

SUMMARY OF ARTICLE: [HTTPS://DX.DOI.ORG/10.12795/REA.2025.I49.11](https://dx.doi.org/10.12795/rea.2025.i49.11)


Integrated GIS and remote sensing tools approach for the management of peripheral areas in Maghreb cities from 1988-2005. Case study: Greater Agadir (Morocco) and the city of Algiers (Algeria)

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KEYWORDS

Urban growth
Periurbanisation
Agricultural land
Satellite images
Graticule
Supervised classification
Land use

INTRODUCTION

This study explores the complex dynamics of urban expansion within the Maghreb region, focusing specifically on how cities expand into their peripheral areas. It addresses a pressing problem which is prevalent in many developing urban areas: the encroachment of urban development on valuable agricultural land. The study recognizes that rapid urban growth in Maghreb cities often does not take into account traditional urban boundaries, and therefore examines how this uncontrolled expansion contributes to the challenges of sustainability and land management. The research focuses on examining peri-urban areas, which often function as spaces connecting urban centers and rural landscapes. The research addresses an important and increasingly common challenge: how technological tools such as integrated geographic information systems (GIS) can contribute to analysis and aid in good governance and decision-making in land management. This study is particularly interested in the urban peripheral transformations related to the urban growth of cities located in the Maghreb countries of North Africa through the effective use of GIS.

DOI: <https://dx.doi.org/10.12795/rea.2025.i49.11>

Formato de cita / Citation: Atik, M., Sebbab, M.M., Ousbih, M., & El Ouahidi, A. (2025). Integrated GIS and remote sensing tools approach for the management of peripheral areas in Maghreb cities from 1988-2005. Case study: Greater Agadir (Morocco) and the city of Algiers (Algeria). *Revista de Estudios Andaluces*, (49), 211-227. <https://dx.doi.org/10.12795/rea.2025.i49.11>

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This study is guided by well-defined research objectives. The first one was to precisely characterize the state of land use and its evolution over time in certain peri-urban areas of the Maghreb region. This spatiotemporal analysis not only identifies current land use, but also examines dynamic patterns over different years from a multi-temporal perspective, focusing on how soils change under urban pressures of built-up areas, and the impact this has on the availability of agricultural land use throughout the 17 to 18 years between analyses (1987-2005 in some regions). The second objective was to quantitatively analyze how land cover shifts between categories, with precise and measurable differences expressed through the use of geographic measures. The study aims to accurately map specific phases of transformation from agriculture to other uses such as fallow, peri-urban areas, and built-up areas. Finally, it seeks to validate the use of the technologies used as adequate solutions for the region. In doing so, it shows not only the effectiveness of the technologies but also the possibility of replicating the methodologies in other cases or in places where the requirements are similar. The objectives of this study make it possible to quantify precise and geographically representative patterns, which allows for better control of resources in the affected regions. Ultimately, such a study provides a baseline for designing and informing new governance options based on sound and technically informed property assessments.

METHODOLOGY

The study uses two primary and complementary methodological approaches for each domain to gain a deeper understanding. Each methodology relies on both remote sensing and GIS tools, which, despite differences, both aimed at measuring changes. One approach focuses on a more detailed level of data classification (using a supervised methodology, for the Greater Agadir study area), while the second uses grid data aggregation methodologies with data classified and interpreted based on categories of pixels according to the type of terrain, they represented by specific coding values assigned to them (as for the cases of Algiers).

For the Greater Agadir, the research utilized Landsat TM and ETM satellite images from 1988 to 2005, along with aerial photographs and orthophotos for validation, to identify land cover types. This involved significant preprocessing including resampling all imagery to a consistent 28.5m resolution through cubic convolution, removing distortions, and ensuring quality data using radiometric corrections. Supervised classification via the maximum likelihood method was then applied, requiring carefully selected training areas that represent urbanized zones, bare soil, and vegetation, confirmed through fieldwork. An iterative process was implemented to adjust the selection and improve results accuracy as part of methodology requirements by ensuring more than a 90% threshold using field validation as a base for evaluation. Spectral overlap correction was also performed after testing all bands, finally selecting only four channels as final settings as those bands presented high image classification without generating spectral confusions between land classes in results. Additionally, a variation of alternating filter methods was used to eliminate roads and enhance build-up data for improved cartographic representation. As output, the method produced detailed cartographic maps that revealed changes over time showing areas where urbanization expanded, consolidated, or decreased throughout the analyzed timeframe, using multiple color combinations as key identifiers of different stages, and highlighting changes for built-up with a distinct green coloration which symbolized the deconstructed areas.

For the eastern periphery of Algiers, the study used a grid-based methodology, overlaying a mesh of equal-sized cells on multitemporal remote sensing images from 1987 to 2005, including satellite and aerial photographs. This mesh framework facilitated spatial analysis by improving the accuracy of data interpretation with less confusion due to spectral overlap issues, which led to a more accurate method for tracking and interpreting landscape transformations. This setup allowed for systematic data collection with all types of imaging datasets that were then quantitatively coded using binary scores (presence or absence), while cellular proportions of land cover were verified by experts with cross-checks against various sources such as document maps or in situ checks. These manually calculated landscape features created a robust, quality-assured assessment. All processes followed rigorous field verification protocols ensuring



minimal data discrepancies when classifying the data sets analyzed. Using validation, the methodology used different sources such as official mapping or government documentation such as municipal urban plans, as well as the results and direct assessment of the case study location, ensuring an accurate representation of the actual spatial geographic change for a clear analysis result. Essentially, the analysis was performed in a spatial analysis framework based on grid units located on surface transformations that resulted in quantified measurements of its change in land use cover, with each gridded cell indicating quantified values of the observed transformation.

The integrated use of supervised classification with direct interpretation with pixel datasets for the study sites in the case of Agadir compared to the mesh system used for the sites in Algiers had, in sum, different values and also different advantages when taken in isolation, although they share data sources with different purposes and applications. Both methodological choices were planned based on a better extraction of landscape interpretations using scientific methods using remote sensing, field validations, and the proper use of appropriate cartographic data. As such, a strong methodological basis and robust datasets derived from these analyses were presented.

RESULTS

The research results reveal significant and consistent trends in urban sprawl and its impact on surrounding agricultural landscapes, demonstrating dynamic changes within urban peripheries over an 18-year analysis period through case studies in the peri-urban areas of Agadir and Algiers. The results indicated a widespread growth of built-up and peri-urban areas, mainly resulting from inadequate land use management in the urban environment studied, which has adverse consequences for agricultural productivity, as its long-term availability is the main source of supply for these urban centers. The results of the data indicate that built expansion has occurred at an alarming rate, particularly in peripheral urban areas, showing the intense consequences for long-term landscape management and sustainable food supply, highlighting the critical need to reform policy planning approaches and improve monitoring procedures.

In Greater Agadir, the analysis showed that the urban footprint increased significantly, from 100,919 hectares in 1988 to 206,625 hectares in 2005, an increase of 145,706 hectares, which corresponds to an expansion of about 60% over a short period of 17 years. This means a high rate of urbanization, which reflects insufficient and deficient long-term spatial planning of regional territories in Agadir, with an annual net growth in construction of about 7.5%. Uncontrolled urban growth has been notably concentrated along the coastal areas, while the peripheral areas around the main urban agglomerations of Agadir and the peripheral rural areas have faced the highest and most rapid, disorderly, and uncontrolled growth. This included numerous irregular and unauthorized land occupations and constructed buildings, areas that served as dormitory centers that lacked proper utilities and basic infrastructure, as many had poor implementation or were neglected for maintenance. In places where proper public planning was in place, the urbanization process significantly reduced the environmental impact, compared to all surrounding municipalities. The data highlight that those irregular urban developments which have occurred due to many political factors have greatly contributed to the current fragmented and unplanned urban spaces.

Conversely, in the eastern periphery of Algiers, the analysis showed similar impacts of urban expansion, where an increase from 2009 hectares in 1987 to 3181 hectares in 2005, which explains the net increase in urbanization to 1172 hectares in just 18 years in the analyzed sites. Land conversions have mainly occurred at the expense of high-value agricultural land and land allocated for non-use, which has had several effects such as fragmentation of agriculture and agricultural areas, reduction in the overall food availability of regional production, and economic dependence on remote production and distribution systems. This explains the environmental problems that occurred due to a heavy reliance on long-distance production cycles for regions with available agricultural potential in nearby areas. Specifically, places like Bordj El Kiffan have suffered the most significant losses, as the results of the data analysis show a considerable negative impact (54% loss on its agricultural space), along places like Dar El Beida that have suffered a minor loss because many areas were



protected, at about 443 ha or 37% loss of agricultural land (due to the environmental safeguard for Houari Boumediene Airport). However, in the parts of the municipality of Bab Ezzouar, agriculture has almost entirely been exhausted due to deficiencies in land use planning. The impact of agricultural land conversion is lowest with an area of 200 ha due to urbanization or a 15% loss of area, but the impact on local production capacities has also been significant, as the areas studied have lost the majority of their regional agricultural potential.

CONCLUSION

Finally, a generalized model was presented where studies showed that the patterns were spatially dynamic, as areas experienced different transformations over different periods of the decades analyzed. These included different strategies of urban sprawl in many localities, on numerous occasions, due to failures of public planning and strong demand-driven growth, without regulatory structures during the study period analyzed, especially during periods of instability such as those spanning from 1990 to 1995, in the regions close to the outskirts of Algiers. In Greater Agadir, however, a lack of proper land governance resulted in continuous sprawl throughout the study period. The combination of these analyses and specific locations highlights not only similar problems in these cities but also a broader trend regarding disorganized spatial occupation impacting high-potential food supply areas, highlighting the need for effective environmental territorial management on a regional scale, when similar spatial transformations have occurred as a common process with consequences. In the end, on average, the two areas recorded a total of 700 ha per year of land loss due to urbanization between the two case studies throughout the period running from 1988 to 2005.

This research reveals the acute challenges of urban expansion in Maghreb cities, exposing a rampant, largely unregulated consumption of high-value agricultural land in peri-urban areas. This is degrading fertile soils and undermining the future of agriculture in these regions. The results confirm the effectiveness of combined GIS and remote sensing techniques as a valid methodology for monitoring and analyzing dynamic changes in urban land use. This is thanks to the fact that grid analysis overcame methodological constraints encountered during data collection that more easily generated results on geographical space and also showed that the highly skilled workforce is a key factor in ensuring a sustainable environment. Generating high-quality data, reconciling diverse interpretations of complex issues, and ensuring a thorough understanding of all spatial features are crucial when collecting geospatial datasets for large-scale areas.

However, these tools also reveal limitations, such as parameter dependencies that still require careful adjustment. The study further shows that the two peri-urban areas, around the municipalities of Algiers and Agadir, have suffered from a dramatic reduction in agricultural landscapes due to, on the one hand, disorderly growth, attributed mainly to weak policy oversight by government agencies, where most regions have experienced varying rates of urbanization because to various geographical and social factors, and on the other hand, the transformation of land that lacks coherence, generating uneven territorial and environmental planning. Patterns of uncontrolled expansion pose serious threats to peripheral communities that have proven vulnerable during this disorderly expansion by fragmenting the territory in an uncoordinated manner, with several social and infrastructure problems, given that many peri-urban localities have acted as informal expansions without having access to appropriate infrastructure networks.

This has generated great territorial vulnerabilities that have an impact on all cities due to disorganization on a regional scale. Therefore, all the regions studied require that long-term integrated urban policies for land conservation, as well as an urgent implementation of spatial planning. Also, it would be recommended to guide urban development models in peri-urban regions while mitigating and reversing existing problems through structured resource protection as well as ensuring long-term urban sustainability with responsible regional territorial planning at the same time. Through the Maghreb urban systems analyzed and based on scientific evidence, the study highlights that remote sensing and integrated GIS analysis strategies are an effective way to provide a deeper understanding of peri-urban transitions for data-driven solutions that ensure long-term urban land use management.