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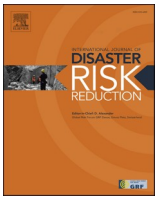

Unpacking drought impacts and adaptive strategies in Morocco – perspectives from small-scale farmers

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ABSTRACT

Droughts in North Africa are increasing in frequency and severity. The most vulnerable include small-scale farming communities and the associated small businesses with wide-ranging impacts and demands on local communities, food production, water allocation, and energy requirements. Our solution-orientated study supports the mitigation of impacts and the management of droughts in two case study areas within Morocco. A 2-day workshop was conducted to engage with local farmers in Settat and El Jadida to better understand the drought impacts and associated adaptive strategies. A Fuzzy Cognitive Mapping (FCM) approach was used to actively engage and interact with the farmers and to gain an understanding of the interconnections between drought, coping mechanisms, adaptation strategies, and issues to their livelihood and as seen through their experiences. The perspectives give new insights into where the policy interventions for the most impact in the system might be.

1. Introduction

The challenges of the Anthropocene are complex and multi-dimensional, and drought is no exception. An estimated 55 million people are directly affected by drought every year although the impacts are not evenly felt, with developing countries suffering the most harm [1]. Vulnerability to drought and conversely, the capacity to cope and adapt, arises from a complex interaction of social, economic, technical, environmental, and hydrological factors. Indicators are often used to measure these factors resulting in a vast and rich literature as indicators, and combinations of indicators are explored, often to better understand resilience and vulnerability to drought [2]; [3,4].

This paper reports on our study of drought indicators with small-scale farmers in Morocco. Agricultural areas in Morocco face significant challenges due to the increasing frequency and severity of dry spells. In these areas, water management becomes even more

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critical, as inadequate irrigation practices can exacerbate soil degradation and reduce crop yields [5]. Key crops like wheat, barley, legumes, vegetables, citrus fruits, and olives are particularly vulnerable to water stress, which can lead to lower productivity and reduced quality. Moreover, drought conditions can intensify the competition for limited water resources, making it harder to balance the needs of both crop and livestock farming, especially in regions where cattle and sheep farming, including dairy production, are essential economic activities [6]. The combination of unsustainable water usage and poor soil health under drought conditions further threatens long-term agricultural viability [7]. Two agricultural regions in Morocco were chosen - Settat and El Jadida, which are becoming increasingly drought-prone [8]; [9].

The study forms part of the wider Management of Disaster Risk and Societal Resilience (MADIS)[3] project where 36 drought indicators were identified from the expanding literature and evaluated with expert input gathered on their useability and importance [10,11]. This study extends the MADIS project by integrating the experiences of at-risk farming communities to understand the interconnections between drought indicators to form cascading impacts or to identify which indicators represent the best policy leverage points. Along with Morocco, farming communities in case study areas in South Africa and Turkiye were also chosen. This paper is the second paper, following the publication of the results in South Africa [12].

From the list of 36 indicators as recommended by the MADIS project, a total of 22 were shortlisted for the Moroccan context, of which 11 were used in relation to impacts of drought and 11 in relation to adaptation. Fuzzy Cognitive Mapping (FCM) was deployed in the workshops with small-scale farmers. The ability of FCM to visualise a complex system and its linkages is of interest to this study where the connections between drought indicators are explored. FCM was chosen as a methodology to draw on the experiences of farming communities and map the potentially complex relationship between drought indicators and enable those relationships to be visualised. The resulting maps also enable new ways of looking at indicators; indicators are not viewed as static but as an influence on other indicators or by other indicators.

Fuzzy Cognitive Mapping (FCM) is a valuable tool for understanding and visualizing the complex interactions in agricultural systems, particularly in regions affected by drought. Once a map is prepared it can enable the simulation of various scenarios to predict the potential outcomes of interventions, such as modifying irrigation techniques or introducing drought-resistant crop varieties or identifying priorities as features that drive the system. This helps in making informed decisions aimed at improving productivity and sustainability in challenging conditions [13]; [14]. The insights generated by FCM highlight key areas where interventions can have the most substantial impact, contributing to mitigate the complex adverse effects of drought and enhancing resilience.

Two workshops with agricultural communities were organized using FCM to identify the various possible interconnections between drought indicators. The composition of working groups for the development of FCM is essential to ensure diversity of perspectives and model accuracy. Notably, whilst women make up 43% of agricultural labour in small scale farming in developing countries, a disparity in terms of rights, equality, and empowerment remain [15]; [16–18]. Female participation is linked to continuing efforts to bridge the gender gap [18] but it still tends to be overlooked in policy generation including in Morocco [19]. Ensuring that the female farming voice is heard, was an important consideration in participant selection for this study.

This paper addresses a gap in the current drought indicator literature as it explores the potential value of drought indicators, not as static, individual entities but within a system, and having influence over each other. By looking at the indicators a different way, the paper explores whether new insights can be drawn in terms of what is driving or central to a system – and so what indicators could be prioritised. This systems approach in turn recognises the complexity of drought, its causes and impacts. The research questions ask what drought indicator 'maps' can tell us about what is most 'important', looking firstly at what is driving adverse impacts of drought and secondly, what can support coping and adaptation to drought. This paper analyses the literature on drought indicators, impacts, and adaptive strategies, and applies this to the drought context in Morocco, as outlined in Sections 2 and 3. For readers less familiar with the FCM approach, the FCM methodology modified for use in the farmer's workshops, is set out in Section 4. The results from the FCM workshops are addressed in Section 5. The discussion in Section 6 brings the data sets together for evaluation. The conclusion in Section 7 summarises the key issues and points for future research.

The paper supports Sustainable Development Goals 2 (Zero Hunger), 5 (Gender Equality), 6 (Clean Water and Sanitation), and 15 (Life on Land) (SDGs: [20]).

2. Moroccan context

Agriculture is a strategic sector of the Moroccan economy. The contribution of the sector into GDP is about 12% for the year 2023 [21]. In terms of employment, agriculture remains the main provider of jobs, followed far behind by the other economic sectors. This situation is more profound in rural areas, almost three quarters of the working population earn their income from the food industry (i.e., agriculture, forestry, and fishing) [22]. Thus, agriculture plays an essential role in the country's food security, the stability of rural populations, the fight against poverty, and its sustainable development is crucial to Morocco.

A large part of Morocco is arid and desert. Irrigation currently uses 86% of water resources [23]. Access to water resources is highly irregular every year, with increasingly recurrent and intense droughts. Water resources are also unevenly distributed across the region with rainfall characterized by decreasing gradients from north to south and from west to east. Some regions receive 600–700 mm per year, while others receive less than 100 mm/year of rainfall [23]. For farming communities, the connection between water, energy and food is a key consideration in a drought context, for example in relation to energy requirements for irrigation or crop selection.

[3] Management of Disaster Risk and Societal Resilience (MADIS) project is funded by Belmont Forum and UKRI-EPSRC, grant no. EP/V006592/1, under the project name: Theory of Change Observatory on Disaster Resilience – TOCO-DR.

Morocco is a country that is heavily dependent on energy import. The share of renewables in the energy mix is increasing, with a share target of 52% by 2030, in terms of the installed capacity [24]. In parallel, the country aims to reduce energy consumption by 20% through a national energy efficiency strategy. Agriculture is one of the four sectors that are considered energy-intensive, which accounts for 7% of final energy consumption. The national strategy targets the reduction of agriculture energy consumption by 13% by 2030 through different sub-sectors, such as irrigated agriculture, dairy industry, cold storage, arboriculture, greenhouses and nurseries, post-harvest processing (packaging), and livestock farming [25].

Agriculture in the Settat and El Jadida regions (Map1) is characterized by a mix of subsistence farming and large-scale commercial operations.

Key crops include cereals such as wheat and barley, along with legumes, vegetables, citrus fruits, and olives. Livestock farming, particularly cattle and sheep, is vital to the local economy, with dairy production being a significant industry. However, the agricultural sector faces several challenges, including recurring droughts, soil degradation, and water management issues, which threaten the sustainability of farming practices in these areas [26]. Addressing these challenges will be critical to ensure long-term agricultural productivity in these regions.

The selection of Settat and El Jadida was intentional to capture distinct regional experiences with drought within Morocco. Settat, located inland, has a semi-arid climate and is characterized by rainfed agriculture, making it highly sensitive to precipitation variability. In contrast, El Jadida, located on the Atlantic coast, benefits from relatively more stable climatic conditions and mixed agricultural practices. The socio-economic structures also differ – Settat exhibits a stronger reliance on subsistence agriculture, while El Jadida reflects more market-oriented production. These differences provide a valuable basis for comparative analysis of local perceptions and adaptive strategies to drought, even though we acknowledge the limitation of not including other agro-ecological zones such as the arid south or mountainous regions. The rationale for this is that the areas chosen are most likely to suffer the greatest changes in terms of climate and weather patterns and where adaption is most needed. Future research will aim to incorporate such diversity for broader generalizability.

3. Literature review

There is a vast and growing body of literature from diverse fields and perspectives addressing drought risk and indicators, reflective

Map 1. Settat and El Jadida, Morocco, Map created using ArcGIS software by Esri. (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview).

of the complexity and seriousness of the issues surrounding drought and its impacts. To focus on recent themes in a Moroccan context, the literature review pays particular attention to drought risk and farming in Morocco over the last 3 years.

Economic impacts of drought are a focus of two studies, one addressing immediate market pressures [27] and the second taking a longer-term view of labour market impacts [28]. The Belhami et al. study [27] explores the connection between livestock productivity and meteorological drought using Standard Precipitation Index (SPI) rainfall data and surveys with farmers. The study notes the importance of agriculture and livestock to food security. The cascading impacts from the onset of drought can be visualised through the connection between meteorological drought and the increase of straw bale and fodder prices, increased mortality of livestock and reduced fertility, farmers selling livestock to reduce expenses, and the consequent collapse of livestock prices. It notes the increased vulnerability of small-scale farmers, although there is no distinction between male and female experiences. Although it makes connections between market response and drought, it does not provide explicit policy recommendations or suggests levers for policy interventions. Looking at wider trends in the labour market, the World Bank Group study on climate shock and job displacement in Morocco, notes that with severe and prolonged drought, share of employment in agriculture decreased significantly with impacts felt up to five years later [28]. The specific policy recommendations are limited but it does note the heterogenous effects of climate injustice on informal workers, women, and younger age-groups in the labour market.

An example of water management and ecosystem focus is seen in the paper by Benabbderrazik et al. [29] noting the increasing threat of drought to agricultural production and livelihoods. It focusses its attention on water demand and exploitation of the decreasing groundwater table. It uses system dynamic modelling to put forward policy scenarios addressing tomato production in Morocco with attention to the potential impact of desalination and water re-use schemes. It notes that in some instances the impacts of drought are not yet being felt because the groundwater is still available, albeit is a diminishing resource with unsustainable coping mechanisms of deepening wells and increasing pumping. Although crop choice is not explicitly dealt with, the subject matter should prompt questions over the extent that some crops are by nature unsustainable and unsuitable for certain locations, yet choice driven by the market or policies. The vulnerabilities of small-scale and female farmers are not explored in depth.

The degree of complexity is expanded further when considering water trading and life cycle assessments while importing or exporting high water demand products (e.g. Ref. [30]). It can be noted how a complex web of policies is required to manage drought risk and the potential complexity of market forces, behaviour, governance, and incentives.

In looking specifically at the web of government policies, the literature review by Ongoma et al. [19] does not focus upon small-scale farmers directly but instead on the wider climate change adaptation strategies within Morocco including drought and desertification. It provides useful grounding information on the policy frameworks in the country encompassing water, energy, and food. As a study it is generally more descriptive than analytical in its commentary although notes the need for more mainstreaming of gender and youth issues in the development of government policy.

In contrast to noting the top-down governance mechanisms, are the lived human experiences during drought through the qualitative and participatory photo-essay by Kmoch et al. [31]. The study gives voice to the experiences of individuals within the agricultural sector who have experienced drought showing communities in a '*system that is literally fuelled by water*' (Kmoch et al. [31], p. 591). As a study it brings home the issues faced by communities; although it does not in itself suggest policies or interventions for resilience.

Drawing these recent studies together, the complexity of the issues that could be focussed upon in addressing drought risk is evident, along with their variety, ranging from ecosystems and water management [29] the lived experience of communities [31], long-term impacts on the labour market [28], immediate economic shocks [27], the complexity of government policies [19], and so on.

Each of these studies focus on a particular field of interest and allow for in-depth discussion on those narrower issues. What is missing are comprehensive yet context specific policy recommendations, including for vulnerable groups and women. The studies reviewed, therefore, provide some recent themes emanating from the Moroccan context, which can be cross-referred with wide-ranging drought indicators. This study starts to grapple with that complexity and look at how more comprehensive advice can be given to policymakers drawing upon a broad range of indicators.

The focus of attention of this current study becomes addressing how those indicators can start to capture the complexity of drought indicators and their interconnectivity. This may be an effective way to support policymakers in decision-making, whilst taking a broad range of factors into account.

4. Methodology

The methodological approach used in Morocco has been used in all three jurisdictions (South Africa, Morocco, and Turkiye) (see Ref. [12]). In all cases the workshops with the farming communities use FCM to map the interconnectivity between different drought indicators. FCM is a modelling tool which can gather qualitative data to form quantitative data, using people to define the variables and relationships in a system and map their connectivity [14,32]. The concept of cognitive mapping is credited to Axelrod [33] with cognitive maps being visualised as 'mental models' that show the links between nodes of an, often complex, system or problem [34]; [35]. The later 'fuzzy' addition to cognitive maps is credited to Kosko and refers to the weighting of those linkages in a range from 'strong to weak', giving a 'fuzzy' quantitative value [13].

FCM, being a participatory method, was chosen to meet the aims of the study to identify the drought indicators of most significance and to draw on the lived experience of at-risk communities in doing so. This complements and extends the work on MADIS, identifying drought indicators and using expert inputs to rank them. In looking at the significance of drought indicators, the aim was not to look at the indicators in isolation but how they link and influence each other. FCM is a technique which enables mapping of complex systems and used in this study to explore those influence points. This allows an assessment of where policy interventions might best be applied.

There is not a single, defined approach to FCM in the existing literature. The same process has been adopted in all of the project teams' FCM studies [12]. There are a range of decisions that need to be made to tailor the project to its aims. The following steps were taken, as summarised in Fig. 1.

The rationale and research questions were carefully tailored and were consistent with the positive experiences from previous FCM sessions (addressing steps 1,2 and 4). To ensure suitability for a different context, the studies took place with the support and input of Mohammed VI Polytechnic University (UM6P) in Morocco and its affiliate entities including Al Moutmir, an NGO that works alongside the agricultural communities. These project partners also supported participants selection (step 3) and acted as interpreters and rapporteurs for the entire 2-day workshop and helped in overcoming any communication barriers. The criterion for participant selection were subsistence or small-scale farmers at risk of drought. The selection of participants for the two workshops was made based on several criteria to capture different perspectives. The choice takes into account the following criterions: diversity of agricultural practices (traditional agriculture, organic agriculture, precision agriculture), farm size (small, medium, large), level of experience (includes both farmers with long experience, as well as young farmers who may bring a different vision of the agricultural sector), gender (with the importance of the role of females), involvement in associations or cooperatives (members of agricultural associations or cooperatives), and accessibility and willingness to participate. For this study, 26 participants (including 7 women) from Settat and El Jadida were selected including local farmers, agronomists, and cooperative representatives. Female participants were included in the workshops after a thorough survey and assessment of the farming communities in both Settat and El Jadida. The aim was to ensure that at least one female farmers group was represented in each workshop, so their voices and perspectives could be heard. The selection was done in close coordination with the project's local collaborators in Morocco, who work directly with the farming communities and have deep knowledge of their composition. Given the relatively low number of female farmers in the region, the representation achieved in the workshops was reasonable and reflective of the broader gender dynamics within the farming communities.

There were 6 groups in total. Table 1 sets out the characteristics of each group.

For step 4, in FCM studies, preliminary work is often undertaken with a view to ensuring the data put to the participants was manageable and relevant [36,37]. In those studies, the nodes to be included in the maps are often predetermined. There is recognised potential bias embedded in this approach and a consequent requirement for the rationale for predetermined data to be clear.

For this study the 'nodes' of the map were partially selected and predetermined by the research team. This was because it is the existing indictors, selected through the extensive Delphi process, that are being tested. In terms of the indicators, the MADIS project identified over 100 drought indicators which were systematically reduced to 36 (see Ref. [38–40]; Sass et al., 2023; [12]). The FCM process was also piloted to see how manageable participants found the process and how they responded to indicators. For the Moroccan context, work took place with local collaborators from UM6P and Al Moutmir, to shortlist 22 indicators from the 36 based on criteria, notably.

- Relevance to regional drought impacts: Indicators were prioritised if they had documented significance in recent Moroccan drought literature or had been highlighted in prior case studies (e.g., crop loss, reduced groundwater levels).
- Local Stakeholder validation: During the preparatory discussions with Al Moutmir indicators were evaluated for potential resonance with farmer experiences in Settat and El Jadida.
- Workshop feasibility and clarity: Indicators had to be easily understood and observable by farmers with varying literacy levels. Visual icons for each indicator as well as written descriptors were used.
- Consistency, or explainable deviation, from those used in other jurisdictions

The indicators were intended as a starting point for the groups. This approach aligned with that taken in previous FCM studies (e.g., Ref. [32,36]). In practice, most of the predetermined indicators were used by the groups, but not all, and often new indicators were drafted and included by the participants.

For step 5, two questions were posed to the groups with a different set of indicators for each question. The variables or 'nodes' for each map were chosen iteratively by the workshop team from the indicators identified through the MADIS project. This was to ensure consistency across the wider project but also allowed for input and consideration from the project partners in Morocco. For the first question the participants were asked to consider a set of 11 indicators relating to impacts of drought and were asked, '*How does drought impact on your livelihood? How can we link indicators together to show this impact?*' Table 2 shows the indicators for Question 1.

The process during the workshops was to provide the indicators to the groups on individual cards with symbols to simplify the identification of key indicators. After considering the indicators, participants were asked if there were connections between the indicators and to draw an arrow on their maps showing how one indicator impacted another during droughts. For each arrow, the group was then asked to say whether the connection was 'strong' or 'weak' on a Likert scale of 1–5 (5 being strongest). The participants were advised that they did not have to use all the given indicators if they thought any indicator was not related, based on their experiences. In addition, they could create their own indicators, considering such indicators were missing from the list but did have an impact on their livelihood. After drawing their maps, the groups presented their maps in a plenary discussion with the rest of the groups. In addition to the developed maps, the discussions and plenary sessions were recorded and transcribed, with the consent of the participants, for future reference.

The process was repeated for Question 2. For Question 2, participants were given a new set of indicators (as shown in Table 3). The

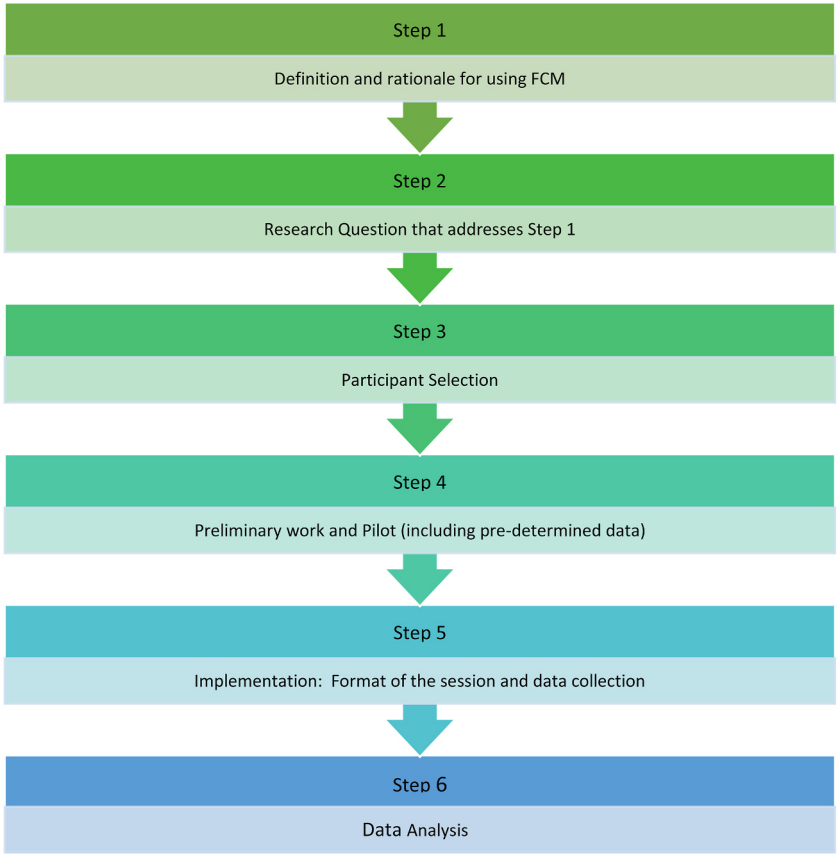

Fig. 1. FCM steps (adapted from Ref. [12]).

question posed to the groups was, *'Do the drought indicators interlink to influence your community's ability to cope or adapt*[4] *to drought risk? If so, please show how the indicators link together on your maps'*. The same exercise was done with the farmer groups from both Settat and El Jadida.

As can be seen from Tables 2 and 3, alongside the written descriptions (also translated into their local language Arabic) each indicator was represented with an icon for ease of understanding and discussion. The icons provided a visual representation of the indicator and allowed the indicators to be observed as they were moved around forming maps, and in turn helping to address different literacy levels. In this way everyone could visualise how the indicators were being connected and enabled questions to be asked (via interpreters) at the same time as the maps were being drawn. This was a simple but effective tool within the methodology that enabled contemporaneous engagement between participants and researchers overcoming language barriers.

For step 6, the data analysis for FCMs derives from graph theory. For each group and question, the final map was transferred to an adjacency matrix of the indicators. After verifying the accuracy of the adjacency matrices, two research team members independently analysed these indicators and connections and checked for inconsistencies or errors. Each weighting given to a connection was normalised from '-5 to +5' to '- 1 to +1'. As an example, an arrow marked as +2 between indicator 1 and going to indicator 5 would be marked at the intersection of the row for indicator 1 and the column for indicator 5 and normalised to 0.4, and so on. This was repeated for each map.

Mental Modeler software, specifically designed for analysing FCMs, was used [41] to convert the spreadsheets into digital maps. This mirrors the approach used in other FCM studies (e.g., Ref. [42,43]). After finalizing and verifying the maps, the indicators' centrality was measured by summing the absolute values of the normalised weights of the arcs connected to each concept node (i.e., the indicators). In Mental Modeler this centrality measure indicates the significance of each indicator within the system's dynamics [44]. A higher centrality value signifies a more influential role of the indicator in the system as it interconnects with other indicators. Drivers were then identified based on their functional roles in FCMs, as described in Ref. [45]. Drivers are indicators that have only outgoing

[4] In the studies, the difference between the terms coping and adaption is acknowledged but not considered material for consideration in the current context or of meaning to the participants in this context.

Table 1
FCM group characteristics.

Settat	Group 1 • 4 male participants • Mostly young farmers • Education level: Secondary education • Mixed crops: Cereals, seasonal crops • Livestock: Cattle and sheep • Crops are mostly irrigated	Group 2 • 4 male participants • Mostly middle-aged farmers • Education level: Mostly secondary education • Mixed crops: Cereals, seasonal crops • Livestock: Cattle and sheep • Crops are mostly rainfed	Group 3 • 3 female participants • Mostly middle-aged wives of farmers • Education level: Primary education • Mixed crops • Livestock: Cattle and sheep • Crops are mostly irrigated
El Jadida	Group 4 • 5 male participants • A mix of young and middle-aged farmers • Education level: Secondary education & higher education • Mixed crops and livestock including equestrian • Transition from irrigated to rainfed cropping systems due to drought	Group 5 • 6 male participants • Mostly experienced farmers • Education level: Secondary education & higher education • Mixed crops: Cereals, seasonal crops • Crops are mostly rainfed	Group 6 • 4 female participants • Mostly experienced farmers • Education level: Secondary education • Mixed crops • Livestock: Cuniculture, poultry, cattle and sheep • Crops are mostly irrigated

Table 2
List of indicators for impacts of drought (Question 1).

No.	Icon	Indicator
1.		Loss of crops
2.		Reduced levels of groundwater
3.		Sale of livestock
4.		Soil degradation
5.		Reduced availability of nutritious food
6.		Reduced water quality
7.		Reduced investment in fertilisers, seeds, machinery
8.		Migration away from the area
9.		Increased poverty and unemployment
10.		Increased gender inequality
11.		Change in energy needs (more or less?)

links, meaning they influence other indicators but are not influenced by them. Drivers serve as the starting points for change in the system.

In addition to the maps, the qualitative data taken from the discussions during the sessions, was explored particularly in how the maps were explained by the groups when the maps were presented by participants to the rest of the workshop. These discussions by the participants themselves sometimes prompted an adjustment within the maps. Notes were taken during the workshop by note takers for example to understand any additional indicators added or those disregarded. The mode of analysis and validation was taken from [46]. The data from the maps and qualitative descriptions were collected and analysed separately initially with the results compared, contrasted and integrated before the whole dataset was interpreted as a whole [46]. In this way the qualitative descriptions were cross-referred with the maps as a form of sense-making and validation of the maps prepared by the groups. The focus of attention was the qualitative aspects of the workshops. Statistical analysis can be utilised in FCM studies notably where maps are merged and for scenario building. Further work to identify and then validate connections between the groups is also conceivable but was not considered necessary for the research aims of the paper but could be an avenue for further work, particularly when comparing maps with those from other countries.

5. Data analysis

The key components of the map for the purpose of the study were indicators considered ‘central’ and indicators that were considered ‘drivers’. ‘Central’ indicators are indicators with the greatest number of arrows leading into them and emanating from them. These are indicators that are considered well-connected and are potentially influential within the system. ‘Drivers’ are indicators that are at the start of a chain of linked indicators. These are the indicators that might represent an early place for intervention that could positively influence the rest of the cascading chain. The data analysis focusses on the ‘centrality’ of the indicators in each map and drawing on ‘driving’ indicators; narrative discussions recorded from the sessions were used to interpret the maps.

The cumulative tables of central indicators for each map are set out in Tables 4 and 5. The data behind the cumulative tables are set in Appendix 1 consisting of photographs of maps, software interpreted maps, and centrality tables for each map.

Question 1. Impacts of Drought

Table 3
List of indicators of coping and adaptation to drought.

No.	Icon	Indicator
1.		Government policies on drought for small farmers
2.		Drought prediction and early warning systems
3.		Advice and coaching on new techniques and technology
4.		More water re-use or more efficient irrigation
5.		Higher % of drought resistant crops cultivated
6.		Access to insurance, finance or credit
7.		Access to fertilisers or machinery
8.		Access to (more) energy
9.		Participation in local farming co-operatives
10.		More local land set aside for conservation and biodiversity
11.		Improved produce storage and transportation capacity

The centrality table with the data from all groups for Question 1 is set out in Table 4. The top 3 and top 5 most central indicators for each group are highlighted. Indicators that are drivers are highlighted in bold. New indicators added by at least one group are shown in italics. For example, 'Lack of precipitation' was added by Group 6, it was one of their top 5 indicators for centrality and was also a driver.

There was a degree of commonality between the groups in terms of which indicators were most central to their individual maps. Central indicators are indicators that have influence within the maps as they connect to most of the other indicators. There was also some commonality in terms of drivers or indicators at the start of a cascading chain of impacts. Both central and driving indicators may be good points to intervene and influence outcomes as they interconnect and influence other impact indicators.

In terms of the water cycle and water management, 'Reduced levels of groundwater' performed highly as a central feature across the groups, except for Group 2, although it was a strong driver in that map. Unlike some of the tomato farmers, discussed in the literature review [29], the reduction in water reserves is already noticeable and driving crop loss. For Group 4 this was a key feature of their experience having moved from irrigated to rainfed conditions due to water mismanagement, aquifer depletion, and increased salinity, resulting in the need for a major and turbulent transition to dryland farming. The reduced centrality for Group 2 was explained by the fact that their farms were rainfed with reduced reliance upon aquifers and groundwater. 'Reduced water quality' had varied responses and was most central to the farmers with irrigated crops, for example in Groups 1 and 3. Group 1 described a cycle of declining aquifers, increased salinity and lower water quality, soil degradation, and reduced crop yields. It was most apparent in the groups with irrigated systems.

In addition to the pre-selected indicators, 'Lack of precipitation' was independently added by three teams. This indicator was not part of the pre-defined set of indicators. 'Lack of precipitation' was a driver in those maps lined to reduced levels of water in aquifers. With one group describing having to dig 130 m to reach water with reduced quality, salinized water and increased costs as a result. From a scientific perspective, this indicator is typically considered a meteorological driver of drought, not an impact. However, from the viewpoint of participants, especially small-scale farmers, this lack is perceived and described in their articulation of the *impacts* of drought which disrupts planting cycles, affects water availability, and ultimately threatens livelihoods. This indicator remains in their system maps to reflect this community-based understanding, while acknowledging the conceptual distinction in line with existing scientific literature.

Whilst aspects of the water cycle were always going to be a significant feature in drought impact maps, often the most central indicator was 'Loss of crops' which was a top 3 central indicator for all groups, in both regions and for both male and female participants. 'Loss of crops' was not often an indicator discussed by the groups or a focus of attention in the narratives but rather came to

Table 4
Cumulated centrality data for question 1.

	Settat			El Jadida		
Indicator	**Grp 1**	**Grp 2**	**Grp 3**	**Grp 4**	**Grp 5**	**Grp 6**
Loss of crops	5.2	3	4.6	4.2	5.2	5.8
Sale of livestock	4.8	3.4	1.4	2	3	2.4
Low investment in fertilisers, seeds and machinery	3	2	1.4	2.4	3	2.8
Soil degradation	2.8	1.2	2.2	1	2.2	1.5
Reduced levels of groundwater	**2.8**	**0.6**	3.8	3.8	**3.2**	3.6
Reduced water quality	2.4	0	**1.6**	1.6	4	2.2
Reduced availability of nutritious food	2.2	0	1.8	1.6	1	0.8
Increased poverty and unemployment	1.4	3.4	4	3.2	4.4	4.4
Migration away from the area	0.8	1.4	0.6	0.6	1	2.4
Change in energy needs	0.6	0.8	1.8	0.8	0.6	1.6
Increased gender inequality	0.4	0	0.8	0	0.8	0.6
Increase in agricultural input prices	0	**1**	0	0	0	0.8
Lack of precipitation	0	0	**2**	**1**	0	**4.2**
Sale of farms	0	0	1.2	0	0	0
Loan accumulation	0	0	0	3	0	0
Increase cost of living	0	0	0	2.4	0	0

Key for Table 4

	Light green, top 5 centrality
	Dark green, top 3 centrality
bold	Driver
italics	New indicator added by participants

light as a central indicator through the maps. This could represent an example of how maps can bring to light features of a system that asking direct questions in an interview may not uncover. Whilst drought may have occurred in the past, its increasing frequency and severity also makes recovery from loss of crops more difficult.

Often leading from 'Loss of crops', the maps also highlighted the financial and economic stresses of drought. 'Sale of livestock', 'Low investment in fertilisers, seeds and machinery' or 'Increasing poverty and unemployment' features as strong central and driving indicators in the maps. Livestock is often viewed as an asset or reserve that can be sold to raise emergency funds in a crisis [47]; [48]. The difficulties of this as a reserve, with increasing frequency of drought and the reduced timeframes to recover before the next drought, were noted during the discussions. Indeed, Morocco's livestock market is currently facing a significant decline in animal populations [49]. Overselling of breeding female livestock for meat production is one of the direct reasons, which is a measure taken by farmers struggling with economic hardship. The financial and market pressures initiated by drought were features of some of the additional indicators added by the groups including 'Sale of farms', 'Loan accumulation', 'Increased agricultural input', and 'Increased cost of living' as well as 'Change in energy needs' linked to increased groundwater pumping. The participants highlighted through their maps the terrible irony of increasing market costs when resources are at their most fragile and needs are highest. The maps provide more support for the conclusions drawn in the literature on economic impacts of drought [27].

In terms of gender roles, two female groups discussed that women were more likely to take responsibility for livestock for the home. The sale of this livestock was used as a strategy to cope with feed shortage due to drought and provide a 'fast' source of income, although resulting in a loss of the use of that asset for the family. This represented the stark realities of economic versus food security and was a cause of stress. Conflict and pressure within family units can be multi-faceted and was not explored in the study, but stress

Table 5
Cumulated centrality data for question 2.

	Settat			El Jadida		
Indicators	**Grp 1**	**Grp 2**	**Grp 3**	**Grp 4**	**Grp 5**	**Grp 6**
Government policies on drought for small farmers	6.8	6.2	**5.2**	**5.4**	**9.4**	**7**
Access to insurance, finance or credit	4.2	5	2	2.6	4	2.8
Advice and coaching on new techniques and technology	4	5.8	2.8	6.4	2.2	5.6
Access to fertilisers or machinery	2.8	3.2	0.6	2	2	0.8
More water re-use or more efficient irrigation	2.8	4	1.8	1.6	1.4	3
Higher % of drought resistant crops cultivated	2.6	3	0.6	2.2	1.6	1.8
Participation in local farming co-operatives	**2.4**	6.6	2.6	**1.8**	3	5.8
More local land set aside for conservation and biodiversity	1	1.6	0.6	1.8	1.6	0.8
Improved produce storage and transportation capacity	0.8	2.8	0.4	3.8	1.6	0.8
Access to (more) energy	0.6	0	1	2.8	2	2
Drought prediction and early warning systems (EWS)	0.4	2.2	1.4	0.6	1	1
Helping small farmers dig wells and access to solar energy	0	0	1.8	0	0	0
Installation of desalination and preservation of water	0	0	0	2	1	0
Creation of a product processing and marketing unit	0	0	0	1	0	0
Law to forbid the random use of water	0	0	0	0	0	1
Awareness through media and education	0	0	0	0	0	1
Exempting farmers from paying loans in case of crop loss	0	0	0	0	0	1

	Light green, top 5 centrality
	Dark green, top 3 centrality
bold	Driver
italics	New indicator added by participants

was noted within a household caused by poverty compounded by drought. The pressures were also noted with the male groups describing being thought of as 'useless' and unable to provide for their families. Female groups described livestock they had looked after for the family being taken and being unable to provide their families with nutritious food. Participants' narratives suggest that emotional impacts such as 'stress' linked to drought could potentially be a useful indicator to explore in understanding and addressing drought impacts. In terms of gender differences, it was observed that male participants primarily focused on indicators related to water scarcity and crop loss. In contrast, female participants expressed greater concern about their livestock, which they typically manage.

Question 2. Coping and Adapting to Drought

The centrality table with the data from all groups for Question 2 is set out in Table 5 using the same key as for Table 4.

For coping and adaptation indicators, the top central and driving indicators were frequently similar across the groups, genders, and locations. 'Government policies on drought for small farmers' was a strong and central feature and was also a driver in four groups. Suggestions on what those policies should consist of were included in additional indicators and ranged from education and behavioural interventions, economic support, and targeted technical interventions.

In relation to technical interventions, the most central indicator was generally for advice and coaching, suggesting this is at least as important an influencer as any specific technological intervention. 'Water re-use and improved irrigation' were top 5 indicators for groups 1, 2, 3, and 6 with groups 4 and 5 adding in desalination as a new indicator to support coping and adaptation.

'Participation in local farming co-operatives' was also generally quite high, but from the narratives the reasons varied as some saw co-operatives as opportunities to work together, create a critical mass for negotiations on price, or more simply as a source of information and training.

In keeping with the response to Question 1 and the market and economic impacts of drought, 'Access to insurance, finance and credit' was in the top 5 for all groups. Group 6 added an additional indicator of 'Exempting farmers from paying loans in case of crop loss' as a suggestion for helping to cope with the financial pressures of loss of crops. 'Access to finance' was considered a major challenge for the small-scale farmers. The discussions within the groups, while developing the maps, added more nuance to the issues around finance and access. Cultural and spiritual preferences were evident for some, with a few forms of financing considered religiously illicit. In addition, not all farmers held legal title to their lands, making them ineligible for insurance, grants, and certain bank financing. This had not been remedied by the farmers, at least, in part to maintain a level of anonymity in terms of their land, how they farmed it, and an uncertainty vis-à-vis decision-makers.

Further on markets, 'Creation of a product processing and marketing unit', suggested by Group 4 highlighted that international markets, especially those in the European Union and other stringent regions, enforce strict quality and food safety standards. The absence of appropriate packaging facilities often prevents Moroccan producers from meeting these standards, restricting their ability to export. As a result, farmers felt they were left with little choice but to sell their produce at lower prices, typically in local markets, missing out on the added value that packaging provides.

Group 3 introduced an additional indicator 'Helping small farmers to dig wells and access solar energy,' reflecting a localised concern for both water and energy access. The group's centrality results placed strong emphasis on reduced groundwater and changing energy needs, suggesting that both water scarcity and energy availability are dual pressing challenges for them.

There were other insightful indicators that were proposed by the female participants in El Jadida, including 'Law to forbid the random use of water' and 'Awareness through media and education', suggesting behavioural factors that could influence coping and adaptation through better collective efforts. This also demonstrates the participants' significant level of awareness regarding the need for more sustainable practices and community-driven solutions.

Indicators that did not feature in the top 5 centrality of any map included 'More local land set aside for conservation and biodiversity' and 'Drought prediction and early warning systems (EWS)'. Both indicators arguably relate to longer term planning and prediction rather than immediate response to drought. The indicator 'More local land set aside for conservation and biodiversity' shows relatively low centrality values across all groups, ranging from 0.6 to 1.8, with the highest value in Group 4 (1.8). This suggests that this factor is not seen as a priority compared to others like government policies or access to resources. The consistently low scores imply that the participants do not view land conservation as a key solution for drought mitigation and their focus appears to be on more immediate concerns such as access to water, technology, and government support. There may also be a lack of awareness about the long-term benefits of biodiversity for sustainable agriculture. The indicator 'Drought prediction and EWS' is perceived as having low importance across most groups, with scores ranging from 0.4 to 2.2. Group 2 gives it the highest value at 2.2, but overall, participants do not see EWS as a major solution for dealing with drought. This may be due to local farmers not being aware of an early warning system, its potential benefits, or even whether it is something to be trusted.

6. Discussion

The FCMs developed from Settat and El Jadida revealed both shared and divergent perceptions among stakeholders. Common issues around lack of rainfall, groundwater over-exploitation, and weak institutional support appeared prominently in discussions in both regions, highlighting national-level drought concerns. However, differences emerged in the structure and weight of causal relationships. In Settat, discussions around agricultural vulnerability and traditional coping practices indicated strong reliance on local adaptive knowledge. Conversely, in El Jadida, factors such as technological interventions and around market dynamics were more influential, reflecting more access to infrastructure and commercial pathways. Additionally, the density of connections in the Settat FCM was higher, suggesting more complex interdependencies among socio-environmental variables as perceived by the farmers. El Jadida's maps, while more streamlined, emphasized policy-level interventions. These differences underscore how local context – climatic, economic, and cultural – shapes community responses to drought. The comparative insights not only validate the utility of the FCM method but also suggest the need for region-specific policy interventions.

The participatory FCM process revealed that drought not only effects on-farm production but also disrupts broader agricultural markets and supply chains. Farmers emphasized that drought-induced yield reductions lead to scarcity in local produce markets, particularly for cereals. This scarcity often causes price volatility, where short-term price spikes may benefit some traders but generally undermine the affordability of staple foods for self-consumption and for livestock. The FCM discussions around the maps captured that prolonged drought periods reduce farmers' purchasing power, decreasing demand for fertilizers, seeds, and equipment, which in turn impacts local agri-dealers and cooperatives reliant on bulk procurement. Furthermore, inter-regional trade of drought-sensitive

products is curtailed, with some regions experiencing surpluses due to lower demand, while others face acute shortages, reflecting an uneven burden across the national agricultural economy. These multi-layered economic disruptions underscore the importance of integrating drought risk into market stabilization policies and investing in resilient supply chains. Farmers proposed that cooperatives could play a more strategic role in market aggregation, storage, and value addition to mitigate these risks.

Drawing from these insights five interconnected policy areas are highlighted.

1. Social Structures and Governance

Arguably the most striking feature of the results is the positioning of social structures and governance, with government policies, coaching and co-operatives all achieving higher centrality, often higher than technical or direct interventions.

Despite the recognition of governmental interventions as a key driver for adaptive capacity, findings from the workshops reveal significant barriers to effective policy implementation in the Moroccan context. Participants cited that delayed implementation often render policies ineffective at the grassroot level.

These challenges highlight a current top-down policy approach and a disconnect between intention and implementation of policies that could be addressed through more locally grounded, transparent, and inclusive policy mechanisms. As noted, recent research by [50] emphasizes the role of polycentric governance in enabling agroecological practices in Morocco, Tunisia, and Lebanon. Their findings underscore how institutional diversity and local actor engagement contribute to adaptive and sustainable agricultural systems. These insights support the importance of inclusive governance and the incorporation of traditional knowledge systems for enhancing community resilience.

Social structures were valued horizontally as well as vertically. There was a generally high appreciation of the benefits of local farming co-operatives. These were discussed in terms of facilitating the exchange and support from government, mainly regarding the improved produce storage, seed supply to increase the usage of drought resistant crops, learning new techniques and technology on irrigation scheduling, which will improve water and soil conservation and biodiversity. Clustering similarly impacted farmers from drought as cooperatives can help direct government strategies for more efficient and significant policies. Initiatives to support co-operatives could also be a useful and trusted conduit to support awareness raising and education.

2. Early Warning Systems

The importance of social structures, governance and coaching is in contrast to the relatively low rating given to Early Warning Systems (EWS). EWS in relation to drought was given relatively low centrality across all groups. This flags an area for further research and investigation. Possible explanations are that more direct interventions were preferred. There was, for example, an equally low centrality given to setting land aside for biodiversity which is again an area where direct effects would not be immediately felt. It may also stem from a disconnect between authority and community where such systems are input but the benefits not felt on the ground as noted in relation to delayed policy implementation in other areas. It does suggest that if an EWS was to be implemented that grassroots engagement on its design and implementation as well as education on the potential benefits would be an essential step.

3. Strengthening economic resilience through market and trade interventions

The study also highlights the significant financial and economic challenges faced by farmers in the region, particularly small-scale farmers. Access to insurance, finance, and loans emerged as one of the priorities to tackle drought, with some suggesting additional measures like exempting farmers from loan payments in case of crop loss. Equestrian activity is part of the culture in El Jadida region and source of income for many farmers. Drought leading to high prices of animal feed greatly affected the equestrian events and income. Cultural and spiritual preferences, as well as lack of land ownership, pose further obstacles to accessing financial resources. Drought can be a costly business and the irony of increasing costs and expenses during a crisis.

This was evident in discussions on livestock but also impacted the whole supply chain. The lack of adequate packaging facilities exposes these goods to higher risks of degradation and significant quality losses. This issue is particularly critical for fruits and vegetables, where post-harvest losses can reach up to 40%. Without proper packaging, the shelf life of these products is shortened, limiting their marketability, and increasing the likelihood of waste. This situation not only affects income potential but also reduces opportunities for job creation and economic growth in rural areas. This supports the prioritisation of financial interventions triggered by the onset of drought conditions and the potential to positively intervene to control markets. There is potential for this to be aligned with EWS and triggered when certain parameters are met.

Concerns were also raised about limited access to financial resources; although credit and insurance schemes exist, many farmers are unable to access them due to lack of awareness, more information of the administrative processes, and the absence of tailored financial products.

To address the systemic vulnerabilities revealed by drought, it is essential to strengthen economic resilience through integrated market and trade interventions. Promoting climate-resilient value chains – especially those involving water-efficient crops and processed goods – can help maintain market continuity and buffer against climatic shocks. In parallel, the development of market-based drought insurance mechanisms can protect small-scale farmers and cooperatives from price volatility and income losses. Empowering cooperatives not only stabilizes supply but also reduces dependency on intermediaries. Furthermore, facilitating coordinated regional trade can help balance mismatches in supply and demand during drought periods, ensuring more equitable resource distribution between affected and unaffected areas.

4. Water management (and managing change)

The context for the study suggests a critical water management crisis in the region, characterised by groundwater depletion, deteriorating water quality, and inefficient water use. The transition from irrigated to rainfed agriculture, driven by aquifer depletion and increased salinity, highlights the unsustainable nature of some current practices. With the general move to irrigated systems from rainfed systems there is an irony in unsustainable water management leaving little alternative but a return to rain. The consequences of trying to remedy this are costly. Within this context, farmers have suggested an array of solutions from technical (e.g., desalination plants, efficient irrigation systems, rainwater harvesting), regulation and behavioural (e.g., stricter water regulations, awareness raising), many of which will require significant time and financial investment. Following the social and governance priorities, the maps also suggest that how decisions are made in relation to water management, are as important as the decisions themselves.

5. Water-Energy-Food Nexus

Leading from point 4, the results touch upon many of the themes explored in the Water-Energy-Food (WEF) Nexus, which considers the complex interactivity of water, energy and food systems and how for sustainable development they cannot be considered in isolation [51]. The especially close links between water availability, energy needs for irrigation, and food production is notably apparent in drought-affected farming communities. It is recognised that the WEF Nexus is often used as a helpful way to frame these interconnections. Important contributions such as those by Mohtar and Daher [52] have shown how the framework can support more 'joined-up' thinking in resource planning, especially in times of crisis. More recently, Al-Saidi and Hussein [53] illustrated how the COVID-19 pandemic revealed the fragility and interdependence of water, energy, and food systems across many countries. Their work highlighted how disruptions in one part of the system such as supply chain breakdowns or limited energy access can ripple through and affect others, particularly for vulnerable communities. This kind of cascading effect is very similar to what small-scale farmers in Morocco described during the workshops: reduced rainfall leads to groundwater stress, which in turn increases energy use for irrigation, raising costs and reducing productivity. The systemic nature of these interactions reinforces the relevance of WEF thinking in practical, on-the-ground contexts.

For policymakers, however there are potential issues with this approach. There is a growing concern in the academic literature about the usefulness and limitations of the Nexus idea. Hussein and Ezbakhe [54] have pointed out that the concept can sometimes feel too abstract or too focused on technical solutions. It may also overlook important social and political issues, including who has access to resources and who gets left out. The results from this paper suggest there is value within the WEF framework in looking for wider and more complex interactions which an FCM approach can support. The FCM tool itself enabled a focus on the real experiences of small-scale farmers in Morocco. For them, the Nexus is not a policy term it is their lived reality. Water shortages, rising energy costs, and reduced crop yields are deeply connected in their daily lives. The FCM is a methodological tool could help bridge the gap between high-level frameworks and the urgent, practical challenges faced by vulnerable communities.

7. Conclusion

This study enabled a holistic and wide-ranging evaluation of impacts and coping to drought, presented in a way that can enhance the wider MADIS project and interconnect a global survey with experiences of drought within communities; thereby integrating both top-down and bottom-up approaches, by capturing both policy-driven perspectives and community-level insights. With the breadth of indicators and their interconnectivity also comes the challenge of prioritising. The maps offer support to policymakers by presenting drought indicators in a system rather than as isolated entities, to identify which indicators are driving or central to a map and thus have the most influence. These represent potential points of interest to policymakers, offering a potential focus for the application of resources where they may have most impact. In answer to the research question, the FCM approach enables indicators to be viewed in a system and explore their connectivity. It gives a perspective on what is 'important' in terms of what should be prioritised as central or driving features of the system. This in turn can aid pinpointing interventions, a significant advantage when resources are limited. It could be viewed as a means of prioritising a list of indicators. With the complexity of drought and the proliferation of drought indicators across multiple domains, this has potential in prioritising what is most likely to have the biggest impact. It also gives a view on the perceptions and experiences of drought.

Whilst this study provides valuable insights into the complexity of drought impacts and adaptation through the use of FCM, limitations should be acknowledged. This FCM study included a set of pre-selected indicators. This was deemed necessary for the purposes of the study, which examined the results from a previous study, to reduce the load on participants and to enable the workshop to be manageable. It is acknowledged this raises issues of the introduction of biases from the research team's perceptions. To reduce the potential for bias the indicators were presented as optional, they could be rejected and the groups were allowed to introduce their own indicators (which they did). Further, FCM is a subjective methodology based on group dynamics, participants' understanding of the process, and perceptions about the indicators and the relations. As with most workshops, the facilitators worked to manage dominant voices during group discussions. All of these factors may influence the maps. The data gathered included both the maps and also the verbal discussions and descriptions from the groups and the qualitative descriptions were transcribed and used by the research team to validate the maps. Statistical methods (often linked to studies where maps are merged) of validation were not explored in addition and further work could be undertaken in this respect. Finally, it is noted that the maps were generally better at capturing the direct impacts of drought than more subtle or complex social changes.

For this study, 26 participants from Settat and El Jadida were selected, including 7 women. Female participants were identified and

invited in close collaboration with local partners who have deep, longstanding ties to the farming communities. The selection aimed to ensure that female farmers' group were represented in each workshop, enabling their perspectives to be heard and included. While these efforts reflect a strong commitment to gender inclusion, the final representation of 7 women out of 26 remains limited. This outcome mirrors broader structural and cultural constraints in rural Morocco, where women farmers are often underrepresented in agricultural leadership and decision-making spaces. Although the insights shared by female participants offer valuable and contextually rich perspectives on drought impacts and coping strategies, this gender imbalance poses a limitation for the generalizability of our gender-specific findings and the findings should be interpreted with this context in mind. Whilst the paper takes a small step forward in seeking out the female voice, clearly more work is required. Further studies will be able to examine, utilise and expand upon the findings of this study.

A potential limitation is scale, although a wide range of participants were selected and commonalities and differences noted. The results will also lend themselves to comparison across jurisdictions in due course. While the FCM approach provided valuable insights into farmers' perceived adaptation strategies and their immediate relationships with disaster and climate risks, this study is limited in its ability to assess the long-term impacts of these strategies on agricultural sustainability. The links in the maps do not reflect causation only perceptions of causal pathways identified through current knowledge and experiences, but with longitudinal data, it will be effective to determine whether these adaptation measures translate into increased resilience over time. Future research could build upon these preliminary findings through repeated mapping exercises or long-term monitoring of environmental, social, and economic indicators. Integrating satellite-based land-use assessments and household-level data over multiple years could offer a more comprehensive evaluation of the sustainability and effectiveness of these adaptation strategies in the context of Morocco.

CRediT authorship contribution statement

Elisabeth A. Shrimpton: Investigation, Supervision, Funding acquisition, Project administration, Conceptualization, Visualization, Data curation, Writing – original draft, Methodology, Writing – review & editing, Formal analysis. **Tanaya Sarmah:** Visualization, Data curation, Formal analysis, Writing – review & editing. **Nazmiye Balta-Ozkan:** Supervision, Project administration, Resources, Data curation, Investigation, Writing – review & editing, Funding acquisition. **Sanaa Malki:** Project administration, Data curation, Writing – review & editing. **Ahmed Jelloul:** Project administration, Writing – review & editing, Data curation. **Mohammed Ouikhalfan:** Project administration, Writing – review & editing, Investigation. **Abdelaziz Nilahyane:** Investigation, Project administration, Writing – review & editing. **Lamfeddal Kouisni:** Writing – review & editing, Project administration, Supervision. **Da Huo:** Data curation, Investigation.

Data availability statement

The data in support of this article is included in the text or supporting sections.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr Elisabeth Shrimpton reports financial support was provided by GCRF and Newton Fund. Professor Nazmiye Balta-Ozkan reports financial support was provided by UKRI-EPSRC. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2025.105732.

Data availability

The data in support of this article is included in the text or supporting sections

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