, Writing – Original draft preparation, Data Analysis. MN & AE: Data collection, Data analysis, Writing – Reviewing and Editing.

Conflicts of interest: The authors declare no conflicts of interest.

References

Afenzar, M.; Achiban, H.; Abahrour , M.; Hmamouchi, M.; Senhaji, M.; Ennaji, N.; Halouan, S. 2025. Using Simulated Rainfall to Assess Water Erosion in the Aghrouz Watershed (Southern Rif, Morocco). *Pesquisas em Geociências*, 52(1): e146225. https://doi.org/10.22456/1807-9806.146225

Alvarez, C.I. & Govind, A. 2025. Assessing climate and land use changes in Morocco (2001–2023): from a geospatial and farmers' perspective. *Theoretical and Applied Climatology*, 156: 420. https://doi.org/10.1007/s00704-025-05656-z

Arari, K.; Amhani, Z.; Tribak, A.; El-Ommal, M.; Laaraj, M.; Azagouagh, K. 2025. Analysis of land use changes and soil erosion in the Wadi Larbâa Basin (Eastern Pre-Rif, Morocco): a spatial assessment from 1984 to 2024. *Mediterranean Geoscience Reviews*, 7: 1007-1025. https://doi.org/10.1007/s42990-025-00200-7

Assede, E.S.P.; Orou, H., Biaou, S.S.H.; Geldenhuys, C.J.; Ahononga, F.C.; Chirwa, P.W. 2023. Understanding Drivers of Land Use and Land Cover Change in Africa: A Review. *Current Landscape Ecology Reports*, 8: 62-72. https://doi.org/10.1007/s40823-023-00087-w

Benbih, M.; Ouammou, A.; Nmiss, M.; Boukdoun, A.; Nait-Si, H. 2025. Impact of human activities on soil degradation and sustainability of oasis ecosystems in the Middle Draa (Morocco). *Revista de Estudios Andaluces*, 50: 266-285. https://doi.org/10.12795/rea.2025.i50.12

Ben-Said, M.; Chemchaoui, A.; Etebaai, I.; Taher, M. 2025. Land use and land cover changes in Morocco: Trends, research gaps, and perspectives. *GeoJournal*, 90: 44. https://doi.org/10.1007/s10708-024-11214-3

Chrif El Idrissi, M.C.; Er-Riyahi Saber, E.; Al Mashoudi, A. 2024. Land use and land cover change analysis using geospatial techniques: A case study of the Dayet Aoua Watershed, Middle Atlas, Morocco. *Environmental & Socio-economic Studies*, 12(4): 45-56. https://doi.org/10.2478/environ-2024-0024

Chrif El Idrissi, M.; El Attar, M.; Saber, E.R.; El Ghalbi, K. 2026. Four decades of land use and land cover change in the Ouiouane forest area (Middle Atlas, Morocco): A remote sensing and GIS-based assessment (1984–2024). *Euro-Mediterranean Journal for Environmental Integration*, 11: 87. https://doi.org/10.1007/s41207-025-01051-2

Cohen, J. 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, 20(1): 37-46. https://doi.org/10.1177/001316446002000104

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37(1): 35-46. https://doi.org/10.1016/0034-4257(91)90048-B

Coppin, P.; Jonckheere, I.; Nackaerts, K.; Muys, B.; Lambin, E.F. 2004. Digital change detection methods in ecosystem monitoring: a review. *International Journal of Remote Sensing*, 25(9): 1565-1596. https://doi.org/10.1080/0143116031000101675.

Debolini, M.; Marraccini, E.; Dubeuf, J.-P.; Geijzendorffer, I.R.; Guerra, C.; Simon, M.; Targetti, S.; Napoléone, C. 2018. Land and farming system dynamics and their drivers in the Mediterranean Basin. *Land Use Policy*, 74: 71-85. https://doi.org/10.1016/j.landusepol.2018.03.035

Dregne, H.E. 2002. Land degradation in the drylands. *Arid Land Research and Management*, 16(2): 99-132. https://doi.org/10.1080/153249802317304422

El Mazi, M.; Saber, E.R.; El-Bouhali, A.; Hmamouchi, M.; Bade, M.; Dhaouadi, L. 2026. Long-term Response of Vegetation to Global Change in the High Rif (Morocco): an Analysis Based on Remote Sensing Data. *Earth Systems and Environment*, (2026). https://doi.org/10.1007/s41748-025-01018-x

Ellis, E.C.; Goldewijk, K.K.; Siebert, S.; Lightman, D.; Ramankutty, N. 2010. Anthropogenic transformation of the biomes, 1700–2000. *Global Ecology and Biogeography*, 19(5): 589-606. https://doi.org/10.1111/j.1466-8238.2010.00540.x

FAO. 2018. *The state of the world's forests 2018: Forest pathways to sustainable development*. FAO. https://openknowledge.fao.org/items/28896bfc-567c-4e4e-a1b2-d28e78867028

Ferreira, R.H.S. & Angelo, N.P. 2018. Change detection in remote sensing multitemporal image data by applying support vector machines using polynomial kernel and radial basis function (RBF) kernel. *Pesquisas em Geociências*, 45(2): e0674. https://doi.org/10.22456/1807-9806.88649

Foley, J.A.; DeFries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; Helkowski, J.H.; Holloway, T.; Howard, E.A.; Kucharik, C.J.; Monfreda, C.; Patz, J.A.;

Prentice, I.C.; Ramankutty, N.; Snyder, P.K. 2005. Global consequences of land use. *Science*, 309(5734): 570-574. https://doi.org/10.1126/science.1111772

Foody, G.M. 2002. Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80(1): 185-201. https://doi.org/10.1016/S0034-4257(01)00295-4

García-Ruiz, J.M.; López-Moreno, J.I.; Vicente-Serrano, S.M.; Lasanta-Martínez, T.; Beguería, S. 2013. Mediterranean water resources in a global change scenario. *Earth-Science Reviews*, 105(3–4): 121-139. https://doi.org/10.1016/j.earscirev.2011.01.006

Geist, H.J. & Lambin, E.F. 2002. Proximate causes and underlying driving forces of tropical deforestation: Tropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations. *BioScience*, 52(2): 143-150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Gouveia, R.G.L.; Galvanin, E.A.S.; Neves, S.M.A.S.; Neves, R.J. 2015. Environmental fragility analysis in the Queima-Pé river basin, Tangará da Serra, MT. *Pesquisas em Geociências*, 42(2): 131-140. https://doi.org/10.22456/1807-9806.78115

Hansen, M.C. & Loveland, T.R. 2012. A review of large area monitoring of land cover change using Landsat data. *Remote Sensing of Environment*, 122: 66-74. https://doi.org/10.1016/j.rse.2011.08.024

Irifi, H.; Sebbab, M.M.; Ousbih, M.; Ziyadi, M.; El Ouahidi, A. 2025. Landscape characterization and dynamics of oases in arid environments: A study of the Timoulay Oumaloukt and Timoulay n'Tozomte oases in Ait Herbil (Guelmim-Oued Noun, Morocco). *Cuadernos de Investigación Geográfica*, 51(2): 233-262. https://doi.org/10.18172/cig.6475

Kennedy, R.E.; Yang, Z.; Cohen, W.B. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms. *Remote Sensing of Environment*, 114(12): 2897-2910. https://doi.org/10.1016/j.rse.2010.07.008

Kennedy, R.E.; Andréfouët, S.; Cohen, W.B.; Gómez, C.; Griffiths, P.; Hais, M.; Healey, S.P.; Helmer, E.H.; Hostert, P.; Lyons, M.B.; Meigs, G.W.; Pflugmacher, D.; Phinn, S.R.; Powell, S.L.; Scarth, P.; Sen, S.; Schroeder, T.A.; Schneider, A.; Sonnenschein, R.; Vogelmann, J.E.; Wulder, M.A.; Zhu, Z. 2014. Bringing an ecological view of change to Landsat-based remote sensing. *Frontiers in Ecology and the Environment*, 12(6): 339-346. https://doi.org/10.1890/130066.

Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C.; George, P.S.; Homewood, K.; Imbernon, J.; Leemans, R.; Li, X.; Moran, E.F.; Mortimore, M.; Ramakrishnan, P.S.; Richards, J.F.; … Xu, J. 2001) The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, 11(4): 261-269. https://doi.org/10.1016/S0959-3780(01)00007-3

Lambin, E.F.; Geist, H.J.; Lepers, E. 2003. Dynamics of land-use and land-cover change in tropical regions. Annual *Review of Environment and Resources*, 28: 205-241. https://doi.org/10.1146/annurev.energy.28.050302.105459

Leghrib, F.; Mazouz, S.; Martellozzo, F. 2025. From palm groves to urban zones: Patterns and past trends of urban sprawl and land use efficiency in semi-arid context, case of Biskra, Algeria. *International Journal of Sustainable Development and Planning*, 20(12): 5043-5057. https://doi.org/10.18280/ijsdp.201202

Loulad, S.; Nguyen, T.T.; Simou, M.R.; Rhinane, H.; Buerkert, A. 2023. Monitoring rural-urban transformation in the coastal region of Rabat-Sale-Kenitra, Morocco. *PLOS ONE*, 18(8): e0290829. https://doi.org/10.1371/journal.pone.0290829

Lu, D. & Weng, Q. 2007. A survey of image classification methods and techniques for improving classification performance. *International Journal of Remote Sensing*, 28(5): 823-870. https://doi.org/10.1080/01431160600746456

Lu, D.; Mausel, P.; Brondízio, E.; Moran, E. 2004. Change detection techniques. *International Journal of Remote Sensing*, 25(12): 2365-2401. https://doi.org/10.1080/0143116031000139863

Meyfroidt, P.; Roy Chowdhury, R.; de Bremond, A.; Ellis, E.C.; Erb, K.-H.; Filatova, T.; Garrett, R.D.; Grove, J.M.; Heinimann, A.; Kuemmerle, T.; Kull, C.A.; Lambin, E.F.; Landon, Y.; le Polain de Waroux, Y.; Messerli, P.; Müller, D.; Nielsen, J.Ø.; Peterson, G.D.; Rodriguez García, V.; Schlüter, M.; Verburg, P.H. 2018. Middle-range theories of land system change. *Global Environmental Change*, 53: 52-67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Nmiss, M.; Amyay, M.; Atiki, N.; Benbih, M.; Nait-Si, H.; Naji, M.E. 2025. Multidecadal evolution of the shoreline change at Agadir beach (Morocco): A GIS and high-resolution satellite imagery analysis. *Pesquisas em Geociências*, 52(1): e145533. https://doi.org/10.22456/1807-9806.145533.

Olofsson, P.; Foody, G.M.; Stehman, S.V.; Woodcock, C.E. 2013. Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129: 122-131. https://doi.org/10.1016/j.rse.2012.10.031

Olofsson, P.; Foody, G.M.; Herold, M.; Stehman, S.V.; Woodcock, C.E.; Wulder, M.A. 2014. Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, 42-57. https://doi.org/10.1016/j.rse.2014.02.015

Richards, J.A. & Jia, X.P. 2006. *Remote sensing digital image analysis: An introduction* (4th ed.). Springer. https://doi.org/10.1007/3-540-29711-1

Roy, D.P.; Wulder, M.A.; Loveland, T.R.; Woodcock, C.E.; Allen, R.G.; Anderson, M.C.; Helder, D.; Irons, J. R.; Johnson, D.M.; Kennedy, R.; Scambos, T.A.; Schaaf, C.B.; Schott, J.R.; Sheng, Y.; Vermote, E.F.; Belward, A.S.; Bindschadler, R.; Cohen, W.B.; Gao, F.; Zhu, Z. 2014. Landsat-8: Science and product vision for terrestrial global change research. *Remote Sensing of Environment*, 145: 154-172. https://doi.org/10.1016/j.rse.2014.02.001

Salvati, L.; Munafò, M.; Morelli, V.G.; Sabbi, A. 2012. Low-density settlements and land use changes in a Mediterranean urban region. *Landscape and Urban Planning*, 105(1–2): 43-52. https://doi.org/10.1016/j.landurbplan.2011.11.020

Scaramuzza, P.L.; Bouchard, M.A.; Dwyer, J.L. 2012. Development of the Landsat Data Continuity Mission cloud-cover assessment algorithms. *IEEE Transactions on Geoscience and Remote Sensing*, 50(4): 1140-1154. https://doi.org/10.1109/TGRS.2011.2164087

Shiferaw, N.; Habte, L.; Waleed, M. 2025. Land use dynamics and their impact on hydrology and water quality of a river catchment: a comprehensive analysis and future scenario. *Environmental Science and Pollution Research*, 32: 4124-4136. https://doi.org/10.1007/s11356-025-35946-y

Singh, A. 1989. Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing*, 10(6): 989-1003. https://doi.org/10.1080/01431168908903939

UNCCD. 2017. *Global land outlook: First edition*. United Nations Convention to Combat Desertification. https://www.unccd.int/sites/default/files/documents/2017-09/GLO_Full_Report_low_res.pdf

Veldkamp, A. & Lambin, E.F. 2001. Predicting land-use change. Agriculture, Ecosystems & Environment, 85(1–3): 1-6. https://doi.org/10.1016/S0167-8809(01)00199-2.

Wulder, M.A.; Loveland, T.R.; Roy, D.P.; Crawford, C.J.; Masek, J.G.; Woodcock, C.E.; Allen, R.G.; Anderson, M.C.; Belward, A.S.; Cohen, W.B.; Dwyer, J.; Erb, A.; Gao, F.; Griffiths, P.; Helder, D.; Hermosilla, T.; Hipple, J.D.; Hughes, M.J.; Huntington, J.; Zhu, Z. 2019. Current status of Landsat program, science, and applications. *Remote Sensing of Environment*, 225: 127-147. https://doi.org/10.1016/j.rse.2019.02.015

Yahaya, I.; Xu, R.; Zhou, J.; Jiang, S.; Su, B.; Huang, J.; Cheng, J.; Dong, Z.; Jiang, T. 2024. Projected patterns of land use in Africa under a warming climate. *Scientific Reports*, 14: 12315. https://doi.org/10.1038/s41598-024-61035-0

Zhu, Z. 2017. Change detection using Landsat time series: A review of frequencies, preprocessing, algorithms, and applications. *ISPRS Journal of Photogrammetry and Remote Sensing*, 130: 370-384. https://doi.org/10.1016/j.isprsjprs.2017.06.013

Zhu, Z. & Woodcock, C.E. 2014. Continuous change detection and classification of land cover using all available Landsat data. *Remote Sensing of Environment*, 144: 152-171. https://doi.org/10.1016/j.rse.2014.01.011

Zhu, Z.; Zhang, J.; Yang, Z.; Aljaddani, A.H.; Cohen, W.B.; Qiu, S.; Zhou, C. 2020. Continuous monitoring of land disturbance based on Landsat time series. *Remote Sensing of Environment*, 238: 111116. https://doi.org/10.1016/j.rse.2019.03.009