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LANDSCAPE CHARACTERIZATION AND OASES DYNAMICS IN ARID ENVIRONMENTS: A STUDY OF THE TIMOULAY OUMALOUKT AND TIMOULAY N'TOZOMTE OASES IN AIT HERBIL (GUELMIM OUED NOUN - MOROCCO)

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ABSTRACT. The Ait Herbil oases (Timoulay Oumaloukt and Timoulay n'Tozomte) represent an ancient center of human settlement and civilization. They feature emblematic landscapes that reflect a profound interaction between humans and the natural environment. These landscapes possess both heritage and spatial identities that distinguish them from neighboring oases, due to their historical adaptation to the region's challenging environmental conditions. A preliminary examination of the Timoulay Oumaloukt and Timoulay n'Tozomte oases reveals distinct functions and land-use patterns. These are agrarian environments shaped by a traditional subsistence economy. Over generations, farmers have molded these highly anthropized landscapes by making use of the available natural resources. However, recent environmental and socio-spatial transformations have triggered an unprecedented crisis, resulting in major imbalances within the landscape systems.

The objective of this study is to characterize the anthropogenic landscapes of the Timoulay Oumaloukt and Timoulay n'Tozomte oases, located in the territorial commune of Aday, by analyzing their spatial organization, functioning, and dynamics. The methodology consists, first, of a general diagnosis and typology of the region's anthropized landscapes. It then focuses on the current state of four specific types of anthropized features: agricultural terraces, threshing floors, collective granaries (locally known as Agadir), and agrarian landscapes. The study is primarily based on field visits and surveys, semi-structured interviews, climate data (1981–2022), and data derived from Geographic Information Systems (GIS), remote sensing, and analysis of photographic documentation collected between 2017 and 2022. NDVI imagery for 1987, 2001, and 2023 reveals a marked decline in oasis vegetation: from 61.35 ha in 1987, to 53.21 ha in 2001, and 47 ha in 2023, mainly due to recurrent droughts between 1981 and 2022.

This differential dynamic reflects two contrasting trends: agricultural abandonment in some areas, and increased human pressure in others—both shaped by natural, socio-economic, and technological factors. Persistent droughts have accelerated agricultural decline, contributing to the socio-spatial exodus of the population. This research provides a scientific foundation for further investigation into oasis landscapes, offering critical insights to inform regional strategies for resource management and heritage conservation.

Caracterización del paisaje y dinámica de los oasis en ambientes áridos: estudio de los oasis de Timoulay Oumaloukt y Timoulay n'Tozomte en Ait Herbil (Guelmim Oued Noun - Marruecos)

RESUMEN. Los oasis de Ait Herbil (Timoulay Oumaloukt y Timoulay n'Tozomte) constituyen un antiguo foco de asentamientos humanos y de civilización. Presentan paisajes emblemáticos que reflejan una profunda interacción entre el ser humano y el medio natural. Estos paisajes poseen tanto un valor patrimonial como una identidad espacial que los distingue de los oasis vecinos, debido a su adaptación histórica a las difíciles condiciones del entorno natural. Un primer análisis de los paisajes de los oasis de Timoulay Oumaloukt y Timoulay n'Tozomte permite identificar funciones y usos específicos. Se trata de entornos agrarios, caracterizados por una economía tradicional de subsistencia. Estos paisajes, altamente antropizados, han sido modelados a lo largo de generaciones por agricultores que han aprovechado los recursos ofrecidos por el medio físico. Sin embargo, los recientes cambios ambientales y socioespaciales han desencadenado una crisis sin precedentes, generando importantes desequilibrios en los sistemas paisajísticos.

El objetivo de este estudio es caracterizar los paisajes antropogénicos de los oasis de Timoulay Oumaloukt y Timoulay n'Tozomte, ubicados en la comuna territorial de Aday, mediante el análisis de su organización, funcionamiento y dinámica. La metodología empleada se basa, en primer lugar, en un diagnóstico general y una tipología de los paisajes antropizados de la región. Posteriormente, se enfoca en el estudio del estado actual de cuatro tipos específicos de paisaje antropizado: terrazas agrícolas, eras, graneros colectivos —conocidos localmente como Agadir— y paisajes agrarios. Este enfoque metodológico se sustenta principalmente en visitas de campo, encuestas, entrevistas, el uso de datos climáticos (1981–2022), información geoespacial derivada de sistemas de información geográfica (SIG) y teledetección, así como en el análisis comentado de fotografías tomadas entre 2017 y 2022. El análisis de imágenes NDVI correspondientes a los años 1987, 2001 y 2023 evidencia una disminución significativa de la vegetación de los oasis: de 61,35 ha en 1987, a 53,21 ha en 2001 y 47 ha en 2023, atribuida principalmente a las sequías recurrentes registradas entre 1981 y 2022.

Esta dinámica diferencial revela dos patrones contrastados: el abandono agrícola en determinadas zonas y una intensificación de la presión humana en otras, ambos condicionados por factores naturales, socioeconómicos y tecnológicos. La recurrencia de períodos de sequía ha exacerbado el abandono de las actividades agrícolas, propiciando un proceso de éxodo socioespacial de la población. Esta investigación establece las bases científicas para futuros estudios sobre los paisajes de oasis y aporta conocimientos clave que pueden orientar estrategias regionales de gestión de los recursos y conservación del patrimonio.

Keywords: Anthropized landscapes, oasis, society interface, Timoulay Oumaloukt, Timoulay n'Tozomt, Ait Herbil, Morocco.

Palabras clave: paisajes antropizados, oasis, interfaz de la sociedad, Timoulay Oumaloukt, Timoulay n'Tozomt, Ait Herbil, Marruecos.

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1. Introduction

The construction of such geographical landscapes in the middle of the desert probably dates back to a very distant period, due to very early sedentary lifestyle. This adaptation to the physical environment was a response to constraints such as the scarcity of soil resources, which led farmers to reshape (Liu *et al.*, 2021) the topography of the slopes and build more agricultural terraces to gain more arable land (Ferro-Vázquez *et al.*, 2017). These humanized landscapes are also the result of the socio-spatial and

socio-economic organization (Ferro-Vázquez *et al.*, 2017; Tarolli *et al.*, 2014) of rural Amazigh society, which over the centuries has been built around a rationale of managing scarcity.

Although southern Morocco generally faces a clear and significant palm grove crisis, the Bani region stands out as being most acutely affected by the adverse consequences of the drought that has plagued Morocco since the late 1970s (Derouich, 2013). The Ait Herbil area, located on the southern slopes of the western Anti-Atlas Mountains, is diverse in both physical and human terms (Derouich, 2013). This diversity has its origins in the reconciliation between the geological structure and the nature of farming practices, which reflect the long human history of this arid zone (Derouich, 2013; Irifi *et al.*, 2020; Liu *et al.*, 2021). Like other Moroccan mountain areas, the Western Anti-Atlas is an ancient populated mountain where there is traditional development of slopes and spectacular talwegs, polycultures on the banks of watercourses and traditional socio-economic management of territorial resources (Ziyadi, 2011). These landscapes, which result from the succession of many generations of farmers, reflect the particular ingenuity of the populations and their adaptation to the conditions of the physical environment (Derouich, 2013; Irifi, 2023; Mecca *et al.*, 2016; Ziyadi, 2011).

The oasis landscape, viewed through the lens of the landscape approach in Geography and Landscape Ecology, is a complex, dynamic, and evolving system characterized by continuous interaction. It encompasses visible and non-visible, abiotic, biotic, and anthropic components, representing a heterogeneous and dynamic organizational level within oasis ecosystems, where human activities are predominant. Interpreting the landscape thus involves deciphering its fundamental components and their mutual interactions. Dynamics and evolution, intrinsic to the landscape, reflect a biophysical and managed response to the driving forces that reorganize existing landscape structures and optimize their functioning. The typology developed in this study is not an end in itself but rather a crucial component of a method for analyzing and cartographically representing these oasis landscapes in the study area. Our approach is based on the analysis and visual assessment of the landscapes, considering their homogeneous appearance and various natural and anthropogenic criteria to achieve a simple classification of the overall landscape into distinct units.

A set of parameters appears to explain the construction of a humanized landscape, allowing the configuration of its structures, which are themselves a spatial arrangement of landscape elements and objects (Irifi, 2023; Irifi *et al.*, 2020; Roche, 2007). Consequently, the dynamics of this landscape are dependent on the dynamics of its components. The current trends in these landscapes, resulting from the conservative management of natural resources, reflect a multitude of changes that have been affected by cultural practices, the constituents of the background and form of the landscape, the virtual absence of the traditional institution known as *Jmâa* (*El Jmaâte*), and the socio-spatial changes that have occurred over recent decades (Derouich, 2013; Ziyadi, 2011).

Located at the foot of the Western Anti-Atlas, the Timoulay Oumaloukt and Timoulay n'Tozomte oases provide a critical lens through which to study landscape dynamics within arid ecosystems. This research undertakes a detailed analysis of the ecological and anthropogenic factors that shape these unique and often stressed environments. Our global aim is to elucidate the complex interactions between human action and natural forces in the formation and the evolution of these oasis landscapes. By understanding these dynamics, we aim to contribute to a broader understanding of the resilience and vulnerability of such vital ecosystems in the face of increasing environmental change and human pressures. The paper also aims to investigate the anthropized landscapes of two oases within the territorial commune of Aday, using a comprehensive landscape approach that considers the interplay between natural features and human modifications. To achieve this, i) the first specific aim is to conduct a detailed diagnosis and characterization of the constituent elements shaping these landscapes, including abiotic and biotic components and tangible evidence of human influence. It is a study of visible constituents and background determinants as basic elements of landscape diversification and creation. Subsequently, ii) we will develop a typology of landscape structures based on their inherent characteristics and spatial organization, iii) to study their spatiotemporal dynamics and processes,

considering both natural and anthropogenic drivers. The main objective of our work is to contribute to the study of two oasian landscape systems in the territory of the Ait Herbil, through the application of the landscape approach as a means of a good knowledge of the components of the landscape. In other words, it is a question of contributing to the study of oasian systems currently in crisis, within a framework of scientific and applied reflection that aims to dissect their landscape components and their inventory. This classification will serve as a basis for addressing their sustainable valuation. It will also allow for exploring strategies that recognize both the ecological and cultural value and the overall resilience of these oasis systems in the face of ongoing human impact and climate change.

2. Geographical and Geological Setting

2.1. Study Area

Timoulay Oumaloukt and Timoulay n'Tozomte are two small oases at the foot of the southern slopes of the Western Anti-Atlas, and present distinct and diverse landscapes (Fig. 1). This part is structured by the combination of two topographic units resulting from a long period of geological evolution, lithological contrasts and an active work of intermittent hydrographic network (Derouich, 2013). It is a territory marked by a landscape of medium topography whose altitudes vary between 780 and more than 1200 m above sea level. It has a mountainous aspect in its northern part and sharp crescent-shaped ridges in its southern part, interspersed by stretches of land composed of *regs* called *faijas*. These two landforms underwent significant morphogenic and tectonic dynamics during the several geological periods, which subsequently defined the main structures of their current landscapes (Berred *et al.*, 2019, 2020; Clementucci *et al.*, 2022).

Crossing the Ait Herbil territory via provincial road N°1317, from the Ifran oasis of the Anti-Atlas to the oasis of Aday, reveals an arid landscape with sparse spontaneous vegetation, surrounded by elongated ridges and small green areas within a mineral landscape. This area includes three oases created at the foot of the Western Anti-Atlas: Timoulay Oumaloukt, Timoulay n'Tozomte, and Taânounte. These oases originated due to resurgent water sources in the mountain foothills. In fact, they have significant water resources, fed in part by water that flows from the intermittent rivers of the Anti-Atlas. These rivers provide irregular flows that partly feed the river table before they flow under a diffuse flow into the *faija* (Derouich, 2013; Dijon, 1966). These flow irregularities, caused by irregular and concentrated rainfall, are characterized by a suddenness that makes them difficult to control. Irrigation is carried out using two water sources located upstream of the two villages. They are likely of karst origin, around which travertine formations have been deposited, and have developed, to varying degrees, a network of subsurface karst drains. The spring that feeds the agricultural plots in Timoulay n'Tozomte has the characteristics of a thermal spring whose water temperature can exceed 30°C (Dijon, 1966).

The whole territory of the Ait Herbil country forms a system of polycyclic Appalachian reliefs, whose current configuration is the result of very long periods of evolution, widely and deeply aerated and incised by the hydrographic network (Berred *et al.*, 2019, 2020). Numerous valleys and steep-sided landscapes characterize the mid-mountain topography in the north and Appalachian ridges in the south of the Ait Herbil territory. To the west and south, the landscape features Appalachian schist and quartzitic reliefs of the Ordovician, with isolated mounds and chevrons ranging from 750 m to over 1200 m in altitude (e.g., Taourirt n'Lahcen 910 m, Adrar n'Sarass 1266 m, Tin Taddant 1108 m). The central and eastern parts of the territory feature vast *faijas* with alluvial fans from the Western Anti-Atlas, creating a gently undulating topography with light slopes and medium altitudes (700-900 m). This area is surrounded by high Appalachian ridges ranging from 800m to over 1000 m (e.g., Adrar Idmissouak 1202 m, Adrar Wazzouzount 1038 m, Adrar n'Zerzem 978 m) and notable mountain ranges and gorges, such as the Amtoudi gorges. The area is heavily eroded and characterized by a dense hydrographic network that structures and make the landscape very airy. This network provides a confluence of various intermittent watercourses, connecting the *faijas* of Ait Herbil. The main rivers

draining this territory are tributaries of the Wadi Eç-çayyad, an important watercourse in the Wadi Noun watershed, including Wadi Tazount, *Assif* Youguit, *Assif* n'Kelmt, Oued Agigal, *Assif* Oujana, *Assif* n'Tebssist, and *Assif* n'Boulqous.

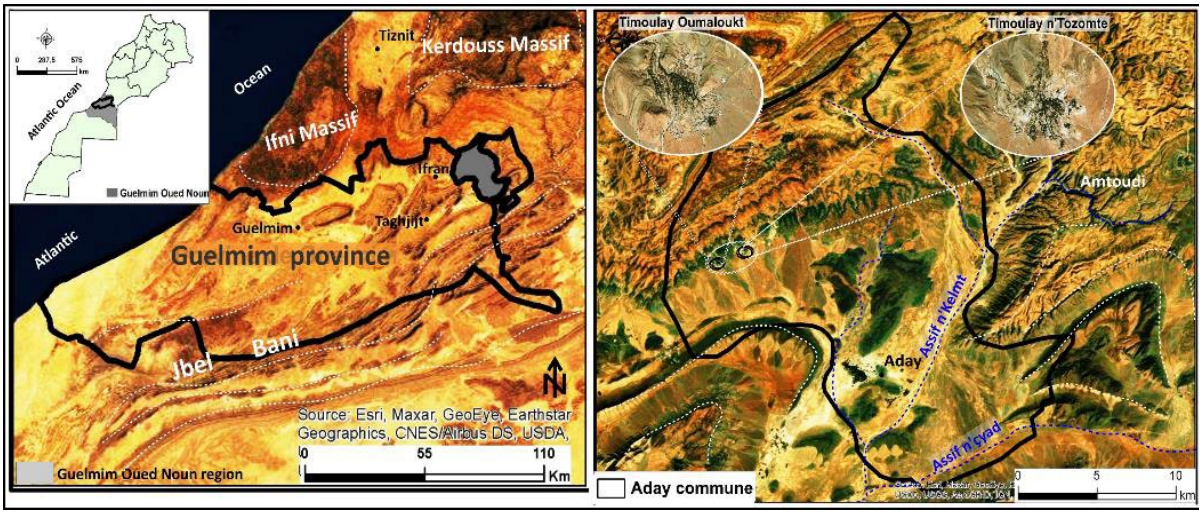

Figure 1. Geographical location of the study area. Source: Own elaboration based on the administrative division of Morocco in 2015 (Bulletin Officiel, 2015)

2.2. Geological setting

Most of the study area is characterized by the outcrop of Acadian shales and Infracambrian and Cambrian limestones, the fragments associated with them have become a territorial resource that is used in the construction of many kinds of humanized landscapes (*Seguias*, agricultural terraces, threshing floors, houses, attics...). The geological context of the study area is part of The Western Anti-Atlas consists of a Precambrian base outcropping in several inliers, among which the Kerdous inlier, and covered by neo-proterozoic and paleozoic formations (Askkour *et al.*, 2022, 2024; Blein *et al.*, 2023; El Basbas *et al.*, 2020; Malek *et al.*, 1998; Thomas *et al.*, 2002, 2004). The subsoil of the Ait Herbil territory as it is represented in the geological map (Fig. 2) consists of various rocks characteristic of an ancient polycyclic mountain range that developed through the Ebournian orogenesis, around 2 billion years and Pan-African orogenesis around 700-600 million years (Derouich, 2013). After this major orogenic phase, the Anti-Atlas underwent only more or less marked local alterations during the Secondary and Tertiary periods (Riser, 1988). Several geological formations stand out in the Ait Herbil region: Andesitic lands of Precambrian II and conglomerate breccias and schists; An extent of limestone terrain and schisto-limestone series on the northern part of the study area, and the terminal shales and sandstones of the same stage. The transitional terrain between the previous facies and the shales series of *faijas* and quartzites of *jebel* Bani, materialized by the series of Acadian sandstones, quartzites and schists; The Middle and Old Quaternary formations having a large extent, are deposited in the form of spreading and glacis over long distances.

Finally, recent formations, mainly colluvial and alluvial, characteristic of rivers, less steep slopes and dense hydrographic heading. Locally, the geology and lithology of the two oases appear diverse and heterogeneous. At Timoulay Oumaloukt, the Lower Devonian is characterized by outcrops of a series of schists and Limestones of the infracambrian in the form of rafters. Like upstream, the oasis of Timoulay n'Tozomte and Timoulay Oumaloukt also have travertine dams in reason to the presence of water resurgences of karst origin, while blocking the two gullies that cross them from deepening their beds by looking for their base level (Fig.3a and 3b).

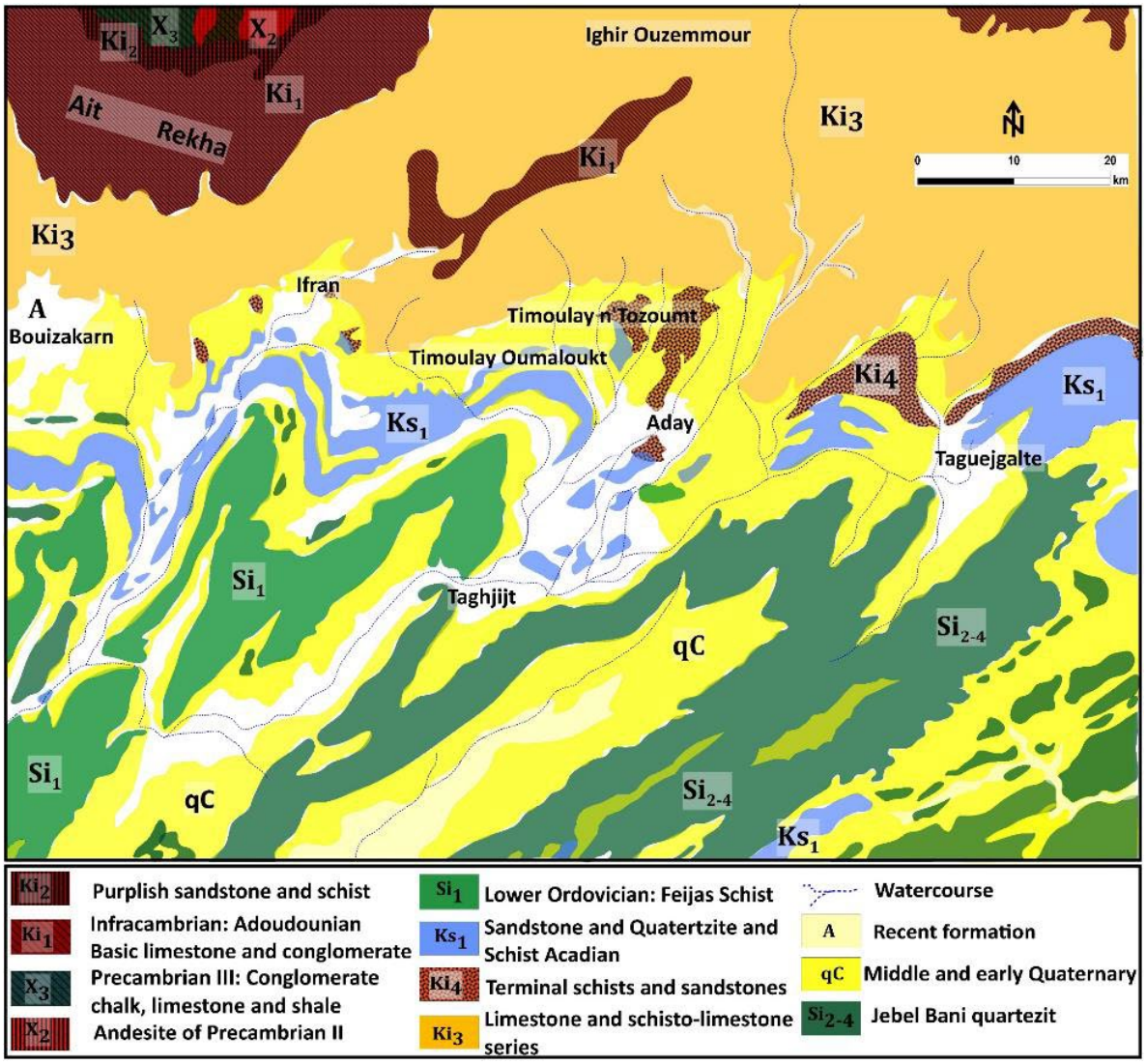

Figure 2. Geological map of the Ait Herbil mountains. Source: Own elaboration based on the geological map of Marrakech 1/500000 (1952).

Figure 3. Geological and geomorphological landscape of Timoulay Oumaloukt and Timoulay n'Tozomte: a) upstream of the Timoulay Oumaloukt oasis; b) travertine dam upstream of Timoulay n'Tozomte (Author: Irifi, 2021).

3. Materials and methods

3.1. Data Source and processing

To study, map, represent and describe landscape systems, we carried out an analysis of the satellite images provided by the Google Earth program and SAS.planete, followed by a thematic and numerical cartographic processing of them based on ArcGIS and Surfer software. Our fieldwork is created on a research methodology based mainly on the direct observation and photography of the most representative landscapes in terms of the arrangement of landscape objects, construction, configuration and the socio-spatial mutations assigned to them. For this purpose, we used a camera as well as smartphones to photograph the landscape over a four-year period (2017-2020-2021-2022). The visual analysis of the photographs is based on a qualitative assessment of changes in agricultural landscapes and human artifacts, focusing on elements such as land use, vegetation, visible built components, and erosion recovery. In addition, we compared the characteristics of the landscape elements through the landscape photos taken during each field mission in order to identify transformations and trends. The interpretation of the results in the light of existing knowledge, landscape photos and GeoEye satellite images, was complemented by random field interviews with farmers from the two oases (Table 1).

Table 1. Types of data used in the study.

Type of data	Date	Resolution	Type of treatment	Data source
Satellite images				
-Landsat 5 TM	1987	30 m	NDVI	https://earthexplorer.usgs.gov
-Landsat 7 ETM+	2001			
-Landsat 8 OLI-TIRS	2023			
GeoEye	2010 and 2023	3.87 km (A)	Visual analysis	Google Earth Pro
SAS.planete-Satellite (Google maps)	2022	21 m	Landscape representation	SAS.planete
Photography	2017-2022	Camera Nikon COOPLIX S3500 20m	Landscape survey and representation	Fieldwork missions
Climate Data	1981-2022	4 observatories (Buizakarne, Ifran Anti-Atlas, Taghjijt and Tamanart	Standardized Precipitation Index (SPI) and Spatial Interpolation IDW	https://power.larc.nasa.gov/data-access-viewer/

3.2. Methodological Approach

Admittedly, the palm grove crisis is a general and obvious fact for the whole of southern Morocco, but the Bani region is the most marked by the adverse effects of the drought that Morocco has suffered since the late 1970s (Derouich, 2013). This resulted in a great rural exodus marked by the abandonment of agricultural and sylvo-pastoral activity. Precisely, in this socio-spatial context, our study of the anthropized landscapes of Timoulay Oumaloukt and Timoulay n'Tozomte, is inscribed, as a complex landscape system, encompassing the three-interacting abiotic, biotic and anthropic elements. It should be based primarily on an understanding of the components, the structures and the functioning of landscapes. Employing the landscape approach to gain a deeper understanding of two oasis landscape systems within the Ait Herbil territory will contribute to a scientific and applied framework that dissects and inventories their landscape elements. This approach leads to knowledge of the landscape qualities of this mountain area, to arouse the interest of researchers and to arouse the curiosity of the various socio-economic actors to carry out actions of enhancement and development appropriate to the natural and cultural characteristics of the region (Irifi *et al.*, 2020). The landscape approach used here is based on a diagnosis of the two small oases, then the identification of the typical and strongly humanized

landscapes that are the result of the conjunction of the set of built landscape elements and objects. And finally, on the basis of this applied approach, our work should not be completed until after the analysis of their recent dynamics (Irifi, 2023) (Fig. 4). This raises the question of the conservation and enhancement of these landscapes from a perspective of local development and/or the implementation of landscape projects (Irifi *et al.*, 2020).

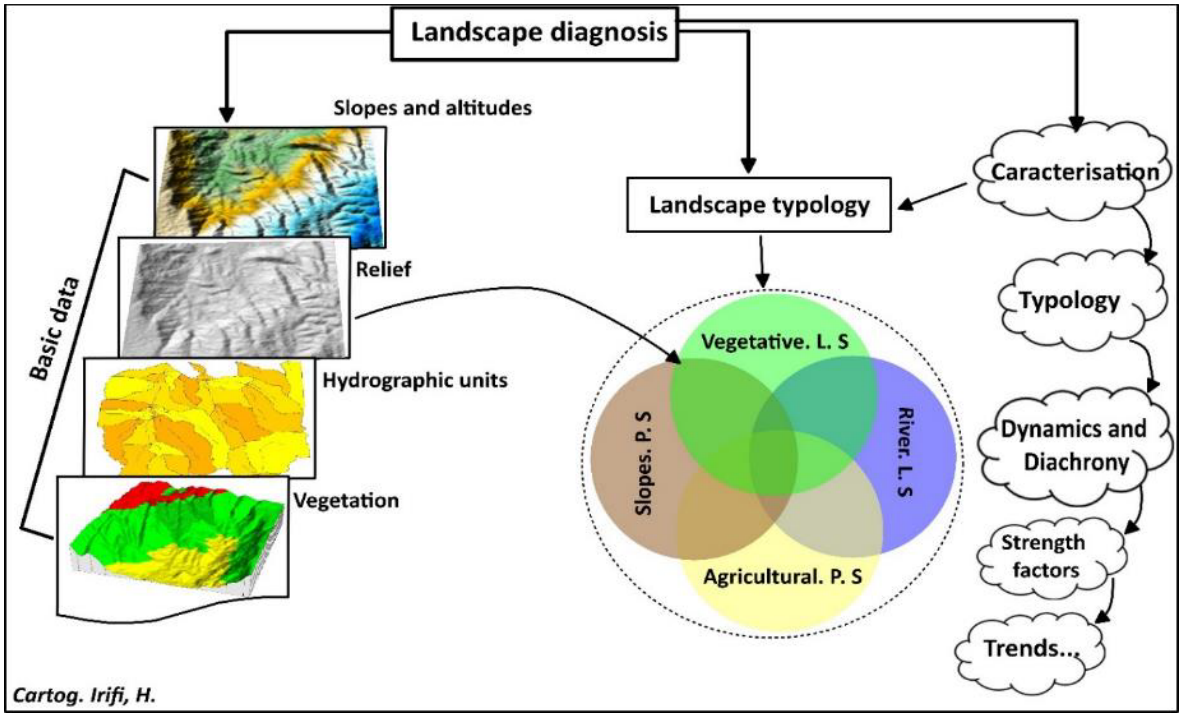

Figure 4. Methodological flowchart of the approaches used (Irifi, 2023).

In addition, the digital processing of satellite images by vegetation indices has allowed us to show these evolutionary trends of the landscape such as the regression of agricultural space, the abandonment, anthropization, fragmentation and dedensification of the oasis landscape, or even conversely the densification of the agricultural space. They provide appropriate data to analyze the trend of changes related to natural and human phenomena (Hmimina *et al.*, 2013), and to identify land degradation and regeneration (Eckert *et al.*, 2015). To reach this aim we calculated the NDVI index of a series of satellite images (1987, 2001 and 2023) (Table 1), By processing a series of multidates satellite images of Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI-TIRS of very high resolution (30 m), we calculated this index widely used for the study of forest and agricultural landscape dynamics based on the following formulas:

$$[NDVI\ (_{Landsat\ 5\ et\ 7}) = Band\ 4 - Band\ 3\ /\ Band\ 4 + Band\ 3]$$

$$[NDVI\ (_{Landsat\ 8}) = Band\ 5 - Band\ 4\ /\ Band\ 5 + Band\ 3]$$

Indeed, we have taken into consideration in this study to process satellite images taken during the summer period, preferably images acquired during the months of June, July and August. This choice of acquisition of images of the summer period allowed us to reduce any confusion related to the presence of annual vegetation (Lucas *et al.*, 2007), but also to avoid the analysis of images that present a high rate of atmospheric effects. The selection of satellite images from 1987, 2001, and 2023 is based on objective and technical reasons. The oldest satellite images with good resolution for the region date back to 1987, while we chose the 2001 and 2023 images as references for years following dry periods. The Normalized Vegetation Index is a traditional index often used in these types of studies (Knight *et al.*, 2006). This index is calculated by combining the spectra of the red band and the near-infrared band with values

ranging from -1 to 1. The interpretation of the vegetation index means that healthy and well-growing vegetation has high values while low values indicate the absence (bare soil) or degradation of the plant environment (Haddouche *et al.*, 2011). Reading and comparing the NDVI maps shows changes and variations in the chlorophyll activity of plants between 1987, 2001 and 2023. The Monthly and annual precipitation datasets were sourced from the Climate NASA Power website data series, with the analysis limited to 1981-2022 to ensure coherence with NDVI dynamics.

4. Results

4.1. Visible constituents and background determinants: elements of landscape diversification

Situated at the interface between the geological substrate, climate, and vegetation cover, soil is an essential element in shaping the physical and ecological characteristics of the oasis landscape (Barathon *et al.*, 2005; Daoud *et al.*, 2016; Fassi, 2017; Irifi *et al.*, 2020). The different characteristics of soils in this area -in particular, their fertility- largely condition their use in agricultural practice. This area is generally characterized by poor and poorly developed soils, and mostly affected by erosion and salinity (Atbir, 2014; Barathon *et al.*, 2005; Chmourk, 2011; Derouich, 2013). The most fertile soils are restricted from fluvial terraces to the bottoms of the rivers crossing the two oases, or agricultural terraces built on the limestone slopes. They are intended for irrigated crops, while bour crops and cereal cultivation are spread over the poor soils of the colluvial land along the *faija*.

The thickness of the soils in this space varies from one area to another. Nevertheless, they are generally thick at the outlets of the rivers throughout the glacis, and become thinner and thinner towards the interior of the *faija*, so they are referred to as *Regs* (Fig. 5) (Berred *et al.*, 2019, 2020). Like most of the territory of Aït Herbil, the study area is characterized by mineral soils (regosols and lithosols) that occupy most of the territory. Fluviosols are found in valleys and gullies, while on the slopes, colluvial inflows consist mainly of fragments of shale and limestone. These glacis line the mountain and eventually merge into a central plain, through which *Ighzer* n'Tinglal flows, formed at the foot of *Adrar* n'Sarass (Atbir, 2014; Berred *et al.*, 2019, 2020). The evolved soils, which provide the best agricultural land, are located at the level of the oases and are formerly cultivated, they are the result of the hydrographic work of the two rivers which have deposited small glacis-terraces. To further fertilize their soils, farmers apply manure and organic fertilizers (Derouich, 2013; Ziyadi, 2011).

The climate of the study area belongs to the range of arid to Saharan climates of the continental type (Atbir, 2014; Barathon *et al.*, 2005; Chmourk, 2011; Derouich, 2013; Dijon, 1966; Fassi, 2017; Riser, 1988). The continentality makes it very cold during the winter and very hot during the summer months. The mountainous heights of the Western Anti-Atlas make it possible to block frontal disturbances coming from the west, the impact that becomes clear on the aridity of space as one advance towards the interior of the land of the Ait Herbil. Here, the parallel Appalachian ridge lines create a barrier-oriented NE/SW that limits the direct oceanic effects but is accessible to the effects of the Saharan depression. In general, the area is characterized by its short winter season and the long summer season, with a corollary of low rainfall and its irregularity in space and time. Rainfall is concentrated during the period of thermal minimums, from October to April, driven by disturbances from the polar front that affect this southern latitude as the Azores anticyclone descends. There are two precipitation peaks: one in November-December and another in February-March (Fig. 6) (Atbir, 2014). Beyond the seasonal irregularity of rainfall between the driest and wettest months, rainfall also exhibits a certain precariousness across consecutive dry years. The thermal component significantly influences vegetation and agriculture, necessitating the calculation of extreme temperatures (M: hottest month's average max; m: coldest month's average min) to determine thermal amplitude and continentality. The ombrothermic diagram (Fig. 6) reveals the study area's thermal characteristics: average maximums around 35°C (ranging 24-44°C) and average minimums around 9°C (ranging 2-17°C). The hottest period is July-August, and the coldest is December-February.

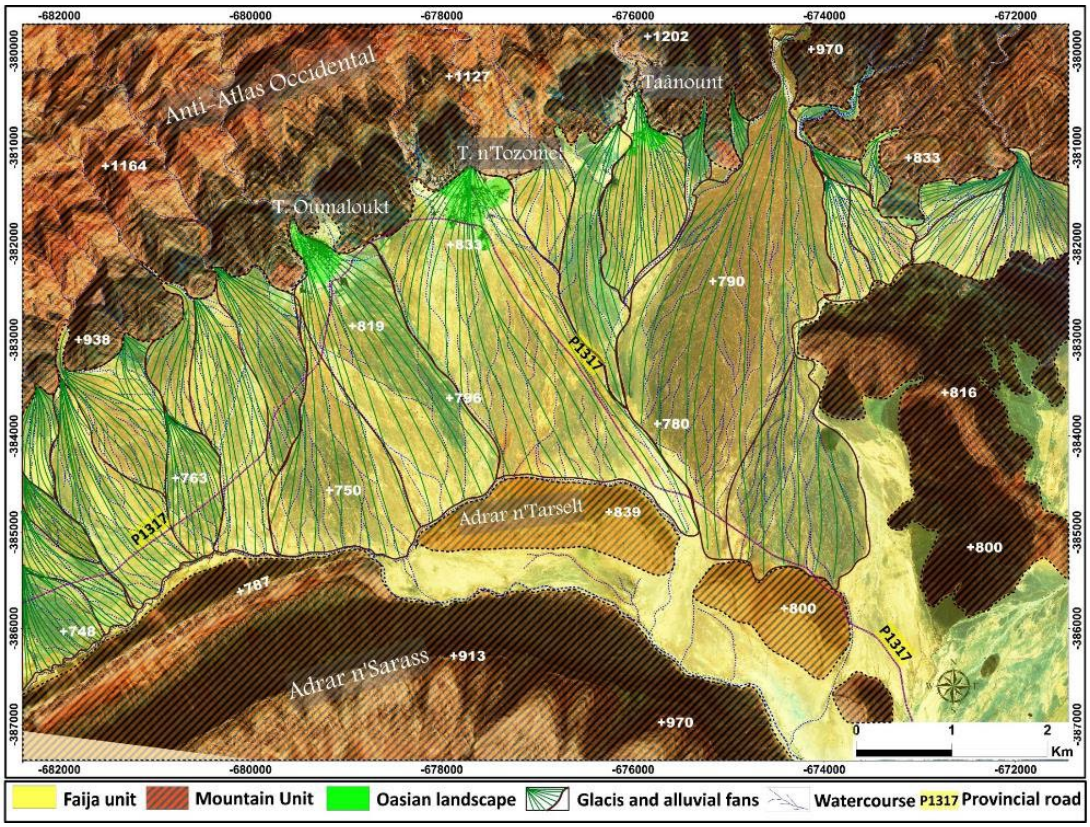

Figure 5. Simplified geomorphological map of the northern side of the Ait Herbil area.

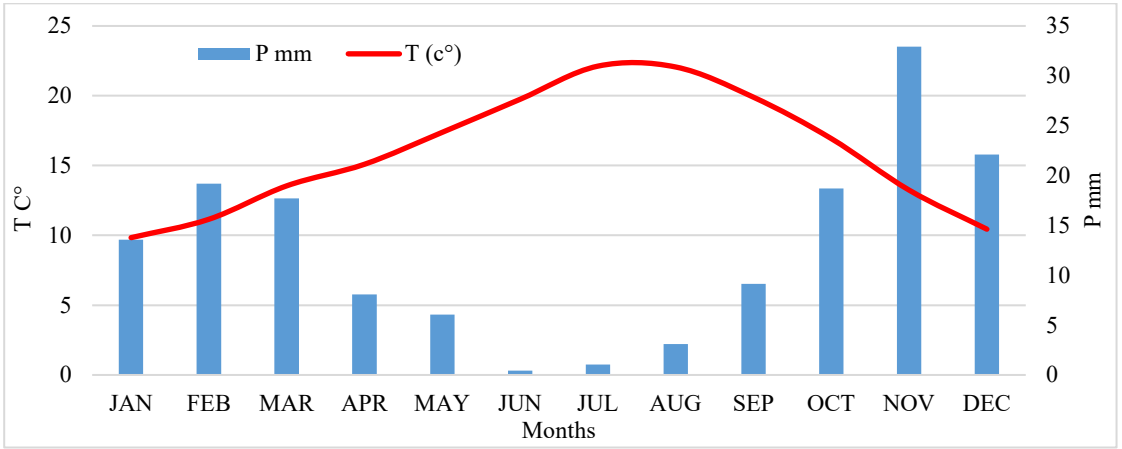

Figure. 6: Ombrothermic diagram of average monthly rainfall and temperature in the study area between 2000-2022. Source: https://power.larc.nasa.gov/data-access-viewer.

The prevailing climatic conditions explain the omnipresence of mineral soils and the very low rate of vegetation cover, the dominant arid bioclimate supports a diverse array of species adapted to aridity and prolonged summer and winter droughts. Certain spontaneous plant species, including *Argania spinosa* lined up along the rivers, *Launea arborescens*, *Ononis natrix*, *Euphorbia beaumierana, Ziziphus lotus, Nerium oleander, Diplotaxis muralis, Colchium gramineum*, *juncus communis, Salvia apiana, heliotropium vulgare, Capparis spinosa, Moricandia arvensis, Rumex vesicarius* etc., contribute to the formation of a veritable mosaic within the oasis plant landscape of the study area. These are species representing 13 botanical families, namely: *Sapotaceae, Fabaceae, Asteraceae, Euphorbiaceae, Apocynaceae, Juncaceae, Polygonaceae, Boraginaceae, Rhamnaceae, Brassicaceae, Colchicaceae,*

Lamiaceae, and *Capparaceae*. These species exemplify endemic flora such as *Argania spinosa, Ononis natrix*, and *Euphorbia beaumierana*, while *Moricandia arvensis*, *juncus communis, Nerium oleander* and *Capparis spinosa* represent the Mediterranean element. The Saharan element is represented by species such as *Launaea arborescens* and *Rumex vesicarius*, while *Salvia apiana* originates from North America.

All these visible and determining background components have resulted in a landscape typology comprising five homogeneous landscape units: agricultural terraces unit (26.06 hectares), agricultural landscape unit (85.69 hectares), building (13.32 hectares), collective granary unit (0.22 ha) and threshing floors unit (0.49 ha) (Fig. 7).

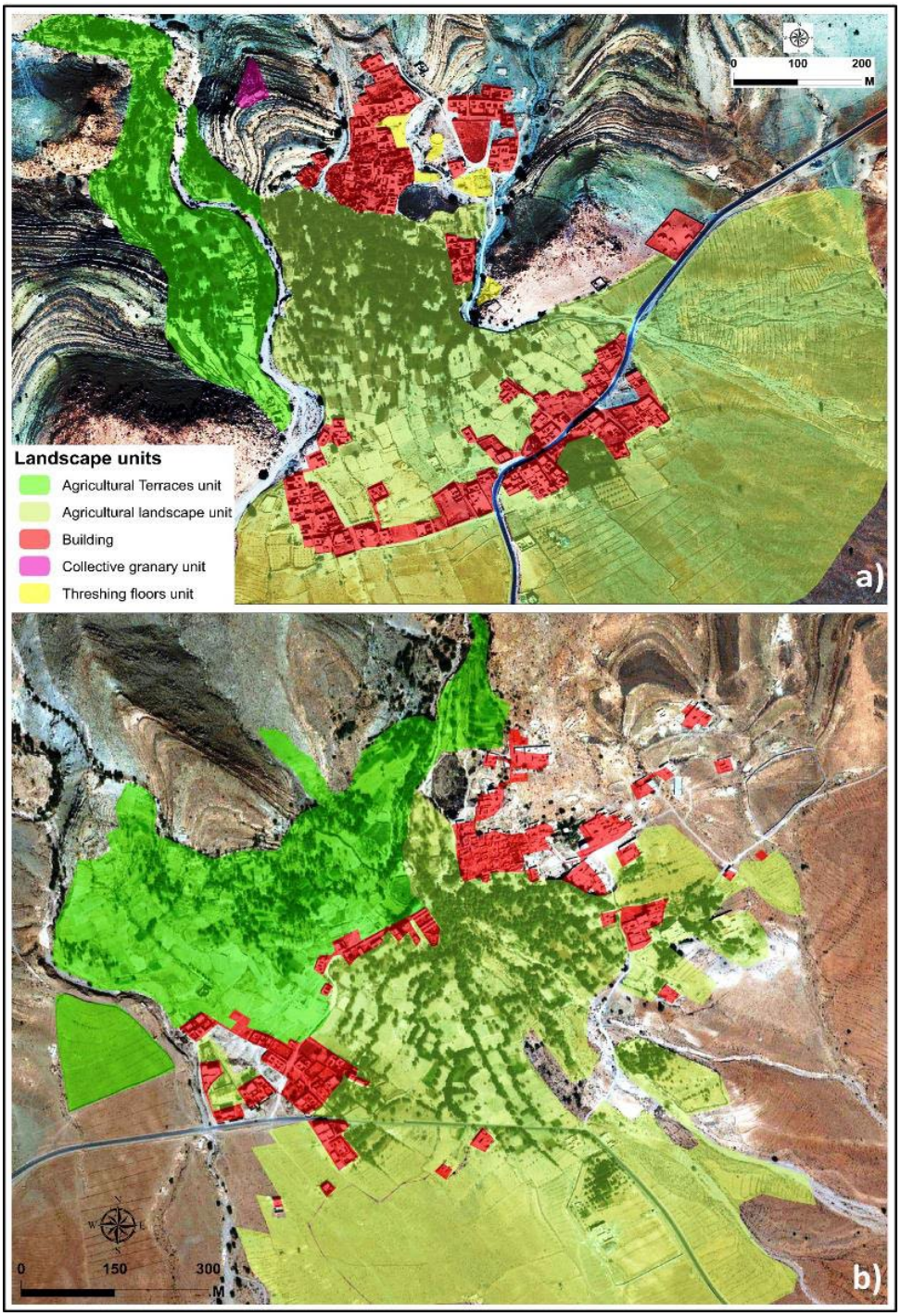

Figure 7. Classification of the oasis landscapes into homogeneous landscape units in a) Timoulay Oumaloukt, and b) Timoulay n'Tozomte oasis.

4.2. Humanized landscapes in the oases of Timoulay Oumaloukt and Timoulay n'Tozomte: human ingenuity of the southern slopes of the Western Anti-Atlas

The construction of this landscape is done to take advantage to both socio-economic (production, land, foodstuffs, etc.) and ecosystem (biodiversity, water cycle, erosion control, etc.) services in an arid and desert bioclimatic and biogeographical domain (Deffontaines, 1985; Irifi, 2023; Sabir *et al.*, 2020; Ziyadi *et al.*, 2019). The producing system of this landscape provides distinct material objects such as traditional human artifacts, diverse landscape features, forms, and structures. This diversity leads to the creation of a visible oasian landscape of the Western Anti-Atlas. This landscape system is symbolic, strongly linked to the land and the most, indicators of changes and socio-ecological crises, and an adaptation to natural constraints that are mitigated and controlled by ingenious developments (Derouich, 2013; Ziyadi, 2011). In fact, they tell the socio-economic and spatio-temporal history of these oases, because the construction of these structures depends on a real collective effort, and a certain social organization of the tribe (*jmaât*), to transform uncultivated substrates into arable land (Irifi, 2023; Ziyadi, 2011).

4.2.1. Agricultural terraces landscape: Traditional ingenious

Agricultural terraces are one of the most characteristic landscapes of the Mediterranean region (Despois, 1956; Heider *et al.*, 2021; Moreno-de-las-Heras *et al.*, 2019; Petanidou *et al.*, 2008; Sluis *et al.*, 2014; Ziyadi, 2011; Ziyadi *et al.*, 2019). On a national scale, agricultural terraces spread unevenly in the four Moroccan mountain ranges. Indeed, in the Anti-Atlas and the High Atlas, terraced fields are the general rule (Tribak *et al.*, 2013; Ziyadi, 2011), entire slopes, from the bottom to the top, are covered with them. The presence or absence of such developments in the landscape can in fact have several natural explanations, such as climate, substrate, topography, soil cover, forest, etc. but also human: demographic pressure, solidarity and collective work between the members of the tribe (*tiwizi*) and local know-how (De Reparaz, 1990; Ziyadi, 2011; Ziyadi *et al.*, 2019). This landscape unit can be classified into two distinct landscape structures in terms of the crops grown. In Timoulay Oumaloukt, around 50% of the agricultural terraces are used for irrigated crops, whereas in Timoulay n'Tozomet, most of the terraces are used for dry cereal crops associated with fruit trees such as olives, pomegranates, almonds and argan trees, or are fallow land (Fig. 8).

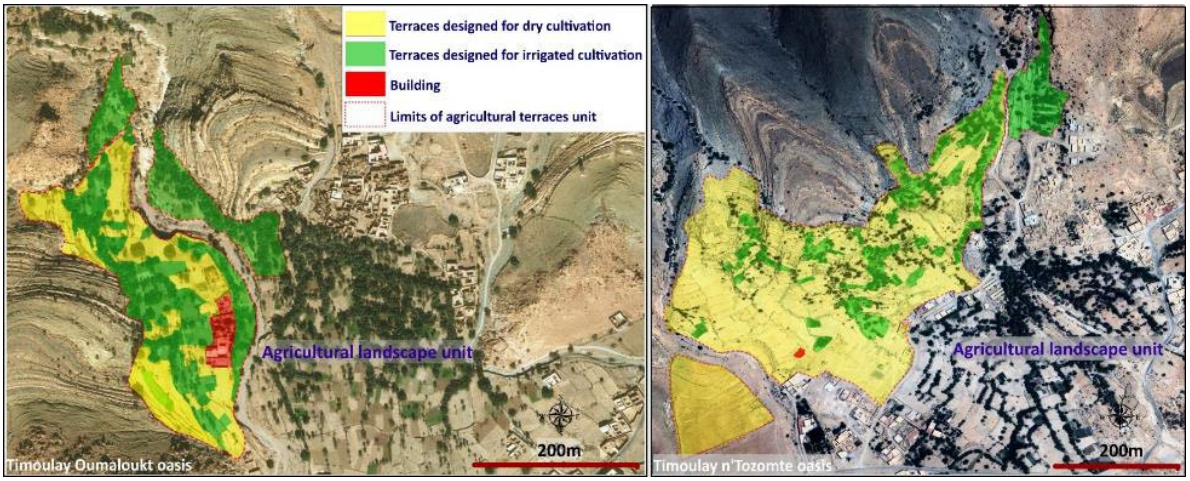

Figure 8. Types of terraces included in the Agricultural Terrace unit. Source: own elaboration.

Agricultural terraces represent the agricultural practices of small-scale farmers within a hierarchical rural society. These communities, often experiencing high population density, leverage their abundant labor force for intensive cultivation to compensate for limited land availability (De Reparaz, 1990). According to (Irifi, 2023; Sabir *et al.*, 2017; Ziyadi, 2011), in sloping areas, the hillside is transformed into a series of steps formed by an embankment protected by grasses or stone walls and a flat (soil) that allows both the storage of a volume of water and soil sufficient for the growth of fruit trees and the development of intensive crops. Their height is very variable, as is the width, but generally, according to our observations in the field, the height does not exceed a maximum of 2 to 3 m, and the width is between 3 m and 10 m and more. In irrigated areas, the constituent elements of terraces: are the terrace platform, the embankment and the retaining wall (Irifi, 2023; Sabir *et al.*, 2017, 2020; Ziyadi, 2011) (Fig. 9). Initially, slopes were transformed into fertile arable land locally called *iderrassen* (singular: *adrass*). Subsequently, hard labour widened these terraces with retaining walls, forming cultivable beds known as *taghoulte*. More recently, such landscape structures have been enhanced with ancillary elements like *seguias*, ridges, and planks, where farmers enrich the soil with organic manure for cereal rotation.

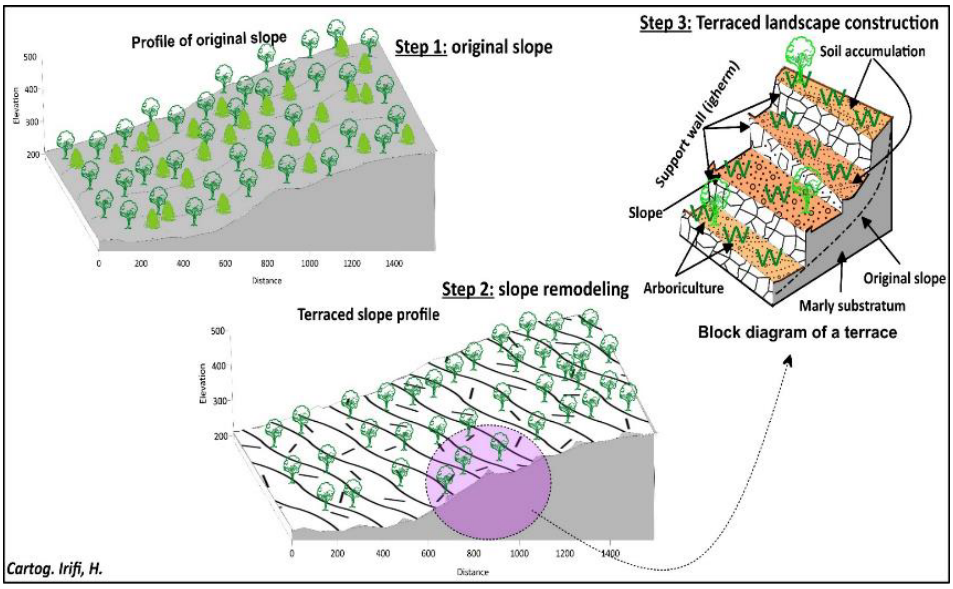

Figure 9. Steps in the construction of an agricultural terrace landscape.

Indeed, in Timoulay Oumaloukt and Timoulay n'Tozomte, we encountered different types of agricultural terraces. These terraces were built on slopes with an inclination between 15° and 20°, i.e. medium slopes, thus highlighting the importance of this parameter in the implementation of these traditional developments. They are thus staggered in the form of stairs that climb the entire mid-slopes. Their heights vary between 1 and 1.5 meters, while their width can reach 10 m sometimes up to 50 meters in Timoulay n'Tozomte, and these terraces conceal a limestone substrate as well as a schist substrate. They are easily identifiable in the field by their stepped shape with their retaining walls. The morphology of these terraces, some of which are poorly maintained, reveals that their construction dates back to ancient periods (Nami, 2017; Ziyadi, 2011; Ziyadi *et al.*, 2019).

Irrigated terraces are built on slopes with mainly calcareous substrate and to a large extent they are less abandoned and well maintained (Ziyadi, 2011). Their irrigation is done in reason to the presence of water springs upstream of the two oases, whose water reaches them via an ingenious system of canals associated with a very well controlled water tower (Dijon, 1966). Technically and architecturally, the construction differs from one area to another; The terraces close to the bottom of the rivers are more or less wide, solid and well maintained than those built on the higher slopes. The peasants here maintain carefully their works, because the building material is widespread, and because of their role in the rural

economy of the two oases, even if it is only a subsistence economy. The terrace is then divided into several beds or ridges called *ouzzons*, each of which may have a distinct type of crop. The height of retaining walls is highly variable, with some generally exceeding one meter, others reaching up to 2m. The size of the blocks used varies greatly, but they are very close to each other, resulting in fairly thick walls. The fence of the plots here is almost absent, since the plots are very close together. The peasants have left their mark on this closed landscape by creating passages and paths to facilitate their movement between plots (Derouich, 2013; Irifi, 2023; Irifi *et al.*, 2020; Sabir *et al.*, 2017; Ziyadi, 2011).

In addition, the farmers took advantage of the flaky and solid character of the green schists to build their terraces, while the large limestone blocks were used as the foundations of the structure. Indeed, the need to build a resistant and stable terrace, the farmers start by putting first in place large limestone blocks at the base both to stabilize the structure as the cultivable bed grows, and to fix the terrace well at the time of rains when the infiltrated water percolates through the interstices of the retaining wall (Ferro-Vázquez *et al.*, 2017; Irifi, 2023; Ziyadi, 2011; Ziyadi *et al.*, 2019). Colluvial landfalls increase the dimensions of the cultivable bed, the peasants add shale flat stones almost every year to store more of the land to be cultivated (Fig. 10). In some places, palm tree trunks are used in the construction of retaining walls and are often positioned in the middle of them. Once this landscape structure is constructed, it is used for various cultivation and land structuring methods. Work starts with stone and weed removal, often done simultaneously with ploughing by family members using sickles or hands. The removed weeds serve as livestock fodder. The land use is varied, with some areas designated for cereal production under *bour* cultivation, and others intended for irrigated crops. Irrigated crops are diverse, encompassing legumes (broad beans, alfalfa, maize, etc.), market gardening produce (onions, carrots, turnips, parsley, aubergines, peppers, pumpkins, etc.), and arboriculture (olive, pomegranate, date palm, carob, and fig trees, etc.).

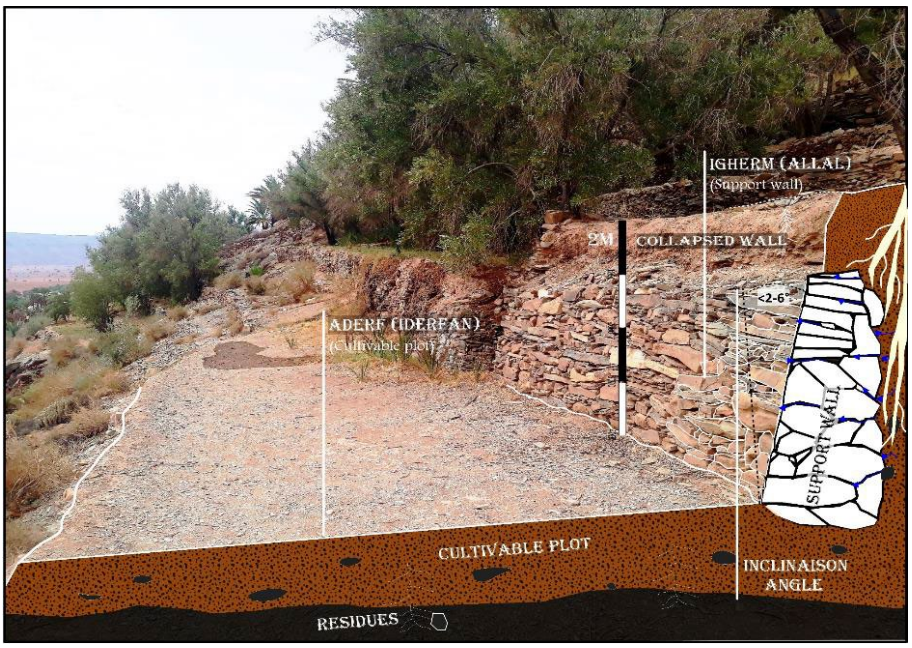

Figure 10. Elements of an agricultural terraces landscape (Douar Timoulay n'Tozomte).

4.2.2. Agricultural landscape: traditional oasis system

The agricultural landscape of Timoulay Oumaloukt and Timoulay n'Tozomte is organized in the shape of a fan following the shape of the glacis at the outlets of the *Assif* n'Taddart in Timoulay Oumaloukt and the *Assif* n'Lala Melouka in Timoulay n'Tozomte. The arable fields are small and often terraced. They are quite narrow in their majority; they usually extend only over a few tens of square meters. The successive subdivisions due to inheritance further accentuate the smallness of the property,

which varies from 500 m^2 to 1 ha. The lack of large areas, and water resources, in a context of recurrent droughts and the absence of the fallow practice mean that productivity is very low and allows rarely for a low rate of food self-sufficiency (Nami, 2017; Ziyadi, 2011; Ziyadi *et al.*, 2019).

Particular care is given to orchards, of which two kinds can be distinguished; the fields called here *urti*, a cultivated and irrigated bed often well landscaped or *bour* fields, located on variable slopes so as to receive rainwater brought in by fine earth or concrete canals. To ensure an irrigated agricultural practice, the peasants exercise what is called *faid* or *ifid* which means flooding of the *urti* by spring water that improves the productivity of all crops (fruit trees, market gardening, legumes, etc.). The smallest spatial unit in the agricultural landscape is the *ouzoun* ridge. The latter divide the agricultural terrace or fields into several small units connected by canals, the main one of which originates in a basin called *charij* located upstream (Derouich, 2013; Irifi, 2023; Ziyadi, 2011).

These landscape structures form the *targa* landscape, which means an agricultural area irrigated by water from the springs upstream of the two oases. The characteristics of the *targa* give these oases the appearance of adaptive and endemic ecosystems within a desert environment, similar to the oases of Aday, Amtoudi, Ifran, Taghjijt, and others. Plots are ploughed semi-deep in the *bled targa*, using a traditional pull plough known as an *aoulou*. However, in the *bled bour*, and more particularly in the *faija*, ploughing is deep.

Agriculture is more varied and diversified in the study area (Fig. 11). Fruit trees, which are fairly diverse, include pomegranate, argan and olive trees, as well as a range of market garden crops. The produce is used mainly to satisfy the food needs of the local population as part of subsistence farming. However, some time ago, the farmers managed to generate a surplus of agricultural production, which they did not hesitate to sell in the past to Ifran, Aday, the Imjade area, Bouizakarne, etc. The argan tree also plays an important role in the rural economy of the two oases. Even if it is not very dense, sparse or even deteriorating, it can be found mixed with fruit trees in some cultivated fields, and close to them, right up to the mountains that overlook (or dominate) the two oases. The argan tree is resistant to heat and makes do with the little rain it receives during the year (Díaz-Barradas *et al.*, 2010; Irifi, 2023; Msanda *et al.*, 2002, 2005; Ziyadi, 2011). It requires no special maintenance. The tree's adaptation to the region's climate can be seen in the constant greenness of its leaves and the thorns on its branches, which prevent evaporation of the water it absorbs (Alahyane, 2004). The argan trees belong to the collective domain and are managed in an ancestral way by the customary *orf* law called *agdal* which guarantees the right of use, fructus and abuse of the heirs who are members of the tribe, whether they are residents or not (Auclair, 1999; Chamikh *et al.*, 2014; Romera Puga, 2022).

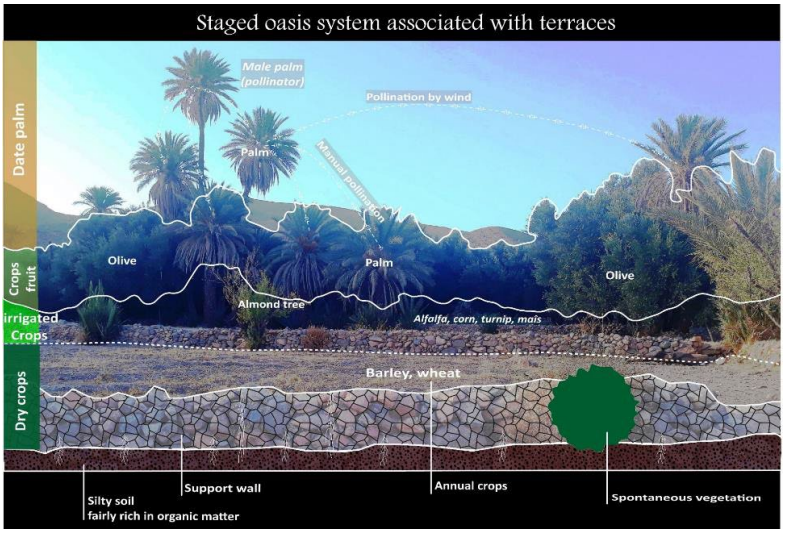

Figure 11. Layering of the agricultural landscape of the of Timoulay Oumaloukt oasis.

4.2.3. Threshing floors: a built component of the oasis landscape

Threshing areas, known as *anrar* in Berber, are integral to the Anti-Atlas terraced landscapes. Their presence, especially near historical settlements and collective granaries, provides strong evidence of the region's past dependence on cereal cultivation, particularly wheat and barley (Musso and Chaker, 1986; Ziyadi, 2011; Ziyadi *et al.*, 2019). In our study area, more than 13 threshing floors were built a long time ago, and whose abundance reveals the importance of cereal production in the area and an expression of population density (Fig. 12).

The threshing floors are often circular platforms with artistic stones, varying in size from 10 to 50 meters in diameter. In most cases, each family has its own threshing floor. They are built horizontally, as much as possible, close to the douar. They are sometimes even glued to the houses, thus limiting or facilitating the transport of grain as much as possible (Musso and Chaker, 1986; Nami, 2017; Ziyadi, 2011; Ziyadi *et al.*, 2019). Sometimes there are more than two threshing areas, coalescing or superimposed, close to each other and connected by a retaining wall, while taking advantage of the abundance of lithic material (schist and limestone). They are also best sited in areas with good exposure to the wind. The stone slabs, for the threshing floors, are bound by a simple clay earth mortar to ensure a perfect seal and thus protect the land against the harmful effects of rainwater (Ziyadi, 2011).

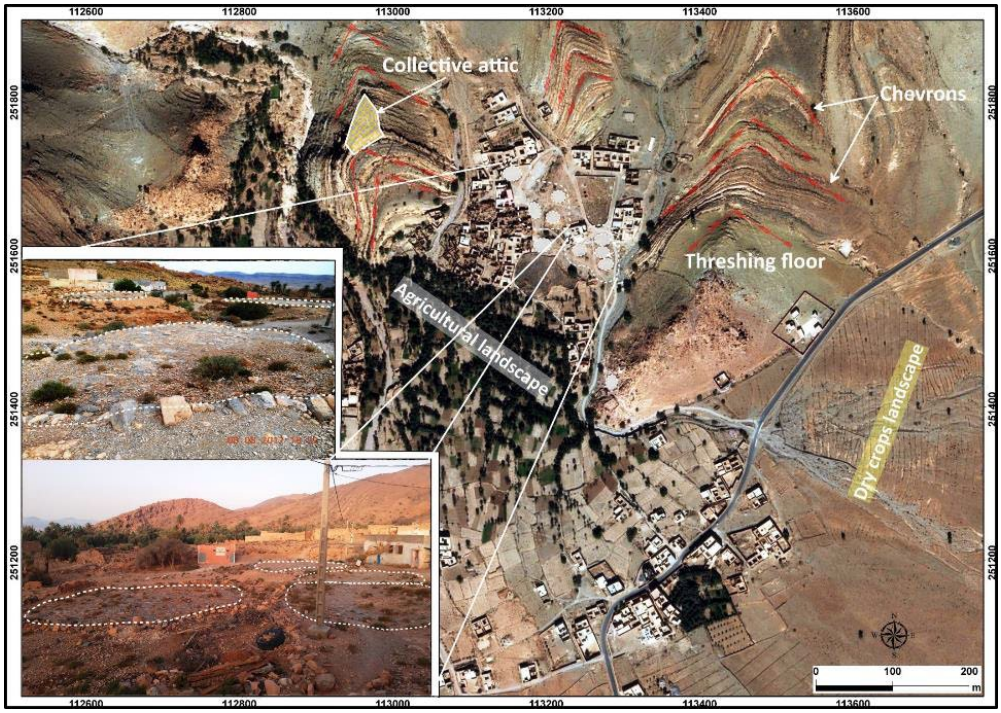

Figure 12. Situation of threshing floors in the douar of Timoulay Oumaloukt.

4.2.4. The collective granary (*Agadir*): an architectural component of the oasis landscape

The collective granary or *igoudar, agadir* in plural are the oldest Amazigh system for storing grains in the whole world. These are Amazigh architectural constructions based on the principles of storage, defense and management (Alahyane, 2004; Delaigue *et al.*, 2011; Derouich, 2013; Naji, 2007, 2020, 2021; Riser, 1988). These are expressions of the prevailing insecurity, tribal management and drought in the region. Here, as mentioned above, the different types of materials traditionally used in the constructions of the *Agadir Sidi Chamharouch* in Timoulay Oumaloukt, come mainly from the subsoil of the study area (Fig. 13). The materials correspond to the large geological formations in the territory, mainly limestone blocks, flat and rectangular pieces of shale, sandstone and sometimes

travertine. Agadir was built on a small hill about 800 meters above sea level on one of the N-S direction chevrons of the Western Anti-Atlas on a schist and limestone substrate.

Architecturally, the attic has an area of 850 m² and a perimeter of 123 m. The building is triangular in shape, it is built from schist rocks and an assembly of different materials (limestone, tuffs, etc.) and is frequently cemented by clay. *Agadir's* walls, like its chambers, were built from a mass of stone, with large limestone blocks forming the base of the edifice. They are made up of two dry-stone walls, a defensive wall and a main wall inside the granary, over 5 meters high. These walls are finished on three sides by three semi-circular guard towers known locally as *Tachrafine* (in singular, *Tachraft*) These towers rise from the ground to a height of over 6 meters and are made up of a dry-stone wall at the base (over 70%) and a wall with a waterproofing layer (30%), which ends in a stone slab overlapping one another, on which a waterproofing layer covers them. The interior of the attic is made up of numerous chambers that serve as storage space for wheat, cereals, oils and all other foodstuffs. These chambers are built small and covered with palm or argan tree trunks and clay mixed with straw. Numerous small windows were made along the walls to serve as guards and controls during wars and/or against thieves and invaders (Delaigue *et al.*, 2011). Outside, *agadir* of Timoulay Oumaloukt had a large cistern called locally *metfias* which is used to collect rainwater that will be used by the *Amine* of the granary, in the maintenance of the attic and in the collective ceremonies previously organized annually, which called locally *El Maârouf*.

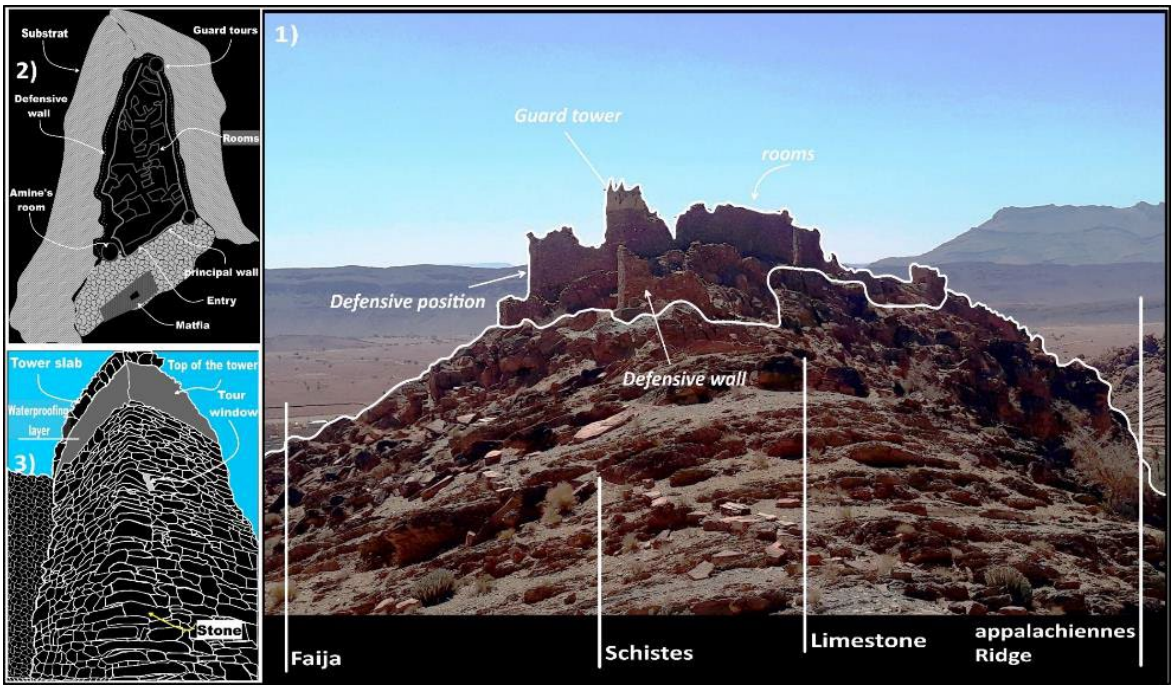

Figure 13. Schematic Sketch of The Sidi Chamharouch Collective Attic in Timoulay Oumaloukt: 1) General View of The Collective Attic; 2) Map of The Attic; 3) Guard Tower (Tachraft).

4.3. Landscapes in crisis: socio-spatial mutations

The oasis landscape of Timoulay Oumaloukt and Timoulay n'Tozomte has undergone an accelerated evolutionary dynamic, combined by the interaction of both natural and human processes, and is therefore an excellent example of a landscape/interface between nature and man. This oasis landscape testifies to significant human ingenuity, it is the result of a noospheric evolution of Man, which is reflected in the construction and implementation of numerous practices and techniques for the exploitation of natural resources (soil, water, forest, etc.), resulting in the creation of a lived, visible and dynamic space (Derouich, 2013; Irifi, 2023) (Fig. 14).

Analysis of the NDVI maps for the years 1987, 2001 and 2023 shows that the late 1980s were characterized by a fairly dense oasis landscape. However, at the beginning of the 1990s a drought hit Morocco in general. From 1995 onwards this drought was interrupted by 4 wet years followed by two dry years (1999-2000). This seems very clear from the NDVI map for the year 2001, which recorded the lowest average of -0.2, This can be explained by water stress and drying out following a long period of drought. As a result, the surface area of the two oases fell from 61.35 ha in 1987 to 53.21 ha in 2001. The vegetation index appears to be very clear and very significant by the processing of the 2023 Landsat 8 OLI-TIRS images, due to their high spectral resolution. On this map, it was visually noticed that there was some remarkable recovery of spontaneous vegetation and irrigated crops, which recorded maximum values of (0.4) and minimum values that have been weakening since 2001, ranging from (-0.2 to 0.02) (Fig. 14 and 15). However, the oasis landscape in 2023 recorded some decrease in its total area (46.94 ha). It is in fact a question of aeration and dedensification of the landscape, both in terms of surface area and density of fruit trees. This land appears to be replaced by abandoned or fallow land. Generally, this last decade, even if it is a mostly dry period, peaks of precipitation have been recorded (2010, 2014, 2017, etc.) and allow a certain development and conservation of spontaneous plant heritage.

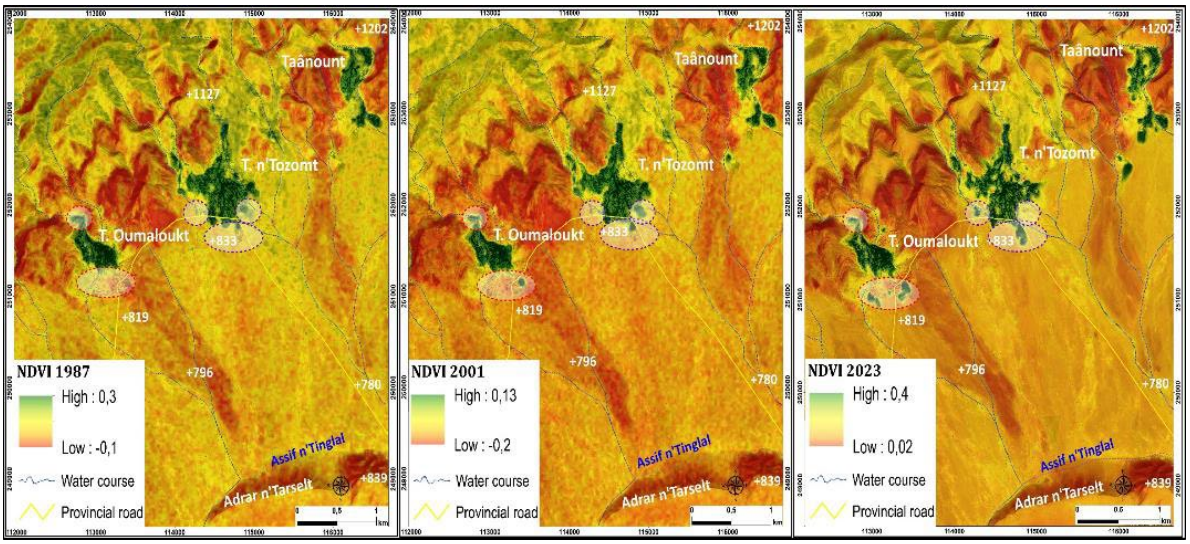

Figure 14. Evolution of the NDVI vegetation index of the agrarian landscapes of Timoulay Oumaloukt and Timoulay n'Tozomte during years 1987, 2001 and 2023.

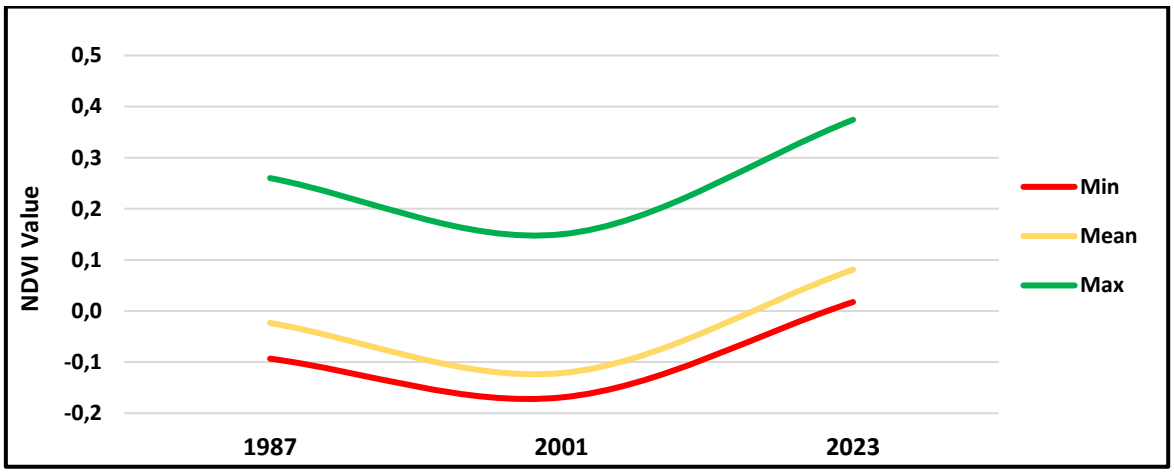

Figure 15. Change in the maximum, minimum and mean values of the NDVI vegetation index of Timoulay Oumaloukt and Timoulay n'Tozomte during years 1987, 2001 and 2023.

Climate is the most significant factor influencing this landscape's dynamics. The variability of seasonal rainfall between the driest and wettest months, coupled with precarious climate conditions during sequences of dry years, exacerbates the situation. As illustrated in Figure 16, the recurrence of dry years is evident, with the most severe periods occurring from 1981 to 1986, from 1990 to 1994, from 1999 to 2008 and from 2016 to 2022. These are three major dry periods, preceded by a dry spell from 1980 to 1985. Conversely, wet years are brief (2 to 3 years on average) and often feature peaks of significant rainfall. In 2014, those stations recorded over 300 mm of rainfall. Over 41 years, this area noted three significant precipitation peaks, the most notable occurring in 1987-1988, followed by a prolonged dry period from 1990 to 1994, during which rainfall rarely exceeded the average, except in 1991 and another precipitation peaks from 1995 to 1997, followed by long dry period from 1998 to 2008. Furthermore, this dry period was followed by a short-wet period of three years from 2009 to 2011. This pattern confirms the area's affinity for the Mediterranean climate, characterized by concentrated rainfall in both time and space.

Diachronic analysis of the agrarian landscape of the two oases over a 13-year period shows a regressive dynamic in the traditional irrigated and agricultural agrarian landscape, compared with a slightly progressive dynamic in the modern agrarian landscape (Fig. 17). Some plots are currently being mechanized and new modern ploughing, irrigation and harvesting techniques are being introduced 2.3 ha in Timoulay Oumaloukt oasis and 2 ha in Timoulay n'Tozomte. While others zone has been abandoned with 7 ha in Timoulay n'Tozomte and only 3 ha in Timoulay Oumaloukt. In terms of surface area, there has been an increased decline in irrigated crops since 2010. This regression is manifested by the degradation of cultivated land. In 2023, the area was further reduced, and fruit trees became increasingly scattered. The reduction in the area of cultivated plots is much more marked in the Timoulay n'Tozomte oasis, falling from 19.9 ha in 2010 to 11.6 ha in 2023, with an average annual reduction of 2.4 ha. In Timoulay Oumaloukt, the figures show an annual decrease of 1.3 ha over the same period, from 11 ha in 2010 to 7 ha in 2023. Thus, the abandonment of agricultural plots on slopes developed into agricultural terraces obviously implies the abandonment of the development of gullies whose flows are torrential at the time of floods. As a result, the resumption of erosion and gullying is possible. This also involves poor maintenance of fruit trees (irrigation, pollination, phytosanitary products, crop rotation, etc.), which leads to aging or wilting of trees in the two oases. However, in other places we are witnessing the development of small private agricultural projects spread over large areas, different from lands based on traditional irrigation. These new areas benefit from the advantages offered by new hydraulic techniques such as wells equipped with motor pumps, drip irrigation and the use of modern plowing equipment.

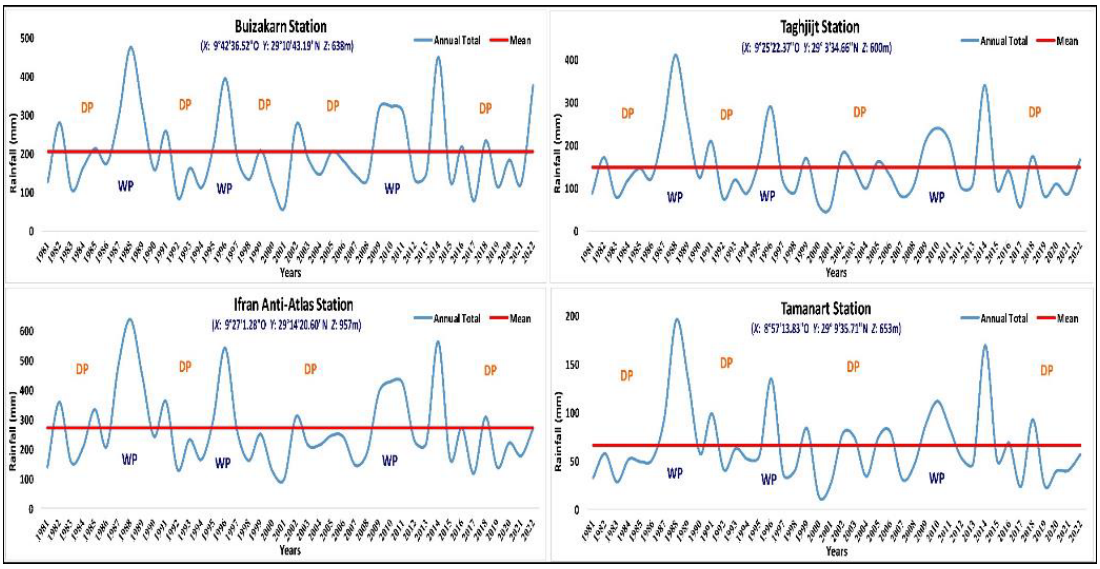

Figure 16. Annual rainfall recorded in four climatic stations within the study area. WP: Wet Period, DP: Dry Period. Source: https://power.larc.nasa.gov/data-access-viewer.

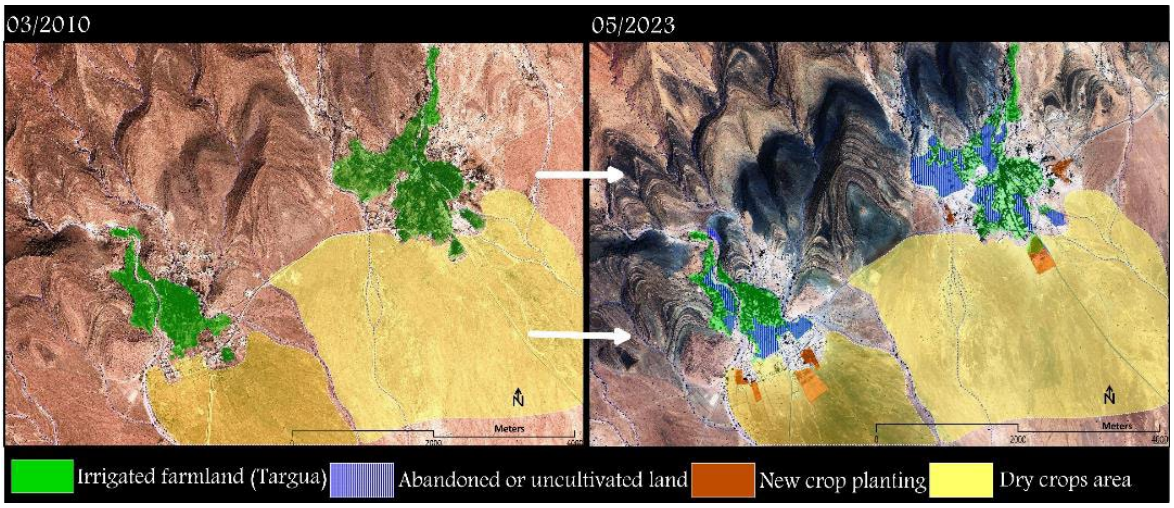

Figure 17. Land cover evolution in the Timoulay Oumaloukt and Timoulay n'Tozomte oases between 2010 and 2023. Source: Google Earth Pro Imagery.

5. Discussion

5.1. Interpretation of landscape dynamics

The dynamics of the oasis landscapes in this region are evolving along two disparate trajectories. In some places, agricultural abandonment is the predominant phenomenon, while in others, the landscapes are still subject to a strong human influence. Both situations can be explained by natural, socio-economic and technological factors. Prolonged periods of drought appear to have accentuated the processes of agricultural abandonment, resulting in the socio-spatial emigration of the population (Irifi, 2023; Ziyadi, 2011; Ziyadi *et al.*, 2019). Indeed, the countryside most affected by drought and the lack of water resources seem to be the most marked by this phenomenon. Similar trends have been observed in other North African oases, notably in Algeria, where palm grove areas have shrunk rapidly, with over 1.5 million square meters lost since 1985 in Timimoun (Chouaib and Baser Kalyoncuoglu, 2022). A similar trend is evident in the Nefzaoua oases of southern Tunisia, where date palm density progressively declines from ancient to public modern, and finally to private modern agro-systems, suggesting planting density as an indicator of agricultural system change (Benaoun *et al.*, 2014).

Agricultural terraces are a cultural heritage that enhance slope stability against erosion (Blond *et al.*, 2018; Despois, 1956; Irifi, 2023; Sabir *et al.*, 2020; Ziyadi, 2011) and increase the infiltration capacity of the soil, thereby increasing its fertility, as well as reducing the surface stripping of particles. However, the majority of these architectural works are now in a state of abandonment and are therefore threatened with disappearance (Lasanta *et al.*, 2017; Otero *et al.*, 2015; Sabir *et al.*, 2021). This situation stems from the major upheaval that oasis society has experienced since the post-independence period, namely: the flagrant population growth, the degradation of the traditional tribal organization, the succession of years of drought and the consequent decline of natural resources (Derouich, 2013; Irifi, 2023). Such a phenomenon has been observed in the most mountainous area in Morocco. In the Anti-Atlas Mountains, this decline negatively impacts both the quality and quantity of cultivated terraces, significantly reducing species and varietal diversity. As a result, many terraced plots are abandoned or poorly maintained, losing their appeal for younger farmers (Ziyadi *et al.*, 2019). Increased drought and water stress in the region now prevent satisfactory yields and soil mineralization, while also degrading the microclimate provided by fruit trees on the terraced slopes. Consequently, the reduced density and persistence of these trees contribute to the renewed erosion of the agricultural terraces (Ziyadi *et al.*, 2019). In the Assargh zone of the Anti-Atlas Mountains, the abandonment of cultivated terraces is directly linked to water scarcity, climate change and rainy days' variability. The climate change could

exacerbate water resource shortages in the future, leading to more accelerating the degradation and abandonment of these terraced agricultural systems (Boselli *et al.*, 2020).

It should also be noted that this phenomenon of abandonment (Irifi, 2023; Otero *et al.*, 2015; Rey Benayas *et al.*, 2007; Sabir *et al.*, 2021; Sluis *et al.*, 2014; Tarolli *et al.*, 2014; Ziyadi, 2011) is much more pronounced for cultivation terraces that are located outside the irrigated terroir (Fig. 18). The destruction of these structures begins with the collapse of their retaining walls, which leads to the destruction of their embankments, resulting in the resumption of water erosion and the almost total destruction of the structure (Ferro-Vázquez *et al.*, 2017; Heider *et al.*, 2021; Inbar and Llerena, 2000; Irifi, 2023; Lasanta *et al.*, 2017; Lloret *et al.*, 2024; Moreno-de-las-Heras *et al.*, 2019; Sabir *et al.*, 2017, 2021; Spanò *et al.*, 2018; Tarolli *et al.*, 2014; Ziyadi, 2011). In the field, several indicators indicate this, such as: the openings created inside the retaining walls, the construction of small embankments and destruction niches testifying to the collapsed part of the structure. Also, the withering of fruit trees and date palms or their incineration weakens the role of their roots in fixing the cultivable area of the terraces. The degradation of traditional agricultural terraces consequently leads to a significant disruption of drainage and hydrological processes, damages irrigation infrastructure, and results in the loss of crucial functional and ecosystem services inherent to these cultivation systems, a pattern observed in regions like the Mediterranean (Moreno-de-las-Heras *et al.*, 2019; Vallés-Planells *et al.*, 2020; Ziyadi *et al.*, 2019).

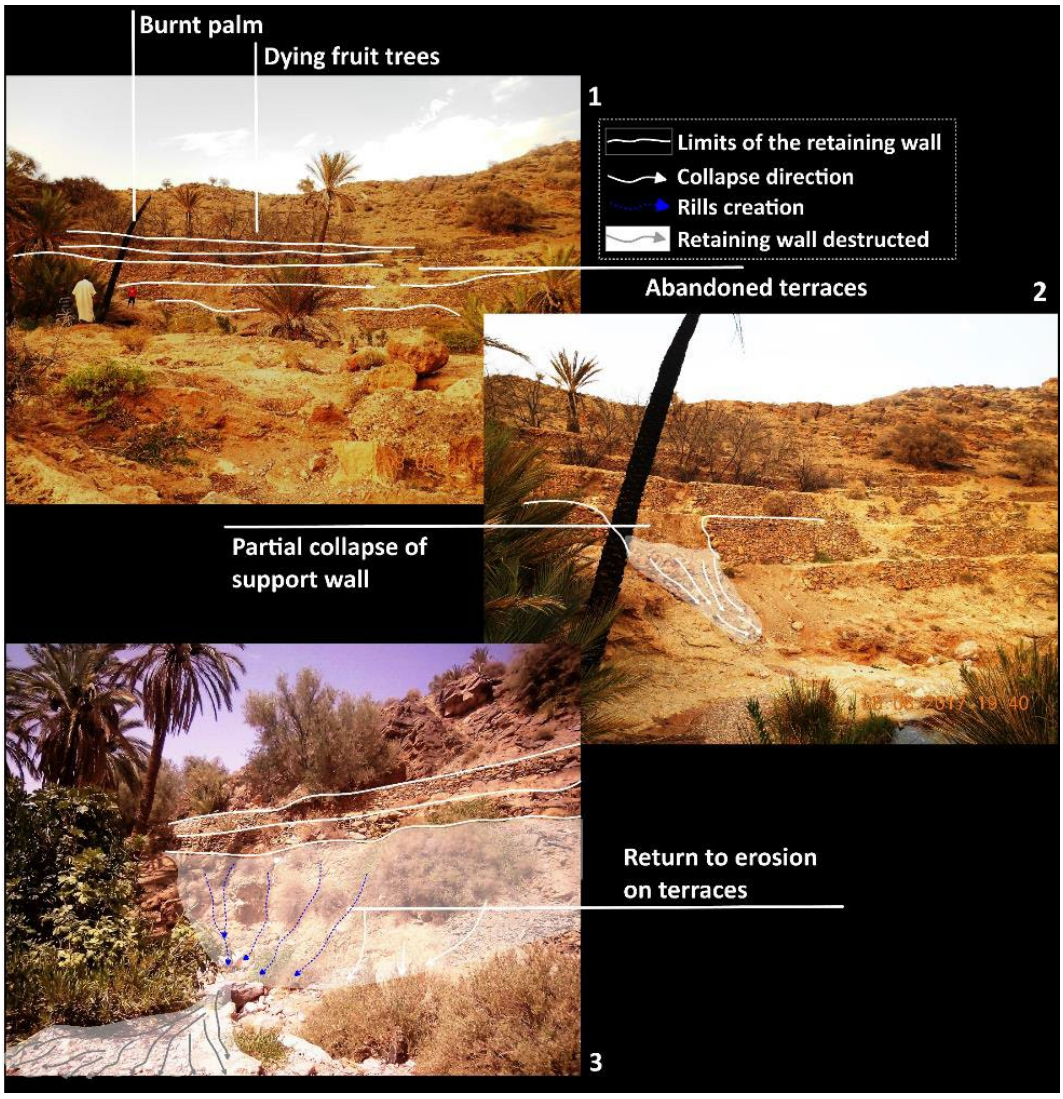

Figure 18. Degradation of the agricultural terraced landscape in the douars of Timoulay Oumaloukt and Timoulay n'Tozomte: 1) Abandoned terraces; 2) Partial collapse of the wall; 3) Total destruction of the terrace.

The process of agricultural abandonment has often spread to all the other landscape components of the southern slopes of the Western Anti-Atlas. They are becoming more and more important with the increased waves of rural exodus, in a context of land fragmentation due to inheritance (Barathon *et al.*, 2005; Sabir *et al.*, 2021; Ziyadi, 2011). In the Timoulay Oumaloukt, some threshing areas have been transformed into plots of land for the construction of new houses (Fig. 19a). The collective attic has also suffered significant deterioration of most of its components. According to the local population, until the 1980s, *Agadir Sidi Chamharouch* was still a solid, well-maintained construction. It is only in recent decades, following the advent of some very rainy years, that the architectural components of the body of the attic have completely deteriorated. The defensive wall has now been completely destroyed, and the dilapidation also extends to the interior and annex construction elements of the enclosure, namely: the central aisle, the rooms, the mosque, the cistern, etc. (Fig. 19b). This process of deterioration and demolition of collective granaries is almost complete in the western Anti-Atlas, except a few *igoudar* that are still well preserved or have recently been restored. The risk of abandonment and destruction certainly applies to the abandoned *kasbahs* (*igherman*) in the Dades and M'Goun valleys, as well as the *ksour* of Tafilalet and Zagora provinces. These sites, like many others across Morocco, are facing significant challenges that threaten their preservation.

Since the 1990s, the urbanization process has doubled or tripled on the oases of Timoulay Oumaloukt and Timoulay n'Tozomte. The villagers have abandoned their traditional houses built of clay (*louh*) and dry stones to build, far from the old center of the village, other new houses in urban style. Thus, the task of the built environment was already being developed in the years 1990-2000, following a first phase of extension during the 1980s. Space consumption was the most intense over the period 2000-2022 (Barathon *et al.*, 2005; Chmourk, 2011; Derouich, 2013). Recent demographic censuses indicate a general population decline in the two oases, from 632 inhabitants in 2004 to 550 in 2014. This suggests that the observed spread of urbanization is not primarily driven by an influx of new residents, but rather by factors such as land fragmentation, inheritance patterns, and the complex effects of both emigration and the return of emigrants (Tribak, 2001).

Figure 19. a) Construction of a habitat basis on a threshing floor; b) Ruins of the collective granary Sidi Chamharouch (Author: Irifi 2017, 2021).

5.2. Development perspectives of an oasis landscape in crisis

The oasis landscape of Timoulay Oumaloukt and Timoulay n'Tozomte in particular, and the territory of the Ait Herbil in general, is the product of nature and the shaping of man. It offers a great diversity of geomorphological and anthropized landscapes. These landscapes are of hydro-agricultural interest and sites of geological heritage and tourist interest (Berred *et al.*, 2019). As a result, the fragility of these humanized and natural landscapes of "remarkable and picturesque" nature seems to be directly dependent on local and regional natural and social changes (Irifi, 2023; Ziyadi, 2011). The construction

of such landscapes takes into account the duty to preserve natural and landscape resources. The notion of landscape integrity (Irifi *et al.*, 2020; Perkl, 2017; Walston and Hartmann, 2018) and landscape project (Gauché, 2015; Irifi *et al.*, 2020; Peyrache-Gadeau and Perron, 2020; Pousin, 2004) takes on its full importance here because it is then a question of connecting the oasis anthroposystem to the mountains. All these landscapes must be listed in the inventory of the natural and cultural heritage of the Guelmim Oued Noun region.

The study area is rich in landscape elements, and any attempt at enhancement must prioritize the conservation of landscape heritage and address the social vulnerability and precariousness of the population's living conditions. The approach applied seems relevant, because it makes it possible, based on landscape elements, to identify the potentialities, constraints, dimensions, dynamics of evolution and the challenges of tourism enhancement of landscapes. The methodology proposed in this work is ambitious in terms of promoting natural resources and ensuring better cohesion and consultation between the various actors on the different themes of the oasis landscape (Irifi *et al.*, 2020). To sustainably preserve the natural wealth and ecological integrity of the oasis environment, institutions, communities, and associations must mobilize to initiate ambitious land-use planning initiatives. Enhancement requires an in-depth knowledge of the region's rich heritage. The rehabilitation of certain landscape elements can enhance the sustainability of the Timoulay Oumaloukt and Timoulay n'Tozomte oasis. The map below summarizes the main landscape units that call for rehabilitation, conservation and enhancement of the homogeneous landscape groups or picturesque and emblematic sites. In fact, the entire territory deserves to be revitalized and invigorated through a tool that we refer to in this article as the 'Landscape Enhancement Map' of the entire area (Fig. 20).

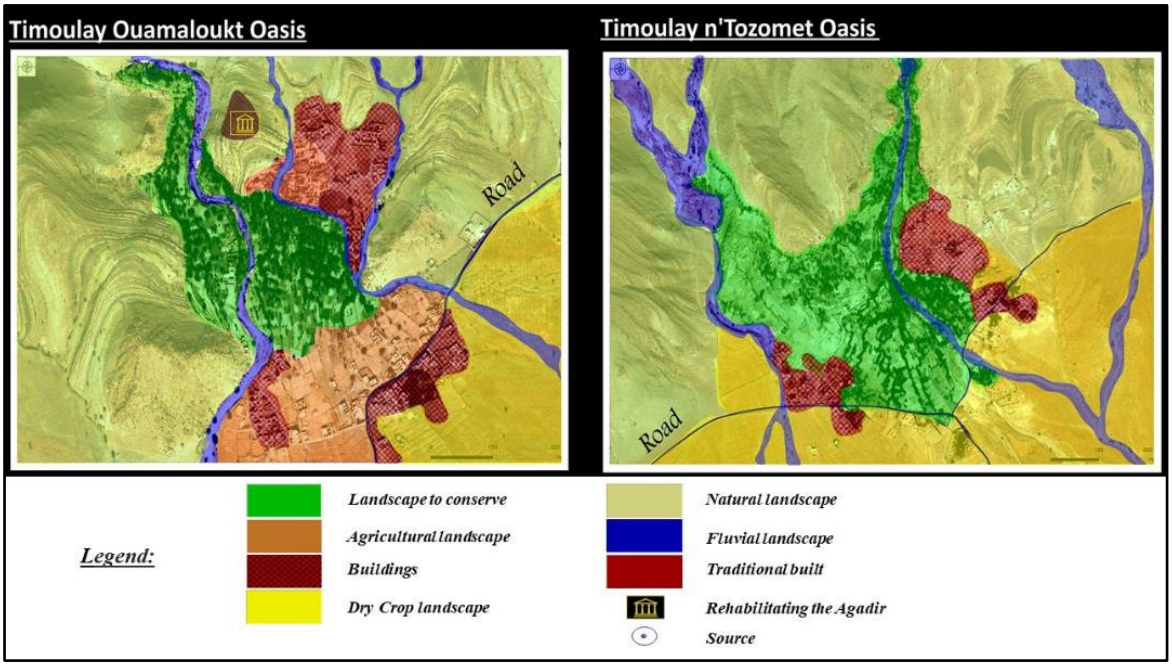

Figure 20. Landscape enhancement maps of the Timoulay Oumaloukt and Timoulay n'Tozomte oases, including the landscape units.

6. Conclusion

The analysis of the heritage and landscape identity of the oases of the Ait Herbil region brings together elements of knowledge relating to the territory, the natural environment and society in agricultural, geological, architectural, socio-demographic and dynamic spatial terms. Through the study of the humanized landscapes units of the Timoulay Oumaloukt and Timoulay n'Tozomte oases, the

opportunity has arisen to take this transversal look at the territory of the Ait Herbil and to better reflect on its evolution. The physical conditions offer an almost unchanging model on a human timescale and constitute a support marked by a diversity of landscapes shaped by human society. All these factors, together with noospheric evolution and human ingenuity, form the basis for landscape units identification. The establishment of the human-made landscape of the region's oases is based on three essential dimensions: a bio-physical dimension (natural potential and constraints), an economic dimension (resources, yield and production) and a social dimension (know-how, practices, heritage, *Melk*, belonging, etc.). A combination of socio-spatial changes, recurrent droughts, and declining natural resources has plunged these oases into a severe crisis, leading to spatial and social transformations that threaten their sustainability, manifested by rural exodus, agricultural abandonment, and the degradation of traditional features.

Based on their landscape features, the Timoulay Oumaloukt and Timoulay n'Tozomte oases are characterized by prominent structures. These include a diverse, tiered oasis agrarian landscape, which offers extensive ecosystem services and acts as a green belt against urbanization, and ingenious agricultural terraces supporting intense polyculture with significant ecosystem benefits. However, these vital elements are now facing abandonment and destruction. Additionally, these oases feature historical threshing floors, representing ancient land exploitation and cultural heritage, alongside the now-eroded collective granaries (*agadir*). These granaries, which serve as symbolic buildings of Amazigh civilization in the Western Anti-Atlas and southern Morocco, are also at risk of abandonment and demolition.

The landscape heritage in the oases of Timoulay Oumaloukt and Timoulay n'Tozomte contains remarkable and picturesque sites, that constitute a kind of regional landscape inscription. This landscape heritage is an example of an emblematic landscape to be enhanced, whose intention and importance should be carried. The Amazigh architecture of the *igoudar*, the traditional, rich and varied rural habitat, the agricultural terraces and the fusion with the diversity of the natural landscape, force the question of the need to carry out development and enhancement projects harmonious with the characteristics of the landscape. In this case, any development intervention must be based on a systemic but also participatory approach.

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The current manuscript has no data associated that has been deposited into a publicly available repository. Data may be made available on reasonable request.

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Appendix. List of local terms

Term	Definition
Agadir	This is an Amazigh term for the collective granary of each tribe in west-central Morocco
Agdal	In the Tamazight language, this term refers to the ancestral practice of protecting argan forests and rangelands for a large part of the year (from June to October)
Amine	Responsible of the collective granary
Anrar, plur. Inraren	Threshing floor
Aoulou	This is an Amazigh term for a traditional plowing technique using an animal-drawn plow (donkey or horse)
Assif	Principal watercourse
Bled bour	Dry crops area
Bour	Dry crops or rainy crops
Charij	Irrigation water basin
Douar	Tribe or Countryside
El faid-Ifid	Flood/flooded area
El Jmaât	This is the traditional assembly of the members of each tribe in Morocco
El Maârouf	Traditional community festivals in the rural areas of the High and Anti-Atlas
Faijas	These are stretches of gently sloping land, or glacis, surrounded by Appalachian ridges in central-western and southern Morocco
Igherman	Retaining wall of agricultural terraces
Ighzer	Ravine which is a hydrographic, geomorphological formation and a form of erosion.
Jebel/ Adrar	Mountain or mountain top
Kasbahs and Ksour	A Kasbah and Ksar/Ksour are a characteristic North African construction, typically serving as a citadel or a fortified quarter within a town. In Morocco, those building exhibit distinct and diverse architectural styles, commonly built from dry stone or rammed earth reinforced with straw
Louh	Walls built in rammed earth
Melk	Personal propriety
Metfias	In rural area of Morocco, it refers to techniques of rainfall water collection and storage.
Orf	It refers to a set of customary practices, traditions and laws, established and followed by rural communities, and handed down from generation to generation
Ouzzons	Small cultivable ground surrounded by centimeters-high ridges
Regs	In the arid and desert environments of Morocco, it refers to a generally flat surface made up of heterometric pebbles. It is the result of wind and water erosion.
Seguias	It's a term of North African origin that designates a traditional or modern open-air irrigation canal, part of the oasis landscape of North Africa
Tachrafine	Traditional windows for collective attics and traditional houses
Taghoulte	It's an Amazigh term referring to delimited cultivable plots, part of agricultural terraces
Targa	Irrigated area/Oasis
Tiwizi	Rural societies in Morocco practice *Tiwizi* or *Twiza*, an ancestral practice based on solidarity and the participation of all tribe members in common tasks (building structures, harvesting, festivals, etc.)
Urti	Irrigated agricultural area