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Drought threatens agroforestry landscapes and dryland livelihoods in a North African hotspot of environmental change

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HIGHLIGHTS

- Drought, environmental changes, and water scarcity intersect in the Atlas Mountains.
- This exerts pressure on Morocco's traditional agroforestry landscapes and livelihoods.
- Wells dry up and irrigation helps some but aggravates many farmers' drought plight.
- New tree stands fall short on providing well-adapted, drought-secure livelihoods.
- Social-ecological fit is crucial for nature-based agroforestry solutions to thrive.

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ABSTRACT

Dryland agroforestry is often hailed as a nature-based solution for rural people's water- and climate-related struggles, yet appraisals of traditional agroforestry practices and interventions in Maghreb countries are scant. In this study, we appraise whether and how agroforestry delivers as a solution to Moroccan farmers' plight with drought. Through an analysis of landscape observations, 75 qualitative interviews, and six group discussions, we show that the region's mountain residents risk losing their livelihoods due to intersecting impacts of failed water governance, maladaptation, and drought. Water scarcity has hampered farmers' production landscapes in recent years, but neither traditional agroforestry practices nor newly planted tree stands provide communities with secure income in times of little rainfall. A key agricultural sector policy – the Green Morocco Plan – incentivized water-intensive tree plantations, which added pressure on groundwater resources as more-affluent farmers built wells. However, it has done little to support most mountain residents in coping with water scarcity or adapting to evolving climate-related risks. Farmers' aspirations and knowledge could offer policy-relevant insights on how to co-create viable livelihoods and plan for sustainable landscape change in the region's tree-crop landscapes. Identified entry points include governance interventions for greater water justice and public spending to tap the sustainable potential of local catchments and establish drought-tolerant crops. Our results underscore the urgent need for regional planning and landscape design in support of North Africa's drought-stricken farming communities. However, without due attention to people's everyday vulnerabilities and resulting water-justice implications, adaptation-oriented tree-planting schemes are misplaced and may well set people off on maladaptive routes.

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1. Introduction

November 3, 2021: A Moroccan farmer waits for rain. When did he last grow wheat? When the soil was moist, village wells were full, and local springs were abundant with water.

> '*I aspire that the drought goes, and the rain falls again. My dream is to see the river flowing and full of water. Then people could farm again, and all the fields, the trees would come back to life.' (Resp. 71).*

> *'Good things happen when there is rain. When there is rain, it will be a good season for everyone. If it is not, it will be a bad season: for people, for the land, for animals. Everyone will be hurt.' (Resp. 66).*

Landscape planning and adaptation stakeholders increasingly look to agroforestry as a nature-based solution to the water- and climate-related struggles of rural people (Albert et al., 2019; Global Center on Adaptation, 2022; Hernández-Morcillo, Burgess, Mirck, Pantera, & Plieninger, 2018; Muthee, Duguma, Nzyoka, & Minang, 2021; Simelton et al., 2021). Droughts are projected to substantially increase throughout the 21st century, adversely impacting rural landscapes and societies (Pörtner et al., 2022). Species and structural changes in terrestrial ecosystems and increasingly frequent climate-related food production losses are already evident (Pörtner et al., 2022). The integration of trees into agricultural landscapes offers advantages in this context given their positive effects on the resilience and productivity of dryland agroecosystems, which billions of people rely upon (van Ginkel et al., 2013).

Farm trees can positively influence temperature patterns and water-cycle processes in dryland landscapes that are subject to climate variability, water scarcity, and frequent droughts (van Ginkel et al., 2013). The mechanisms behind this are manifold (Gassner & Dobie, 2022). Trees protect crops in their understory from sun overexposure and extreme heat. Their roots tap water from deeper soil layers, and their crowns aid soil moisture retention through reduced evapotranspiration by virtue of the partial shade cover they provide. Trees mitigate soil erosion processes and enhance the retention and infiltration of water in agricultural soils, for instance decomposition tree-leaf litter can raise soil organic matter stocks (Gassner & Dobie, 2022). Socio-economic benefits from dryland farm trees include their contribution to diversified household income portfolios and the potential to buffer income shocks, if their productivity is less affected by climate-related stressors than that of annual crops (Hernández-Morcillo et al., 2018).

In the Mediterranean basin, agroforestry practices hold the potential to diminish the adverse impacts of climatic changes and weather extremes and have long prevailed throughout the region (Hernández-Morcillo et al., 2018; Wolpert, Quintas-Soriano, & Plieninger, 2020). This includes terraced fruit-tree gardens and silvopastures such as the Spanish Dehesa and Portuguese Montado in the northern Mediterranean (Cicinelli, Caneva, & Savo, 2021; Plieninger et al., 2021; Sørensen, Torralba, Quintas-Soriano, Muñoz-Rojas, & Plieninger, 2021), as well as community-governed rangelands, oasis systems, and fruit-tree groves (for instance olive, carob, and argan stands with grain and vegetable understories or shaded pastures for grazing sheep and goats) in the southern Mediterranean (Dhaouadi, Karbout, Zammel, Chahata, & Abdeyem, 2021; Leauthaud, Ben Yahmed, Husseini, Rezgui, & Ameur, 2022; Plieninger et al., 2022). The promotion of dryland agroforestry as a nature-based solution to North African farmers' plight with drought thus stands to reason (Global Center on Adaptation, 2022).

The European Union-funded 'Regreening Africa' partnership (Regreening Africa, 2019) and the African Union's 'Great Green Wall Initiative' (United Nations Development Programme, 2023) are but two examples of large-scale agroforestry programs in African dryland landscapes. They promote tree-planting, agroforestry adoption, and farmer-managed natural regeneration techniques in response to increasing climate-related risks throughout the continent's West, Horn, and Sahel regions. Yet, research evaluating the effectiveness of such initiatives – i.e., for whom, in which timeframes, through which social-ecological pathways, and in which agroecological contexts – is still lacking, especially in Africa (Global Center on Adaptation, 2022; Simelton et al., 2021; Woroniecki et al., 2022; Mills-Novoa, 2023). This also holds true for one of the most conspicuous government-driven tree-planting strategies in Northern Africa – the Green Morocco Plan (GMP). This agricultural-sector policy of the Moroccan government, established in 2008 (since succeeded by the 2020–2030 Green Generation Strategy), aimed at stimulating and future-proofing the country's agricultural sector in the context of climate-related adversities (Hajjaj, 2009). Although nearly 438,455 ha of land were planted with trees under the GMP's solidarity agriculture line (Pillar II) (Agency for Agricultural Development, 2023), research evaluating whether the adaptation promise of this type of landscape intervention actually holds true is scarce (Miller et al., 2020; Asedrem, 2021).

The few existing studies touching this question in fact suggest that orchards established under the GMP aggravated farmers' water dependency and exposure to market volatilities (Asedrem, 2021; Elder, 2022; Jacques, 2023; Mathez & Loftus, 2022; Ouassanouan et al., 2022). These studies stress the climate-related sensitivity of Moroccan tree-crop value chains (Verner et al., 2018) and demonstrate date farmers' vulnerability to escalating water-scarcity constraints in the country's oases landscapes (Elder, 2022; Fico & Kenti, 2023). Here, we further this line of evaluative research by focusing on Morocco's High Atlas tree-crop landscapes, which remain understudied. Our aim was to appraise the effectiveness of dryland agroforestry as a nature-based solution to mountain farmers' water-related struggles through a qualitative analysis of the impacts of recent drought and environmental changes on the region's rural communities, traditional agroforestry landscapes, and newly planted tree stands.

Three research questions guided our inquiry:

1. How does drought manifest in the study area and intersect with longer-term environmental changes and socio-technical drivers of water scarcity?
2. How does this affect the region's traditional agroforestry landscapes and local people's livelihoods?
3. How effective are adaptation-oriented tree planting schemes (such as the Green Morocco Plan) in this context, and how are they perceived by local residents?

Our analysis contributes to the literature on nature-based solutions and landscape planning by bringing rural people's perceptions of drought-related landscape changes and agroforestry appraisals into dialogue. It goes beyond existing research on climate-related hazards and water scarcity in North Africa's drylands, as we explicitly link these drivers to impacts on some of the region's archetypal tree-crop landscapes and to policies aimed at securing dryland communities through adaptation-oriented tree-planting schemes (Hajjaj, 2009).

2. Materials and methods

2.1. Conceptual framework

Our framework links concepts from the fields of agroforestry, nature-based solutions, livelihoods, (mal-)adaptation, and social-ecological systems research. *Agroforestry* is the interaction of trees with agriculture and people, 'through the integration of agroforestry practices in land-use systems at plot, farm or landscape scale' (Sinclair, 1999, 2004, p. 27). *Nature-based solutions* are 'interventions that: (1) are inspired and powered by nature; (2) address (societal) challenges or resolve problems; (3) provide multiple services/benefits, including biodiversity gain; and (4) are of high effectiveness and economic efficiency' (Sowińska-Świerkosz & García, 2022, p. 1). *Livelihood activities*, *strategies*, *assets* and *systems* refer to rural people's choices and modes of making a living, and to the means that they may lose or mobilize to withstand crises and reach their goals (Department for International Development, 2001).

The *maladaptation* concept describes interventions that are 'counter-productively increasing vulnerability rather than reducing it' (Schipper, 2022, p. 1), while interactions between social-ecological system attributes and institutions that lead to successful resource governance outcomes are captured by the concept of *social-ecological system fit* (Epstein et al., 2015).

2.2. Study area

The study area was the northern part of Tifni (31°43′27′'N, 6°58′17′'W), a rural commune with ~11 800 residents (in 2014) (Haut-Commissariat au Plan, 2023b) located in the foothills of the Central High Atlas Massif (Fig. 1). Villages in three adjacent communes (Imlil, Sidi Boulkhalf, and Aït Blal) and the city Demnate were also included (see 2.3). Demnate is the second-largest city in Azilal province, home to ~29 400 residents (in 2014) (Haut-Commissariat au Plan, 2023a), hosting administrative and public services (hospitals, secondary schools, etc.), regional markets, and public transport hubs. Remittances and income from seasonal, salaried, or self-employed work are the backbone of people's livelihood systems.

The study area spans an altitudinal gradient from the lowest point of the Tissilt River Gorge near Demnate (at ~900 m) to the terraced fields of Aït Blal (at ~1600 m). Most farmland in the northern part of Tifni commune is situated between 1000 m and 1100 m. The landscape's soils are sandy clay loams and clay loams (USDA Texture Class), and land is rather flat, but in places steeply sloped (>25°) and then often terraced (Innovative Solutions for Decision Agriculture (iSDA), 2022). Smallholder farming remains common, but primarily as a secondary livelihood activity or *'pastime'* of the elderly (Resp. 55). Only a handful of agricultural entrepreneurs and poor community members devoid of other options engage in full-time farming. Demnate has a hot-summer Mediterranean climate (Köppen-Geiger classification: Csa), with an average yearly temperature of 14.1 °C and 628 mm of annual rainfall (Climate-Data.org, 2023). Recent analyses of Moroccan meteorological data indicate a positive trend for temperature extremes (warm days and nights) in the region over the period of 1964–2016 (Driouech et al., 2021).

2.3. Qualitative interviews and group discussions

This study draws from 75 individual, semi-structured interviews and six group discussions (GD) (n = 3 to 13 participants) with residents of the study area. All interviews were conducted in Tamazight (the local language), by the second author, from October to November 2021. The recruitment of research participants aimed at capturing a wide range of perspectives on the topics studied while reaching saturation on key interview themes. We began by selecting respondents from a list of households residing in the northern part of Tifni commune, prepared by a local key informant. The list specified the names of household heads and their primary occupation, as well as characteristics of interest to us (e.g., if the potential respondents had a migration history, experienced economic poverty, or were widowed).

After first speaking to respondents from households with a migration history (as this was one of our primary research themes), we expanded the scope of our recruitment strategy to capture perspectives contrasting those that had already been obtained. Through an iterative process of interviewing, transcribing, and selecting new interviewees, we captured accounts of the following respondent groups: i) younger and older community members; ii) male and female farmers; iii) local trades- and businessmen; iv) people engaged in migration or seasonal work; v) residents of nearby villages, with better and worse access to irrigated farmland; and vi) residents of Aït Blal (representing a more mountainous commune) (c.f. Fig. 1).

Qualitative content analysis software (MAXQDA) was used to transcribe, organize, and code all interviews through a combination of deductive and inductive techniques. Interview passages were first assigned to broad, pre-defined categories matching the study's research questions and key themes. Subsequently, inductive coding served to

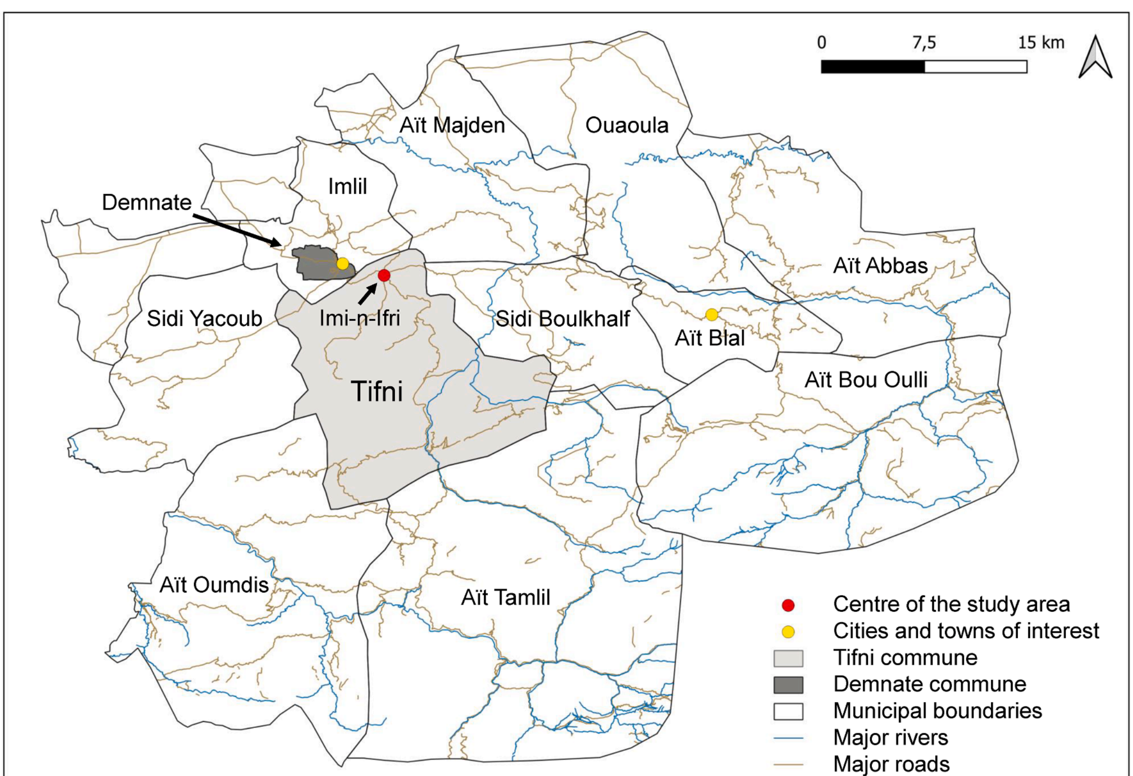


Fig. 1. Map of the study area. Mapping software and data: QGIS, OpenStreetMap, MapCruzin, QGIS.

identify sub-themes, for instance, statements about different land-use/-cover categories and patterns of respondents' divergent or shared perspectives and experiences.

2.4. Landscape observations

In addition to interview data, our study incorporates landscape observations made by the first and second authors during daily reconnaissance walks in the study area over two months, taking note of the diverse annual and perennial crops and aromatic herbs that farmers grew. Several hundred irrigated and rainfed agricultural plots were inspected in a radius of ~10 km around the center of the study area (the UNESCO Geosite Iminifri), along with local shepherds' off-farm rangelands, respondents' villages (except those of seasonal workers who came from afar), and local rivers, groundwater sources (wells and natural springs), and irrigation channels.

Five main land-use types were identified (Fig. 2): i) irrigated farmland; ii) rainfed farmland; iii) recent plantations (olive and almond trees); iv) shrublands and forests; and v) residential land. Agroforestry practices were integral to all of these land-use types, but they were differentiated by characteristic species and landscape features (Table 1). Agro-industrial inputs (seeds, fertilizers, pesticides) were used on all cropland types, dependent on the plot size, quality, and the households' affluence. Land tenure was often customary, and plots were used by individual households or extended family groups, under input and crop-share agreements.

Irrigated farmland (igran) is managed traditionally, using draught animals to plough and human labor to harvest annual and perennial crops. Most crops are consumed at home, with surpluses sold in local markets, except for olive fruit, which is commonly sold per tree to local aggregators or via dedicated regional markets.

Rainfed farmland (bour) is used to grow grains for human consumption and as livestock fodder, with grains often interspersed with almond and olive trees. Farmers plough using traditional means or pool monetary resources from relatives to hire tractors and seasonal workers.

Recent plantations of olive and almond trees have been established on former cropland by private investors, and as part of the Green Morocco Plan from 2008 onward.

Shrublands and forests are used by shepherds to feed their animals ahead of Eid Al Adha (a religious holiday during which livestock is slaughtered) and during lean periods. The most commonly owned animals are sheep, alongside a few cows, donkeys, rabbits, chickens, or goats.

Residential land features small home gardens. Much of this land can no longer be irrigated and has been repurposed as restaurant grounds (near Iminifri).

3. Results

3.1. Manifestations of drought, environmental changes, and water scarcity

3.1.1. Manifestations of drought

Multiple manifestations of drought (Table 2) had disrupted communities' wellbeing and caused great personal hardship for our respondents in recent years: *'We all suffer from the drought. No more sources, no more water in the rivers, and also in the wells. […] 'The three wells that the people in the village built are all dry now. They are abandoned. The last well dried out two years ago.'* (Resp. 42). These challenges were prevalent across the region: '*The drought affected all of Morocco, and our village is only one example of the other villages around'* (Resp. 42).

2015 was often named as the year of the drought's onset, but estimates ranged from two to twenty years back. This ambiguity was linked to respondents' dissimilar exposure and vulnerability to drought-related hazards. Those who primarily engaged in rainfed cropping and livestock rearing saw their agricultural livelihood options dwindle earlier than community members with secure access to surface water, traditional irrigation systems, or wells. '*If you depend on the rain, it's like gambling'* is how one respondent put it (Resp. 45).

Interviewees from two of the most drought-affected villages lacked access to surface water sources, as former streams and springs in their surroundings had run dry. They were thus at acute risk of potable and domestic water shortages as their communities' wells had also all but dried up. Other villages closer to springs on mountain hillsides or in river valleys were relatively better off. One of these communities even witnessed a modest well-building boom, fueled by residents' desire to keep

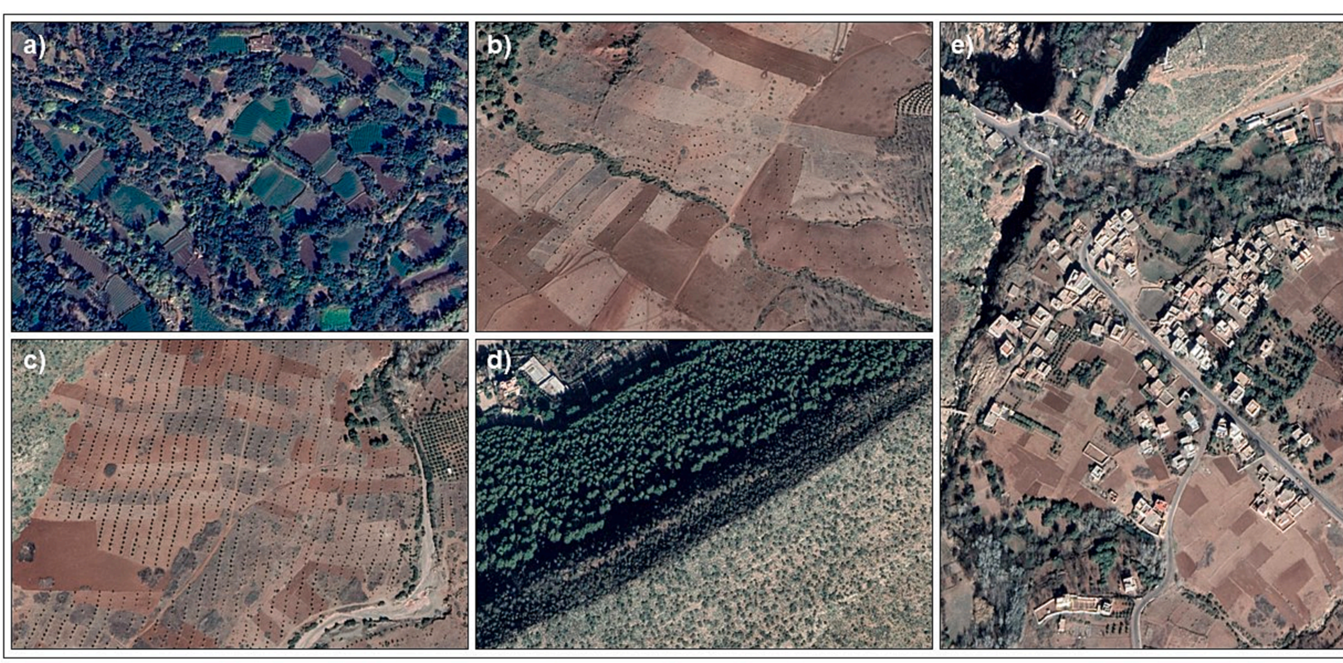
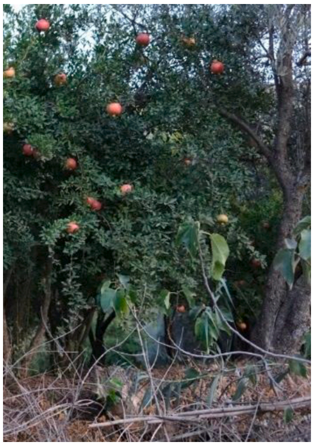
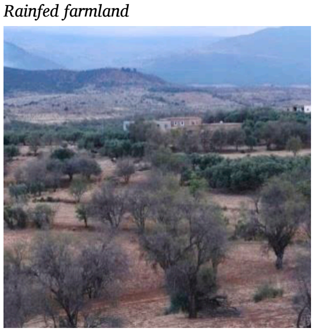


Fig. 2. Remote sensing imagery depicting examples of the study area's main land-use types: a) irrigated farmland; b) rainfed farmland; c) recent plantations; d) shrubland and forests, and e) residential land. Images: © Google Earth Pro, 2022 Maxar Technologies, 2022 CNES/Airbus.

Table 1
Main land-use types in the study area.

Land-use type	Characteristic features and species
Irrigated farmland 	Terrain and landscape elements: Numerous small, terraced plots of farmland, situated on sloped land, downhill from springs and adjacent to natural rivers and streams. Trees are cultivated along plot boundaries or widely spaced across fields (especially old, traditional-variety olive trees). Soil mounts around olive trees for traditional basin irrigation are common. Irrigation: Water is directed to fields via concrete and clay channels. Spring water access is regulated through customary inter- and intra-community water-governance practices. Woody perennials: Olive (*Olea europea*), pomegranate (*Punica granatum*), fig (*Ficus carica*), carob (*Cerotonia siliqua*), quince (*Cydonia oblonga*), grape (*Vitis* spp.), ash (*Fraxinus dimorpha*), walnut (*Juglans regia*), apple (Malus domestica), pear (*Pyrus* sp.) Crops: Alfalfa (*Medicago sativa*), maize (*Zea mays*), onion (*Allium cepa*), carrot (Daucus carota subsp. *sativus*), tomato (*Solanum lycopersicum*), paprika (*Capsicum annuum*), lentil (*Lens culinaris*), green bean (Phaseolus vulgaris), fava bean (*Vicia faba*), artichoke (*Cynara cardunculus* var. *scolymus*) Aromatic herbs: Oregano (*Origanum* sp.), basil (*Ocimum* sp.), wormwood (*Artemisia* spp.), maidenstears (*Silene vulgaris*), saffron (*Crocus sativus*)
Rainfed farmland 	Terrain and landscape elements: Variously sized plots of plane or moderately sloped farmland on mountain-adjacent plains. Trees are cultivated in small groups (old, traditional-variety olive trees) or widely spaced across some (but not all) fields. Sloped land is often terraced, with trees growing upside of traditional drystone walls. Some fields are affected by woody encroachment. Many almond trees die back or are covered in lichens. Irrigation: Cultivation is rainfall-dependent; annual crops are sown at the onset of winter rainfalls from November up until January and harvested in June and July. Woody perennials: Olive (*Olea europea*), almond (*Prunus dulcis*) Crops: Barley (*Hordeum vulgare*), wheat (*Triticum* spp.), fava bean (*Vicia faba*) Aromatic herbs: Thyme (*Thymus satureioides; Thymus pallidus),* lavender (*Lavandula dentata*)
Recent plantations 	Terrain and landscape elements: Variously sized plots of plane or moderately sloped farmland on mountain-adjacent plains. Trees are widely spaced across rainfed farmland, previously used for annual crops (wheat, barley). Irrigation: Most plantations were established by contractors as part of the government's Green Morocco Plan – these are rainfall-dependent or irrigated from water gallons where feasible. A few plantations are owned by agricultural entrepreneurs – these are regularly flood- or drip-irrigated with water from private groundwater wells. Woody perennials: Olive (*Olea europea*) – foreign varieties, almond (*Prunus dulcis*) Crops: Barley (*Hordeum vulgare*), wheat (*Triticum* spp.)
Shrublands and forests	

(*continued on next page*)

Table 1 (*continued*)

Land-use type	**Characteristic features and species**
	Terrain and landscape elements: Juniper-cacti shrublands and pine forests on steeply sloped hillsides. Pine trees grow regularly spaced, managed for recreation and hillside stabilization. Juniper, cacti, and aromatic herbs grow naturally interspersed – serving shepherds as rangelands. Woody perennials and cacti: Pine (*Pinus* sp.), juniper (*Juniperus* spp.), ash (*Fraxinus* sp.), cacti (*Cactaceae*) Aromatic herbs: Thyme (*Thymus satureioides; Thymus pallidus*), lavender (*Lavandula dentata*)
Residential land 	Terrain and landscape elements: Community settlements on plane or modestly sloped land. Walnut trees (in Tifni and Aït Blal) grow among houses and across formerly irrigated vegetable gardens; in Iminifri, the latter now serve as restaurant grounds. Cactus pear, poplar, and oleander encroach formerly irrigated cropland, where springs have dried up or discharge has diminished. Woody perennials: Walnut (*Juglans regia*), cactus pear (*Opuntia* spp.), poplar (*Populus* sp.), oleander (*Nerium* oleander)

farming and financed with remittances from relatives abroad.

'My brother has lived in Algeria – for more than 12 years now' explained one respondent (Resp. 71). *'Once the river had less water, he was the one who financed the well'*, he elaborated, highlighting how intersectional factors such as households' economic affluence shaped the drought's impacts on individuals at least as much as the climatic hazards and the biophysical characteristics of the surrounding landscapes. A less well-endowed interviewee drove this point home: *'Only people who have money still go farming in this region […], because there are only a few who can build wells'* (GD 2).

3.1.2. Perceived longer-term environmental changes

The depletion of springs and drying up of rivers and others surface water sources were the environmental changes that concerned respondents the most (Table 3). Older community members recalled how earlier droughts had disrupted their livelihoods, for instance by causing harvest shortfalls: *'In 1987, there was a very bad drought season that lasted 2–3 years. There was almost no rain.' (Resp. 12)*. Yet, the current drought was described differently – as being entangled with longer-term environmental change processes. Many interviewees perceived these changes to reinforce societal shifts that led to a de-agrarianization dynamic in the region's tree-crop landscapes, which had been ongoing for some time.

3.1.3. Drivers of water scarcity

Despite the centrality of climate-related drivers, a broad range of socio-technical factors also exacerbated respondents' water insecurity. These fell into four interlinked categories: hydrogeological and technical; financial; governance-related; and cognitive/behavioral factors (Fig. 3).

The most prominent of the *hydrogeological and technical factors* was the ever-increasing depth of the water table. Some wells were already close to 200 m deep, yet required further deepening every two to three years. Even private well owners, whose number had increased in in recent years, struggled in some villages as their wells replenished slowly and provided no more than drinking water, and only every other day. Some of the poorest households even lacked access to the most basic technical amenities, such as piped drinking water. They could not afford the connection fee that their local provider charged and were upset about the lack of a municipal sewage system, as wastewater polluted the surface source that they relied on to meet their domestic water needs.

Financial factors included high costs of building or restoring and deepening existing wells. Authorities' authorization fees were prohibitive for many. Others were simply too capital poor to invest at all. The poorest could not even pay for connecting to the municipal domestic water-supply system. Finally, respondents also bemoaned an outdated water-sharing arrangement at the interface of financial and governance-related concerns, which was agreed upon decades ago with downstream communities and Demnate city under terms that have since become outdated. Downstream water users now farm less and no longer pay their agreed-upon dues in harvest shares. Yet, their water needs increase unabated.

Governance-related factors included excessive processing times for residents' water-related subsidy applications and their requests for support from agricultural extension agencies (e.g., to build wells or install drip-irrigation systems). At times, these requests remained entirely unacknowledged. Many lacked titles for their land or owned agricultural plots that were too scattered to justify the individual construction of wells. Others aggravated the situation by continuing to withdraw irrigation water from private wells. *'Wells destroy the underground reserve of water […] and this is not fair – that one person benefits and the others, no'* exclaimed one respondent (GD 2). However, collective water-infrastructure investments were seen as challenging, primarily because of concerns related to fairness in the absence of supportive public regulation: *'Imagine – I have ten trees, and the other guy has 100, and another 1000',* said one respondent. *'How can we set a well? It is really hard. It is something that the authorities should think about, not people.'* (Resp. 13).

Cognitive/behavioral factors included decreasing value assigned to the region's farming landscapes and traditions, which seemingly led respondents to disengage from collective land stewardship and management activities such as the joint maintenance of irrigation channels. Other frequently mentioned factors were the ceaseless irrigation and the establishment of new water-intensive tree crops despite acute water insecurity affecting the region's agroforestry landscapes.

3.2. Impacts on traditional agroforestry landscapes and livelihoods

3.2.1. Perceived impacts on traditional agroforestry landscapes

The confounding impacts of drought, longer-term environmental changes, and water-scarcity severely disrupted respondents' land-based livelihood activities in the study area (Fig. 4). They faced substantial production losses, for example declining yields from their olive trees and the dieback of hundreds of almond trees.

Farmers' *irrigated farmlands* were least affected, at least where regular flooding schedules could be upheld. Nonetheless, large tracts of terraced land on the edges of irrigated perimeters dried out. Feeder sources and irrigation channels in these areas ran dry and stream flows dwindled, with tree-crop, vegetable, and fodder yield losses mounting in consequence.

Table 2
Manifestations of drought in the study area.

Drought type and manifestations	Quotations	Respondent ID
Meteorological drought		
Lack of snowfall	*'The last year that it was snowing here was ten years ago. The snow is one of the big sources of underground water.'*	14
	'[…] when it snowed the last time – 10 years ago, it was only a few centimeters, and it only lasted for two days. It was not like before – when it could be a layer of 20–30 cm that could block people's door.'	23
Limited rainfall	*'The village suffers from the drought season, and most of the water sources are dry and the rain was too little during the last three years.'*	15
	Before, there was enough water here and a lot of good things. People lived only for farming. Since the time when the electricity was installed – that was the time since when the rain has gone.'	19
Hydrological drought		
Reduced streamflow	*'The whole farming village depends on the river of Iwaridane. The last five years it has not been like before. There is less water.'*	20
Springs run dry	*'The main [spring] is Aghbalou – but the last two years the water has become really less, and not enough for the people, because they used to use it for drinking water, and also to farm.'*	34
Wells run dry	*'Now there are almost eleven wells in this village. But without water –nowadays. We build the wells starting from 2010 – but the wells now have no water.'*	23
Agricultural drought		
Dying trees	*'The village is suffering from the drought season – the trees are dying. Olives and almonds. The sources have been gone for more than 20 years now.'*	43
Socio-economic drought		
Reduced food supply	*'The traditional farming doesn't really help people anymore, in a way that they can provide as much food as they did before. When there was enough water, they used to have their own grain, olives, almonds – for the whole year.'*	31
High fodder prices	*'The drought is affecting the landscape, farming, water to drink, sheep – we used to have many sheep, but we ended up selling them last year because we could not afford the fodder for them. The fodder in the market is so expensive, so we sold them.'*	34

Table 3
Longer-term environmental changes in the study area.

Environmental changes	Quotations	Respondent ID
Snow cover loss	*'Normally, the snow stays in the mountains from November, until June. […] That was before 2010. […] nowadays you can see the snow but only in the wintertime, but after its less. Before it was too white – the snow was surrounding the whole area'.*	20
	'Before - especially in the 70s and 80s, the snow stayed until the summer - on the mountains. And sometimes, our houses were blocked from the snow in the wintertime.'	23
Decreasing rainfall	*'The weather is changing – there is less water, less rain'*	10
	'The rain started to fall less from 2000, and from that time – from 2000 to 2015 people started to farm less. From 2015 it got even less. From 2000 to 2015 we still had rain at times – although unregularly. Some years may be bad but then the next one would be good.'	33
Drying rivers	*'The river – Tizgui – it used to flow […] 30 years ago. When I was a young guy, the river never stopped. Now it has been 30 years ago that it stopped. It still flows when it rains but 30 years ago there was always water there […]'.*	18
	'The water from the riverbed that the village depends on has stopped flowing 30 years ago'	42
Depleting springs	*'This was the main source for water to drink, kitchen, to wash clothes, and to irrigate the land. There used to be a lot of water, and sometimes the water would flood the fields, and flow over, and get out of the trench, but now it is a lot less.'*	12
	'Between the 80s and 90s the sources started to dry out. And they dried fully in the beginning of the 2000 s.'	48
Surface water and vegetation loss	*'When I just moved to the village — 30 years ago - there was more water and green fields and now everything is gone.'*	1
	Before, only ten years ago, it was snowing during the winter time - a lot - and the snow could last two months in the hills, and the water was flowing from up the mountains, to water all the fields down. And the hills were much greener.	GD4

Rainfed farmland ceased to serve as a basis for cereal cropping and post-harvest livestock ranging. All but the most obstinate older farmers stopped sowing annual crops, as they lost more than they gained when labor and cash were invested in the absence of rain. A widespread dieback of almond trees on rainfed land was attributed to the drought, an unknown disease, and insufficient arborist care.

The fate of *recent plantations* was species-dependent. Many almond saplings succumbed to the drought, whereas young olive trees persisted but delivered no noteworthy crop as farmers lacked means for their irrigation.

Shrublands and forests did not show obvious signs of damage but provided less fodder than before. This challenged pastoralists, who drastically reduced their flocks in response to surging fodder prices, dwindling profits, and a need to mobilize assets to cover their everyday living costs.

Despite these dire impacts, not all activity in the region's traditional agroforestry landscapes stalled. *'We still farm* […] *because we still have some water in the channel'*, explained a river-adjacent farmer (Resp. 45). Yet, even where irrigation helped, lack of rainfall was seen as a threat to tree vitality: *'The olives, carob, and almond trees need rain. This rain could wash […] the sickness off the trees. So even if you irrigate the trees, the rain is something important.'* (Resp. 16).

Elsewhere, interviewees made more futile attempts to maintain their natural assets: '*A few people of the village try to water their trees, by using the source. They take their donkeys and try to bring water to irrigate the trees, but it is not really a practical way'*, explained one interviewee. *'People just give up in the end. Especially for us – we have more than 1000 trees – so how can we do it? It's not practical.'* (Resp. 35*)*. Nonetheless, one of the region's few water-secure farmers confirmed that good olive and almond harvests were entirely within reach for some, as long as the trees were irrigated once every 10 to 20 days.

3.2.2. Perceived effects on livelihoods and coping strategies

Respondents' coping strategies in the face of drought were manifold. Some entailed changing land-based livelihood activities, such as adopting less water-intensive crops (e.g., green beans on formerly irrigated land), using various irrigation techniques (new wells, drip irrigation, barrels), and reducing their livestock flocks. Yet, the most common shift was into non-farm activities, including construction work, local day labor, and temporary work requiring migration (Fig. 4). *'Since the drought season, people are migrating more to find new jobs. Some of them, they come back during the harvest and planting time. Some – they don't'*, recapped one respondent (Resp. 38). Another hinted at a self-reinforcing dynamic playing out between farm-labor shortage and out-migration:

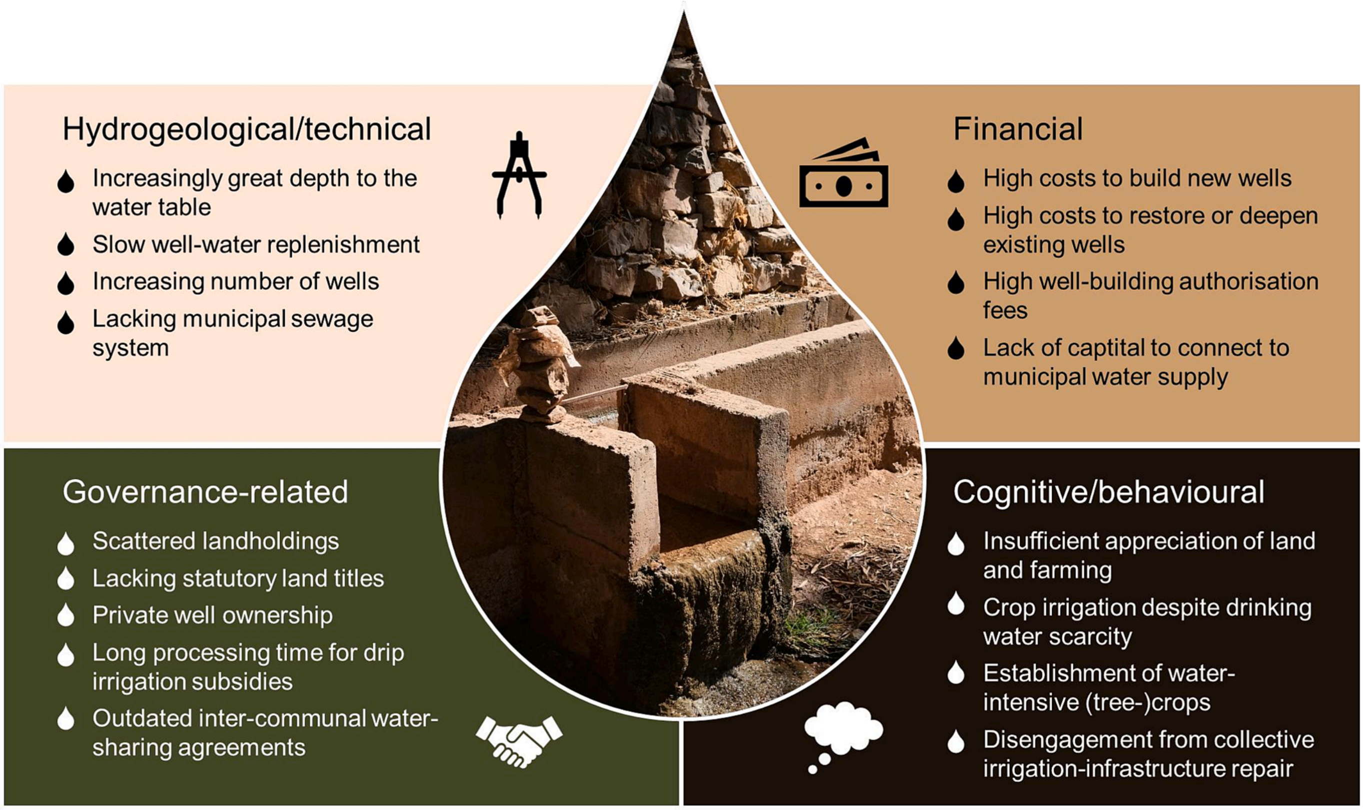


Fig. 3. Interlinked socio-technical drivers of water-scarcity arising in four domains: i) hydrogeological/technical; ii) financial; iii) governance-related; and iv) cognitive/behavioral.

'*People don't farm as they did in the past. Because of the drought season, and less labor – because most of the people are migrating. All of my friends are working in different jobs out of Iminifri, in the construction or tourism sector, factories, and other jobs.*' (Resp. 30).

Although prevalent, most saw labor migration as a necessary rather than desirable livelihood choice. One respondent likened migration to '*a fact that no one can avoid*', for instance. '*Look around you, what do you see?*', he said. '*Nothing. Only dead trees – or close to dying, dry rivers – there is no future here for young people. They have to leave – one way or another.*' (Resp. 15). Another respondent exclaimed: '*If it rains, people would farm again – for sure. They are very attached to the land. The only thing that keeps them away from the land is a lack of rain. So, migration is the best way to make a living.*' (Resp. 16). Nonetheless, migration was not for everyone. '*The land needs men*', reasoned an older famer: '*it's like animals or other creatures. They always need people to take care of them. I was born as a farmer and I will die as one.*' (Resp. 18).

Beyond livelihood effects in the narrow sense (i.e., disruption of respondents' customary ways of making a living), the drought evoked emotional burdens too. It has taken a toll on people's motivation, trust in farming, and outlook on life. '*People lost confidence in their land*', said one respondent. '*They need to take care of a lot of things – children, health care, transport, electricity, food. And the land cannot provide all these needs anymore.*' (Resp. 37). Explaining why the drought had such profound effects, an older woman reasoned: '*The rain is the power that pushes people to be in the farm, to be more hard-working*', (Resp. 66). '*It can heal the land, the animals, and even the human being [...] it [the rain] is a mercy – not only water coming from the sky*', added another respondent (Resp. 45).

3.3. Local perspectives on adaptation-oriented tree-planting schemes

3.3.1. Disparate engagement pathways, eligibility, and experiences with the Green Morocco Plan

Respondents' heterogenous perspectives on adaptation-oriented tree-planting schemes that may help them withstand droughts – such as the Green Morocco Plan – were shaped by their disparate material assets and social identities. No respondent spoke unequivocally positively about the policy's implementation in the study area. Respondents' views on the Green Morocco Plan's success, associated benefits, and potential for improvement varied with their paths of engagement, eligibility, and experiences with the policy (Fig. 5). Three principal pathways of engagement with this intervention stood out: i) as a local government employee; ii) as a tree-planting contractor or employee; and iii) as a potential smallholder beneficiary.

A representative of the first pathway declined to comment on the plan, saying he was '*not into that [...], not really into politics.*' (Resp. 12). However, a former contractor shared nuanced reflections; his company had planted approximately one million olive trees, primarily elsewhere in Morocco, for which he '*got a big amount of money.*' (Resp. 9). This enabled him to later invest in the hospitality and tourism sector, which he saw as '*a business that is social work*', as it benefitted not only him but also provided a living for poor rural people, whose challenging life circumstances he knew from earlier in his life. He thought that the GMP was a good plan, as much had been achieved, including the planting of many trees. Yet, he remarked that the promotion of species with high water needs '*just creates problems, as it uses up the water resources.*'

The employee of another contractor corroborated that many people benefited from the government's agricultural-sector policies. But he also witnessed local farmers struggling with the recent die-back of GMP-financed olive and almond trees, as few could irrigate their trees. The

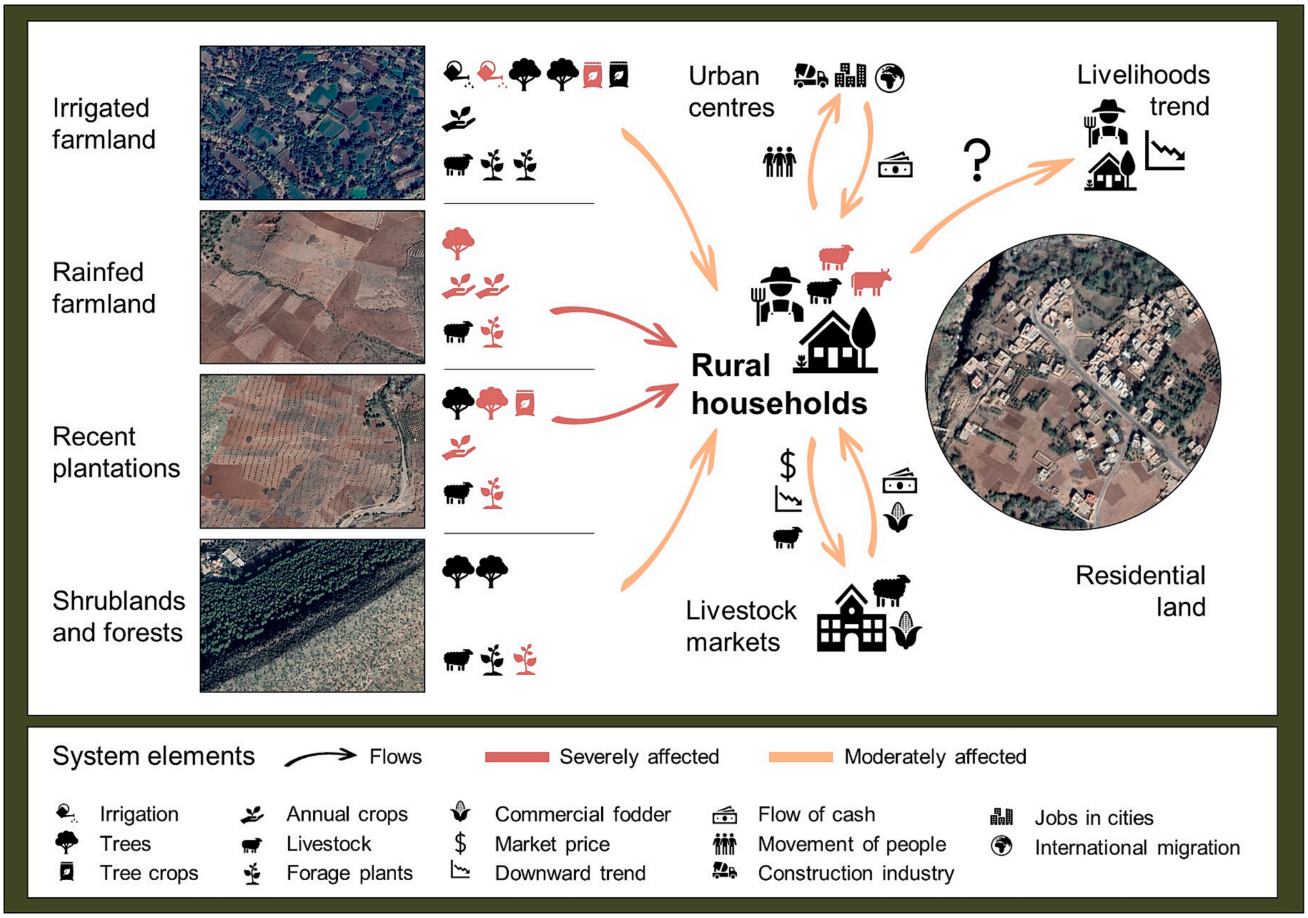


Fig. 4. Impacts of drought and water scarcity on farming systems and livelihoods in the study area. Images: © Google Earth Pro, 2022 Maxar Technologies, 2022 CNES/Airbus.

policy worked *'for people who have money'* he mused, i.e., those who could buy land and receive support from the authorities (Resp. 40). Yet, his own situation was different, as *'this kind of project needs a lot of time – and for me – I don't have savings or money to survive.'* (Resp. 40).

Most smallholders who were potential beneficiaries likewise voiced critique. One thought that the *'plan was a good idea, for people who already have land'*, but not for his landless family, so he did factory work instead (Resp. 37). Other barriers, linked to respondents' eligibility and engagement decisions, also stood in the way of deriving benefits. Households with irrigated rather than rainfed land were ineligible. Others opted out. *'Most people from the village did not want to get trees'*, explained one resident (Resp. 34), a perspective backed by another who recalled bad outcomes of similar initiatives in the past. Others lacked knowledge about their eligibility, though one respondent positively remarked: *'one did not use* [need] *to apply. People came and asked for people with land, and if they were interested in planting these trees'* (Resp. 3). Yet, others said they *'prefer the old* [traditional variety] *olive trees'*, and found their engagement meaningless as too few trees had been handed out; *'we did not benefit, as we only got three to ten – maximum, trees.'* (GD 4).

3.3.2. Implementation insights and suggested improvements

Respondents who participated in the scheme had mixed experiences with the policy's implementation, but nearly all had thoughts on desired improvements or alternatives to share. A respondent with a positive outlook stressed that *'they got the plants for free'*, with large landholdings yielding olive crops of up to one metric ton (Resp. 3). *'Everyone in the village who got* [had] *land benefitted'*, said another (Resp. 42). Yet, both respondents quickly recognized that *'the results will be seen in the future, as it's kind of a new plan'* (Resp. 3), and that irrigation needs were a challenge: *'Last year we planted almond trees instead of olives, as some of the olives already died. It did not really work from the beginning. They did not really grow, as they need to be irrigated.'* (Resp. 42).

One respondent criticized the local implementation of the Green Morocco Plan for failing to care for the trees in the longer run. He saw the plan as an example of the region's water-related challenges at large, saying: '[it was] *a good initiative at the beginning. But they did not really plan for the long term'*. […] *'It's like giving birth to your son, and throw him out on the street, and say – go and grow – deal with yourself.* […]. *'They* [the authorities] *spent a lot of money. They should have thought about that there will be a drought season. They should have found a new source of water – and thought about how to keep all the land irrigated.'* (Resp. 13). For this respondent, the path to sustainable landscape futures in the High Atlas entailed tapping new water sources, agricultural commercialization, and low-interest smallholder loans for local job creation, aimed at benefiting everyone. Others proposed more drought-resistant perennial species such as carob and aromatic plants – high-value crops that state-funded rainwater-harvesting schemes may be able to sustain.

Other visions for better landscape design entailed different intervention types, as not all post-implementation concerns were linked to water scarcity. Two additional drivers of perceived tree loss were grazing sheep and theft: *'The sheep can destroy the trees'*, explained one farmer (Resp. 13). Another recounted a GMP-related conflict between a neighboring village and his own: *'This bour* [rainfed] *area is really far away from* [our village]*, at the border of* [the other] *village. It is used by people from* [the other village] *to take care of their sheep. So, they damage some of the olive trees, and others – of the small olive trees – were stolen.'* (Resp. 34). To address these challenges, one respondent proposed that

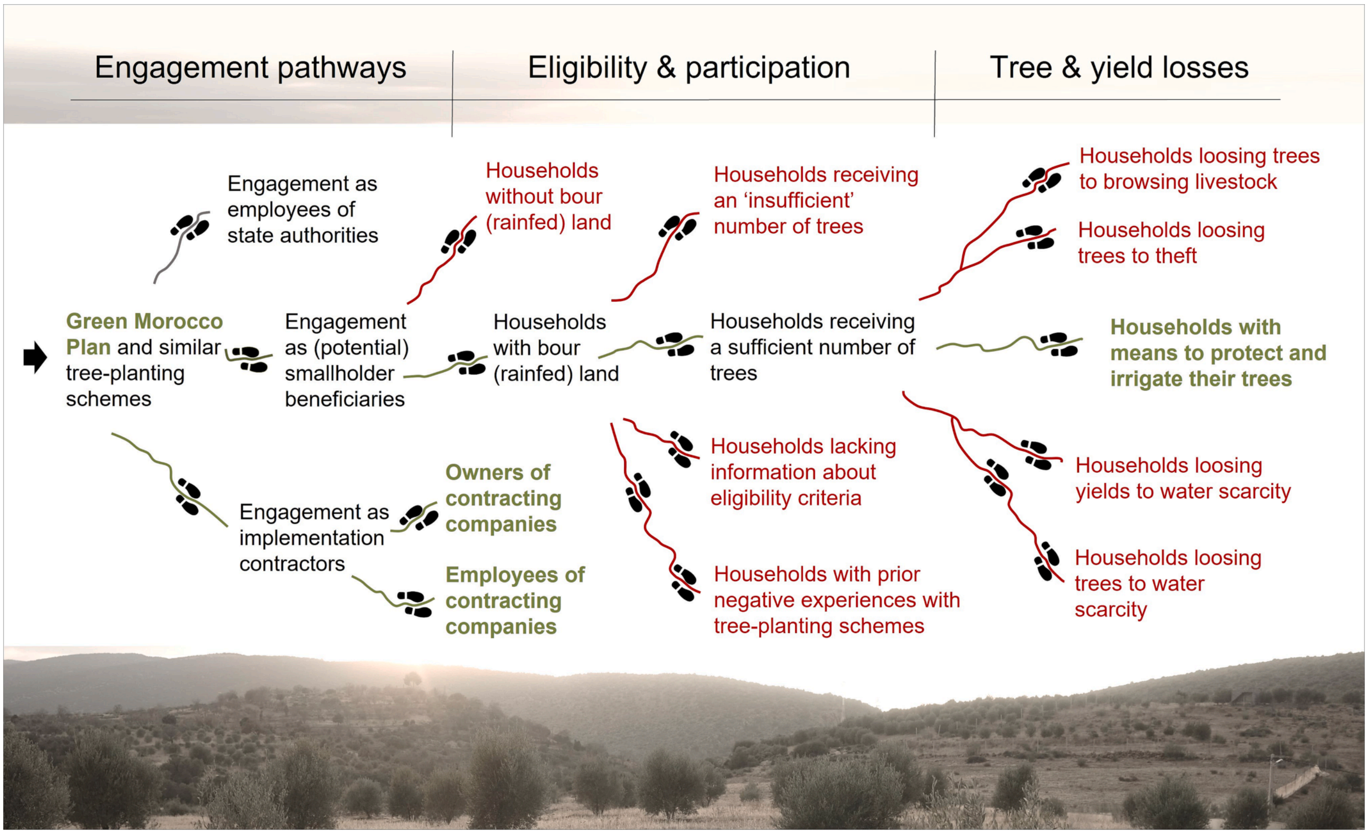


Fig. 5. Illustration of respondents' pathways of engagement, eligibility, and experiences with the Green Morocco Plan (GMP): Green paths symbolize positive outcomes for engaged individuals, whereas red paths indicate challenges encountered.

'the authorities should hire a "security agent" for each 100 ha – to look after the trees – irrigate the trees with drip irrigation' (Resp. 13), while another suggested that *'we should have someone there to look after the trees, especially at night.'* (Resp. 34).

4. Discussion

To appraise whether and how dryland agroforestry constitutes a solution to North African farmers' plight with drought, in this study we engaged with High Atlas communities and their everyday water- and climate-related struggles. We encountered rural people in a tight spot. Their agrarian livelihoods falter as the land dries out. Years of drought, environmental changes, and socio-technical drivers of water scarcity play causal roles in this dynamic, concurrently reenforcing livelihood shifts to commercial farming, migration, and off-farm work. Here, we draw upon our findings to reflect on three questions relevant to policy. First, who is responsible for addressing water-related risks in our study area, and how could this be done? Second, which dryland futures may enable rural ways of life and traditional agroforestry landscapes to persist? Third, do tree-planting schemes represent a solution to smallholders' water related struggles, or a case of maladaptation playing out?

4.1. Addressing water-related risks: Who is responsible and what options exist?

Untangling how drought, environmental changes, and socio-technical drivers of water-scarcity intersect in Morocco's tree-crop landscapes is important for impeding 'deflection of responsibility' and for identifying adequate response strategies (Raju, Boyd, & Otto, 2022, p. 2). Through a livelihood lens, our findings underscore the extent to which North African smallholders already suffer the effects of inter-annual climate variability and foreshadow the potential future impacts of human-induced climatic change.

Our results demonstrate a need for decisive adaptation support for mountain communities, as well as for enhanced action to meet ambitious greenhouse gas reduction targets and halt further global warming. Climate change is a global challenge that local stakeholders cannot tackle on their own. Yet, drought-related hazards only trigger disasters where they concur with vulnerable communities (Raju et al., 2022), and socio-technical drivers of adverse environmental changes affecting North African dryland landscapes, such as irrigation-driven groundwater depletion and water scarcity, can be addressed at local and national scales.

Research participants' concerns about the lack of support for alleviating water-related challenges and injustices in the study area – caused by overexploitation of groundwater resources by better-off households in addition to climatic drivers – point to misdirected policy priorities and foregone opportunities to alleviate pressure on drought-affected communities. For instance, one manner would have been to work with and govern in the interests of marginalized rural people who lack the means and political power to cope with such hazards and to challenge the unequal distribution of water resources on their own (Ennabih, 2020). Ennabih argues that 'Morocco's water scarcity is deeply linked to the way water is used in irrigation', and calls for a paradigm shift under which water- and agricultural sector policies should prioritize smallholders' food security, fair water (re-)allocation, and equitable rural development (Ennabih, 2022; 2020, para. 2). Our findings similarly point to improved extraction planning and regulation, targeted irrigation- and adaptation-related extension services, and timely financial support to water-insecure households as levers for more sustainable and just water governance outcomes in the High Atlas.

4.2. Dryland futures: Which ways of life and agroforestry will persist?

Our results show that many drought-affected households struggle to sustain livelihoods based on just their trees and land. Irrigation enables some to continue their farm activities, albeit at a reduced scope. Many others lack alternatives to seeking off-farm work as crop yields falter and hopes for an impending turnaround become clouded by exceedingly dry aquifers and a persistent lack of rain. A noteworthy feedback dynamic that our research revealed is that migrants' material remittances contribute to an escalation of irrigation-water extraction and widening water inequalities in the study area as farmers use the money to finance wells.

These insights resonate with photojournalistic work on Morocco's oasis systems documenting how century-old palm groves in Tinghir Province die back 'during desperately dry times' (Elshamy, 2022, para. 4). Residents' traditional agroforestry practices cease to provide a living, triggering outmigration in consequence (Elshamy, 2022). Similarly, to our respondents, some oasis farmers cope with technical fixes, motorized wells, and drip irrigation technology (Elshamy, 2022). Yet, it is apparent that it will require more than tree planting, greater water justice, and a stop to 'pumping races' (Petit et al., 2021, p. 2) to viably sustain rural ways of life and agroforestry traditions in the North African drylands.

Drought played a critical role in driving people off the land because their crops perished without sufficient rain (Kmoch et al., 2022). Exceptionally dry years thus accelerated the dynamic of land abandonment and point-wise commercialization that has been long underway (Ziyadi et al., 2019), in which semi-subsistence farming communities integrate into the market economy and peoples' cash needs and livelihood aspirations change. It appears to be high time for an inclusive engagement of land-sector stakeholders in deliberate partnerships and genuine co-creation processes (Puskás, Abunnasr, & Naalbandian, 2021) to generate a broad portfolio of sustainable landscape and livelihood futures for the region (Ziyadi et al., 2019). Transformative, solution-oriented research practices (Albert et al., 2019; Mertens, 2021) could be one cornerstone of such an approach, which could also draw from existing practices of development and civil-society actors in the High Atlas. Examples include workshops that empower rural women through self-discovery and programs for increasing revenues of rural artisans, cooperatives, and female entrepreneurs (High Atlas Foundation, 2023; Moroccan Biodiversity and Livelihoods Association, 2023; The Anou, 2023).

Landscape futures in which traditional agroforestry provides enough value from conventional crop sales and landscape products (García-Martín et al., 2022; García-Martín, Torralba, Quintas-Soriano, Kahl, & Plieninger, 2021) to meet local communities' evolving financial needs through the 21st century are hard to imagine for our study area. Only a privileged few – namely those with large land holdings, conducive capital, and buffers for coping with income shocks – may build secure livelihoods on farming alone and in the face of daunting climate-related hazards. However, many additional households could arguably derive a partial living from the region's diverse biocultural landscape values. For instance, the beauty and tourism potential of the different land-use systems could be valorized through targeted support that addresses current sectoral challenges such as a lack of marked trails, public toilets, and deficient waste management. Farmers' contributions to safeguarding biodiversity, cultural heritage, and critical watershed functions by means of their traditional land-use practices could further be rewarded through innovative funding mechanisms (van Ginkel et al., 2013).

For such a strategy to succeed, it should build on context-sensitive adaptation approaches (Sinclair & Coe, 2019) and an agricultural-sector policy turn away (Ouassanouan et al., 2022; Zouiten, 2022) from incentivizing commercial crops that rely on regular irrigation, such as olives and almonds (in the first years after planting) in our study area or watermelon in the Drâa Valley (Bossenbroek, Ftouhi, Kadiri, & Kuper, 2023; Fico & Kenti, 2023). Morocco's rich biocultural heritage – including mountain farmers' centuries-old (but now often semi-abandoned) agroforestry landscapes and the Imazighen's (indigenous people of the Maghreb region) traditional ecological and technical irrigation-related knowledge, social capital, and agency – could instead serve as anchors for socially just land-sector policies and adaptation pathways (Jacques, 2023; Marks, Bayrak, Jahangir, Henig, & Bailey, 2022; Montanari, 2012; Ouassanouan et al., 2022; Ziyadi et al., 2019). Policy actors could further draw inspiration from systematic efforts to establish diversified tree-based bio-economies, as in the argan sector in southern Morocco's drylands, while ensuring that new programs account for identified mechanisms to distribute derived benefits more equitably, e.g., through shorter market linkages (Santoro et al., 2023).

4.3. Tree-planting schemes: A case of maladaptation playing out?

Rather than prioritizing innovations to revitalize mountain farmers' traditional tree-crop landscapes, substantial public funds have been spent under the umbrella of the Green Morocco Plan to establish new tree stands throughout Morocco, including in our study area (Mathez & Loftus, 2022). By capturing local perspectives on this land-change process, we sought to appraise its adaptive effects and associated livelihood outcomes. Our results indicate that the initiative fell short of meeting its objectives, at least to date and in our research context. Large tracts of rainfed cereal farmland have been converted to tree stands as per the Green Morocco Plan's intent, but failed to deliver substantial enhancements in food and social security to drought-affected households (Hajjaj, 2009). These findings beg the question of whether tree-planting schemes can generally be interpreted as a nature-based solution (Sowińska-Świerkosz & García, 2022) to rural people's adaptation needs, or if they rather represent a case of maladaptation (Schipper, 2022) playing out.

The landscape intervention we investigated met some – but not all – defining characteristics of a nature-based solution. It can be interpreted as being 'powered by nature' (Sowińska-Świerkosz & García, 2022, p. 2), where an expansion of tree-cover nominally served as a lever to harness adaptive benefits for rural farmers. It is also aimed at solving environmental, societal, and economic challenges, but these were not successfully addressed; far from all households received trees, and those who did could not rely on them as a secure income source. The stands do provide multiple services and benefits and they contribute to a diversification of farmers' production systems, so biodiversity gains may be claimed. Yet, this is not a given, as biodiversity outcomes of this landscape intervention will depend on how intensively the trees are managed and which resultant cascading agrarian changes may be triggered in the long run. The effectiveness and economic efficiency of the intervention are certainly questionable, as indicated clearly by farmers' dissatisfaction and accounts of perishing trees and haphazard planting practices (Kmoch et al., 2022).

Our case study provides learning points for the implementation of Morocco's current Green Generation Strategy, the newly adopted EU-Morocco Green Partnership 'Terre Verte', and for other African nations planning to follow Morocco's policy model (e.g., Guinea and the Republic of Côte d'Ivoire (Asedrem, 2021)). Insufficient engagement with the causes of vulnerability, for instance, is a common driver of maladaptation (Schipper, 2022). In our case, the tree-planting solution was founded on a broad-stroke framing of mountain smallholders as comparatively unproductive, poor farmers who waste water on growing cereals (Mathez & Loftus, 2022). According to this modernization logic, their vulnerability arises from a stubborn adherence to 'traditional' farming practices that may be resolved by the Green Morocco Plan's export-oriented production focus (Mathez & Loftus, 2022). By that, the design intervention was ignorant of smallholders' very own priorities and vulnerability perceptions (linked to social conflicts, environmental barriers, and socio-technical drivers of water scarcity), with negative consequences for the projects' longer-term legacy and perceived success (Mills-Novoa, 2023). Another pitfall to avoid is the frequent appendage of adaptation aims to development projects (Schipper, 2022), such as the 'tick-box' addition of environmental sustainability concerns to the Green Morocco Plan that Mathez and Loftus criticize (2022, p. 13). This illustrates that tree-planting policies, without meticulous fitting to smallholders' social-ecological circumstances and concerns (Epstein et al., 2015), risk leaving communities worse off – despite their doubtless potential as a solution to dryland people's water-related struggles.

5. Conclusion

As the adverse landscape impacts of climate-related hazards and water scarcity in North Africa become increasingly harder to ignore, it becomes critical to question the development interventions that are being framed as landscape-level solutions for mountain farmers, and whether – and under which circumstances – such claims hold. In this study, we engaged with rural peoples' everyday experiences with drought to establish whether and how dryland agroforestry represents a nature-based solution to their water- and climate-related struggles. We conclude that dryland tree planting does not offer a simple solution to mountain farmers' plight with drought.

Tree-based interventions certainly play a key role in adaptation strategies for North African smallholder communities. However, our research indicates that existing pressures on traditional agroforestry stands, as well as contextual options and barriers to the establishment of new tree orchards, need to be well-understood if adaptation-oriented tree-planting strategies are to secure the region's biocultural landscapes and the livelihoods of dryland farmers. The Green Generation Strategy signals (at least on paper) a widening scope of Morocco's agricultural-sector policy agenda away from its formerly narrow focus on commercial tree planting towards paying greater attention to social concerns and youth-related indicators. Our results support this trajectory and indicate a need for even wider cross-sectoral policy design and landscape planning to encompass the entire trees-society-water nexus at which rural people's water- and land-use related challenges play out.

Three tentative paths forward for landscape governance and planning can be deduced from the results of this study. First, it is high time to address mountain communities' water- and climate-related struggles, as water-governance failures and drought impacts push North African smallholders' livelihoods to the brink. Improvements are needed in efforts to harness scarce water resources and in the implementation of governance interventions that ensure their fair distribution, to the benefit of all community members.

Second, desirable landscape changes should be proactively envisioned and co-created together with the region's residents. Their ways of life are shifting, and new options for sustaining their livelihoods and the region's agroforestry landscapes must be found. This could entail prioritizing value-chain investments for drought-resilient perennials that local farmers aspire to grow, such as carob or medicinal and aromatic herbs. Tourism developments could complement this path if they open niche markets for farmers' products and capitalize on the cultural heritage values provided by diversified agroforestry landscapes and the Imazighen communities' traditional agro-ecological knowledge. However, the associated risks of increasing pressure on scarce water resources would require careful navigation.

Finally, there is little room for top-down policy approaches in the region if dryland adaptation strategies are to be just and viable. Instead, we encourage genuine engagement with rural peoples' everyday vulnerabilities, agro-ecological knowledge, and agency in order to develop landscape design solutions that enhance communities' resilience, foster sustainable landscape trajectories, and fit appropriately in the local context.

CRediT authorship contribution statement

Laura Kmoch: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Aimad Bou-Lahriss:** Conceptualization, Investigation, Writing – review & editing. **Tobias Plieninger:** Conceptualization, Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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