

AGROECOLOGY, IRRIGATION AND INSTITUTIONAL PATHWAYS FOR RESILIENT OASIS AGRICULTURE IN TUNISIA

AGROÉCOLOGIE, IRRIGATION ET VOIES INSTITUTIONNELLES POUR UNE AGRICULTURE OASIENNE RÉSISTANTE EN TUNISIE

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ABSTRACT

The oases of southern Tunisia are a vital part of the agricultural and food systems of the country, notably for date production, and they support local economic, social, environmental and cultural life. These unique agroecosystems face major threats, such as climate change, loss in quality and quantity of the North-Western Sahara Aquifer System, and desertification. They require agriculture to evolve and present both efficiency and sustainability. Two dominant agricultural models are often present and opposed: traditional and modern oases, with distinct practices, performances, and trade-offs, raising critical sustainability challenges.

With the need for sustainability, agroecology provides a relevant technical, analytical and governance framework to guide the study of agricultural systems and environmental health. As a paradigm, it encourages synergies between agricultural practices and ecosystem processes, enhancing the regenerative capacity of ecosystems and their resilience, and improving long-term sustainability of resource use.

This article proposes a comparative analysis of traditional and modern oasis systems through the 13 agroecological principles defined by the HLPE (2019). The results highlight that neither model is inherently sustainable: traditional systems face constraints in productivity and water management, whereas modern systems intensify pressure on water resources and weaken ecological balances. Both models therefore require targeted transformations to better align with agroecological principles.

Focusing on water as a transversal and crucial element of oasis agroecosystems, the analysis illustrates the importance of appropriate institutional settings to facilitate agroecological practices. This is visible especially with water governance and a non-renewable fossil aquifer system, where sustainable uses need to be embedded and directed by institutions. The governmental PIHOS project highlighted opportunities in adaptive, bottom-up governance to support sustainable oasis development.

The article offers an example of institutional and governance settings as enabling environment to promote agroecology and sustainability in the oases of southern Tunisia, tackling agroecosystems relying on non-renewable groundwater.

Keywords: agricultural and food systems; sustainable oasis development; agricultural systems; environmental health; water management; water resources; ecological balances.

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RESUME

Les oasis du sud de la Tunisie constituent un élément essentiel des systèmes agricoles et alimentaires du pays, notamment pour la production de dattes, et elles soutiennent la vie économique, sociale, environnementale et culturelle locale. Ces agroécosystèmes uniques font face à des menaces majeures, telles que le changement climatique, la dégradation de la qualité et la diminution du volume du système aquifère du nord-ouest du Sahara, ainsi que la désertification. Ils exigent une évolution de l'agriculture qui allie efficacité et durabilité. Deux modèles agricoles dominants coexistent souvent et s'opposent : les oasis traditionnelles et modernes, avec des pratiques, des performances et des compromis distincts, ce qui soulève des défis majeurs en matière de durabilité.

Face à ce besoin de durabilité, l'agroécologie offre un cadre technique, analytique et de gouvernances pertinentes pour orienter l'étude des systèmes agricoles et de la santé environnementale. En tant que paradigme, elle favorise les synergies entre les pratiques agricoles et les processus écosystémiques, renforçant ainsi la capacité de régénération des écosystèmes et leur résistance, tout en améliorant la durabilité à long terme de l'utilisation des ressources.

Cet article propose une analyse comparative des systèmes oasiens traditionnels et modernes à la lumière des 13 principes agroécologiques définis par le HLPE (2019). Les résultats mettent en évidence qu'aucun des deux modèles n'est intrinsèquement durable : les systèmes traditionnels se heurtent à des contraintes en matière de productivité et de gestion de l'eau, tandis que les systèmes modernes accentuent la pression sur les ressources en eau et affaiblissent les équilibres écologiques. Les deux modèles nécessitent donc des transformations ciblées afin de mieux s'aligner sur les principes agroécologiques.

En mettant l'accent sur l'eau en tant qu'élément transversal et crucial des agroécosystèmes des oasis, l'analyse illustre l'importance de cadres institutionnels appropriés pour faciliter les pratiques agroécologiques. Cela est particulièrement visible dans le domaine de la gouvernance de l'eau et dans le cas d'un système aquifère fossile non renouvelable, où les usages durables doivent être intégrés et orientés par les institutions. Le projet gouvernemental PIHOS a mis en évidence les opportunités offertes par une gouvernance adaptative et ascendante pour soutenir le développement durable des oasis.

Cet article présente un exemple de cadre institutionnel et de gouvernance constituant un environnement favorable à la promotion de l'agroécologie et de la durabilité dans les oasis du sud de la Tunisie, en traitant la question des agroécosystèmes dépendant d'eaux souterraines non renouvelables.

Mots-clés : Systèmes agricoles et alimentaires; Développement oasien durable; Systèmes agricoles; Santé environnementale; Gestion de l'eau; Ressources en eau; Equilibres écologiques.

PART 1 OASES OF SOUTHERN TUNISIA: HIGH VALUES AGROECOSYSTEMS FACING FRAGILITIES AND OPPORTUNITIES LINKED TO WATER RESOURCES

Oases have historically constituted genuine hubs of interaction, exchange, circulation and territorial control in Tunisia (Miller, 2007; Carpentier et al., 2017). Today, the regions of Tozeur, Kébili, Gabès and Gafsa, where most of the country's oasis systems are located, remain central to the socio-economic balance of southern Tunisia through agricultural production, employment generation, poverty reduction, territorial cohesion and tourism activities (World Bank, 2020; Carpentier et al., 2017).

From an economic point of view, oases agriculture largely rely on date palm cultivation. In 2021, Tunisia counted more than 5.2 million date palms, including approximately 3.9 million productive trees, of which nearly 69% belong to the high-value Deglet Nour variety. Heavily exported, their production reached 331,500 tons in 2019 – 2020, with exports generating 732 million dinars in 2020 and accounted for over 15% of agri-food exports (STUDI International & GKW, 2023).

Beyond their economic contribution, the oases of southern Tunisia play a major environmental, cultural and social role. Supporting nearly 10% of the Tunisian population, oasis agroecosystems play a key ecological and cultural role (STUDI International & GKW, 2023). Their traditional multi-layered farming systems, combining date palms, fruit trees and understory crops, support a high level of agrobiodiversity while preserving knowledge and water-management practices developed over centuries (Miller, 2007; Carpentier et al., 2017). Beyond their productive functions, oasis landscapes constitute a distinctive component of Tunisia's cultural heritage and tourism identity (Miller, 2007; World Bank, 2020).

However, these agricultural and food systems are increasingly threatened by severe environmental and climatic pressures. Southern Tunisia is experiencing rising temperatures, declining precipitation and increasing frequency of drought episodes associated with climate change. These climatic factors, combined with the expansion and intensification of irrigated agriculture, have induced higher groundwater abstractions of the fossil North-West Sahara Aquifer System (NWSAS) that exceed the least favourable scenarios developed in the 2000s SASS modelling (STUDI International & GKW, 2023; Besbes, 2025). The fragility of oasis systems is further aggravated by desertification processes, degradation of ecosystems, agricultural diseases and the increasing vulnerability of monoculture systems (STUDI International & GKW, 2023).

As environmental pressures increasingly affect water availability, agricultural productivity and ecosystem stability, they are progressively translating into broader economic and social vulnerabilities. These challenges highlight the need for approaches capable of simultaneously addressing environmental sustainability, agricultural performance and institutional governance. Agroecology offers such a framework by examining the interactions between farming practices, ecosystem functions and socio-economic dynamics, thereby providing a useful basis for analysing the future of oasis agriculture in southern Tunisia.

PART 2 THE CONCEPT OF AGROECOLOGY: A REFERENTIAL TO THE SUSTAINABILITY OF OASIS AGRICULTURE

The concept of agroecology aims to improve agricultural practices by aligning production systems more closely with ecological processes and by optimising interactions between agricultural production and ecosystems, enhancing their synergies (FAO 2018; HLPE 2019), like their regenerative capacity. It seeks to reconcile productivity objectives with sustainability, particularly in the context of growing pressures on agricultural systems such as climate change, water scarcity and biodiversity loss.

Agroecology initially emerged as a bottom-up, scientific and technical approach at the farm level. Over time, it has expanded to become a more multi-dimensional and systemic concept, integrating food systems as well as economic, social and cultural dimensions (HLPE 2019; GIZ 2024; EU Commission 2025). This evolution is reflected in international frameworks such as the FAO's 10 Elements of Agroecology (FAO 2018) and the HLPE's 13 Principles (HLPE 2019), which structure agroecology as a holistic and multi-scalar approach to the transformation of agricultural systems.

Agroecology is not a governance tool in itself, as it doesn't provide specific regulatory mechanisms or operational instruments. However, its principles can guide policy choices, public investment, regulatory design and coordination among actors. Their implementation requires implementation through appropriate institutional settings (IFAD 2021). The FAO refers to the governance aspects of agroecology as "enabling environment" (FAO 2018, p.2).

Agroecology relies on territorial processes, co-creation of knowledge and multi-stakeholder engagement, which require structured governance arrangements (FAO 2018; Navarrete Cruz et al. 2024). Studies also show that agroecological transitions depend on coordination across actors and scales and are shaped by different governance models (Navarrete Cruz et al. 2024). More broadly, these transitions are influenced by power relations, institutional dynamics and political choices, which can either enable, constrain or co-opt agroecological approaches (Anderson, C.R. et al. 2020). As such,

agroecology requires appropriate governance frameworks and institutional conditions to move beyond the farm level and be effectively implemented at scale.

In this article, agroecology is used as a conceptual guide to analyse the functioning of oasis agroecosystems and to link technical practices with institutional dimensions. It serves as a referential framework to explore synergies in the pursuit of more sustainable systems. The comparative analysis of agricultural models in the oases of southern Tunisia is structured through the 13 Principles of the High Level Panel of Experts for Food Security and Nutrition: recycling, input reduction, soil health, animal health and welfare, biodiversity, synergy, economic diversification, co-creation of knowledge, social values and diets, fairness, connectivity, land and natural resource governance and participation (HLPE 2019).

This analytical framework also makes it possible to identify institutional weaknesses, gaps and opportunities that affect the implementation of agroecological principles and to highlight the conditions required for their effective scaling.

PART 3 COMPARATIVE STUDY OF OASIAN AGROECOSYSTEMS IN SOUTHERN TUNISIA THROUGH THE LENS OF THE 13 PRINCIPLES

The agroecological assessment of agricultural systems in the arid and semi-arid regions of southern Tunisia highlights a complex systemic transition trajectory. It contrasts the traditional oasis model—whether continental in the Jerid (Tozeur) and Nefzaoua (Kébili) regions or coastal (Gabès)—with modern oasis extensions (particularly in Kebili and Tozeur) (Kassah, 1996; Carpentier, 2021). While the former is perceived as an archetype of socio-ecological resilience, the latter is primarily oriented towards intensive monoculture and integration into the global market. As illustrated in Figure 1, the current regional trajectory is trapped in a "Business as usual" loop characterized by an unsustainable level of water dependence and weakening governance capacities. Moving away from this vulnerability requires identifying explicit transition pathways. This section comparatively evaluates these two systems through the lens of the 13 principles of agroecology defined by the High-Level Expert Group (HLPE, 2019).

3.1 Bio-technical processes: Flows, biodiversity and ecological regulations

The traditional Tunisian oasis embodies the principle of circularity through strict integration of biomass flows. Palm tree pruning residues, by-products from lower-level crops, and manure from oasis livestock (Barbarine sheep or local goats) undergo direct organic recycling (bedding, composting), which maximizes the system's autonomy from input markets (Battesti, 2005). Conversely, the modern oasis in southern Tunisia breaks this cycle. The limited reintegration of plant biomass there imposes a structural dependence on synthetic chemical fertilizers and pesticides, replacing ecological regulation mechanisms with exogenous technological crutches (Kassah, 1996; Marlet & Mekki, 2010).

In the traditional oasis of Chenini (Gabès) or the old palm groves of Tozeur, ecological functioning relies on strong microclimatic synergies (reverse greenhouse effect). The plant architecture allows for natural thermal regulation: the shade provided by the palm reduces potential evapotranspiration (PET), maintaining a humidity level favorable to the intermediate (tree crops) and lower (market gardening) strata (Battesti, 2005). This maintenance of the canopy and the contribution of diverse litter feed the soil food webs. In modern expansions, the geometrization of space and the elimination of underlying strata deactivate these synergies. Direct exposure of Saharan soil to solar radiation induces accelerated mineralization of organic matter and capillary rise of salts, degrading the biological health of the soil through aridification and salinization (Mamou & Kassah, 2002; Marlet & Mekki, 2010). Consequently, as formalized in the transition framework, modern intensive oasis systems display high initial water consumption, making them structurally vulnerable to water table decline.

Agrobiodiversity is the pillar of the functional resilience of the traditional oasis. It combines vertical spatio-temporal heterogeneity (three-stage stratification) and major intra-specific genetic diversity, materialized by the conservation of dozens of common date varieties (Alig, Kenta, Rochdi, Besser)

adapted to different ecological micro-niches (Lasram, 1990; Koohafkan & Cruz, 2011). This biodiversity acts as a primary buffer, generating a higher water-use efficiency per cubic meter. The modern oasis carries out a radical ecosystem simplification through the exclusive monoculture of the commercial variety Deglet Nour. This genetic homogenization eliminates ecological barriers against pests, triggering chronic outbreaks of the palm mite, or the date palm moth.

3.2 Socio-economic dynamics: Diversification, autonomy and relocalization of flows

Agroecological analysis also encompasses socio-economic dimensions, particularly the capacity of agricultural systems to diversify livelihoods, reduce vulnerabilities and contribute to local food systems. Traditional oasis agriculture relies on a diversified production structure combining date palms, fruit trees, market gardening and, in some cases, livestock activities. This diversity strengthens household resilience by spreading economic and production risks while contributing to local food supply and territorial food security (Romdhane, 2008; Koohafkan & Cruz, 2011). In contrast, modern oasis systems are largely specialized in the commercial production of Deglet Nour dates for export markets. While this specialization generates higher economic returns, it also increases dependence on international market fluctuations and external value chains, reducing the adaptive capacity of farming systems (Carpentier, 2021).

The modern oasis, on the other hand, is embedded in impersonal global value chains. By directing all of the environment's biophysical resources (particularly fossil water) to processing plants destined for export, it transforms a nourishing agroecosystem into an extractive enclave, disconnected from the food needs and social values of the local community (Romdhane, 2008; Carpentier, 2021). To counter this trend, the transition pathways must prioritize economic diversification and promote higher economic value and employment per unit of water, rather than expanding physical crop surfaces.

3.3 Political and Governance Dimensions: Knowledge, Shared Institutions, and Equity

The agroecological transition requires governance systems capable of integrating local knowledge, collective action, and equitable resource allocation. In traditional oasis systems, agricultural practices and water management have historically relied on locally developed knowledge transmitted across generations, enabling communities to adapt to arid conditions and manage scarce resources through collective arrangements (Battesti, 2005). However, hydraulic modernization and the introduction of standardized technologies have progressively weakened the role of local knowledge in decision-making processes.

Important differences also emerge in terms of governance. Traditional oasis systems are generally based on collective management institutions, currently organized through Agricultural Development Groups (GDAs), which historically ensured the sharing of water resources and the coordination of agricultural activities. Although many of these institutions are now weakened by declining water availability and aging infrastructure (Marlet & Mekki, 2010), they still provide a framework for collective action. Conversely, modern extension areas are largely characterized by individual investment strategies and private groundwater abstraction, often operating outside effective regulatory frameworks. The proliferation of illegal boreholes, widely documented in southern Tunisia, illustrates the limited capacity to regulate access to groundwater and contributes to increasing pressure on fossil aquifers (Mamou & Kassah, 2002; Carpentier, 2021).

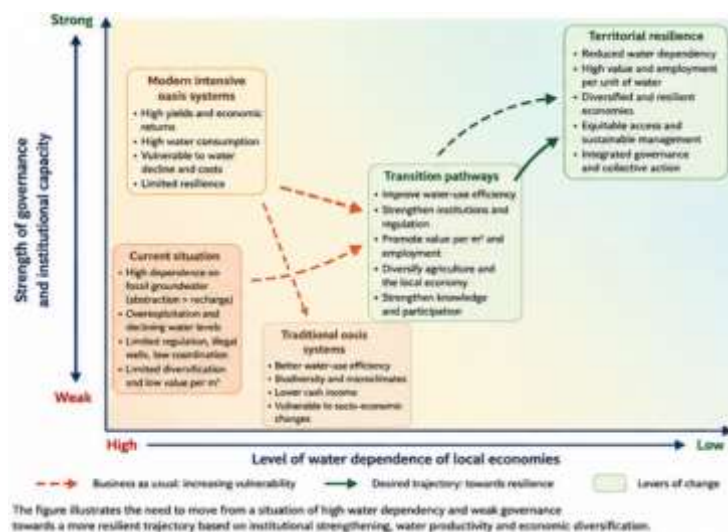


Figure 1. From water dependency to territorial resilience in fossil aquifer oasis systems

These observations suggest that the sustainability of oasis systems depends not only on technical or agronomic improvements but also on stronger institutional arrangements capable of combining local participation, collective action, and effective resource regulation. These governance challenges are examined in the following section through a water and institutional perspective.

PART 4 WATER, INSTITUTIONAL DYNAMICS AND TERRITOTIAL PATHWAYS FOR RESILIENT OASIS SYSTEMS: PIHOS PROJECT CASE STUDY

4.1 Agroecology and sustainability of oases through a water lens

Water is the defining element of oasis systems and a central component of both agroecology and sustainable development. In Southern Tunisia, where agriculture depends almost entirely on groundwater resources, water provides a relevant analytical lens through which to examine the interactions between agricultural practices, environmental constraints and governance arrangements. Additionally, the study of the two main oasis models above highlights important and structural limitations. In both cases, these limitations relate to gaps or weaknesses in governance and irrigation management. Traditional oases rely on collective systems that are often fragile, whilst modern agricultural expansions rely heavily on poorly regulated individual boreholes, contributing to the increasing overexploitation of groundwater resources (Gharbi & Elloumi, 2023; Molle & Closas, 2019). This duality highlights the limitations of current water governance models in arid regions.

In this context, the regulation of water abstraction emerges as a key issue for the sustainability of oases. Research on groundwater governance shows that efficiency gains remain insufficient in the absence of effective mechanisms for controlling abstraction and institutional coordination (Molle & Closas, 2019). Sustainable management of water resources therefore depends heavily on the ability of institutions to regulate access to the resource and to arbitrate between competing uses. This is even more vital in systems relying on non-renewable aquifers.

Beyond the technical aspects, the sustainability of oasis systems also depends on their ability to improve the value generated per unit of water consumed. Research on water management in agriculture highlights the importance of shifting from a focus on land productivity to a focus on water productivity in arid regions (Molden et al., 2007). From this perspective, the challenge is not merely to reduce consumption, but also to promote systems capable of reconciling water efficiency, economic diversification and territorial resilience. These changes in values linked to water, practices and works must be created or enabled by the appropriate institutional setting and regulation.

4.2 Institutional constraints and governance challenges

Water governance in Southern Tunisia is characterised by fragmented responsibilities, weak enforcement capacity and limited control over groundwater abstraction. These weaknesses are reflected in both traditional oasis systems, where collective management structures often struggle to maintain infrastructure and ensure efficient service delivery, and modern expansion areas, where widespread illegal boreholes contribute to unregulated abstraction and increasing pressure on aquifers. Although regulatory frameworks formally exist, their implementation remains insufficient at local level, illustrating the persistent gap between national policies and field realities.

In traditional oases, public irrigation schemes rely on collective management structures that are often dysfunctional, characterised by a lack of infrastructure maintenance, weakened local governance and limited institutional capacity, leading to relatively low levels of productivity. Conversely, modern expansion zones are largely driven by individual initiatives based on private, often illegal boreholes, which allow for rapid intensification but escape any effective control and contribute to unregulated exploitation of aquifers (Molle & Closas, 2019). The proliferation of illegal boreholes is therefore a major issue, observed in many arid regions and identified as a key factor in the overexploitation of groundwater resources (Villholth, 2013). This situation reflects systemic governance failures, notably inadequate monitoring mechanisms, limited enforcement capacity and poor institutional coordination.

Furthermore, although regulatory frameworks for water resources exist in theory, their implementation remains largely inadequate at the local level. The disconnect between national policies and local practices is a well-documented challenge in the literature on water governance, reducing the effectiveness of public action and preventing the emergence of coherent management regimes (FAO, 2010).

These challenges are particularly acute in oasis systems relying on fossil aquifers. Because groundwater resources are finite and non-renewable, sustainability depends on the capacity of institutions to regulate access, monitor abstraction and arbitrate between competing uses. In this context, agroecology provides a useful framework for identifying pathways that improve water efficiency, strengthen resilience and reduce pressure on groundwater resources.

4.3 Insights from the PIHOS project: an integrated analytical framework

The analysis presented in this article draws on work carried out as part of the 2025 PIHOS project (Water Infrastructure Project for the Oases of Southern Tunisia), funded by the EBRD, which combines investment in water infrastructure with technical assistance focused on institutional reform. This project aims to strengthen the resilience of oasis systems by improving access to irrigation water for tens of thousands of farmers, whilst supporting a gradual transformation of water management practices.

In this context, the institutional support study part of PIHOS on which the authors worked⁵ allowed the development of a systemic analysis of the challenges associated with water management. It is drawing specifically on a SWOT analysis aimed at identifying the main obstacles and levers for action. This approach highlights the deeply structural nature of the observed imbalances, linked both to the overexploitation of resources, the limitations of agricultural systems and governance failures.

This approach identified strategic priorities centred on strengthening institutional frameworks, integrated water resources management (IWRM) and improving water productivity. It provides a framework for analysing the implementation of agroecological principles in oasis systems.

⁵ The authors are experts within the consortium Hydroconseil – TCS Environnement, awarded the contract of the Institutional Reform in the PIHOS, from May 2025 to its expected end mid-2026.

4.4 From institutional constraints to agroecological levers: a SWOT-based analysis

The SWOT analysis carried out as part of the project highlights a number of structural constraints that limit the sustainability of oasis systems, but also opportunities that can be harnessed from an agroecological perspective. Among the main weaknesses identified are the overexploitation of water resources, the low efficiency of irrigation systems, institutional fragmentation and the weakness of regulatory mechanisms.

These shortcomings are directly linked to several principles of agroecology and have been introduced above in the comparative study of the two main oasian models. These limits particularly relating to the sustainable management of natural resources, governance and the resilience of systems. For example, the lack of effective regulation of water abstraction is a major obstacle to any improvement in efficiency, whilst the low economic value placed on water limits incentives to move towards more sustainable systems.

Conversely, the analysis also highlights several opportunities, such as the existence of national strategic frameworks (Water Strategy 2050, PAGIRE), the potential for developing unconventional resources, and local initiatives for economic diversification. These elements can be interpreted as levers compatible with agroecological principles, particularly in terms of reducing dependence on resources, diversification and adaptation to local conditions.

This cross-analysis thus enables a shift from diagnosing shortcomings to identifying structural levers for action, highlighting the need to integrate technical, economic and institutional dimensions. It also emphasises that the transition to more resilient systems cannot rely solely on changes in agricultural practices but requires a broader transformation of governance frameworks and development models. This reflects the evolution of the concept of agroecology itself and its expansion into a multidimensional concept that is both practical and aspirational.

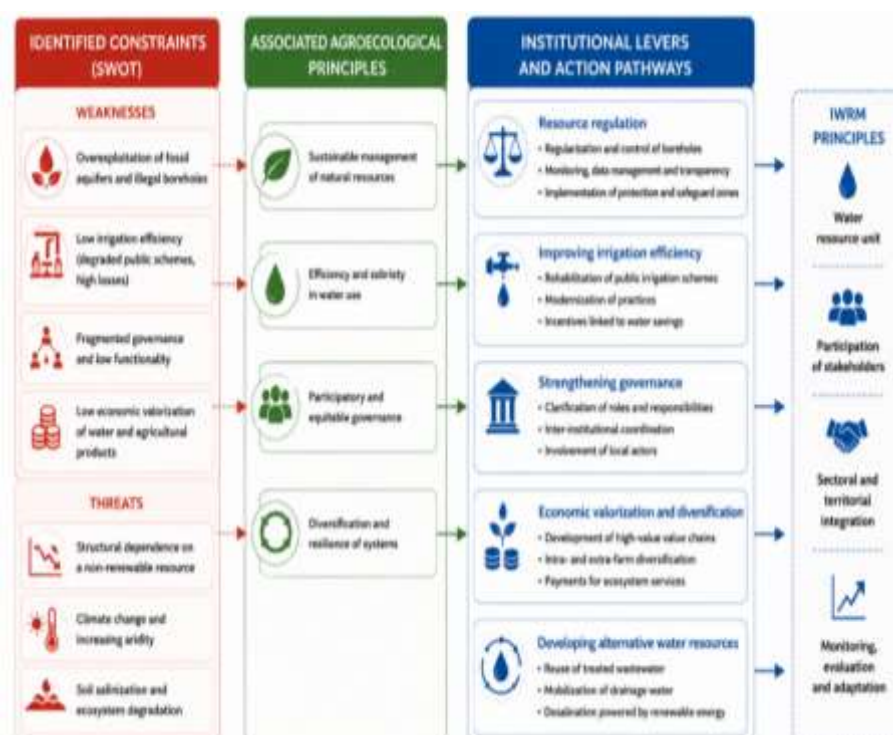


Figure 2. From institutional constraints to agroecological levers: an IWRM-oriented analytical framework

4.5 Operational pathways: aligning institutional reforms with agroecological principles

The following measures are excerpts of the integral and complementary parts of an action plan presented as conclusion from the SWOT analysis presented above. Regulation and economic incentives In the context of fossil aquifer exploitation, the sustainability of oasis systems largely depends on the ability of institutions to regulate groundwater abstraction and align economic incentives with water conservation objectives. In modern expansion areas, where agricultural development has been driven by individual and often illegal boreholes, weak regulation has led to uncontrolled increases in withdrawals. Restoring regulatory capacity therefore requires the regularisation of illegal boreholes, strengthened monitoring and enforcement mechanisms, and the establishment of aquifer protection zones. At the same time, subsidy schemes should be reoriented towards investments that improve water productivity and contribute to measurable reductions in groundwater abstraction. Together, regulatory and economic instruments constitute essential levers for reducing pressure on groundwater resources and guiding agricultural development towards more sustainable trajectories.

Tailoring strategies to different agricultural systems

Transition pathways must be adapted to the specific characteristics of oasis agricultural systems. In expansion areas, characterised by intensive export-oriented production, the priority is to improve water productivity and economic efficiency while limiting pressure on groundwater resources. In traditional oases, the challenge is to strengthen systems that already embody many agroecological principles but remain constrained by economic fragility and institutional weaknesses. Supporting collective management, improving the valorisation of agricultural products, and enhancing local livelihoods are therefore key to maintaining their long-term viability.

Improving the economic value of water through diversification Reducing pressure on water resources cannot rely solely on technical efficiency gains. It also requires a shift in economic thinking, aimed at increasing the added value and jobs generated per unit of water consumed. From this perspective, the diversification of economic activities is a key driver. Processing industries, differentiated marketing channels and oasis tourism can strengthen regional resilience while reducing dependence on water-intensive agriculture.

Developing alternative water resources within a regulatory framework the use of alternative water resources, such as the reuse of treated wastewater, the recovery of drainage water or desalination, can help to reduce pressure on conventional water resources. However, these options must be considered with caution and integrated into strict regulatory frameworks. To avoid rebound effects, these resources should be used as substitutes rather than additions to existing supplies.

Promoting traditional systems through a 'sustainable oasis' label the introduction of a 'sustainable oasis' label could serve as a key driver for promoting traditional oasis systems. By recognising practices that promote sustainable water management, biodiversity and local expertise, such a scheme would help differentiate products in the marketplace, generate further added value and open opportunities in the food and agricultural systems. This type of approach helps align economic incentives with sustainability objectives, whilst enhancing the appeal of oasis regions.

Integrating measures towards agroecology through institutional development, IWRM and regional level Finally, these measures can only produce lasting effects if they are integrated into an adequate institutional framework. This involves strengthening coordination between stakeholders, linking the different levels of management, and establishing monitoring and evaluation mechanisms to enable policies to be adjusted over time.

Similarly to the concept of agroecology with its territorial, bottom-up approach turned multi-dimensional paradigm, these activities, designed in link with field observations and problematics, need to be viewed as complementary, inseparable and in need for a more systemic higher approach. Water management in oases, because of its transversal nature, cannot be considered solely at the level of the individual farm but must be part of a regional and systemic approach.

CONCLUSIONS

The article illustrated through the evaluation of traditional and modern oases as agroecological models that one-size-fits-all models for sustainable agricultural system is not efficient nor desirable.

The results show that the transition to more sustainable systems cannot be reduced to the adoption of a single agricultural model or to the implementation of standardised practices. On the contrary, it relies on a combination of differentiated pathways, adapted to the diversity of agricultural systems and territorial contexts. Traditional oases appear to be systems already partly aligned with agroecological principles, but requiring institutional and economic strengthening. Modern oases, with areas of expansion require above all improved efficiency and effective regulation of water use.

In both cases, technical measures, whilst necessary, remain insufficient in the absence of institutional frameworks capable of regulating access to water resources and guiding behaviour. Good governance is particularly important where agriculture relies on non-renewable resources.

An integrated, systemic and territorial sustainable approach, like agroecology, is necessary for appropriate water management in the oases as introduced. This approach can directly echo the approach of IWRM, that feeds into similar principles.

Agroecology should therefore be viewed as a framework linking agricultural practices, water constraints and institutional dynamics. Especially in a context of non-renewable resource use, the resilience of oases will depend on the ability to implement integrated public policies that promote diversity of practices, regulate water use and improve the value generated per unit of water consumed.

In conclusion, it is evident and crucial that the future of the oasian agrosystems depend on appropriate institutional settings, adapted to the territorial specificities but at a wider interconnected scale than the farm level, to promote more sustainability or values inspired by agroecology, or IWRM in the case of water resources.

This approach opens new perspectives for rethinking agricultural development strategies in arid regions, far beyond the Tunisian case alone.

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