

Re-evaluating drought indicators: Learning from small-scale farmers in South Africa

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1. Introduction

Of all natural hazards, it is drought that has recently caused the largest loss of life with approximately 650,000 deaths between 1970 and 2019 [1]. Significantly, the occurrence of death and the severity of drought impacts varies widely between communities [2]. It is increasingly understood that the impact of drought depends upon factors beyond reduced rainfall and involves a complex interaction of social, environmental, economic, as well as hydrological vulnerabilities [3,4]. Drawing upon the multidimensional nature of drought risk, studies from different disciplines have identified an array of indicators to understand and measure vulnerability and resilience to drought impacts ([5,6]; Sasset al., 2024; [7]). These dimensions include indicators on water availability, hydrology, and soil conditions but also seek to capture the wide range of social and economic indicators such as migration [8], access to energy [9], and gender inequalities [10,11].

This investigation into indicators has resulted in a wealth of knowledge but has added complexity. In evaluating this knowledge, this study is affiliated with the Management of Disaster Risk and Societal Resilience (MADIS) Project¹ [12], which seeks to better understand and rank indicators in the context of agricultural drought for small-scale farmers. During the MADIS project over 100 indicators were identified from the existing literature [13]. Despite the number of indicators, there is a gap in how the literature engages with the complexity and interactivity within a set of indicators [14–16]. The literature often presents indicators as fixed measurements. However, there is much less understanding of how indicators link to form cascading vulnerabilities or interconnect to improve resilience [16].

This paper starts to fill the gap by visualising indicators in a map, identifying the key indicators that interact with others to influence outcomes. In doing so, it seeks to identify indicators that have the most influence over the system. The benefit of identifying influence points is to help pinpoint a priority or leverage point for policymaking and assist decision-makers in focussing often limited resources. It does this by using Fuzzy Cognitive Mapping (FCM) workshops to draw upon the experiences of those who have suffered from drought and who remain at risk. Whilst FCM has been used in drought studies previously it is believed this is the first time it has been used to identify the interaction and interdependency of drought indicators for impacts and adaptation. The results highlight the indicators that have the most influence on other indicators. From this, suggestions are made for areas where early policy intervention could be focussed. The result, and the contribution of the study, is a new way of looking at how indicators can be selected and used to

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¹ 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.

focus resources on areas with the potential for the biggest impact.

The study explores the connectivity and escalation of drought impacts on small-scale farmers in South Africa, using workshops within two communities in Free State, South Africa. South Africa has the largest area of agricultural land in Africa [17]. Despite this, agriculture's potential as a major driver in the economy remains unfulfilled [18]. Amongst social, economic, and political challenges, South Africa has suffered from several severe agricultural drought events most recently from 2014 to 2019 and is a country which faces significant challenges over water saving, irrigation techniques, and farming adaptation [19]. The focus is on small-scale farmers as a group particularly vulnerable to drought impacts [20,21]. Challenges are felt acutely within the farming communities as they battle with food production against depleting groundwater supplies, energy insecurity, and social impacts such as migration to urban areas.

The paper analyses the literature on drought indicators in section 2. The South African context is discussed in section 3. The methodology is set out in section 4. The results from the FCM workshops are addressed in section 5 and split into two sections, firstly analysing the results around the impacts of drought and the second addressing coping and adaptation to drought. 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 study aims to align with Sustainable Development Goals (SDGs) 2 (Zero Hunger), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), and 15 (Life on Land) and the methodological application (Section 4) specifically supports Gender Equality (SDG 5) (United Nations, 2023).

2. Literature review

The impacts of drought are not evenly spread, with the most vulnerable often the most seriously affected. Social, environmental, and economic factors affect how the impacts of drought are experienced as well as the resources available to cope and adapt [22]. Assessing vulnerability and resilience becomes a complex, multi-faceted task.

Drought indicators measuring vulnerability and resilience can be amalgamated into composite indices or models which can then be used to determine strategies or assess levels of vulnerability and adaptability (e.g., Ref. [23,24]). Commonly, it is not only the hydrological and meteorological levels that are concentrated upon but the availability of wider resources such as social capital, income, degree of education through to the availability of reasonable credit [23,25]. Drought indicators can be used to show the impacts of recurring events over time, with decreasing resilience as farmers use up their reserves to cope with adverse events. This is particularly relevant with the increasing frequency, yet unpredictability, of weather pattern changes due to the climate crisis with less time to recover before the next onset [25].

The connection between access to water to meet needs and societal vulnerabilities are evident in a study based in South Africa where historical differences in support between commercial and small-scale farming are noted [19]. The study notes differences in the availability of irrigation systems which reduce drought impacts with the most vulnerable having the least in terms of infrastructure support [19]. A further study in the KwaZulu-Natal region in South Africa noted nine indicators of social factors and drought vulnerability articulated in a way relevant to the local context such as social dependence on grants, gender of head of household, and external support from the Government [26]. Adaptation and reduced vulnerability were also linked to the availability of Early Warning Systems (EWS) [26], representing an additional resource that can be drawn upon to support planning and response. The importance of context in understanding vulnerabilities and the resources to cope and adapt are evident in these studies.

In looking at the context and the quality of data behind drought indicators, there is a recognition that scientific data can be incomplete or have insufficient granularity to be useful at a local level [27]. Climate change and changing weather patterns may also mean past datasets are not reliable indicators of future trends [57]. In addition to gaps in objective and scientific datasets there is a growing question around who is an 'expert' for the purpose of gathering data and the extent that local experiences and other forms of knowledge can be captured [24]. This represents another challenge for the use, credibility and reliability of indicators.

With these challenges in mind, participatory approaches have been utilised, using a range of 'expert' input to fill gaps. Although no other study using FCM to both rank and link drought indicators was identified, there are studies that use FCM around drought indicators albeit with different aims. It has been used, for example, in drought risk monitoring [28] and drought indicator generation (Masinde et al., 2018). The latter sought to integrate indigenous knowledge and scientific data forecasts using FCM for a drought EWS. Indigenous knowledge, for example, around bird nesting patterns and flowering and fruiting of crops, was used to identify indicators of drought which could then be quantified and integrated into scientific datasets. FCM in the Masinde et al. study (2018) offers structure to a workshop, an agreed output (being a map), and a stimulus for thinking and discussion using the maps as prompts. This has parallels to the current study as it seeks to integrate local knowledge with the global expert data obtained via the MADIS project [12]. This bottom-up approach, using FCM, integrates local knowledge with the scientific knowledge evaluated in the MADIS project, recognising the importance of local knowledge and engagement in resilience building [29].

In considering participatory processes and drought experiences, the issue of gender arises with the literature noting gender differences in responses to droughts [30]. Whilst there is often an equal number of males to females in small-scale farming, disparities in terms of rights, equality, and empowerment remain with these issues being recognised as barriers to achieving the SDGs [55]. A difference in vulnerability to drought linked to the gender of the head of the household has already been noted [26]. The ability to cope and adapt differs with gender, for example, through a reduced availability of off-farm employment or reduced access to mitigating technologies [30] and constraints in accessing markets, infrastructure, and services (Food and Agriculture Organization of the [31]). Gender stereotyping and discrimination against women have been identified in this context [32]. In considering drought impacts and adaptation context both male and female voices need to be captured.

3. Case study

South Africa is a water-stressed country and has suffered from several severe droughts in recent times [19,33]. The causes of drought are complex and include water governance, infrastructure, and demand management challenges [33]. On top of these challenges climate change and weather variability add further pressures to water security. Agriculture is responsible for some 60 % of water use across the country [34]. Agricultural production however has been described as ‘dualist’ between large scale commercial farmers from predominantly white communities, and small scale predominantly black farmers [35] with drought impacts felt differently between the groups [19]. Despite the significant land mass allocated to agriculture and the degree of water consumption, its contribution to the gross domestic product (GDP) remains low [36] although it plays an important part of the economy for employment as well as a source of food both internally and for neighbouring countries. In terms of energy systems, 95 % of electricity is supplied by Eskom, a para-national company. Energy services in the country were once lauded but now face significant problems around capacity and load-shedding with multiple, complex causes cited [37]. With the source of energy being mostly fossil fuel, the need of water for energy production is also a competing necessity.

Two village communities were chosen for the workshops, Dubanchu and Sediba, both within the Thaba Nchu region of the Free State of South Africa on the central plains representing small-scale black farming communities. Most people in Thaba Nchu and its surroundings belong to the Barolong clan. The farmers in the two villages we interviewed, farm on communal land belonging to the Government but the traditional authority controls land management. The Barolong people have a long history of settlement in the area and were guaranteed land rights in the mid-1800s because they supported the colonial settlers during various wars [38]. Thaba Nchu was an enclave of Bophuthatswana (the apartheid state’s attempts to create nation-states) under apartheid rule [39]. The Government applied betterment planning resulting in various rural villages like the two in this study. Betterment planning also entailed strict control over stock and land use. However, by the late 1980s, these rules disappeared, and the Tribal Authority and farmers managed the land communally. Today, Thaba Nchu and its rural area resonate under the Mangaung Metropolitan Municipality with its headquarters in Bloemfontein. Many villages have been supported with electricity access, although water and sanitation systems remain rudimentary.

The workshops took place within a homestead in the community of Dubanchu and in the local village hall in Sediba.

4. Methodology

This section sets out the methodology that was used for the FCM workshops with the South African communities. This section starts with a brief discussion of FCM followed by the process adopted. This method offers a contrast to the frequently used mixed methods technique of survey then interview or focus group (e.g., Ref. [40–42]), and reflects the aim to view indicators from a systems perspective.

4.1. Overview

The origins of cognitive mapping are attributed to Axelrod [43] as a semi-qualitative modelling tool using people to define the variables and relationships in a system and to map their connectivity [58]; [59]. Drawings or maps are created showing how different elements (nodes), are linked to one another through arrows. The finished maps become visualised mental models showing the chains and links between nodes and results in a complex system [27]. The ‘fuzzy’ addition to cognitive mapping is credited to [56] and provides a mechanism for the links between nodes to be weighted numerically as strong or weak and for the relationship to be recorded as positive or negative.

Unlike some other participatory methods, mapping makes it possible for a system change to be simulated, by altering parameters within the system map [61] as well as the potential for different maps to be aggregated. For the current study this means it may be possible to visualise how an indicator in a ‘map’ is linked and influences other indicators. FCM appears suited to a face-to-face workshop environment where discussions can be facilitated and where mutual learning can take place between all attendees [44]. Noting the gender issues already raised, it is necessary to consider the female voice in the selection of participants. The workshop groups were segregated by gender to allow the female voice to be heard and to neutralise power dynamics between groups as far as possible [45].

The drought indicators for use on the workshops were taken from the published work of the MADIS project (see Ref. [13]). The methodological approach of FCM enabled the drawing in of community drought experiences in a way that could be integrated into the full range of data collected through MADIS. It is believed that this is the first time FCM has been used in this way for this purpose.

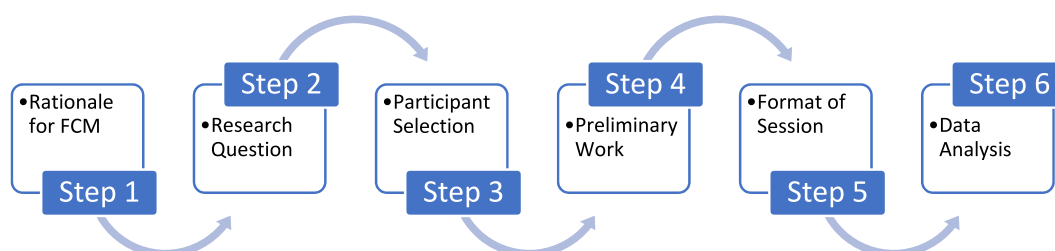


Fig. 1. Overview of methodology.

4.2. Technique: Fuzzy Cognitive Mapping (FCM)

FCMs have been used in diverse contexts and as a result there is variation in how the methodology is applied, for example, in ecological modelling integrating expert and local knowledge [60] and studies of interventions for sustainable water management using a range of stakeholders [46]. There is not one single format for FCM used in these studies and there are several decisions to be made in applying it as a methodology. Drawing upon these studies, the design of the FCM workshops was created following a six-stage process and summarised in Fig. 1.

Steps 1 and 2 test and set the boundaries for the FCM workshops [46]. The Step 1 rationale for this study is to capture drought indicator connectivity and complement the MADIS expert findings. Step 2 defines the research questions to be addressed. In this case there are two research questions. The first being, 'Which indicators impact upon your livelihood in a drought and how do those indicators interact with one another?' The second map to answer the question, 'Which indicators influence your community's ability to adapt to drought risk and how do those indicators interact with one another?'

In setting out the remaining steps to the methodology, Section 4.4 below addresses participant selection in line with Step 3. Section 4.5 explains the format of the sessions in line with Steps 4 and 5 Section 4.6 addresses data analysis for Step 6.

4.3. Participant selection (Step 3)

Participant selection under Step 3 was undertaken with the support of University of the Free State with care taken to ensure that the female voice was heard. Emerging farmers were identified in two communities; the requirements being those that had suffered from drought, and those that were continuing to suffer due to the impacts of climate change. Two settlements were chosen within Free State, South Africa drawing upon the expertise and local knowledge of the University of the Free State (Fig. 2). The first, Dubanchu is a settlement near Thaba Nchu. The second settlement is within Sediba, some 30 Kms north of Ramakgari. There were 16 participants in total.

In each workshop there were two groups split into male and female. In Dubanchu the groups consisted of five male participants and three female participants. In Sediba there were five female participants and three male participants.

4.4. Preliminary work and format of sessions (Steps 4 and 5)

Advance decisions were taken about the information to be presented to the participants. This is acknowledged in Step 4 [46]. For both questions, the indicators were pre-selected by the MADIS team from the MADIS indicators developed through the Delphi process [13], relevant to impacts and coping and adaptation. Icons were chosen to represent the indicators along with their written description (translated into the local language, Setswana). The reason for this was to address any issues around literacy and to enable a multi-national research team to be able to easily identify and track the indicators as they were moved around the maps.

The indicators that were selected for Question 1 are shown in Table 1 together with their icons, representing the indicators describing the impacts of drought.

The second map addresses coping and adaptation and the selected indicators are shown in Table 2.²

Step 5 addresses the format of the workshop sessions. The sessions were piloted before the formal workshops took place. At the start of each workshop, there was an explanatory session. Each group had a facilitator who functioned as an interpreter to support the map generating process.

The groups were given large sheets of card to draw their group map with the indicator icons and descriptions on smaller cards to be moved on the large sheet. The indicators were connected with arrows drawn onto the sheets by the teams. These links were marked with $\pm$ markings to indicate a positive or negative causality and scored between 1 and 5 with 5 being a high correlation. The allocating of scores between 1 and 5 worked well and was grasped by participants in the pilot as well as in the formal workshops easily. The $\pm$ correlation was more challenging. In keeping with a solution identified by Singh and Chudasama in an earlier FCM work, the $\pm$ correlation was added by the facilitators drawing on the explanations given by the participants [8].

4.5. Data analysis (Step 6)

In analysing the data, the scores between each link were normalised and the data was transposed onto a spreadsheet. To interpret the spreadsheets, online software Mental Modeler³ was used as applied in previous studies [47]. The software translates the spreadsheets into a digital map and provides a statistical analysis of the connections between indicators. The maps are included in Appendix 2. Mental modeler helped define and identify the following features of each map.

- Drivers: also referred to as 'outdegree', the number of links starting from the indicator.
- Receivers: also referred to as 'indegree', the number of links ending with the indicator.
- Centrality: representing the number of links in and out of an indicator; its connectivity.
- Density: the number of links against the number of nodes.

For the study, 'centrality' was the feature used to explore how the maps could represent 'importance' to support the ranking of indicators. Whilst the most central indicator may not be the most 'serious' or the most subjectively important to a participant, through the maps it provides a semi-quantitative view of the indicator that connects and so influences the most other indicators – the most well-

² Although it is acknowledged that the distinction between coping and adaptation is significant in many instances, the distinction was not considered relevant for the purpose of this study [62].

³ More information can be found at <https://www.mentalmodeler.com/>.



Fig. 2. Regional map of the case study regions – Dubanchu and Sediba.

Table 1

List of indicators of impacts of drought.

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

Table 2
List of indicators of coping and adaptation to drought.

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

connected. ‘Drivers’ were also noted which are at the start of a cascade of indicators. The study seeks to explore the potential use of ‘drivers’, which have several links starting from them. This may suggest an area where an early intervention could inhibit the cascade of impact indicators in Question 1 or support the move towards coping and adaptation indicators in Question 2. Conversely, ‘receivers’, being at the end of a chain suggest indicators where intervention may be less influential.

In addition to the data from the maps, the discussions and descriptions from participants are noted and qualitative data incorporated to inform narratives or help explain the rationale for decisions made by the groups.

5. Results and analysis

The results of the FCM workshops are presented in two sections. The first section, 5.1, addresses the results on the impact of drought and section 5.2 addresses the results for coping and adapting. The maps are compared highlighting similarities and differences between the two locations (Dubanchu and Sediba) and gender.

5.1. Impacts of drought

Four maps were created in total by the groups, each addressing the relationship between 11 drought impact indicators (Table 1). A table of results (Table 3) is also included in Appendix 1. Each map digitalised by Mental Modeler is included in Appendix 2.

5.1.1. Dubanchu

There was commonality between the two maps in Dubanchu. The centrality rankings of each indicator were very similar (within three ranked places of each other). Further, the same indicators were in the top four in terms of centrality being.

- loss of crops

- reduced levels of groundwater
- sale of livestock
- increased poverty and unemployment

Although placed towards the top of the rankings by each group, the focus on 'sale of livestock' was particularly strong in the female group with the indicator being the most central component i.e., the indicator with the most connections to other indicators. In digging deeper through the narratives and the influences in the maps, the importance of livestock as a 'bank' or 'buffer' was shown; livestock was a resource that could be sold to improve cash flow. Livestock was however also a burden which had to be disposed of to reduce the requirement for other resources such as fodder and water. This was a theme evident in all groups in all regions.

The cascading impacts and influences between indicators was also seen in discussions around loss of crops and soil health, including the loss of food production for livestock. The male group also created new indicators, 'wild [veld] fire' due to drought, and depleted soils were added as a problem for their region. As explained by a male participant:

Veld fires, I am thinking of maybe overgrazing when there is drought, they will be putting all of the cattle together in one field. Drought and over-grazing, most of the time go hand in hand because what happens is that when there is drought, the grass dries.

In cascading impacts, the participants explained how drought forced them to buy animal fodder as less useable grass was available and this fodder became more expensive with the increased demand caused by drought. 'Wildfire' decreased the available grass further and forcing up the price of animal fodder. This was represented on the map as a connection between 'wildfires' and 'price increases for animal feed'.

Along with 'wildfires', the spiralling impacts of drought were also flagged by an additional indicator added, being the prevalence of 'animal diseases' connected to drought.

Normally when there is drought there are types of diseases we experience, like he's talking the Lampi-skin

This was a feature also independently flagged in subsequent workshops with the Sediba community and may reflect issues with animal health care problems in the country [48].

Poverty was also explained in terms of a driver as well as an outcome of drought. Rather than poverty being an outcome or 'receiver' at the end of a cascading chain of indicators, the male group depicted 'increased poverty and unemployment' as a driver behind other indicators. For example, the map noted 'increased poverty and unemployment' leading to 'migration away from the area', 'sale of livestock', and 'wildfire' (through over grazing). The downward spiralling cycles prompted by drought were expressed in the narratives.

You lose production because we have to sell the animals and the market price at that time will not be good, because the market will then take advantage, they will give you a low price, meaning you are going to sell more to feed the others.

And another commenting:

The market price (of livestock) falls because when there is drought everybody wants to sell, so its too much in the market

For the female group, 'increased poverty and unemployment' was also part of a cycle rather than at the end of the chain. They also articulated part of a cascade of indicator links, this time connected to food production.

Nutrients will be reduced because of water, no water then nutritious food becomes reduced, when it reduces then we sell [livestock] ... and then this one (indicator) will be created, poverty and unemployment.

'Increased poverty and unemployment' prevented them from finding resources such as buying supplies of water.

'Increased gender inequality' did not feature strongly in either map but was a feature within the narratives. For the female group,

Gender inequality is the most important one as women we are not taken into consideration

Although an important issue for this group, this did not materialise as a 'driver' or 'central indicator' in the maps. Gender inequalities were mostly expressed in general terms rather than linked to drought. One clear example was articulated where it was felt lower prices were achieved for the sale of livestock if a woman rather than a man went to market. This was a feature also discussed in more detail by the female group in Sediba (Section 5.1.2).

'Increased gender inequality' was discussed as an indicator by the male group as,

It (drought) affects everybody because you can be female, lets say you were married and the husband died, and you are now taking over responsibility of the whole, its going to be affecting just like it affecting the male, so there is no difference

The perception of this male group initially was of drought being a problem for landowners and predominantly male issue. However, on reflection within the group, examples could be seen where women would be equally impacted by drought. With that in mind, rather than being a male only issue, drought as perceived by the male group, is an issue that could affect male and female similarly. Within this male group, there was no recognition of women suffering differently or even worse than men; the issues and differences the female farmers faced were not recognised.

There were two indicators which were ranked very differently by the two groups in this region. The first was 'migration away from the area' which was a more central theme with the male farmers than with the female group. The migration theme may warrant further study and could conceivably be an issue over the ability of different genders to move away from a region or vary with personal

experiences. Secondly, was the 'change in energy needs' with again the male participants considering this more central. The increase in energy consumption during a drought was noted by this group with pumping required to access water from boreholes.

This one [referencing access to water] comes from drought and that makes the usage/demand if using electricity become very high

And further,

We have to use more electricity to pump the water

The 'change in energy needs' indicator was found to be very context dependent on individual and local conditions including the area of land farmed and the type, cost, and reliability of energy sources for pumps for irrigation. In this context, it was not considered to be an issue by the female group whose power sources were mostly free access to wind turbine rather than grid, canister gas or diesel.

5.1.2. Sediba

A further workshop took place in the local village hall in Sediba. There were two groups of local farmers - one with 5 female and the other with 3 male participants.

The experiences of the two groups, as depicted by the maps, showed some differences although two of the highest 'central indicators' were the same for both groups. Both groups gave high (top 2) 'centrality' to 'increased poverty and unemployment' (in line with Dubanchu groups) and both male and female groups in Sediba placed 'soil degradation' in the top 3 (in agreement with the male group but contrasting with the female group in Dubanchu).

There were differences over the position of 'loss of crops' between genders (2nd in male group, 6th in female group) and 'sale of livestock' (11th in male group, 4th in female group). This could be explained by the difference in importance of crops versus livestock within the participant groups and the dependence on livestock as a 'bank' or 'reserve'. The female group in Sediba, expressed the livestock position in similar terms to Dubanchu. This group expanded upon the issues around needing to sell livestock. The need for increased fodder was noted, but in addition the need for medicines for livestock because of drought was also flagged, mirroring the comments by the earlier group on costs impacts and 'animal diseases' from drought. They explained that they sell livestock so that they can raise funds to buy medication and fodder for the remaining livestock. The latter being important enough for the group to want this as an additional indicator.

Both groups gave relatively low 'centrality' to 'reduced levels of groundwater' although it was a 'driver' in both maps. Although not a central connector, it was at the start of cascading impacts, for example, from increasing energy requirements, loss of crops, and through to the remaining indicators. Less 'centrality' about groundwater levels could be explained by the water storage and re-use position which, from the discussions in the workshops, appeared much more resilient and robust for this village. The groups animatedly discussed their community 'jojo' tanks with water storage being shared via the tanks when needed and if groundwater was in low supply. The tanks, filled by rainwater, had appeared during the last drought. When water levels were low, they were part of a scheme whereby a water company would fill the tanks. After the drought, all but two of the tanks were returned. The remaining tanks were used by the community for rainwater storage and re-use with the water being used for agriculture and boiled or sterilised for domestic use. An informal, communal arrangement over the use of the water from the 'jojo' tanks was in operation for community events including funerals. As a result, the quality of water for the community appeared a more prevailing concern than groundwater levels.

The difference in gender responses was seen in terms of 'change in energy needs' with male and female groups considering it moderate (male) and low (female) in terms of 'centrality'. This was like the Dubanchu groups. In the male group, there were also comments that sometimes less energy was needed in a drought, with less crops being produced in a drought and so less energy required for production, for example.

'Increased gender inequality' had a relatively high degree of 'centrality' for the female group (ranked 5th) and was articulated with an example, with the 'sale of livestock' being linked to drought,

You will find that most women are not going to auction, and there is a reason. Instead they send males to go, the reason is because auctions they undermine the female, so they are going to reduce the price if it is me, not a male figure.

With the remaining participants in the group agreeing, this reflects a similar experience within the Dubanchu female group and a 'hidden' prejudice.

'Increased gender inequality' had a low 'centrality' (ranked 10th) in the male group, but this group also highlighted the emotional stress of drought that is not always captured in indicators and objective measurements. This group added 'strain on relationship' with this impact flowing from 'increased poverty and unemployment' and 'loss of crops'. This was an additional indicator added by this group, with this indicator having a joint third degree of centrality in their map.

5.2. Coping and adaptation to drought

Question 2 considered a different set of indicators linked to coping and adaptation (Table 2). The groups remained the same. By this stage, the groups were well versed in the process and the maps were developed quickly. A table of results for Question 2 is included in Appendix 1 (Table 4).

5.2.1. Dubanchu

For the female group, the maps were denser, with noticeably more connections than earlier maps. Several indicators had similar

degrees of 'centrality'. At the top, in terms of centrality, were 'higher % of drought resistant crops cultivated' and 'advice and coaching on new techniques and technology' aligning with a narrative from this group around self-sufficiency and managing their own risk. 'More water re-use or more efficient irrigation', 'access to energy', and 'Government policies on drought for small farmers' were also towards the top of the list.

At the bottom of the list of 'centrality' for the female group was 'drought prediction and EWS'. This indicator was interpreted by the group as a tool to support Government policy making only, thus being an indicator that flowed into and supported informed policy making at an administrative level. The connection to their farms was not made out. 'Drought prediction and EWS' was not a tool the group interpreted as something they would use themselves or where they could see its role in their own management of drought.

There were similarities and contrasts with the male group. The male map was less dense with fewer indicators used and fewer connections between them. Indicators on 'advice and coaching on new techniques and technologies', 'access to energy', and 'more water re-use or more efficient irrigation' were also towards the top of the list in terms of 'centrality' for the male group, with advice and coaching being at the very top. Government policies, whilst not central to the map, was a 'driver' behind cascading initiatives and was also clear from the narratives. One participant put forward his view as,

It all starts with Government policies, when there is drought the Government help to draw a plan or policy on how to deal with the drought ...

A noticeable difference was the placing of the indicator for 'more local land set aside for conservation and biodiversity' (10th in female map, 2nd in male map). This indicator was interpreted differently by the male group. This group concentrated on soil type and the environmental conditions that arose when they used land and when they set it aside. It was not a biodiversity issue but a field suitability issue with some land set aside as less useful in normal conditions but that could be used in drought conditions.

What we normally do is that we have fields that we plough in ... but we know that when there is a drought 'this on' this particular field I can still use because of the type of soil ... What we do is if its clay, clay soil holds water for longer period ...

There were very similar interpretations from the Sediba groups discussed below (Section 5.2.2). Further comments suggested that if there was early warning from the Government of drought conditions, the farmers would be better able to judge which land to set aside. It was explained that this use of land was becoming more important not just because of drought but due to the weather pattern changes with the predicted rains not falling as they used to, thus negatively impacting on farming planning and cycles.

'Improved produced storage and transportation capacity' and 'access to insurance, finance or credit' did not feature in the male map at all and were at the middle or lower end of 'centrality' in the female group. In relation to finance, there were issues of this being perceived as relevant for large farmers not emerging farmers and thus of no use to them, with further issues over access to these types of resources.

The problem is accessibility to the requirements we have to make certain thing before we can get it. It becomes difficult to access money ... there are certain things they check, your ability to deal with credit, they check and then your ability to pay it back ... they cannot take a risk. So it makes it difficult for emerging farmers

In addition, issues were noted around 'access to insurance, finance or credit' that some of the groups did not want to openly discuss, referencing unlawful practices inhibiting their access to finances.

The link between water and energy was expanded upon in the groups. Continuing with explanations from Question 1 about needing energy to pump groundwater, comments about the need of water for fertilisers in poor soil were also again noted. One participant commented,

We use fertilisers and then because of the electricity that we use to water, because these fertilisers they will need water, and we need electricity to water them

The groups highlighting that with depleted soil because of drought, nutrients or fertilisers could be added, but there remained a need for water and a cost in pumping it for the fertilisers to be effective.

There was one additional indicator, and this was added by the male group. It was a new indicator labelled 'windmills and jojo tanks' and was a 'driver' in the map expressed as supporting 'more water re-use or more efficient irrigation'; the water tank system again materialising as important for the communities.

5.2.2. Sediba

The differences in terms of 'density' were also noticeable in these maps, with the female group having significantly more connections between indicators.

For the male group in Sediba, the most central component and a 'driver' was 'Government policies on drought for small farmers'. 'Access to fertilisers or machinery' and 'higher % of drought resistant crops cultivated' also had central, connected roles in the map. 'Drought prediction and EWS' also had a low 'centrality' ranking as did 'participation in local farming co-operatives'.

Co-operatives were a central component in both maps but particularly the female map, where the co-operatives indicator was the strongest central component overall. For this female group, the benefits of information and exchange along with the use of local people and local resources was seen as an enabler into other indicators. A 'higher % of drought resistant crops cultivated', for example, flowed from co-operatives, as did advice on technology. As explained by a participant,

Technology can also help me because I am learning, so this technology will help us to run the co-operative properly.

The Sediba groups articulated positive experiences of co-operatives which they could draw upon and expand upon.

Similar to a group in Dubanchu, the female group in Sediba wanted to add an additional indicator around 'jojo' tanks, linking this to water re-use. The 'jojo' tanks were again given a high importance and prominence in the discussions. The connections were described by a participant summarising the map for the female group as,

This water from the jojo tanks, helps us to irrigate more, okay, we use jojo tank water and it can be re-used, we fertilise the soil with it. And then drought prediction and early warning system, we will tell the Government in time and they will help us with advises on coaching and new techniques and technology. And then technology will help us with the land that we set aside, and then the land that is set aside we will then use. Improved transportation and storage will be used for the co-operative. The co-operative will help us to plough or plant crops that are drought resistant ...

Another similarity of Sediba to Dubanchu was around 'local land set aside for conservation and biodiversity' and this was again interpreted as fallow land which could be used in drought conditions. This was not to increase biodiversity for the greater good, but of having the availability of different soil types and conditions that could be used in the event of dry conditions. Participants explained how this set aside land was left but the soil conditioned and could be drawn upon if needed.

'Drought prediction and EWS' again had a mixed response. Although Government policy was ranked centrally, the actual role of the Government was unclear within the group narratives and this was particularly evident in relation to EWS, as was the potential use and accessibility of EWS information. For some it was information from the Government, whilst others felt they needed to warn the Government about the drought and for the Government then to respond.

It is important we tell the Government earlier or in time

In contrast with,

During drought, we have to be told in time right, early warning signs

And another participant added,

We have to be told and then we tell the Government

A clear view of what an EWS was and what it would consist of was missing; as was a chain of communication. No existing communication structures bottom-up or top-down were evident in the narratives from the groups.

6. Discussion

6.1. Question 1–impacts

It was anticipated from the literature that local context would be significant in understanding the impact of drought and this was the case, with the maps helping to account for the nuances between each village community.

The maps were not identical, representing the different contexts and experiences of the groups, but there were common themes and areas of overlap. For example, the 'centrality' of 'increased poverty and unemployment' achieving top four centrality for all groups. To stress the point, the central indicator was not water. This accords with a view of the importance of socio-economic resilience [49]. The poverty indicator was frequently driving cascading chains or had high 'centrality' to other indicators suggesting an influence over other parts of the maps. The relentless drive towards poverty created by drought and vulnerabilities was also evident in discussions around the market forces and how increased fodder prices, for example, triggered by market demand in drought, exacerbated issues. The drought triggered higher prices for inputs such as fodder and reduced prices for sales of livestock. 'Increased poverty and unemployment', is not just an indicator of vulnerability to drought impacts but has a central role in driving vulnerabilities deeper.

There are two reflections to draw from this, the first around poverty alleviation and the second around markets.

The centrality around poverty provides support for decision-making or policies that focus upon poverty alleviation not just as a general policy goal but as a key, central drought mitigation step and calls for its inclusion in drought mitigation planning for these communities.

Secondly, it also suggests that targeted policies that address socio-economic impacts of drought may limit the downwards spiral. In addition to direct financial support, it may be useful to consider Government-backed market controls when a drought is declared, to mitigate against the unfavourable market price fluctuations triggered by drought response. As well as in relation to fodder prices, this is seen in the maps in relation to the 'sale of livestock' indicator. The importance of livestock was of clear significance to three of the four groups and the narratives highlighted how livestock had dual conflicting goals as both an essential 'bank' or reserve, and a burden. The role of livestock as a 'bank' or reserve has been seen previously when exploring coping mechanisms to drought [50], with further evidence of that phenomenon here. What is flagged by the participants though, is the issue around the 'sale of livestock' at the 'wrong' time prompted by drought and the market forces that drove prices down – just when money was needed – were also highlighted. The implications to other indicators were also noted, again suggesting a potential leverage point for policy focus.

A feature which did not align with the literature was in relation to gender. 'Increased gender inequalities' had higher rankings in the female groups and were not recognised by the male groups. There was a general sense of inequality with the female groups but, save for one exception over 'sale of livestock' at market, issues were not clearly linked to the indicators. That is not to say gender inequalities do not exist, but that the drought indicators did not prompt a detailed discussion on different gender impacts, or arguably that differences had become normalised.

There may also be an issue with the indicator itself as being too diffuse a term. Gender differences were noted in the construction of

the maps, the female maps being noticeably denser (the reasons for this fall outside the remit of the study but would be of interest in further FCM work). There were also difference in preferences within the maps between genders. Energy was a less prominent issue for female groups, for example. This may be due to the energy supply availability to the female groups as energy was not something they had access to or relied upon outside drought, but could also reflect findings noted in existing literature, for example around accessibility to technical mitigation (often requiring energy) [32]. In exploring gender differences, it may be these less direct but more specific indicators can help give a clearer articulation of gender issues than a discussion on 'gender inequalities'.

Three new indicators were added by the groups. One around the stress of drought was articulated by a group adding 'strain on relationship' as an indicator in their map. This was not an indicator located in the 100 plus indicators identified in the literature or raised in expert discussions. There are reflections that can be drawn from this. Engagement with communities who have experienced drought draws upon their reality and lived experiences. A discussion on quantitative data and even indicators can miss the immense stress that drought can bring - as was evident in discussions with participants talking about the loss of crops and the distress in watching the death of their livestock, this being the basis of their livelihoods. The maps as evidence can support policy decisions but can also be a powerful means of articulation and communication of the issues faced. It also highlights the tensions and stress that build up on communities and when we consider support it is not just financial that is required.

A further finding accords with discussions on what can be missed when there is a focus on large-scale technical infrastructure systems that ignore informal local structures and human behaviour. Irwin et al. [51], for example, discussed the close connection between technological acceptance and human behaviour around shocks to the water-energy-food system caused by events such as climate change. From the discussions within the groups the 'jojo' tanks appeared to provide a sense of security around groundwater replacement following their introduction in the previous drought. The 'jojo' tanks is also an example of collective action with the 'jojo' tanks being seen as a shared resource [51]. The issue around 'jojo' tanks provides further evidence of the importance of understanding context when applying indicators as the situation with 'jojo' tanks will not be replicated in all regions, but conversely also provides support for their introduction elsewhere.

6.2. Question 2-coping and adaptation

Question 2 addressed a different set of 11 indicators, this time focussing on coping and adaptation to drought. Whilst there was some alignment with the literature there were more differences.

In terms of the two regions, there were areas of commonality. High 'centrality' by all groups was awarded to the indicator for 'advice and coaching on new techniques and technology' and mostly very high 'centrality' was also seen for drought resistant crops cultivated. The communities appeared willing to learn and embrace new technologies as they coped not only with drought, but changing weather patterns, meaning the seed and land selection, water-saving, and soil improvement techniques needed to be adapted alongside. The narratives were more around wanting to learn to support themselves. This could be construed as a desire for outside support but does not necessarily align with literature around social dependency on grants or over-reliance on government support [26].

Although a desire from the farmers for practical support was a strong feature of the maps, a contrast can be made with indicators around economic support for example 'access to finance, insurance or credit' which did not feature strongly; this was contrary to expectation. The finance indicator was the 6th most central feature in two maps, and 9th and 10th respectively in the remaining maps. This is despite 'increased poverty and unemployment' being a key concern around impacts for the groups. This appears counter-intuitive in view of the strong poverty indicator and contrary to the studies where access to finance was considered positive [25].

Looking deeper into the maps and discussions, participants explained that whilst financial services existed, they were not available to them or had many bureaucratic hurdles to overcome. This may align with literature around the duality of farming experiences between different farming communities in South Africa, [35]. On further analysis, the participants echo studies on agricultural financing which highlight the risk aversion behaviour of financial institutions requiring Government policy intervention particularly around new farmers, women, and small holders [52]. Low experience and accessibility with finance appears behind its relatively low 'centrality' in the maps. 'Access to insurance, finance or credit', is worthy of further exploration bearing in mind the importance of socio-economic resilience suggested by the impact maps. It suggests current means of improving socio-economic resilience through available finance mechanisms are not valuable or not perceived to be valuable. In addition to ensuring finance is available in reality as well as in theory, with barriers to access removed, it suggests work is needed preferably in hand with communities to ensure the products meet requirements and the potential benefits are clearly articulated.

Communication issues were also evident in relation to EWS. It was anticipated that 'drought prediction and EWS' would receive high 'centrality' ratings being a tool that would support planning, seed and land selection for example. The placing of this indicator between the four groups was 4, 5, 10, and 11, so two groups giving this very low 'centrality'. In the discussions this could be explained by the lack of existing information flows between government and community; there did not appear to be structures and norms already in existence for information to be communicated along. The possible finding of a disconnect is supported by the literature. South Africa is said to have comprehensive Disaster Risk Reduction policies but the extent these are successfully implemented is an issue [33]. A disconnect between Government departments has been noted together with a disconnect with some communities [35]. Rather than dismiss EWS as a suitable tool for the community it may mean that more fundamental structures around communication need to be in place before it 'makes sense' to those that would use it.

In terms of outside support beyond the Government, the role of local farming co-operatives achieved higher 'centrality' in Sediba groups, possibly explained by their current positive experience of co-operatives as opposed to the position in Dubanchu. At their best, co-operation within local farming communities is seen in the literature as enhancing social capital and in turn reducing vulnerability [53], although anecdotally, when speaking to farming communities', their experiences vary. Similar to finance and EWS, whether the

potential benefits of this are appreciated appears to be linked to previous experience. In a similar way to EWS, simply introducing them without structures, communication, and liaison with the communities will be insufficient if there is to be take-up and for the potential benefits to be achieved.

The biodiversity indicator was interpreted by the groups in the same way – albeit not in the way intended by the study. Rather than an indicator for biodiversity for public well-being, it was seen as reflecting good farming practices of having fallow land. Rather than an endorsement of the biodiversity indicator, the ‘availability of fallow land’ could be an additional indicator and a further contribution to MADIS indicators. In relation to biodiversity, the benefits of having land set aside to enhance biodiversity are well established and noted in indicator research [23]. Despite this, there remains an issue over whose land this should affect and how they are ‘compensated’ for providing a public good. The development of policy principles of public payments for public goods, to include payments for increasing biodiversity on land are beginning in the United Kingdom, as a way of establishing incentives for the loss of productive land as well as education on the benefits [54]. An identical policy or incentive cannot be assumed to be applicable in all jurisdictions, but it does suggest some form of Government intervention, in a context suitable way, is required to stimulate movement towards improving biodiversity.

The different gender responses were more noticeable in Question 2, partly because of the content of the maps and responses, but also because of the density of the finished maps. The number of connections in the female maps were noticeably higher than the less dense maps created by the men. It would be overreaching to postulate on why there are density difference in the study to the extent that generalisations could be made. The results do, however, endorse the view that there are potential differences between genders both in approach to mapping and in experiences, and care is required to ensure all voices, approaches, and perspectives are noted [30,32].

7. Conclusion

The goal to understand a drought indicator out of a static silo and in a system was achieved. Through narratives highlighting the strain on relationships and discussions on crops and livestock dying, the indicators were brought to life. The FCM workshops were able to show how drought indicators interconnect and offer opportunities that can be further explored, providing guidance around where resources or policies could be applied to be most effective. For impacts in Question 1 the centrality of poverty and unemployment was noted as was the sale of livestock, with socio-economic and market control policies therefore strongly indicated. Question 2 responses suggest current availability of financial services, Government communications, and EWS are not meeting needs.

The paper explores how indicators should be viewed, not as static quantitative entities, but in a system and how viewing indicators in this way with communities provides new insights into the question of the ‘influence’ of an indicator with impacts on decision-makers (such as where good policy intervention points may lie). We believe this offers a fresh perspective in the field of drought indicator selection. Further, this research paper answers questions of how we can connect scientific datasets (in this case around drought indicators) with local knowledge. It showcases a methodology, FCM, which has significant and under-used potential in the field of drought indicator research as a tool to link communities with science-led indicator selection in a way that prompts deeper thinking from participants than a survey or interview. The results validate, challenge, enhance, and add nuance to scientific datasets by drawing upon the lived experience.

This paper has shown the potential of an FCM approach to drought indicator research. The goals of this paper were considered with decision-makers in mind to find a way of cutting through the array of indicators and focussing on where limited resources could be most beneficially applied. This has refigured what may be considered ‘important’ in terms of ranking an indicator. Future work could focus upon engaging with decision-makers to create their own maps to cross refer with those created by their communities. A joint workshop, being sensitive to power imbalances, could also be explored. There were some unanswered questions in terms of gender both in terms of how the maps were created and the content. A session that focussed more widely on gender inequalities rather than a drought context could be insightful.

The FCM workshops encouraged thinking, debate and engagement on issues beyond that which would have been achieved through means such as interviews. FCM workshops could be used to identify financial tools for support, preferences communication with Government and EWS, and the wider introduction of farming-co-operatives.

As well as areas of commonality, there were differences between the groups in terms of gender, context and experience, and this was reflected in the maps created. This acts as a reminder of the context dependence of drought indicators and a reflection on how generalisable they could or should be. The participants were able to offer new indicators that are important to them. This does remind us of the benefits but also the limitations of indicators, that they are a useful tool but the lived experience and context cannot be ignored. Despite the input of experts from around the globe in relation to drought indicators, the insights from affected communities are (at least) equally valid offering context and depth to our knowledge base and holistic data sets that can be used to support them.

Data statement

Data supporting this study are included within the article and/or supporting materials.

CRediT authorship contribution statement

Elisabeth A. Shrimpton: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nazmiye Balta-Ozkan:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation. **Tanaya Sarmah:** Writing – review & editing, Visualization, Software, Methodology, Data curation. **Da Huo:** Writing –

review & editing. **Lochner Marais:** Writing – review & editing, Resources, Project administration, Methodology, Formal analysis, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Professor Nazmiye Balta-Ozkan reports financial support was provided by UKRI EPSRC GCRF and Newton Fund Consolidation Account Block Funding. 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.

Data availability

Data supporting this study are included within the article and/or supporting materials

Acknowledgements

Funding: The authors wish to acknowledge the support of UKRI-EPSRC GCRF and Newton Fund Consolidation Account block grant funding under grant number EP/X527919/1 in conducting the workshops.

The indicators used in these workshops form part of the Management of Disaster Risk and Societal Resilience (MADIS) project which is funded by Belmont Forum and UKRI-EPSRC (Grant no. EP/V006592/1) (Old project name: Theory of Change Observatory on Disaster Resilience – TOCO-DR). We also acknowledge the support of all MADIS team members from Pennsylvania State University (led by Professor Mike Jacobson and Prof Abdullah Konak) and the University of Sao Paulo (led by Professor Adelaide Nardocci and Professor E. Mario Mendiondo) during this work.

Appendix 1. Tables

Table 3

Centrality rankings for impact indicators

(= represents rankings shared by more than one indicator)

Indicator no.	Indicator (Impacts)	Female Dubanchu	Male Dubanchu	Male Sediba	Female Sediba
1	Loss of crops	2	2	= 1	= 5
2	Reduced levels of groundwater	4	3	9	10
3	Sale of livestock	1	= 4	11	4
4	Soil degradation	= 8	= 5	3	3
5	Reduced availability of nutritious food	7	= 5	4	9
6	Reduced water quality	6	= 5	= 6	1
7	Reduced investment in fertilisers, seeds, machinery	= 4	7	5	= 7
8	Migration away from the area	11	= 4	8	= 7
9	Increased poverty and unemployment	= 4	1	= 1	2
10	Increased gender inequality	= 8	11	10	= 5
11	Change in energy needs	10	= 5	6	11
Added 1	Increased animal feed price		5x		
Added 2	Wildfire		3x		
Added 3	Animal diseases		5x		
Added 4	Strain on relationship			3x	
Added 5	Medicine and fodder for animals				10x

Table 4

Centrality rankings for coping and adaptation indicators

Indicator no.	Indicator (Coping and adaptation)	Female Dubanchu	Male Dubanchu	Male Sediba	Female Sediba
1	Government policies on drought for small farmers	= 3	= 6	1	2
2	Drought prediction and EWS	11	= 4	10	5
3	Advice and coaching on new techniques and technology	2	1	= 4	3
4	More water re-use and more efficient irrigation	= 3	= 2	9	7
5	Higher % of drought-resistant crops cultivated	1	= 6	3	10
6	Access to insurance, finance or credit	6	10	6	= 9
7	Access to fertilisers or machinery	6	= 6	2	= 9
8	Access to energy	= 3	= 4	7	11
9	Participation in local farming co-operatives	= 8	9	= 4	1
10	More local land set aside for conservation and biodiversity	10	= 2	8	4
11	Improved produce storage and transportation capacity	= 8	10	11	6
Added 1	Wind mills and jojo tanks		9x		
Added 2	Jojo tank				7x

Appendix 2. Maps

As a key for the maps, 'blue arrow' indicates a positive relation; 'orange arrow' indicates a negative relation; 'grey box' is a pre-selected indicator; 'green box' means the indicator was not considered by the group while developing the map; and 'yellow box' refers to the new indicator added.

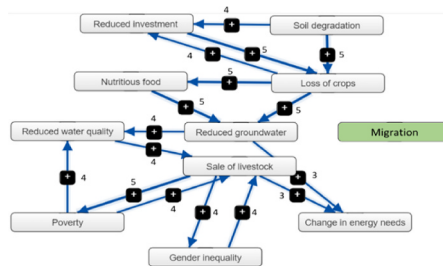


Fig. 3. Map created by female group in Dubanchu for impact indicators.

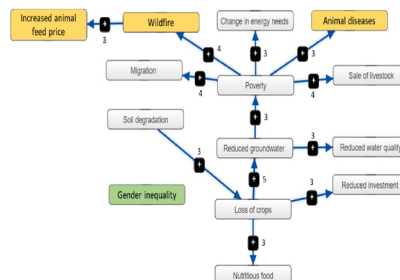


Fig. 4. Map created by male group in Dubanchu for impact indicators.

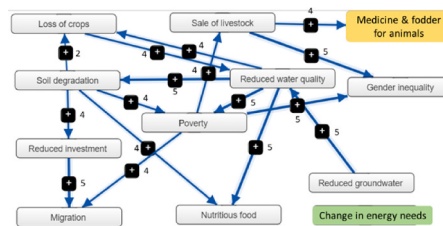


Fig. 5. Map created by female group in Sediba for impact indicators.

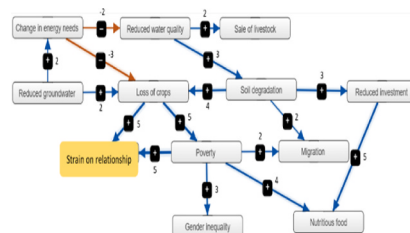


Fig. 6. Map created by male group in Sediba for impact indicators.

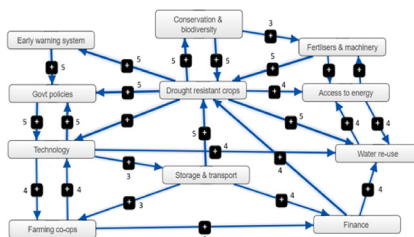


Fig. 7. Map created by female group in Dubanchu for adaptation indicators.

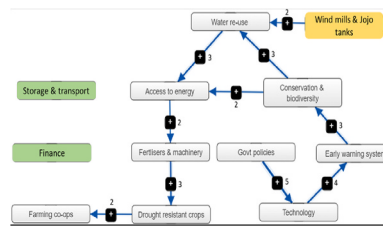


Fig. 8. Map created by male group in Dubanchu for adaptation indicators.

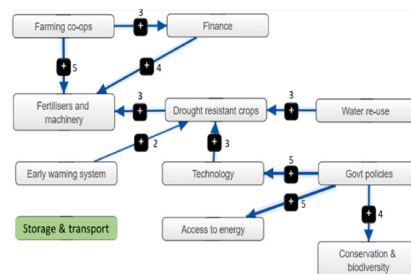


Fig. 9. Map created by male group in Sediba for adaptation indicators.

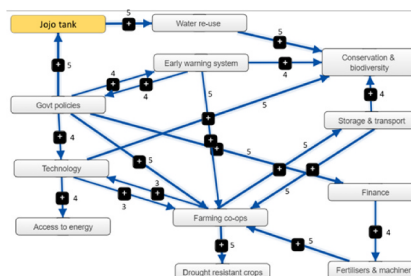


Fig. 10. Map created by female group in Sediba for adaptation indicators.

References

- [1] United Nations, Drought in numbers 2022. <https://www.uncced.int/sites/default/files/2022-06/Drought%20in%20Numbers%20%28English%29.pdf>, 2022.
- [2] UNESCO World Water Assessment Programme., *The United Nations World Water Development Report 2019: Leaving No One Behind, Facts and Figures*, 2019.
- [3] Y.T. Bahta, Nexus between coping strategies and households' agricultural drought resilience to food insecurity in South Africa, *Land* 11 (6) (2022), <https://doi.org/10.3390/land11060893>.
- [4] A.K. Mishra, V.P. Singh, A review of drought concepts, *J. Hydrol.* 391 (1–2) (2010) 202–216, <https://doi.org/10.1016/J.JHYDROL.2010.07.012>.
- [5] S.R. Fragaszy, T. Jedd, N. Wall, C. Knutson, M.B. Fraj, K. Bergaoui, M. Svoboda, M. Hayes, R. McDonnell, Drought monitoring in the Middle East and north Africa (MENA) region: participatory engagement to inform early warning systems, *Bull. Am. Meteorol. Soc.* 101 (7) (2020) E1148–E1173, <https://doi.org/10.1175/BAMS-D-18-0084.1>.
- [6] A. Rassoul Zarei, M. Reza Mahmoudi, A.R. Zarei, M.R. Mahmoudi, Assessing and predicting the vulnerability to agrometeorological drought using the fuzzy-AHP and second-order Markov chain techniques, *Water Resour. Manag.* 2022 (2022) 1–22, <https://doi.org/10.1007/S11269-022-03260-8>.
- [7] M. Yan, B. Yang, S. Sheng, X. Fan, X. Li, X. Lu, Evaluation of cropland system resilience to climate change at municipal scale through robustness, adaptability, and transformability: a case study of hubei province, China, *Frontiers in Ecology and Evolution* 0 (2022) 598, <https://doi.org/10.3389/FEVO.2022.943265>.
- [8] P.K. Singh, H. Chudasama, Pathways for drought resilient livelihoods based on people's perception, *Climatic Change* 140 (2) (2017) 179–193, <https://doi.org/10.1007/S10584-016-1817-8/TABLES/1>.
- [9] T. Mabhaudhi, S. Mpandeli, L. Nhamo, V.G.P. Chimonyo, C. Nhemachena, A. Senzanje, D. Naidoo, A.T. Modi, Prospects for improving irrigated agriculture in southern Africa: linking water, energy and food, *Water* 10 (2018), <https://doi.org/10.3390/w10121881>.
- [10] A.O. Awiti, Climate change and gender in Africa: a review of impact and gender-Responsive solutions, *Frontiers in Climate* 4 (2022) 101, <https://doi.org/10.3389/FCLIM.2022.895950>.
- [11] Y.N. Ghimire, P. Shivakoti, S.R. Perret, Household-level vulnerability to drought in hill agriculture of Nepal: implications for adaptation planning, *Int. J. Sustain. Dev. World Ecol.* 3 (2010), <https://doi.org/10.1080/13504501003737500>.
- [12] Belmont Forum, MADIS. Belmont Forum. <https://sites.psu.edu/belmont/>, 2023.
- [13] de Macedo, et al., Brief communication: lessons learned and experiences gained from building up a global survey on societal resilience to changing droughts, *Nat. Hazards Earth Syst. Sci.* (2024).
- [14] S. Bachmair, K. Stahl, K. Collins, J. Hannaford, M. Acreman, M. Svoboda, C. Knutson, K.H. Smith, N. Wall, B. Fuchs, N.D. Crossman, I.C. Overton, Drought indicators revisited: the need for a wider consideration of environment and society, *WIREs Water* 3 (2016) 516–536, <https://doi.org/10.1002/wat2.1154>.
- [15] V. Blauhut, The triple complexity of drought risk analysis and its visualisation via mapping: a review across scales and sectors, *Earth Sci. Rev.* 210 (2020) 103345, <https://doi.org/10.1016/J.EARSCIREV.2020.103345>.

- [16] K.S. Sass, A. Konak, M. Batalini de Macedo, M.R. Benso, E. Shrimpton, N. Balta-Ozkan, T. Sarmah, E.M. Mendiondo, G. Jesus da Silva, P.G. Câmara da Silva, A. C. Nardocci, M. Jacobson, Enhancing drought resilience and vulnerability assessment in small farms: a global expert survey on multidimensional indicators, *Int. J. Disaster Risk Reduc.* 110 (104616) (2024), <https://doi.org/10.1016/j.ijdr.2024.104616>.
- [17] Statistica, Agriculture in South Africa. Statistica. <https://www.statista.com/topics/9876/agriculture-in-south-africa/>, 2023.
- [18] J. Greyling, The role of the agricultural sector in the South African economy. <https://doi.org/10.13140/RG.2.2.33852.39049>, 2012.
- [19] I. Meza, E. Eyshi Rezaei, S. Siebert, G. Ghazaryan, H. Nouri, O. Dubovyk, H. Gerdener, C. Herbert, J. Kusche, E. Popat, J. Rhyner, A. Jordaan, Y. Walz, M. Hagenlocher, Drought risk for agricultural systems in South Africa: drivers, spatial patterns, and implications for drought risk management, *Sci. Total Environ.* 799 (2021) 149505, <https://doi.org/10.1016/j.scitotenv.2021.149505>.
- [20] FAO, The impact of disasters and crises on agriculture and food security: 2021, Food and Agriculture Organisation of the United Nations (2021). <https://www.fao.org/3/cb3673en/cb3673en.pdf>.
- [21] J.F. Morton, The impact of climate change on smallholder and subsistence agriculture, *Proc. Natl. Acad. Sci. U.S.A.* 104 (50) (2007) 19680–19685, <https://doi.org/10.1073/PNAS.0701855104>.
- [22] K. Smith, *Environmental Hazards: Assessing Risk and Reducing Disaster*, sixth ed., Routledge, 2013.
- [23] M. Masroor, M.H. Rahaman, H. Sajjad, Assessing farmers' perception based composite drought vulnerability in Godavari Middle Sub-basin, India, *Int. J. Disaster Risk Reduc.* 92 (2023) 103747, <https://doi.org/10.1016/J.IJDRR.2023.103747>.
- [24] M. Savari, M. Shokati Amghani, SWOT-FAHP-TOWS analysis for adaptation strategies development among small-scale farmers in drought conditions, *Int. J. Disaster Risk Reduc.* 67 (2022) 102695, <https://doi.org/10.1016/J.IJDRR.2021.102695>.
- [25] M. Savari, H.E. Damaneh, H.E. Damaneh, Effective factors to increase rural households' resilience under drought conditions in Iran, *Int. J. Disaster Risk Reduc.* 90 (2023) 103644, <https://doi.org/10.1016/J.IJDRR.2023.103644>.
- [26] S.J. Lottering, P. Mafongoya, R.T. Lottering, Assessing the social vulnerability of small-scale farmer's to drought in uMzinga, KwaZulu-Natal, *Int. J. Disaster Risk Reduc.* 65 (2021) 102568, <https://doi.org/10.1016/J.IJDRR.2021.102568>.
- [27] M. Masinde, M. Mwagha, T. Tadesse, Downscaling africa's drought forecasts through integration of indigenous and scientific drought forecasts using fuzzy cognitive maps, *Geosciences* 8 (4) (2018) 135, <https://doi.org/10.3390/GEOSCIENCES8040135>, 2018, Vol. 8, Page 135.
- [28] R. Giordano, E. Preziosi, E. Romano, Integration of local and scientific knowledge to support drought impact monitoring: some hints from an Italian case study, *Nat. Hazards* 69 (1) (2013) 523–544, <https://doi.org/10.1007/s11069-013-0724-9/FIGURES/9>.
- [29] A. Rashidfarokhi, Resilience by whom and for whom? Empowering local communities for community-led resilience-building, in: T. Saija, H. Sirkka, I. Verma, R. Castano-Rosa, S. Wilkinson (Eds.), *Real Estate and Sustainable Crisis Management in Urban Environments: Challenges and Solutions for Resilient Cities*, CRC Press, 2024, pp. 39–56, <https://doi.org/10.1201/9781003474586-3>.
- [30] P. Agamile, R. Dimova, J. Golan, Crop choice, drought and gender: new insights from smallholders' response to weather shocks in rural Uganda, *J. Agric. Econ.* 72 (3) (2021) 829–856, <https://doi.org/10.1111/1477-9552.12427>.
- [31] United Nations, SDGs, United Nations, <https://sdgs.un.org/goals>, 2023.
- [32] Y.T. Bahta, A. Jordaan, F. Muyambo, Communal farmers' perception of drought in South Africa: policy implication for drought risk reduction, *Int. J. Disaster Risk Reduc.* 20 (2016) 39–50, <https://doi.org/10.1016/J.IJDRR.2016.10.007>.
- [33] M.-A. Baudoin, C. Vogel, K. Nortje, M. Naik, Living with drought in South Africa: lessons learnt from the recent El Niño drought period, *Int. J. Disaster Risk Reduc.* 23 (2017) 128–137, <https://doi.org/10.1016/j.ijdr.2017.05.005>.
- [34] Department of Rural Development and Land Reform South Africa, Agricultural statistics South Africa 2018. OpenAFRICA. <https://africaopendata.org/dataset/agricultural-statistics-south-africa-2018/resource/dac8036e-7928-4ee8-b222-fc34c3fa92b>, 2018.
- [35] R.K. Adom, M.D. Simatele, M. Reid, Addressing the challenges of water-energy-food nexus programme in the context of sustainable development and climate change in South Africa, *Journal of Water and Climate Change* 13 (7) (2022) 2761–2779, <https://doi.org/10.2166/wcc.2022.099>.
- [36] OECD, Agricultural policy monitoring and evaluation 2021: addressing the challenges facing food systems. OECD ILibrary. <https://www.oecd-ilibrary.org/sites/3a64b9ab-en/index.html?itemId=/content/component/3a64b9ab-en>, 2023.
- [37] A. Harding, South Africa load-shedding: the roots of Eskom's power problem. BBC News, May 24, <https://www.bbc.co.uk/news/world-africa-65671718>, 2023.
- [38] C. Murray, *Black Mountain: Land, Class & Power in the Eastern Orange Free State*, Edinburgh University Press, 1992.
- [39] D.S. Krige, Bleomfontein, in: A. Lemon (Ed.), *Homes Apart: South Africa's Segregated Cities*, David Phillips, 1991, pp. 104–119.
- [40] S.D. Molla, M.T. Zeleke, S.M. Tamiru, Assessing livelihood resilience in drought-affected areas: lessons from Raya Kobo district, northeast Ethiopia, *Heliyon* 10 (1) (2024) e23399, <https://doi.org/10.1016/j.heliyon.2023.e23399>.
- [41] M. Slayi, L. Zhou, I.F. Jaja, Exploring farmers' perceptions and willingness to tackle drought-related issues in small-holder cattle production systems: a case of rural communities in the Eastern Cape, South Africa, *Appl. Sci.* 13 (13) (2023), <https://doi.org/10.3390/app13137524>, Switzerland.
- [42] S.B. Wassie, D.A. Mengistu, A.B. Birlie, Agricultural livelihood resilience in the face of recurring droughts: Empirical evidence from northeast Ethiopia, *Heliyon* 9 (6) (2023), <https://doi.org/10.1016/j.heliyon.2023.e16422>.
- [43] R. Axelrod, *Structure of Decision: the Cognitive Maps of Political Elites*, Princeton University Press, 1976.
- [44] M. van Vliet, K. Kok, T. Veldkamp, Linking stakeholders and modellers in scenario studies: the use of Fuzzy Cognitive Maps as a communication and learning tool, *Futures* 42 (1) (2010) 1–14, <https://doi.org/10.1016/J.FUTURES.2009.08.005>.
- [45] P.K. Singh, K. Papageorgiou, H. Chudasama, E.I. Papageorgiou, Evaluating the effectiveness of climate change adaptations in the world's largest mangrove ecosystem, *Sustainability* 11 (23) (2019) 6655, <https://doi.org/10.3390/SU11236655>, 2019, Vol. 11, Page 6655.
- [46] E.H. Cakmak, H. Dudu, O. Eruyur, M. Ger, S. Onurlu, Ö. Tonguç, Participatory fuzzy cognitive mapping analysis to evaluate the future of water in the Seyhan Basin, *Water & Climate Change* 4 (2) (2013), <https://doi.org/10.2166/wcc.2013.029>.
- [47] A. Singer, S. Gray, A. Sadler, L. Schmitt Olabisi, K. Metta, R. Wallace, M.C. Lopez, J. Introne, M. Gorman, J. Henderson, Translating community narratives into semi-quantitative models to understand the dynamics of socio-environmental crises, *Environ. Model. Software* 97 (2017) 46–55, <https://doi.org/10.1016/J.ENVSOF.2017.07.010>.
- [48] S. Marais, SA's dire animal health situation is a constraint on livestock production. Farmer's weeks, January 12, <https://www.farmersweekly.co.za/agri-news/south-africa/sas-dire-animal-health-situation-is-a-constraint-on-livestock-production/>, 2022.
- [49] S. Hallegatte, A. Vogt-Schilb, J. Rozenberg, M. Bangalore, C. Beaudet, From poverty to disaster and back: a review of the literature, *Economics of Disasters and Climate Change* 4 (2020) 223–247, <https://doi.org/10.1007/s41885-020-00060-5>.
- [50] E. Bryan, T.T. Deressa, G.A. Gbetibouo, C. Ringle, Adaptation to climate change in Ethiopia and South Africa: options and constraints, *Environ. Sci. Pol.* 12 (4) (2009) 413–426, <https://doi.org/10.1016/J.ENVSCL.2008.11.002>.
- [51] E. Irwin, J. Campbell, R. Wilson, A. Faggian, R. Moore, N. Irwin, Human adaptations in food, energy, and water systems, *Journal of Environmental Studies and Sciences* 6 (1) (2016) 127–139, <https://doi.org/10.1007/s13412-016-0375-8>.
- [52] L. Onyiriuba, E.U.O. Okoro, G.I. Ibe, Strategic government policies on agricultural financing in African emerging markets Government policies on agricultural financing 563, *Agric. Finance Rev.* 80 (4) (2020) 563–588, <https://doi.org/10.1108/AFR-01-2020-0013>.
- [53] D. D'Agostino, M. Borg, S.H. Hallett, R.S. Sakrabani, A. Thompson, L. Papadimitriou, J.W. Knox, Multi-stakeholder analysis to improve agricultural water management policy and practice in Malta, *Agric. Water Manag.* 229 (2020), <https://doi.org/10.1016/J.AGWAT.2019.105920>.
- [54] DEFRA, *Environmental Land Management (ELM) Update: How Government Will Pay for Land-Based Environment and Climate Goods and Services*, UK Government, 2023. June 21.
- [55] Food and Agriculture Organization of the United Nations, Goal 5: achieve Gender Equality and empower all women and girls. FAO. <https://www.fao.org/sustainable-development-goals/goals/goal-5/en/>, 2023.
- [56] B. Kosko, Fuzzy cognitive maps, *Int. J. Man Mach. Stud.* 24 (1) (1986) 65–75, [https://doi.org/10.1016/S0020-7373\(86\)80040-2](https://doi.org/10.1016/S0020-7373(86)80040-2).
- [57] T. McPhearson, C. M Raymond, N. Gulsrud, C. Albert, N. Coles, N. Fagerholm, M. Nagatsu, A.S. Olafsson, N. Soininen, K. Vierikko, Radical changes are needed for transformations to a good Anthropocene, *Npj Urban Sustainability* 1 (1) (2021) 1–13, <https://doi.org/10.1038/s42949-021-00017-x>, 1:1.

- [58] I. Mouratiadou, D. Moran, Mapping public participation in the Water Framework Directive: A case study of the Pinios River Basin, Greece, *Ecol. Econ.* 62 (1) (2007) 66–76. <https://doi.org/10.1016/J.ECOLECON.2007.01.009>.
- [59] U. Ozesmi, S. Ozesmi, A Participatory Approach to Ecosystem Conservation: Fuzzy Cognitive Maps and Stakeholder Group Analysis in Uluabat Lake, Turkey, *Environ. Manag.* 31 (2003) 518–531. <https://doi.org/10.1007/s00267-002-2841-1>.
- [60] U. Özesmi, S.L. Özesmi, Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach, *Ecol. Model.* 176 (2004) 43–64. <https://doi.org/10.1016/j.ecolmodel.2003.10.027>.
- [61] G.A. Mendoza, R. Prabhu, Participatory modeling and analysis for sustainable forest management: Overview of soft system dynamics models and applications, *For. Pol. Econ.* 9 (2) (2006) 179–196. <https://doi.org/10.1016/J.FORPOL.2005.06.006>.
- [62] A. Alemayehu, W. Bewket, *Local Environment The International Journal of Justice and Sustainability Smallholder farmers' coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia*. <https://doi.org/10.1080/13549839.2017.1290058>.



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2024-10-15

Elsevier

<https://doi.org/10.1016/j.ijdrr.2024.104820>

Shrimpton EA, Balta-Ozkan N, Sarmah T, et al., (2024) Re-evaluating drought indicators: learning from small-scale farmers in South Africa. International Journal of Disaster Risk Reduction, Volume 113, October 20024, Article number 104820