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Enhancing Drought Resilience and Vulnerability Assessment in Small Farms: A Global Expert Survey on Multidimensional Indicators

Karina Simone Sass, Abdullah Konak, Marina Batalini de Macedo, Marcos Roberto Benso, Elisabeth Shrimpton, Nazmiye Balta-Ozkan, Tanaya Sarmah, Eduardo Mario Mendiondo, Greicelene Jesus da Silva, Pedro Gustavo Câmara da Silva, Adelaide Cassia Nardocci and Michael Jacobson

Abstract: The purpose of the paper is to evaluate drought vulnerability and resilience within the context of small-scale farms. Small-scale farms are distinguished by their family-oriented motives, which prioritize maintaining the stability of the household farm system. This type of farming is responsible for a significant part of the world's food production, thus identifying their vulnerability and resilience to drought is essential to avoid adverse socioeconomic impacts. The paper contributes to this issue by presenting the findings of a comprehensive global survey conducted among experts on drought risk analysis, focusing on indicators related to drought resilience and vulnerability in small-scale farming. An online questionnaire was sent to experts asking them to rate a list of 36 indicators in terms of five metrics: relevancy, accessibility, objectivity, understanding, and temporal consistency. Each indicator was rated on a three-point scale (low, medium, and high). The survey was entirely completed by 120 experts from 42 countries and different areas of expertise. The survey results offer a comprehensive evaluation of multiple indicators, contributing to future research by guiding the selection of indicators for composite drought resilience indexes and enhancing the understanding of farmers' and food systems' climate resilience. The survey results indicate that: *i)* government and institutional indicators are very relevant for drought resilience assessment; *ii)* there is an undefined role for social indicators in drought vulnerability assessment; *iii)* experts still do not perceive the importance of local engagement in drought risk management; *iv)* the use of relevant indicators in drought risk assessment can be limited because of a lack of accessibility and temporal consistency.

Keywords: drought risk management, drought vulnerability, drought resilience, expert elicitation, small farms.

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1) Introduction

Droughts have long posed a significant threat to global food production, with their frequency and intensity expected to escalate due to climate change (IPCC, 2022). Droughts can lead to reduced crop production, social conflict over water allocation, outmigration, and even famine (van Ginkel & Biradar, 2021). Within this context, understanding the nuances of drought resilience and vulnerability within regions and communities aims not only to comprehend the underlying factors causing such impacts but also to pave the way towards effective mitigation strategies (Wilhite, Sivakumar & Pulwarty, 2014). This process involves considering information from multiple sources, which is particularly relevant for creating targeted policies (Pischke & Stefanski, 2016). Therefore, addressing resilience and vulnerability improves drought management and policy, shifting from a reactive paradigm to a risk reduction paradigm, as Wilhite, Sivakumar & Pulwarty (2014) suggested.

Researchers often employ composite indexes to assess a system's drought resilience and vulnerability and inform effective public policies. These indexes combine multiple indicators deemed significant for resilience and vulnerability assessments, with their weights subjectively assigned (Cai et al., 2018). For instance, Rao et al. (2020) evaluated indicators for agricultural sustainability, categorizing them into four dimensions: ecological, economic, social, and institutional. Likewise, Meuwissen et al. (2018) proposed a framework to identify resilience-enhancing strategies for farming systems, encompassing indicators related to agricultural production, farm demographics, and governance.

Despite their broad applicability, constructing composite indexes encounters knowledge gaps, including the challenge of selecting appropriate indicators that accurately represent resilience and vulnerability amidst the abundance of drought indicators that predominantly focus on quantifying drought as a natural hazard. Additionally, limited data standardization, temporal and spatial scales, and time series availability hinder cross-context and cross-country comparisons. Aggregating diverse indicators into a unified index also lacks clear guidelines, often resulting in linear relationships and arbitrary weight assignments. Data for drought indicators come from many different sources and scales and might be aggregated at multiple levels before calculating the final index. Applying best practices of the indicator weighting methods to drought risk or vulnerability index development requires a theoretical and practical understanding of the indicator weighting methods. Drought risk also has a local context. Availability of local data or downscaling national statistics to the local level is a concern for data-intensive methods.

Despite the literature reviewing drought indicators, their operational use in decision-making support systems through composite index requires a more context-specific assessment tailored to the type of system being evaluated. In the literature, we can find a large number of indicators—often numbering in the hundreds—making the simultaneous use of all of them within a decision support system impractical. Additionally, from a policy development perspective, resilience and vulnerability indicators are highly relevant but remain underexplored in terms of objectivity, clarity, and data availability. The result is that at present the potential of drought indicators to be reliable tools to inform on issues beyond hazard to resilience and vulnerability is not fully achieved. If we can work towards resolving

the knowledge gaps, indicator selection, and weighting issues then composite indices could be an invaluable tool for policy and decision-makers.

To improve the selection of indicators for drought resilience and vulnerability assessment, we carried out a formal global expert elicitation survey on the most common drought resilience and vulnerability indicators for small farms. Experts were asked to complete an online questionnaire to assess a compilation of 36 indicators across five evaluative criteria: relevance, accessibility, objectivity, comprehensibility, and temporal consistency. Ratings for each indicator were assigned on a three-point scale comprising low, medium, and high levels. This survey is part of the broader Management of Disaster Risk and Societal Resilience (MADIS) project[1] funded by the Belmont Forum. This project aims to construct a drought resilience index framework to better facilitate disaster management decisions.

Small farms are systems distinguished by their family-oriented motives, which prioritize maintaining the stability of the household farm system. We focused on them because of their relevance for food production worldwide. According to Lowder et al. (2021), there are more than 550 million family farms in the world, producing around 80% of the world's food in value terms. Small farms are also much more vulnerable to climate change and weather shocks compared to large-scale farming (also known as commercial or industrial farms)[2]. Their vulnerability, i.e., the susceptibility to the impacts of droughts (IPCC, 2018), stems from two primary factors: their predominant location in tropical regions and the combination

[1] https://sites.psu.edu/belmont/

[2] We defined large-scale farming as agricultural operations that cover extensive areas and produce significant quantities of crops or livestock for commercial purposes. For more information see Tittonell et al. (2020).

of socioeconomic, demographic, and policy trends that restrict their ability to respond effectively and adapt to climatic risks (Morton, 2007). Furthermore, existing indicator frameworks for small farms' resilience assessments frequently need more grounding in theoretical definitions, leading to incomplete explanations of resilience levels (Dixon & Stringer, 2015).

In the upcoming section, we delve into the research background, encompassing definitions, and summaries of related surveys. Section 3 outlines the survey methodology, while Section 4 presents the survey results. Following this, Section 5 examines the policy implications stemming from these findings. Finally, Section 6 offers the paper's conclusion

2) Background

The survey we conducted is a formal expert elicitation, which is a systematic approach to collecting insights and expertise from individuals recognized as experts in a particular field or discipline (Dewispelare et al., 1995). The focus areas for such elicitation may encompass probability encoding, scenario development, or model selection (Dewispelare et al., 1995). Experts' opinion is also one of the weighting methods to calculate composite indices (Libório et al., 2022).

Some works evaluated indicators to be considered for drought management and Disaster Risk Reduction (DRR). World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2016) published a report to introduce some of the most commonly used drought indicators/indices to quantify the level of drought and categorize them in terms of

data availability and ease of use. Blauhut (2020) reviewed the existing drought risk indexes in the literature and categorized them in terms of location and scales, thematic foci, and temporal orientation. Bachmair et al. (2016) surveyed to identify the reasons for selecting individual drought indicators used in drought indexes. Meza et al. (2019) conducted an expert survey to weigh drought vulnerability indicators based on their relevance to agricultural systems and domestic water supply.

Our study expands on previous studies by providing a comprehensive evaluation of the most common indicators used to assess drought vulnerability and resilience in the context of small farms. By examining the relevance, accessibility, objectivity, understanding, and temporal consistency of these indicators, our study offers a thorough analysis that enhances the understanding of how these factors impact drought risk assessment for small-scale farms.

Our survey relies on concepts and definitions that generally vary according to the focus of the analysis. Subsequently, we delineate the primary concepts we embraced in structuring the survey and interpreting the outcomes.

Drought: droughts are slow-onset events that can last from weeks to years (UNDRR, 2021) and are commonly characterized as either meteorological, hydrological, agricultural, or socio-economic (Mishra & Singh, 2010). However, in practice, these represent evolving aspects of a single drought event as it progresses through the hydrological cycle (UNDRR, 2021). For this work, we understood drought as a hazard with a natural and a social context, as not all droughts result in disaster (UNDRR, 2021). A drought becomes a hazard event

when it fails to meet water demands, transitioning into a significant risk when the capacity to mitigate water scarcity diminishes (UNDRR, 2021).

Small farms: the concept of small farms (also called smallholder agriculture or small-scale farms) can be understood through different lenses, depending on the specific goal of the analysis. In a broad context, smallholders are farmers who face structural limitations, including limited access to resources, technology, and markets, which affect their agricultural operations (Rapsomanikis, 2015). This work relies on the definition from the Food and Agriculture Organization (FAO): "Small farms have been defined as household units that make most management decisions, control most of the farm labor supply and normally much of the capital as well" (Devendra, 1993).

Indicators: we defined indicators as parameters, measures, measurement endpoints, or variables from which conclusions on the phenomenon of interest can be inferred (Heink & Kowarik, 2010). Indicators can be aggregated into a single measure, often referred to as a composite index.

Resilience: we adopted the concept of resilience used in the Sendai Framework (UNDDR, 2015). Resilience is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management." (UNISDR, 2009). For small farms, resilience entails the adaptive ability to sustain crop (e.g. grains, fruits, and

vegetables) productivity amid climatic fluctuations, enabled by their possession of socio-economic resources (education, wealth, and management skills), natural assets (soil and water), and their integration within the agricultural system (Lamichhane et al., 2020)

Vulnerability: we adopted the concept of vulnerability used in the Sendai Framework (UNDDR, 2015). Vulnerability involves the conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards (UNISDR, 2009).

3) Methodology: The expert global survey

In this section, we are presenting the survey development process including the methods used to evaluate responses. A detailed discussion regarding the decision-making process for selecting evaluation criteria and indicators, as well as the challenges of each step of the formulation of the survey can be seen in de Macedo et al. (2023).

3.1) Indicator selection

As an initial step in our survey, we conducted a comprehensive literature review focused on drought vulnerability and resilience indicators relevant to small farms. We identified 136 indicators related to drought vulnerability and resilience assessments and classified them by

type (hazard, vulnerability, and resilience indicator) and category (agricultural, government & policy, infrastructure & technology, social, socioeconomic, and water/stream). The 136 indicators can be seen in Appendix A in the Supplementary material.

To reduce the list of indicators to be evaluated by experts, we first excluded the indicators classified as hazard indicators[3]. Most of these indicators are already consolidated in the literature and can be obtained from global open databases or even satellite information and geoprocessing. In addition, the literature frequently discusses the use cases of drought hazard indicators and their advantages and disadvantages (Mukherjee et al., 2018). We then focused on the resilience and vulnerability indicators that can be classified into the dimensions of the Sendai Framework (vulnerability, exposure, and capacity of persons and assets) (UNDRR, 2015).

Following a meticulous pre-selection of indicators, the MADIS team members independently evaluated the remaining 54 vulnerability and 51 resilience indicators on a 4-point Likert scale from "relevant" to "not relevant at all". The results of the survey were shared with the research team and discussed. Through this process, team members shared their ratings and provided justifications for their assessments of why an indicator should be included or not in the final list. The objective was to reach a consensus on the final set of indicators to be

[3]Drought hazard indicators include meteorological indexes (e.g., Standardized Precipitation Index, Standardized Precipitation Evapotranspiration Index, and Palmer Drought Severity Index), soil moisture indexes (e.g., Potential Soil Moisture Deficit, Soil Moisture Index, and Soil Water Holding Capacity), vegetation indexes (e.g., Normalized Difference Vegetation Index, and Vegetation Supply Water Index), and climate conditions indexes (e.g., Annual Rainfall, Aridity Index, and Precipitation Anomaly Percentage).

included in the survey. At this stage, the list comprised 33 indicators that warranted evaluation.

3.2) Ranking criteria

To ensure a comprehensive assessment of the indicators, the group established specific criteria to gauge their quality based on the literature (Sweya et al., 2021). The chosen criteria were relevancy, understanding, accessibility, objectivity, and temporal availability. Each indicator underwent scrutiny of these criteria, facilitating a comprehensive evaluation of its merit. For the rating process, a three-point scale was employed, allowing respondents to categorize indicators as low, medium, or high, depending on the specific question or parameter under consideration. The definitions of these rating levels varied according to the context of each question. Additionally, respondents had the option to select "Not know" when faced with indicators that they were uncertain about. Table 1 provides a concise summary of the metrics used for evaluation and the adopted three-point scale.

Table 1. Definition of the metrics and the scales to evaluate the indicators

Metric	Question	Low	Medium	High
Relevancy	How relevant are the indicators to include them in a drought resilience index?	The indicator is somehow irrelevant to the information needs of decision-makers and stakeholders to improve drought resilience policies and better manage resources.	The indicator is moderately relevant to the information needs of decision-makers and stakeholders to improve drought resilience policies and better manage resources.	The indicator is relevant to the information needs of decision-makers and stakeholders to improve drought resilience policies and better manage resources.
Understanding	How would you rate the indicators in terms of their ease of understanding for decision-makers?	The indicator may be interpreted differently by various decision-makers. The indicator is not connected to a policy objective.	The indicator is understood by most decision-makers with some clarification. The indicator conveys useful information.	The indicator is readily understood by decision-makers and, preferably, the broad audience. The indicator conveys useful, relevant information for

			decision-makers on a specific policy objective.	
Accessibility	How would you rate the indicators in terms of data accessibility for a reasonable cost or level of effort?	The indicator data is not easily accessible or available over the entire study region or for the desired period. Collecting and processing the data requires significant time and effort.	The indicator data is available, but accessing and processing the data requires some effort.	The indicator data is publicly accessible and readily available. Processing the data requires minimal effort.
Objectivity	How would you rate the indicators in terms of data objectivity?	The indicator is a subjective measure. The procedures to evaluate the indicator are not easily and persistently accessible.	The indicator is a somewhat objective measure.	The indicator is an objective, evidence-based measure that can be quantified and backed up by high-quality data.
Temporal	Is the data for the indicator available consistently over different temporal scales?	The indicator data is collected in an ad-hoc manner, limiting the ability to monitor and compare the indicator over different temporal scales.	The indicator data is collected periodically but not frequently enough for comparing the indicator in different temporal scales.	The indicator data is collected regularly and available over different time scales, allowing for monitoring and comparing the indicator over different temporal scales.

The survey was beta-tested with a small group of experts, who gave feedback on the list of indicators, the questions, the definitions, and the survey layout. Following the recommendations, three more indicators were added, totaling 36 indicators to be evaluated in the survey. The final list of indicators is given in Table 2. The survey has been approved by the Institutional Review Board (IRB) of Penn State University for Human Subjects Protection (IRB # STUDY00021208).

Table 2. Indicators evaluated in the global expert survey

Indicator	Description	Type	Category	Reference
1. Crop and livestock income dependence	Percentage of the contribution of crop and livestock production in the income of smallholder farming	Vulnerability	Agricultural	(Lindoso et al. 2011)
2. Crop loss	Crop Damage & Sensitivity (Crop Loss)	Vulnerability	Agricultural	(Hao et al. 2012; Antwi-Agyei et al. 2012; Simelton et al. 2009; Epule 2021)
3. Drought resistance crops	Cultivation of drought-resistant crops (%)	Resilience	Agricultural	(Meza et al. 2019)
4. Crop varieties	Farmers use different crop varieties (%)	Resilience	Agricultural	(Meza et al. 2019)

Indicator	Description	Type	Category	Reference
5. Protected area	Area protected and designated for the conservation of biodiversity (%)	Vulnerability	Agricultural	(Meza et al. 2019)
6. Use of agricultural inputs	Use of Insecticides and pesticides (Use of agricultural inputs)	Vulnerability	Agricultural	(Meza et al. 2019)
7. WUE	Crop water use efficiency (WUE)	Vulnerability	Agricultural	(Meza et al. 2019)
8. Land degradation	Degree of land degradation and desertification	Vulnerability	Agricultural	(Meza et al. 2019)
9. Land rights	Land rights clearly defined (yes/no)	Resilience	Agricultural	(Lindoso et al. 2011; Leguizamo et al. 2020)
10. Drought management policies	Existence of drought management policies	Resilience	Government & policy	(Kampragou et al. 2015)
11. Technical assistance	Technical assistance from local entities	Resilience	Government & policy	(Leguizamo et al. 2020)
12. Drought insurance	Farmers with crop, livestock, or drought insurance (%)	Resilience	Government & policy	(Meza et al. 2019)
13. Water use rights	Water use rights are clearly defined	Resilience	Government & policy	(Kampragou et al. 2015)
14. Prediction system	Availability of drought prediction and warning systems or climatic predictions	Resilience	Infrastructure & Technology	(Lee and Yoo 2021; Xu et al. 2021; Leguizamo et al. 2020)
15. Transportation network	Transportation network	Resilience	Infrastructure & Technology	(Simelton et al. 2009)
16. Electricity	Access to electricity (Access to energy)	Resilience	Infrastructure & Technology	(Meza et al. 2019)
17. Conflict	Prevalence of conflict/insecurity	Vulnerability	Social	(Meza et al. 2019)
18. Sanitation condition	Population without access to (improved) sanitation (%)	Vulnerability	Social	(Meza et al. 2019)
19. Gender inequality	Gender inequality (categorical)	Vulnerability	Social	(Meza et al. 2019)
20. Rural population	Rural population (% of the total population)	Vulnerability	Social	(Meza et al. 2019)
21. Unemployment	Unemployment rate (and/or proportion of formal work)	Vulnerability	Socioeconomic	(Meza et al. 2019)
22. Working-age population	Population ages 15-64 (% of the total population)	Vulnerability	Social	(Meza et al. 2019)
23. Displaced population	Percentage of the population displaced internally or transboundary	Vulnerability	Social	(Meza et al. 2019)
24. Drivers of migration	Presence of drivers of migration and displacement	Vulnerability	Social	(Meza et al. 2019)
25. Poverty	Poverty Rate	Vulnerability	Socioeconomic	(Antwi-Agyei et al. 2012; Epule 2021)
26. Food source reliability	Food source reliability and diversity	Resilience	Socioeconomic	(Luetkemeier and Liehr 2018)
27. Participation in local policy	Public participation in local policy	Resilience	Social	(Meza et al. 2019)

Indicator	Description	Type	Category	Reference
28. Cooperatives or associations	Participation in farming cooperatives or associations	Resilience	Social	(Lindoso et al. 2011)
29. Employment in small farms	% of the population employed in small farms	Vulnerability	Socioeconomic	(Lindoso et al. 2011; Kampragou et al. 2015)
30. Financing and credit	Access to financing and credit	Resilience	Socioeconomic	(Huai 2017; Leguizamo et al. 2020)
31. Water stress	Baseline water stress (ratio of withdrawals to renewable supply)	Vulnerability	Water/stream	(Meza et al. 2019)
32. Water quality	Water quality (categorical)	Vulnerability	Water/stream	(Meza et al. 2019)
33. Groundwater level	Groundwater level/sources	Vulnerability	Water/stream	(Kampragou et al. 2015; Wu et al. 2013; Alonso et al. 2019; Murthy et al. 2015)
34. Integrated policies	Integrated land and water management policies	Resilience	Water/stream	(Lerner et al. 2018)
35. Retained renewable water	Percentage of retained renewable water	Resilience	Water/stream	(Meza et al. 2019)
36. Dam capacity	Total dam capacity	Resilience	Water/stream	(Meza et al. 2019)

3.3) Recruitment process

To recruit a diverse pool of experts in the field of drought research, the MADIS team compiled a comprehensive list of contacts based on the most recent publications found in Web of Science and Scopus databases. These databases served as reliable sources for identifying prominent researchers actively contributing to the domain of drought-related studies.

In early 2023, the online survey was sent along with the confidential consent agreement to more than 2,000 identified experts. Acknowledging the importance of expert input, a timely follow-up was conducted by resending the survey to non-respondents twice over the following month. Appendix B in the Supplementary material contains the questionnaire that was administered to the experts, encompassing all aspects of the evaluation process.

3.4) Methods for analyzing results

To analyze the survey results, we employed the following steps: *i)* Check the level of agreement in the responses with the Fleiss' Kappa statistics; *ii)* Calculated the scores per indicators; *ii)* Perform the Multivariate Analysis of Variance (MANOVA) to examine differences in responses based on respondents' demographics; and *iv)* Perform a cluster analysis to classify the indicators. The following paragraphs detail the application of these methods.

After data cleaning by removing the experts who did not complete the survey or selected the "Not know" option many times, we first calculated Fleiss' Kappa statistics, which is a measure of inter-rater reliability used to assess the level of agreement among multiple raters when categorizing items. The Fleiss' Kappa method also allows the calculation of the *z*-statistics of significance to assess the extent to which the observed agreements are beyond a random process.

To analyze the data from the survey, we transformed the qualitative evaluation into a quantitative score, setting 1 for "Low", 2 for "Medium", 3 for "High" and 0 to "Not know" answers for each metric *m* (Equation 1). Blank items are not included in the score. The overall score per indicator *i* (Equation 2) is the average of scores of the five metrics (relevancy, understanding, accessibility, objectivity, and temporal).

$$Score_{im} = 1(\%\ Low) + 2(\%\ Medium) + 3(\%\ High) + 0(\%\ Not\ Know) \quad (1)$$

$$Overall\ score_i = \frac{\sum_{m=1}^{5} Score_{im}}{5} \quad (2)$$

To verify if the demographical of the respondent influenced their responses we performed the MANOVA. It is a statistical test used to determine whether there are significant differences between the means of multiple dependent variables across multiple groups. We checked the results of the two most common MANOVA statistics, the Wilks statistic (it tests the null hypothesis that there are no differences between groups), and Pillai's statistics (it measures the proportion of variance in the dependent variables explained by group differences). Small p-values (< 0.05) for these statistics indicate significant differences between the groups.

We used cluster analysis (CA) to group the indicators using five metrics as clustering dimensions. The objective of the CA was not only to identify the groups of similar indicators in terms of the metrics but also to discover which metrics were influential in the formation of the clusters. CA is a method for finding hidden groups in a dataset. For example, if we have a dataset $D = \{x_1, x_2, \dots, x_n\}$, clustering means grouping D into K disjoint subsets denoted by $C = \{C_1, C_2, \dots C_K\}$. Not all the elements in C "qualify as good or useful clustering, and what is demanded of a good C can depend on the particular approach one takes to cluster analysis" (Hennig et al., 2015).

There are several approaches for clustering. For our score database, we selected the most widely used form of clustering, K-means clustering. This method classifies objects into multiple groups so that intra-cluster variation is minimized by summing the squares of the Euclidean distances between items and their centroids (Equation 3).

$$W(C_k) = \sum_{x \in C_k} (x_i - \mu_k)^2 \quad (3)$$

where x_i is the point belonging to C_k and μ_k is the average value of C_k.

Clustering with the K-means technique requires the definition of the number of clusters in the indicators that must be grouped. To define the optimal number of clusters, we adopted the Elbow and the Silhouette methods (Charrad et al., 2014).

4) Results

In this section, we present the results obtained from the global survey. The survey reached a substantial number of experts, with 326 respondents initially starting to fill out the questionnaire. However, the final analysis includes data from the 120 experts who completed the entire survey. While this subset of respondents offers valuable insights, it is essential to acknowledge that the sample is not representative of the entire population of researchers dedicated to studying drought indicators.

4.1) Demographical

Figure 1 presents the demographic information of the 120 responders who completed the survey. Among these respondents, 70% identified as male, and 79% indicated that they work in Universities or Research Institutions (Figure 1a). The distribution of responders was well-

represented across four continents, namely Africa, America, Asia, and Europe, with the United States and India having the highest number of participants (Figure 1c).

The most important issue when choosing experts is their familiarity with the topic or phenomenon under study, closely followed by their level of expertise (Al Fozaie & Wahid, 2022). Regarding expertise in drought in our survey, 51% of the responders affirm having more than six years of experience working on drought, and more than 60% declared they have a fair, full, or high knowledge of droughts (Figure 1b).

In the survey, responders were asked if they have expertise in the following sectors: agriculture, water sector, energy, and water-energy-food nexus. They could select more than one option. Of the 120 respondents, 66 (55%) declared they have expertise in the agriculture and water sector, only 6 (0.05%) declared to be experts in the energy sector, and 39 (33%) have expertise in Water-Energy-Food Nexus (Figure 1d).

We also asked if they have expertise in the following areas: Agricultural Sciences, Anthropology and Development, Climate Change, Climate Science/Services, Drought Hazard and Disaster Risk Assessment, Economics (water, environmental), Environmental Sciences, Geography, Health, Hydrology, Interdisciplinary, Sociology, Soil, and Water Conservation, Water Resource Management, and Data and Information Science. The most selected areas were Climate Change (72%), Drought Hazard and Disaster Risk Assessment (58%), and Agriculture (50%). Only 18% have experience in social sciences (Anthropology and development and Economics) and 5% in health. According to a review of resilience

studies made by Cai et al. (2018), Environmental Science and Geography were the two disciplines dominating the literature on disaster resilience.

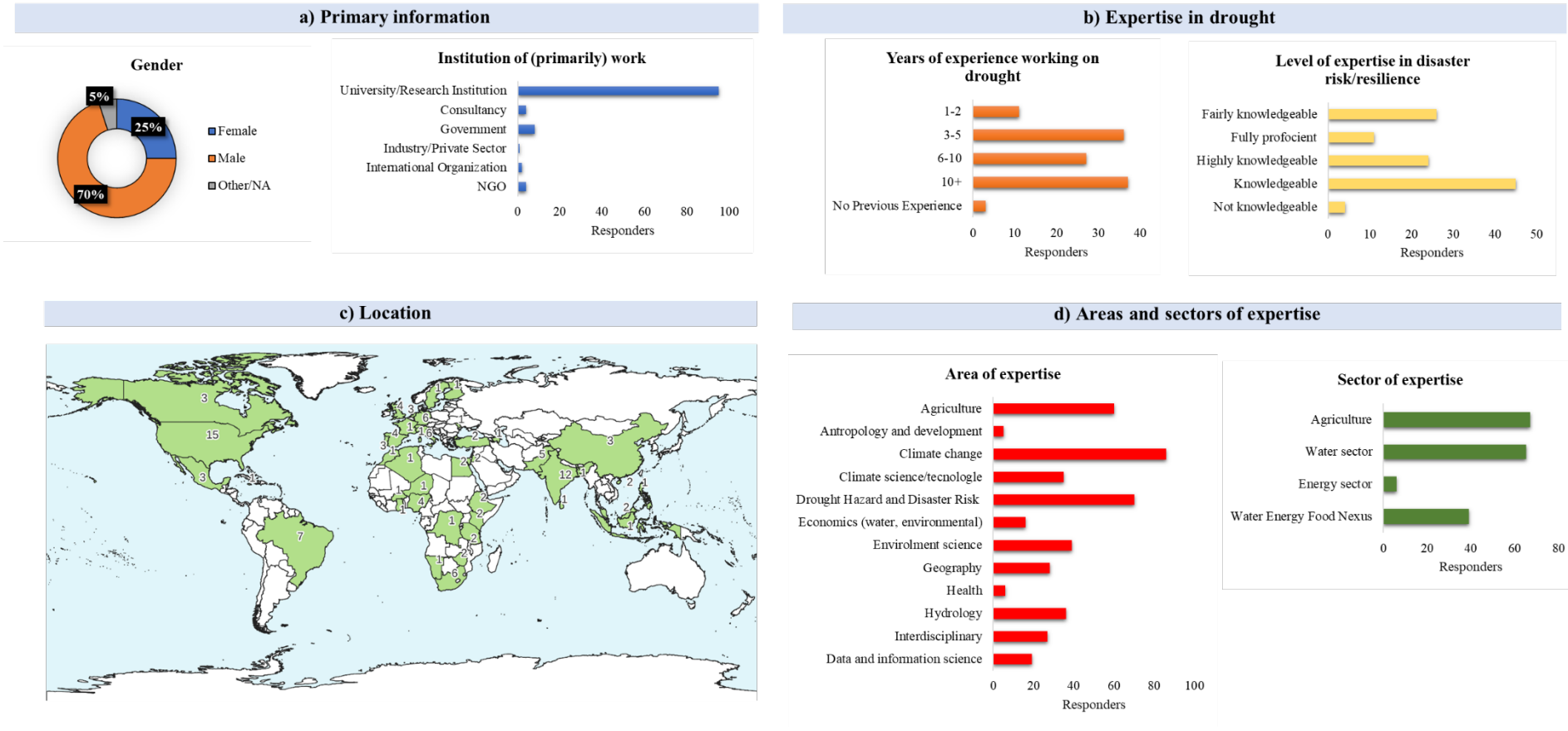

Figure 1. Demographics from responders who finished the survey.

4.2) Indicator scores

Table 3 summarizes the Kappa values, *z*-value of significance, and conditional probability (i.e., the probability of observing a specific category) of the experts' agreements on the three categories (Low, Medium, High) for the five quality metrics.

The observed extremely high z-values supported that the null hypothesis of agreements being random could be rejected with a high confidence level (the benchmark z-value is 1.64 for the significance level α=0.05), excluding the Temporal-Medium category. The agreement levels were consistently higher for the categories of Low and High compared to Medium, indicating that the experts were in more agreement when they categorized the indicators as Low or High. All Kappa values were between 0 and 0.1, suggesting slight agreement (Sim & Wright, 2005). However, the interpretation of Fleiss' Kappa becomes less intuitive when a large number of raters categorize many subjects (Sim & Wright, 2005), as in this study. Having a large number of categories and subjects can lower agreement, as there are more options for raters to distribute ratings. In our study, 120 experts evaluated 36 drought resilience indicators across 5 categories using three levels, the high number of combinations can reduce the Kappa value despite our efforts to provide consistent rating definitions. Therefore, rather than interpreting the low Kappa values as a weak absolute agreement in our study context, it is more meaningful to assess the relative level of agreement between categories and indicators. The consistently higher Kappa values for the Low and High categories indicate raters agreed more when assigning these extreme ratings, compared to the more ambiguous

Medium category. Hence, the kappa values in Table 3 should be used to compare the level of agreements relatively. In summary, the statistics in Table 3 provide adequate evidence to support the consistency of the experts' ratings for further statistical analysis.

Table 3. Summary Statistics for Reliability of Expert's Ratings

Metric	Statistics	Low	Medium	High
Relevancy	Kappa	0.07	0.04	0.11
	z-value	28.08	18.57	57.16
	Cond. Probability	0.18	0.38	0.57
Understanding	Kappa	0.02	0.02	0.06
	z-value	8.88	7.96	24.90
	Cond. Probability	0.17	0.39	0.48
Accessibility	Kappa	0.04	0.01	0.077
	z-value	19.11	4.97	33.00
	Cond. Probability	0.31	0.40	0.36
Objectivity	Kappa	0.024	0.03	0.08
	z-value	10.47	12.72	32.76
	Cond. Probability	0.23	0.38	0.44
Temporal	Kappa	0.02	0.01	0.05
	z-value	9.88	0.52	20.47
	Cond. Probability	0.29	0.38	0.29

Table 4 shows the scores and their standard deviations (Sd) per indicator and metric. The standard deviation indicates the variation of agreement and disagreement among the experts. High values indicate a higher range of opinions, whereas low values represent a high level of agreement. Indicators are ranked from the highest to the lowest overall score.

At the top of the rankings are Crop loss and Poverty rate (vulnerability indicators), and Dam capacity (resilience indicator). Estimates of crop monetary losses due to droughts are often collected in affected areas seeking federal disaster relief (Ding et al., 2011) or for insurance payments. Poverty can be hard to define, varying from region to region. But the standard

definition of poverty rate from the World Bank - the percentage of people living below the poverty line, that don't have enough to meet their basic needs (currently, the line is $1.90 per day), makes it an easily measured indicator. Dam capacity, being a tangible and objective measure, holds particular significance in drought or water stress situations, as it is one of the main variables that authorities consider.

Conversely, at the bottom of the ranking, we find indicators such as Drivers of migration, Displaced population, and Gender inequality. These indicators can be challenging to define and quantify, which contributes to their lower rankings. Men and women present different vulnerabilities to droughts, and even though the links between gender, food insecurity, and climate have been depicted in some case studies (Stehlik et al., 2002; Mapedza et al., 2019; Austin, Noble & Berndt, 2021), the subject remains underrepresented in drought policy. Likewise, drought-induced migration is complex and depends on individuals' subjective sentiments and behaviors (Jarawura, 2021). As a result, these indicators are less commonly included in composite indicators due to their inherent complexities and challenges in quantitative measurement.

The indicators with higher scores and greater agreement among experts, such as Crop loss, Poverty rate, and Dam capacity, indicate their significance and applicability in assessing drought vulnerability and resilience in small farms. Conversely, indicators with low scores and high agreement, such as Participation in local policy, Cooperatives or associations, and Food source reliability, highlight areas where experts converge in their assessments but may

not perceive these indicators as highly relevant or readily accessible in practice. Similarly, indicators with less agreement, like Water use efficiency (WUE), Land rights, and Land degradation, reflect the diverse perspectives and challenges in evaluating these aspects, particularly considering their relevance and data viability across different countries and spatial levels of analysis.

Examining the scores based on the five metrics reveals certain issues with the applicability of indicators. For instance, Groundwater level and Water stress are deemed highly relevant but suffer from limited accessibility due to the lack of well-consolidated databases on groundwater sources. Consequently, their overall scores are not as high as their relevance would suggest. Similarly, Drought management policy is considered highly relevant but scores lower in terms of temporal availability, making it challenging to assess its evolution and compare vulnerability and resilience over time.

Among indicators with lesser relevance, there is a general trend of lower scores across other categories as well, potentially contributing to their lower relevance. The exception to this pattern is the working-age population indicator, which remains relevant (score of 1.90) and scores higher than 2.3 in all other categories, primarily due to its easy accessibility through census information.

The dimension with the lowest standard deviation is understanding, which shows that all the indicators are generally easy to understand. Relevancy is the dimension with a greater variation over different categories of indicators under analysis. Meza et al. (2019) had similar results in their survey, the degree of relevance among the indicators varied considerably.

Accessibility and Temporal are the ones with the lowest average scores, which shows that these two factors can be the main problems regarding the operationalization of a composite indicator on a global scale.

1 Table 4. Indicators score

Rank	Indicator	Overall score		Relevancy		Accessibility		Objectivity		Temporal		Understanding	
		Score	Sd	Score	Sd	Score	Sd	Score	Sd	Score	Sd	Score	Sd
1	Crop loss	2.44	0.82	2.84	0.59	2.04	0.79	2.42	0.81	2.12	0.91	2.75	0.63
2	Poverty	2.44	0.74	2.58	0.69	2.46	0.70	2.39	0.74	2.23	0.86	2.50	0.68
3	Dam capacity	2.42	0.78	2.51	0.68	2.36	0.78	2.44	0.83	2.30	0.84	2.46	0.74
4	Rural population	2.39	0.79	2.22	0.75	2.59	0.73	2.54	0.77	2.21	0.91	2.39	0.71
5	Working-age population	2.32	0.81	1.90	0.82	2.58	0.69	2.52	0.77	2.33	0.83	2.29	0.74
6	Prediction system	2.27	0.84	2.65	0.70	2.11	0.87	2.23	0.81	1.93	0.89	2.43	0.74
7	Employment in small farms	2.26	0.80	2.23	0.78	2.21	0.79	2.45	0.77	1.97	0.87	2.45	0.72
8	Crop and livestock income dependence	2.25	0.84	2.63	0.71	1.84	0.78	2.38	0.79	1.92	0.89	2.48	0.76
9	Drought management policies	2.24	0.83	2.71	0.65	2.14	0.81	2.09	0.79	1.82	0.84	2.42	0.79
10	Groundwater level	2.22	0.85	2.68	0.60	1.83	0.83	2.27	0.87	2.01	0.87	2.31	0.80
11	Drought insurance	2.21	0.85	2.38	0.77	1.99	0.83	2.33	0.81	1.94	0.88	2.42	0.85
12	Water stress	2.16	0.88	2.67	0.63	1.85	0.85	2.10	0.91	1.83	0.93	2.32	0.75
13	Water quality	2.16	0.84	2.54	0.61	1.87	0.84	2.21	0.86	1.85	0.87	2.29	0.80
14	Unemployment	2.15	0.85	1.95	0.88	2.23	0.77	2.32	0.84	2.11	0.88	2.16	0.85
15	Land degradation	2.13	0.89	2.62	0.68	1.93	0.87	2.04	0.85	1.79	0.94	2.26	0.84
16	Technical assistance	2.13	0.78	2.46	0.74	2.01	0.74	1.97	0.72	1.85	0.82	2.32	0.73
17	Integrated policies	2.11	0.84	2.61	0.64	1.93	0.85	1.98	0.82	1.78	0.79	2.25	0.82
18	WUE	2.10	0.89	2.64	0.68	1.70	0.80	2.21	0.82	1.71	0.93	2.23	0.85
19	Financing and credit	2.09	0.84	2.32	0.76	1.89	0.87	2.08	0.78	1.92	0.91	2.25	0.78
20	Drought resistance crops	2.08	0.84	2.48	0.68	1.72	0.83	2.15	0.80	1.75	0.86	2.29	0.75
21	Sanitation condition	2.07	0.86	1.96	0.86	2.06	0.83	2.23	0.82	1.89	0.92	2.23	0.82
22	Electricity	2.07	0.84	2.09	0.81	2.04	0.79	2.22	0.80	1.85	0.93	2.17	0.81
23	Food source reliability	2.07	0.80	2.55	0.63	1.83	0.78	1.90	0.75	1.75	0.81	2.29	0.75
24	Use of agricultural inputs	2.07	0.84	2.06	0.84	1.90	0.78	2.20	0.84	1.94	0.87	2.23	0.80

Rank	Indicator	Overall score		Relevancy		Accessibility		Objectivity		Temporal		Understanding	
		Score	Sd	Score	Sd	Score	Sd	Score	Sd	Score	Sd	Score	Sd
25	Cooperatives or associations	2.05	0.77	2.24	0.64	2.00	0.79	2.07	0.72	1.65	0.82	2.27	0.71
26	Crop varieties	2.03	0.86	2.22	0.74	1.80	0.86	2.13	0.93	1.76	0.88	2.25	0.78
27	Water use rights	2.02	0.84	2.30	0.84	1.92	0.82	2.02	0.77	1.66	0.83	2.17	0.80
28	Retained renewable water	2.00	0.88	2.43	0.75	1.65	0.84	2.06	0.88	1.70	0.88	2.13	0.83
29	Protected area	1.97	0.88	1.91	0.88	2.01	0.87	2.13	0.88	1.85	0.96	1.96	0.82
30	Transportation network	1.96	0.84	2.06	0.84	1.83	0.84	2.08	0.79	1.69	0.92	2.13	0.76
31	Conflict	1.87	0.85	2.21	0.82	1.79	0.87	1.76	0.77	1.44	0.80	2.11	0.76
32	Land rights	1.85	0.89	1.93	0.94	1.76	0.87	1.87	0.83	1.55	0.86	2.13	0.85
33	Participation in local policy	1.81	0.79	2.09	0.73	1.65	0.80	1.74	0.76	1.55	0.79	2.03	0.75
34	Gender inequality	1.76	0.84	1.89	0.85	1.71	0.86	1.81	0.85	1.55	0.89	1.82	0.74
35	Displaced population	1.75	0.83	1.84	0.86	1.61	0.81	1.86	0.81	1.53	0.83	1.89	0.79
36	Drivers of migration	1.73	0.83	1.94	0.83	1.58	0.82	1.68	0.76	1.54	0.87	1.89	0.80
	Average	2.10	0.83	2.31	0.75	1.96	0.81	2.14	0.81	1.84	0.87	2.25	0.78

2

We examined potential differences in the scores based on the responders' continent, gender, areas of expertise, and roles (academic versus practitioner) using the MANOVA test (Table 5). By comparing the scores of experts with specific expertise to those without, we aimed to assess if certain areas of expertise influenced the responses. However, the MANOVA results for gender, areas of expertise, and role also did not indicate any statistically significant differences in the responses, as illustrated in Table 5. There are also no substantial variations among experts from different continents.

Table 5. MANOVA for the continent, gender, role, and areas of expertise

	Wilks' statistic			Pillai's statistic		
Independent variable	**Value**	**approx F**	**p-value Pr(>F)**	**Value**	**approx F**	**p-value Pr(>F)**
Continent	0.815	1.434	0.131	0.196	1.439	0.128
Gender	0.979	0.442	0.818	0.021	0.442	0.818
Role (Academic)	0.976	0.509	0.769	0.024	0.509	0.768
Social science	0.986	0.294	0.915	0.014	0.294	0.915
Interdisciplinary	0.921	1.777	0.124	0.079	1.777	0.124
Hydrology	0.933	1.480	0.203	0.067	1.48	0.203

Note: the MANOVA test was performed using the function manova{stats} from R software.

Overall, the findings suggest that, on average, the experts' responses were consistent across different continents, gender, roles, and areas of expertise. This level of agreement and convergence among experts from diverse backgrounds enhances the reliability and robustness of the survey results, affirming the validity of the selected indicators for drought vulnerability and resilience in small farms.

4.3) Cluster analysis

The cluster analysis was based on the data from Table 4 and aims to classify the indicators into similar groups. Both the Elbow and the Silhouette methods indicated the optimal number of clusters is 4 (Figure 2).

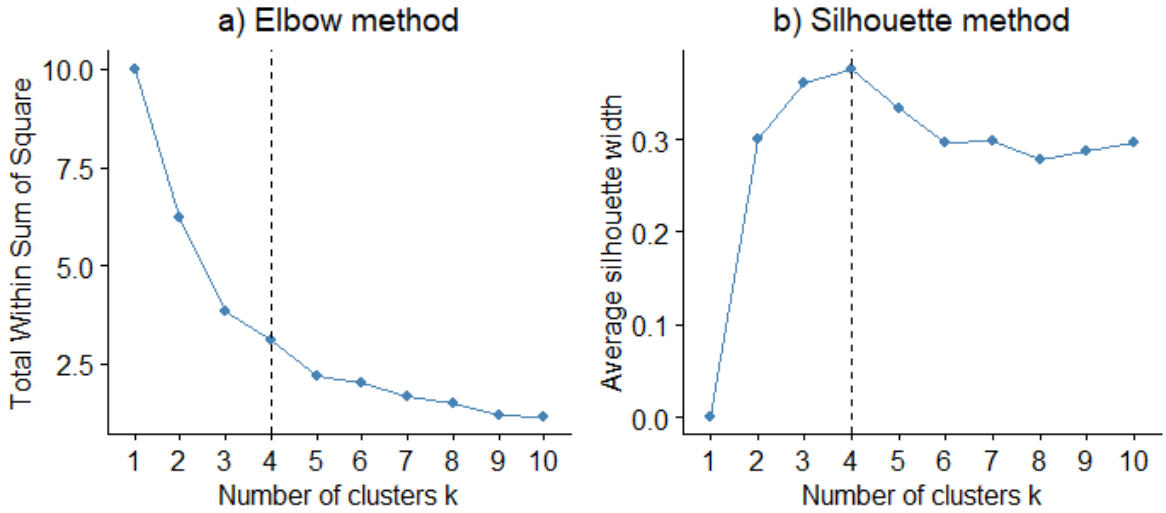

Figure 2. The optimal number of clusters

Looking at the average score per cluster and metric (Figure 3), we can characterize each of the four clusters:

- **Cluster 1**: Most relevant high-quality indicator. The indicators in this group have higher scores in all the metrics.
- **Cluster 2**: Least relevant low-quality indicator. The indicators in this group have low scores in all the metrics.
- **Cluster 3**: Most relevant low-quality indicator. Despite being relevant, this group encompasses indicators that have low scores in the other metrics.

- **Cluster 4**: Least relevant high-quality indicator. In this group, the indicators have good scores on quality metrics, but they are irrelevant.

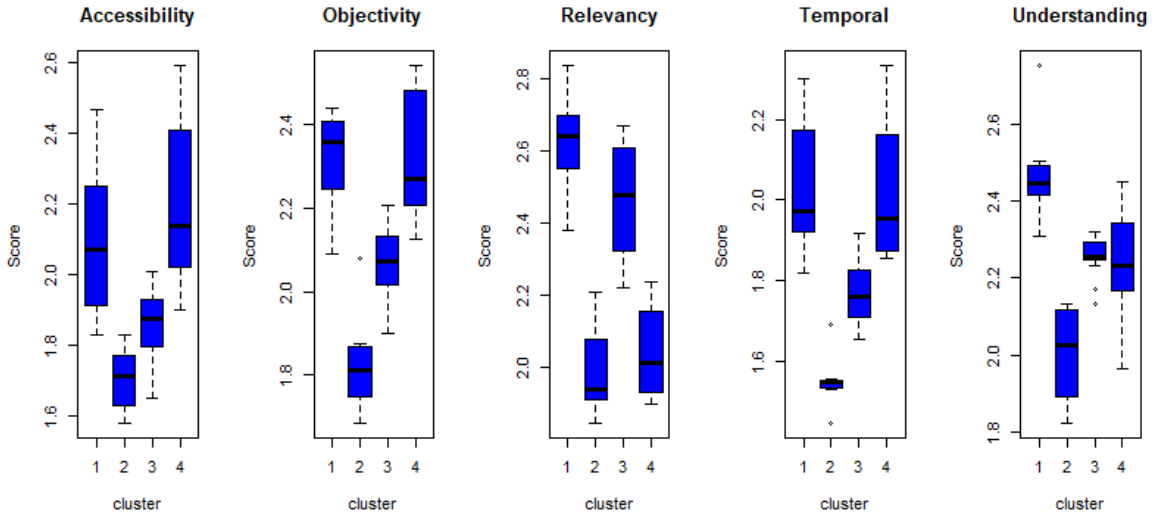

Figure 3. Average score by cluster and metric

Table 6 presents the resilience indicators grouped into four clusters based on their scores and characteristics. Cluster 1 includes the most favorable indicators for drought resilience, which are Drought management policies (10), Drought insurance (12), Prediction system (14), and Dam capacity (36). These indicators are highly relevant for policy-making and readily accessible at the local level. The relevance of Drought management policies aligns with findings from a survey conducted by Meza et al. (2019), where the indicator "Existence of adaptation plans and policies" appeared as one of the most relevant for the agricultural system.

In Cluster 2, we find the worst-rated indicators, which are considered least relevant for inclusion in a drought resilience index due to their limited availability at any spatial scale. Land rights (9), Transportation networks (15), and Participation in local policy (27) fall into this category. These indicators exhibit low scores across all dimensions, particularly in consistency and accessibility, indicating challenges in obtaining consistent and accessible data over time. Participation in local policy (27) also faces difficulties in objectivity, as evaluating it involves complex and region-specific procedures.

Cluster 3 comprises indicators that are all relevant for drought resilience but pose challenges in obtaining the necessary quantitative measures for inclusion in a composite index. For instance, the Existence of crop varieties (4) and Drought resistance crops (3) are critical for planning policies for small farmers, but data availability on these indicators is limited, resulting in lower scores in accessibility and consistency. Similarly, Financing and credit (30), a crucial tool for reducing farmers' economic vulnerability, may lack information at the local level. Water use rights (13), Integrated policies (34), and Retained renewable water (35) are also likely to face difficulties in obtaining data at the local level.

Cluster 4 has only one resilience indicator: Access to electricity (16). While this indicator is considered the least relevant for drought resilience, its data quality is good, ensuring reliable information for analysis.

Table 6. Resilience indicators clustering

Code	Indicator	Category	Cluster	Cluster description
10	Drought management policies	Government & policy	1	Most relevant high-quality indicator
12	Drought insurance	Government & policy	1	Most relevant high-quality indicator
14	Prediction system	Infrastructure & Technology	1	Most relevant high-quality indicator
36	Dam capacity	Water/stream	1	Most relevant high-quality indicator
9	Land rights	Agricultural (land)	2	Least relevant low-quality indicator
15	Transportation network	Infrastructure & Technology	2	Least relevant low-quality indicator
27	Participation in local policy	Social	2	Least relevant low-quality indicator
3	Drought resistant crops	Agricultural (crop)	3	Most relevant low-quality indicator
4	Crop varieties	Agricultural (crop)	3	Most relevant low-quality indicator
11	Technical assistance	Government & policy	3	Most relevant low-quality indicator
13	Water use rights	Government & policy	3	Most relevant low-quality indicator
26	Food source reliability	Social	3	Most relevant low-quality indicator
28	Cooperatives or associations	Social	3	Most relevant low-quality indicator
30	Financing and credit	Socioeconomic	3	Most relevant low-quality indicator
34	Integrated policies	Water/stream	3	Most relevant low-quality indicator
35	Retained renewable water	Water/stream	3	Most relevant low-quality indicator
16	Electricity	Infrastructure-Energy	4	Least relevant high-quality indicator

In Table 7, the drought vulnerability indicators are divided into four clusters based on their scores and characteristics. Cluster 1 comprises the best indicators for drought vulnerability assessment, including Crop and livestock income dependence (1), Crop loss (2), Poverty rate (25), and Groundwater level (33). Both Crop loss (2) and Poverty rate (25) consistently rank in the top 10 across all dimensions analyzed, indicating their strong significance and applicability for assessing drought vulnerability in small farms.

Cluster 2 contains the worst-rated indicators, all of which are social indicators, such as Conflict (17), Gender inequality (19), Displaced population (23), and Drivers of migration (24). As discussed previously, these indicators are challenging to define and measure precisely, and their relevance for inclusion in the drought index is also rated low. The difficulty in quantitatively measuring these indicators may contribute to a lack of

comprehensive understanding of their importance in evaluating small farms' vulnerability to drought. A possible solution to this issue is to select more precise indicators. For example, the proportion of female farm owners can replace Gender inequality and Conflict can be replaced by crime rates. Drivers of migration generally include economic, environment, social, and political dimensions (Kwilinski et al., 2022), so a possible indicator could be the presence of crises in such dimensions.

Cluster 3 encompasses more technical vulnerability indicators, such as Water Use Efficiency (WUE) (7), Land degradation (8), Water stress (31), and Water quality (32). While these indicators are relevant for drought assessments, they present difficulties in measurement at the local level and may only be available at broader scales, such as watershed levels.

In Cluster 4, we find social and socioeconomic vulnerability indicators that can be easily obtained from census data and other official statistics. However, the survey responders rated them as having lower relevancy. Additionally, Protected area (5) is also placed in this group, as it is not commonly associated with drought vulnerability.

Table 7. Vulnerability indicators clustering

Code	Indicator	Category	Cluster	Cluster description
1	Crop and livestock income dependence	Agricultural (crop)	1	Most relevant high-quality indicator
2	Crop loss	Agricultural (crop)	1	Most relevant high-quality indicator
25	Poverty	Social	1	Most relevant high-quality indicator
33	Groundwater level	Water/stream	1	Most relevant high-quality indicator
17	Conflict	Social	2	Least relevant low-quality indicator

Code	Indicator	Category	Cluster	Cluster description
19	Gender inequality	Social	2	Least relevant low-quality indicator
23	Displaced population	Social	2	Least relevant low-quality indicator
24	Drivers of migration	Social	2	Least relevant low-quality indicator
7	WUE	Agricultural (general)	3	Most relevant low-quality indicator
8	Land degradation	Agricultural (land)	3	Most relevant low-quality indicator
31	Water stress	Water/stream	3	Most relevant low-quality indicator
32	Water quality	Water/stream	3	Most relevant low-quality indicator
5	Protected area	Agricultural (general)	4	Least relevant high-quality indicator
6	Use of agricultural inputs	Agricultural (general)	4	Least relevant high-quality indicator
18	Sanitation condition	Social	4	Least relevant high-quality indicator
20	Rural population	Social	4	Least relevant high-quality indicator
21	Unemployment	Social	4	Least relevant high-quality indicator
22	Working-age population	Social	4	Least relevant high-quality indicator
29	Employment in small farms	Socioeconomic	4	Least relevant high-quality indicator

Overall, the clustering of resilience and vulnerability indicators based on their scores and characteristics provides valuable insights into their relevance, accessibility, and potential challenges in their inclusion in a composite index. These findings can guide policymakers and researchers in identifying key, meaningful, and feasible indicators for assessing drought resilience in small farms.

5) Discussion and policy implications

The contributions of this paper are twofold. First, our results offer a list of indicators with quantitative measures of relevance (as presented in the previous section), which can be used to guide the selection of indicators in empirical analyses of resilience and vulnerability to droughts. Second, the survey findings provide valuable insights into critical aspects of

drought vulnerability and resilience assessment. We discuss these insights in the following paragraphs:

i) ***Government and institutional indicators are crucial for drought resilience assessment.*** The government and institutional indicators are essential for identifying a region's ability to respond effectively to drought events, as all the indicators in this category are rated as very relevant. However, to include these indicators in drought risk or resilience assessment, it must be considered that Drought management policies will only contribute to resilience if they are fully implemented and effective. Besides, the usual government's response to droughts and related practices is more reactive than planned (Choudhury & Sindhi, 2017). For example, drought management in Africa remains reactive and crisis-driven rather than proactive and risk-based, as most African governments prioritize short-term emergency measures over adequate preparedness and long-term development of resilience (Tadesse, 2016). Therefore, the response is to treat the effects of drought rather than the underlying causes and associated vulnerability (Choudhury & Sindhi, 2017). Pisano (2012) suggests that drought resilience is a prerequisite for achieving sustainable development, and governments can integrate drought resilience into long-term sustainable development policies and practices by promoting participatory and inclusive governance. Involving multiple stakeholders from different sectors and levels of government is crucial for effective drought policy and building resilience by allowing coordination across water users, awareness of impacts in different sectors, and targeted responses (Mishra & Singh, 2010).

ii) ***There is an undefined role for social indicators in drought vulnerability assessment.*** The survey showed that, except for the Poverty rate, all other social indicators are rated as the least relevant indicators. We interpreted this in two ways. Firstly, it is plausible that social indicators may genuinely hold lesser importance in evaluating vulnerability to drought in small farm contexts. Other factors, such as crop loss, crop and livestock income dependence, and access to water resources, might exert more direct and tangible impacts on drought vulnerability in agricultural settings, garnering greater attention from survey respondents. Alternatively, an expertise bias among survey participants may influence the observed trend. The majority of respondents are from the natural sciences, potentially leading to a stronger focus on the biophysical aspects of drought and its implications on crop production and water resources. Consequently, social indicators may have received less consideration, given the respondents' relative unfamiliarity with the broader socioeconomic ramifications of drought on small farming communities. Furthermore, the perception of low data availability at the community level and the subjectivity of social indicators may affect expert opinions. Previous research also mentioned the lack of data availability, uncertainty, and subjectivity of social indicators at local levels and suggested alternative methods to address this data gap, such as fuzzy cognitive maps (Masinde, Mwagha, & Tadesse, 2018), focus groups (Lottering, Mafongoya, & Lottering, R. T, 2023), and thematic narrative analyses (Bryan et al., 2020).

iii) ***Experts still do not perceive the importance of local engagement for drought risk management.*** The results showed that experts have a high agreement on the low relevance of indicators related to the engagement of the community (small farmers) for drought risk management, e.g., Participation in local policy, Cooperatives or associations, and Food source reliability. There is an international consensus regarding a model of Integrated and Participatory Water Management, which highlights the importance of actions and decisions for water management being taken at the most decentralized level possible and with the participation of civil society, public authorities, and users (Soncini-Sessa et al, 2007; Villamor et al., 2022). This model aims to reduce conflicts over water use by bringing together those directly involved in negotiation and policy formulation, in addition to decentralization making it possible to incorporate local aspects, which are too complex to be evaluated by a single centralized body. From various international experiences, it is clear that this model allows for better water governance and the effectiveness of actions and policies. The same perspective can be adopted concerning drought risk management and from a climate change perspective. However, this view is not yet reflected in the perception of experts in the area, as our survey showed. Thus, there is a need to increase discussions regarding participatory governance in risk management analyzes and reflections. However, such low final relevance may also have been affected by the profile of the selected experts (mainly academics), who do not work directly with governance.

iv) ***The use of relevant indicators in drought risk assessment can be limited due to a lack of accessibility and temporal consistency.*** This is the case with indicators such as drought-resistant crops, Crop varieties, Technical assistance, Cooperatives or associations, and Financing and credit. Data gaps or poverty is still an obstacle to implementing disaster risk reduction (DRR) in many countries, as Leidig et al. (2016) discuss.

Based on these insights, we propose the following actions aimed at enhancing drought resilience and vulnerability assessment in small farms:

i) ***Foster interdisciplinary collaboration and communication among researchers from diverse disciplines***. Collaborative efforts can culminate in more accurate vulnerability assessments, underpinning the formulation of effective policies and strategies to address drought impacts on small farms and farming communities. The importance of interdisciplinary collaboration for DRR is already recognized in the literature. For example, Martinez et al (2018) affirmed that interdisciplinary collaboration in DRR has led to the conclusion that human resilience to natural disasters cannot be achieved while disciplines are working in isolation. However, there are several barriers to interdisciplinary disaster research, like differences in language and methodology, difficulties in data integration, institutional structures not conducive to interdisciplinary collaboration, and nuanced tension between disciplines (Johnston, Lindt; 2022). To overcome these limitations, Johnston and Lindt (2022) suggest facilitated conversation, providing more institutional and structural support, and using metacognition among others.

ii) ***Foster the collaboration and communication between the scientific community and policymakers***. The collaboration of researchers, policymakers, and other stakeholders is crucial to improving the efficacy of climate adaptation strategies and interventions aimed at risk reduction (Innocenti & Albrito, 2011). The Report of the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2023) clearly stated the role of collaboration for DRR. Integrating socioeconomic data, prioritizing stakeholder involvement, co-designing solutions, and transparent correlation between hazards and socioeconomic data can significantly enhance Earth observation data (UNDRR, 2023). This enables data-driven solutions to foster local ownership and encourage greater investment in risk management (UNDRR, 2023). In turn, local data ownership is crucial for disaster risk reduction, as it allows for the customization of open data and governance systems to local conditions (Kanbara & Shaw, 2021).

iii) ***Improve data quality for calculating the indicators listed in the survey***. As this action is subject to regional variation in policy implementation, we propose a set of overarching strategies as a starting point for the formulation of such policies: *i)* ensure that data collection methods and tools are standardized and well-documented, which can help ensure consistency and comparability across different regions and periods; *ii)* promote open data sharing; *iii)* encourage local data collection and engage small-scale farmers in the process; *iv)* develop user-friendly data dissemination platforms and translate key information into local

languages; and *v)* offer capacity-building workshops and user-friendly manuals for data interpretation.

iv) ***Suggestion of data sources that can be used to calculate the indicators listed in the survey.*** Information to calculate the indicators in our list can be accessed by the Census of Agriculture. According to FAO (2017), the census of agriculture is the only data collection instrument that produces statistical information on farms at the lowest geographical level. They offer a comprehensive overview of a country's agriculture, presenting an opportunity to discern trends, structural shifts within the sector, and potential areas for intervention (FAO, 2017). The extent of agricultural censuses can differ based on resource availability, the importance of agriculture, established census practices, and the priorities of each country. In the absence of national census information, researchers and policy managers can use alternative data sources. For example, the Smallholders dataportrait (FAO, 2015) provides a comprehensive, systematic, and standardized data set on the profile of smallholder farmers across the world; the portal Our World in Data (Ritchie & Roser, 2022) has information on farm size and productivity, land use, crop yields, etc.

The results from our web survey are subject to some limitations. One of them is the self-selection bias (Bethlehe, 2010). The voluntary participation of respondents could introduce self-selection bias, with those more interested or knowledgeable in the topic being more likely to respond. In our study, this bias is minimized as we targeted the experts more

interested or with knowledge or experience in the themes of our project, i.e. drought risk management. Another limitation lies in the subjective nature of the survey, as it relied on respondents' interpretations and scoring of indicator relevancy. This subjectivity might introduce biases and variations in the ratings. For instance, respondents' perceptions might have been influenced by current events, trends, or priorities in their location, which may not be fully representative of long-term perspectives. Additionally, some indicators were deemed less relevant, which could be due to data unavailability or challenges in obtaining local-level information rather than their true significance in drought vulnerability assessment. Finally, the majority of experts were from academia or research institutions. These experts may prioritize different factors while evaluating the indicators compared to practitioners, which may introduce potential biases in our data. For example, practitioners may prioritize immediate drought impacts, while academicians may focus on long-term trends. In this study, however, we did not observe any statistical difference between the perspectives of academicians and practitioners.

Further study is needed to understand better the differences between the perspectives of scientists and practitioners. Expanding the expert sample to include more drought managers, policymakers, agricultural producers, community leaders, and other stakeholders would provide valuable complementary insights. However, the use of forms may not be the most appropriate tool for eliciting these other stakeholders. A more direct approach is recommended to understand the local reality, such as focus discussion groups.

6) Conclusion

The analysis of resilience and vulnerability to drought using composite indexes requires researchers to decide which indicators to use. Without a clear starting criterion, the decisions can be arbitrary, leading to an index that can fail to present the overall vulnerability or resilience level. The results presented in this paper can be a starting point in selecting the indicators related to vulnerability and resilience. They have revealed a set of indicators that hold high relevancy for drought resilience and vulnerability assessments, as well as indicators that pose challenges in measurement and accessibility.

Government and institutional indicators have emerged as crucial components of drought resilience assessment, with indicators such as Drought management policies and Prediction systems ranking highly in relevancy and ease of obtaining local information. However, the effectiveness and full implementation of such policies are essential for their contribution to building resilience, as reactive responses to droughts may not address the underlying causes and vulnerabilities effectively. On the other hand, social indicators, such as Gender inequality and Displaced population, have been rated as less relevant for inclusion in the drought index due to difficulties in definition and measurement. Efforts should be made to improve the accessibility of technical vulnerability indicators like Drought resistance crops and Financing and credit, which are important for drought assessments but pose challenges in obtaining quantitative measures at the local level.

Despite some limitations, the findings from this survey have practical implications for policymakers and researchers alike. The identified relevant indicators can guide the

development of composite indices for drought resilience and vulnerability assessments in small farms, enabling more informed decision-making and targeted interventions. Strategies to minimize the negative effects of drought on small farmers, including providing technical assistance, promoting efficient water use, and developing integrated drought monitoring and early warning systems, can be informed by a better understanding of the relevant indicators.

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SUPPLEMENTARY MATERIAL

Appendix A. List of indicators from the literature
Appendix B. Questionnaire of the survey

Indicators	Reference
1. Annual mean normalized difference vegetation index	(Veettil et al. 2018; Nhamo et al. 2019)
2. Annual Rainfall (Mean or Distribution)	(Ranjan 2013; Chen et al. 2019; Hoque et al. 2021; Xu et al. 2021; Lindoso et al. 2011; Simelton et al. 2009; Antwi-Agyei et al. 2012; Murthy et al. 2015; Epule 2021)
3. Aridity index	(Meaza et al. 2021; Elagib 2014; Lindoso et al. 2011; Alonso et al. 2019)
4. Climatic Moisture Index	(Nhamo et al. 2019; Hogg et al. 2013)
5. Evaporation	(Hoque et al. 2021)
6. Level of groundwater	(Ranjan 2013; Lin et al. 2021)
7. Normalized Difference Vegetation Index (NDVI)	(Schwarz et al. 2020; Elagib 2014; Fang et al. 2011; Murthy et al. 2015)
8. Palmer Drought Severity Index	(Zhao et al. 2018; Chang et al. 2016)
9. Potential Soil Moisture Deficit	(Holman et al. 2021)
10. Precipitation Anomaly Percentage (PAP)	(Chang et al. 2016; Carrão et al. 2016; Fang et al. 2011)
11. Runoff Anomaly Percentage	(Chang et al. 2016)
12. Soil depth	(Hoque et al. 2021; Murthy et al. 2015; Leguizamo et al. 2020)
13. Soil Moisture Index	(Lee and Yoo 2021; Hoque et al. 2021; Fang et al. 2011; Xu et al. 2021; Luetkemeier and Liehr 2018)
14. Soil Type	(Xu et al. 2021)
15. Soil Water Holding capacity	(Huai 2017)
16. Standardized Precipitation Evapotranspiration Index (SPEI)	(Veettil et al. 2018; Bernal et al. 2017; Tefera et al. 2019; Niu et al. 2019; Zhao et al. 2020; Alonso et al. 2019; Luetkemeier and Liehr 2018)
17. Standardized Precipitation Index (SPI)	(Lin et al. 2021; Dabanli 2018; Chang et al. 2016; Holman et al. 2021; Wang et al. 2011; Walz et al. 2020)
18. Standardized runoff index	(Wang et al. 2011)
19. Standardized soil water index SSWI	(Wang et al. 2011)
20. Temperature	(Hoque et al. 2021; Antwi-Agyei et al. 2012)
21. Total Season rainy Days	(Murthy et al. 2015)
22. Vegetation Condition Index (VCI) or VHI	(Walz et al. 2020; Alonso et al. 2019; Luetkemeier and Liehr 2018)
23. Vegetation Coverage	(Antwi-Agyei et al. 2012)
24. Vegetation Supply Water Index (VSWI)	(Fang et al. 2011)
25. Water levels in hand-dug wells and boreholes	(Meaza et al. 2021)
26. Water Requirements Satisfaction Index (WRSI)	(Jayanthi and Husak 2013)
27. Population and Population Density	(Simelton et al. 2009; Yuan et al. 2015; Lin et al. 2021; Zhao et al. 2020; Dabanli 2018; Xu et al. 2021)
28. Total agricultural and irrigated land	(Dabanli 2018; Xu et al. 2021; Zhou et al. 2022; Walz et al. 2020; Zhao et al. 2020; Simelton et al. 2009; Wu et al. 2013; Antwi-Agyei et al. 2012; Alonso et al. 2019)
29. Grassland or Pastureland	(Walz et al. 2020; Zhao et al. 2020)
30. The proportion of the population depended on agriculture	(Xu et al. 2021; Zhou et al. 2022; Walz et al. 2020)
31. Crop Damage / Failure /Loss	(Hao et al. 2012; Simelton et al. 2009; Huai 2017)
32. Ratio of the irrigated area to cropland	(Simelton et al. 2009; Wu et al. 2013; Alonso et al. 2019)
33. The ratio of cultivation area to the total land area	(Wu et al. 2013)
34. The ratio of the irrigation area to cropland	(Zhao et al. 2020; Kampragou et al. 2015; Wu et al. 2013)
35. Water Pressure / Stress / Water availability per km2	(Zhao et al. 2020; Wu et al. 2013; Leguizamo et al. 2020)

Indicators	Reference
36. Number of reservoirs	(Zhao et al. 2020; Wu et al. 2013; Leguizamo et al. 2020)
37. Groundwater level/sources	(Kampragou et al. 2015; Wu et al. 2013; Alonso et al. 2019; Murthy et al. 2015)
38. % of the population employed in small farms	(Lindoso et al. 2011; Kampragou et al. 2015)
39. Net income of rural populations or farmers	(Wu et al. 2013; Antwi-Agyei et al. 2012)
40. % of establishments with rainfed farming	(Lindoso et al. 2011)
41. Water consumption per agriculture value-added	(Yuan et al. 2015)
42. Water consumption per industry value-added	(Yuan et al. 2015)
43. Irrigation water usage ratio	(Wu et al. 2013)
44. Percentage of participation of crop and livestock production in the income of smallholder farming	(Lindoso et al. 2011)
45. Access to water for human consumption	(Lindoso et al. 2011; Luetkemeier and Liehr 2018)
46. Crop Damage & Sensitivity (Crop Loss)	(Hao et al. 2012; Antwi-Agyei et al. 2012; Simelton et al. 2009; Epule 2021)
47. Crop Pattern Diversity	(Kampragou et al. 2015; Antwi-Agyei et al. 2012)
48. Water and food demand	(Luetkemeier and Liehr 2018)
49. Agriculture land	(Simelton et al. 2009; Yuan et al. 2015)
50. Paddy fields	(Yuan et al. 2015)
51. Access to fodder (kg purchased per year)	(Meza et al. 2019)
52. Agricultural machinery in use (#)	(Meza et al. 2019)
53. Agriculture (% of GDP)	(Meza et al. 2019)
54. Area protected and designated for the conservation of biodiversity (%)	(Meza et al. 2019)
55. Baseline water stress (ratio of withdrawals to renewable supply)	(Meza et al. 2019)
56. Degree of land degradation and desertification	(Meza et al. 2019)
57. Dependency on agriculture for livelihood (%)	(Meza et al. 2019)
58. Access to electricity (Acess to energy)	(Meza et al. 2019)
59. Expenditure on health (out-of-pocket) (%)	(Meza et al. 2019)
60. GDP per capita, PPP	(Meza et al. 2019)
61. Gender inequality (categorical)	(Meza et al. 2019)
62. GINI index (income inequality)	(Meza et al. 2019)
63. Illiteracy rate (%)	(Meza et al. 2019)
64. Use of Insecticides and pesticides (Use of agricultural inputs)	(Meza et al. 2019)
65. Life expectancy at birth (years)	(Meza et al. 2019)
66. Livestock health	(Meza et al. 2019)
67. Market fragility	(Meza et al. 2019)
68. Population ages 15-64 (% of the total population)	(Meza et al. 2019)
69. Population below the national poverty line (%)	(Meza et al. 2019)
70. Population undernourished (%)	(Meza et al. 2019)
71. Population with ill-health (%)	(Meza et al. 2019)
72. Population without access to (improved) sanitation (%)	(Meza et al. 2019)
73. Population without access to clean water (%)	(Meza et al. 2019)
74. Presence of drivers of migration and displacement	(Meza et al. 2019)
75. Percentage of the population displaced internally or transboundary	(Meza et al. 2019)
76. Risk perception (% of the population who has experienced droughts in the past 10 years)	(Meza et al. 2019)

Indicators	Reference
77. Rural population (% of the total population)	(Meza et al. 2019)
78. Soil depth (mm)	(Meza et al. 2019)
79. Soil organic matter (g*kg)	(Meza et al. 2019)
80. Tourism (% of GDP)	(Meza et al. 2019)
81. Unemployment rate (and/or proportion of formal work)	(Meza et al. 2019)
82. Use of fertilizer (ton)	(Meza et al. 2019)
83. Water quality (categorical)	(Meza et al. 2019)
84. Percentage of retained renewable water	(Meza et al. 2019)
85. Corruption (e.g. Corruption Perception Index)	(Meza et al. 2019)
86. Cultivation of drought-resistant crops (%)	(Meza et al. 2019)
87. Disaster risk taken into account in public investment and planning decisions (yes/no)	(Meza et al. 2019)
88. Distance to closest market (km)	(Meza et al. 2019)
89. Existence of adaptation policies/plans (yes/no)	(Meza et al. 2019)
90. Farmers use different crop varieties (%)	(Meza et al. 2019)
91. Farmers with crop, livestock, or drought insurance (%)	(Meza et al. 2019)
92. Farmers/laborers without access to bank loans/(micro-) credits (%)	(Meza et al. 2019)
93. Farmers/laborers without savings (%)	(Meza et al. 2019)
94. Farmers/laborers without savings (%)	(Meza et al. 2019)
95. Government effectiveness	(Meza et al. 2019)
96. Irrigated land (% total arable)	(Meza et al. 2019)
97. National investment in disaster prevention & preparedness (US$/Year/capita)	(Meza et al. 2019)
98. Number of (drought-related) adaptation projects in the past 10 years	(Meza et al. 2019)
99. Public participation in local policy	(Meza et al. 2019)
100. Research and development expenditure (% of GDP)	(Meza et al. 2019)
101. Total dam capacity	(Meza et al. 2019)
102. Participation in farming cooperatives or associations	(Lindoso et al. 2011)
103. Connectivity to external connectors	(Leguizamo et al. 2020)
104. Availability of drought prediction and warning systems or climatic predictions	(Lee and Yoo 2021; Xu et al. 2021; Leguizamo et al. 2020)
105. Water-conservation irrigation technologies	(Xu et al. 2021; Zhou et al. 2022; Kampragou et al. 2015; Yuan et al. 2015; Wu et al. 2013)
106. Water storage and harvesting capacity	(Xu et al. 2021; Zhou et al. 2022)
107. Access to electricity	(Lindoso et al. 2011)
108. Electricity usage	(Huai 2017)
109. Access to alternative water sources	(Kampragou et al. 2015; Yuan et al. 2015)
110. Fixed assets for drought mitigation	(Yuan et al. 2015)
111. Emergency irrigation	(Yuan et al. 2015)
112. Transportation network	(Simelton et al. 2009)
113. Machinery power	(Simelton et al. 2009)
114. Fertilizer usage	(Simelton et al. 2009; Antwi-Agyei et al. 2012)
115. GDP	(Yuan et al. 2015)
116. Crop revenue	(Huai 2017)
117. Labor Usage	(Huai 2017)
118. Poverty Rate	(Antwi-Agyei et al. 2012; Epule 2021)
119. Fixed capital per farmer	(Simelton et al. 2009; Huai 2017)
120. Investment in agriculture	(Simelton et al. 2009)
121. Access to financing and credit	(Huai 2017; Leguizamo et al. 2020)

Indicators	Reference
122. Phone Chargers	(Huai 2017)
123. Diversity of income sources	(Lindoso et al. 2011; Simelton et al. 2009)
124. Housing quality	(Leguizamo et al. 2020)
125. Land rights clearly defined (yes/no)	(Lindoso et al. 2011; Leguizamo et al. 2020)
126. Literacy / Education	(Lindoso et al. 2011; Wu et al. 2013; Antwi-Agyei et al. 2012; Epule 2021; Leguizamo et al. 2020)
127. Livestock production	(Maltou and Bahta 2019)
128. Household Produced Food	(Maltou and Bahta 2019)
129. Food source reliability and diversity	(Luetkemeier and Liehr 2018)
130. Technical assistance from cooperatives or government	(Lindoso et al. 2011; Leguizamo et al. 2020)
131. Water use rights are clearly defined	(Kampragou et al. 2015)
132. Existence of drought management policies	(Kampragou et al. 2015)
133. Technology assistance	(Leguizamo et al. 2020)
134. NDWI (Normalised Difference Water Index)	(Shashikant et al. 2021)
135. Integrated land and water management policies	(Lerner et al. 2018)
136. Existence of concurrent multi-hazard risks (dynamic vulnerabilities)	(Boult et al. 2022)

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Consent_EU

Dear Researcher:

We are a Belmont Project Consortium requesting your expert opinion to evaluate drought vulnerability and resilience indicators.

Research on drought risk modeling relies on numerous indicators to quantify the magnitude and frequency of drought, its ecological, economic, and social impact, and coping mechanisms that can reduce or avoid the negative impacts of drought. The use and selection of indicators depend on the objectives, data availability, and the target region. **In this survey, you will rank the importance of the indicators related to drought, classifying them in their representativeness of the risk and resilience components and their relevance in different local contexts.**

This survey has been approved by the Institutional Review Board (IRB) of Penn State University for Human Subjects Protection (IRB # STUDY00021208). Your participation is voluntary, and you may decide to stop at any time. You do not have to answer any questions that you do not want to answer.

The survey will take approximately **15-20** minutes to complete. All of your answers will be kept in strict confidence, and the information will be used only for research purposes.

Consent to Collect, Use, Store, and Process Personal Information under the General Data Protection Regulation: As part of this study The Pennsylvania State University will be collecting, using, storing, and processing the personal research information that you will provide in connection with the research for the purposes described in this Consent for Research. Because you are in the European Union, all personal research information that you provide in connection with the research study will be collected, used, stored, and processed in accordance with the provisions of Regulation (EU) 2016/679 (“Regulation on the protection of natural persons with regard to the processing of personal data and on the free movement of such data”), as well as all other applicable laws and The Pennsylvania State University policies. These laws and regulations, depending on the type of information involved, provide you certain rights with regard to your personal information. You may elect to withdraw your consent to the collection, use, storing and processing of your personal research information prior to completing the research procedures described in this Consent for Research. If you decide to withdraw your consent during the study, to the extent required by law and we are able to identify you from the information retained as part of this study, any personal research information you have already provided will be destroyed or deleted, and will no longer be collected, used, stored, or processed. You may also withdraw your consent to the use, storing, and processing of your personal research information from the research study after your participation in the study has ended. If you withdraw your consent to the use,

storing, and processing of your personal research information after the study has been completed, to the extent required by law and we are able to identify you from the information retained as part of this study, your personal research information will be destroyed or deleted, and will no longer be collected, used, stored, or processed. You may withdraw your consent to the use, storing, and processing of your personal research information at any time by contacting the Principal Investigator of the study, Michael Jacobson at 814-865-3994, (email mgj2@psu.edu). You can also contact the Office for Research Protections at (814) 865-1775, (email irb-orp@psu.edu) if you are not able to reach the investigator. We do not believe that the information about you that we will retain for use in this study will allow us to identify you at a later date.

I have read the preliminary description of this study. I agree to allow my survey evaluations to be released to this study's principal investigator and the research team. I understand that I am free to discontinue my participation without penalty. By selecting YES, I allow de-identified data to be used in publications and presentations.

You must be 18 years or older to consent to participate in this research study. If you agree to participate in this research study and the information outlined above, select **YES** and **click the following button to complete this Consent for Research.**

- ○ YES
- ○ NO

Consent

Dear Researcher:
We are a Belmont Project Consortium requesting your expert opinion to evaluate drought vulnerability and resilience indicators.

Research on drought risk modeling relies on numerous indicators to quantify the magnitude and frequency of drought, its ecological, economic, and social impact, and coping mechanisms that can reduce or avoid the negative impacts of drought. The use and selection of indicators depend on the objectives, data availability, and the target region. **In this survey, you will rank the importance of the indicators related to drought, classifying them in their representativeness of the risk and resilience components and their relevance in different local contexts.**

This survey has been approved by the Institutional Review Board (IRB) of Penn State University for Human Subjects Protection (IRB # STUDY00021208). Your participation is voluntary, and you may decide to stop at any time. You do not have to answer any questions that you do not want to answer.

The survey will take approximately **15-20** minutes to complete. All of your answers will be kept in strict confidence, and the information will be used only for research purposes.

If you have any questions regarding the survey or this research project in general, please contact me. If you have any questions concerning your rights as a research participant, please contact the office for Research Program at Penn State at (814)865-1775 or protections@psu.edu and inquire about IRB# STUDY00021208.

I have read the preliminary description of this study. I agree to allow my survey evaluations to be released to this study's principal investigator and the research team. I understand that I am free to discontinue my participation without penalty. By selecting YES, I allow de-identified data to be used in publications and presentations.

You must be 18 years or older to consent to participate in this research study. If you agree to participate in this research study and the information outlined above, select **YES** and click the following button to complete **this Consent for Research.**

- ○ YES
- ○ NO

Questions

Instructions:
In this survey, you will rate the relevance and data quality of a set of indicators for a drought resilience index **for small to medium size farms.**

At the end of the survey, you will be asked for your willingness to participate in an **online workshop** about drought resilience indicators. The online workshop will take place in Spring 2023, and workshop participants will be compensated with a $20 digital gift card.

Indicator Relevancy:

Please rate how **relevant** the following indicators are in terms of the information needs of decision-makers for improving drought resilience policies and better managing resources.

Option	Definition
Low	The indicator is irrelevant to the information needs of decision-makers.
Medium	The indicator is moderately relevant to the information needs of decision-makers.
High	The indicator is highly relevant to the information needs of decision-makers.

	Relevancy			
	Low	Medium	High	Don't know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	○	○	○	○
Crop loss	○	○	○	○
Percentage of drought-resistance crop varieties cultivated	○	○	○	○
Percentage of farmers who use different types of crops	○	○	○	○
Percentage of area protected and designated for the conservation of biodiversity	○	○	○	○
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	○	○	○	○
Crop water use efficiency (WUE)	○	○	○	○
Degree of land degradation and desertification	○	○	○	○

	Low	Medium	High	Don't know
Land rights clearly defined (yes/no)	○	○	○	○
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	○	○	○	○
Technical assistance from local entities (e.g., cooperatives/NGO/government)	○	○	○	○
Percentage of farmers with crop, livestock, or drought insurance	○	○	○	○
Water use rights clearly defined	○	○	○	○
Availability of drought prediction and warning systems or climatic predictions	○	○	○	○
Produce storage and transportation capacity	○	○	○	○
Access to energy	○	○	○	○

	Low	Medium	High	Don't know
Prevalence of conflict/insecurity	○	○	○	○
Percentage of the population without access to (improved) sanitation	○	○	○	○
Gender inequality	○	○	○	○
Percentage of the rural population	○	○	○	○
Unemployment rate and/or proportion of formal work	○	○	○	○
Percentage of population ages 15-64	○	○	○	○
Percentage of population displaced internally or transboundary	○	○	○	○
Presence of drivers of migration and displacement	○	○	○	○

	Relevancy			
	Low	Medium	High	Don't know
	Low	Medium	High	Don't know
Poverty Rate	○	○	○	○
Food source reliability and diversity	○	○	○	○
Level of public participation in local policy	○	○	○	○
Participation in farming cooperatives or associations	○	○	○	○
Percentage of the population employed in farms	○	○	○	○
Access to financing and credit	○	○	○	○
Ratio of annual withdrawals to available water	○	○	○	○
Water quality	○	○	○	○
	Low	Medium	High	Don't know
Groundwater level/sources	○	○	○	○
Integrated land and water management policies	○	○	○	○
Percentage of retained renewable water	○	○	○	○
Total dam capacity	○	○	○	○

Ease of Understanding:
Please rate the following indicators for **ease of understanding by decision-makers** to be used in a drought resilience index for **small to medium size farms**.

Option	Definition
Low	The indicator may be interpreted differently by various decision-makers. The indicator is not clearly connected to a policy objective.
Medium	The indicator is understood by most decision-makers with some clarification. The indicator conveys useful information.
High	The indicator is readily understood by decision-makers and, preferably, the broad audience. The indicator conveys useful, relevant information for decision-makers on a specific policy objective.

	Ease of understanding by decision-makers			
	Low	Medium	High	Don't know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	○	○	○	○
Crop loss	○	○	○	○
Percentage of drought-resistance crop varieties cultivated	○	○	○	○
Percentage of farmers who use different types of crops	○	○	○	○
Percentage of area protected and designated for the conservation of biodiversity	○	○	○	○
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	○	○	○	○
Crop water use efficiency (WUE)	○	○	○	○
Degree of land degradation and desertification	○	○	○	○

	Low	Medium	High	Don't know
Land rights clearly defined (yes/no)	○	○	○	○
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	○	○	○	○
Technical assistance from local entities (e.g., cooperatives/NGO/government)	○	○	○	○
Percentage of farmers with crop, livestock, or drought insurance	○	○	○	○
Water use rights clearly defined	○	○	○	○
Availability of drought prediction and warning systems or climatic predictions	○	○	○	○
Produce storage and transportation capacity	○	○	○	○
Access to energy	○	○	○	○

	Low	Medium	High	Don't know
Prevalence of conflict/insecurity	○	○	○	○
Percentage of the population without access to (improved) sanitation	○	○	○	○
Gender inequality	○	○	○	○
Percentage of the rural population	○	○	○	○
Unemployment rate and/or proportion of formal work	○	○	○	○
Percentage of population ages 15-64	○	○	○	○
Percentage of population displaced internally or transboundary	○	○	○	○
Presence of drivers of migration and displacement	○	○	○	○

	Ease of understanding by decision-makers			
	Low	Medium	High	Don't know
Poverty Rate	○	○	○	○
Food source reliability and diversity	○	○	○	○
Level of public participation in local policy	○	○	○	○
Participation in farming cooperatives or associations	○	○	○	○
Percentage of the population employed in farms	○	○	○	○
Access to financing and credit	○	○	○	○
Ratio of annual withdrawals to available water	○	○	○	○
Water quality	○	○	○	○

	Low	Medium	High	Don't know
Groundwater level/sources	○	○	○	○
Integrated land and water management policies	○	○	○	○
Percentage of retained renewable water	○	○	○	○
Total dam capacity	○	○	○	○

Data Accessibility and Effort:

Rate the following indicators in terms of **data accessibility for reasonable cost/level of effort** as described below.

Option	Definition
Low	The indicator data is not easily accessible or available. Collecting and processing the data requires significant time and effort.
Medium	The indicator data is mostly available, but processing the data requires some effort.
High	The indicator data is publicly accessible and readily available. Processing the data requires minimal effort.

	Data Accessibility			
	Low	Medium	High	Don't know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	○	○	○	○

Data Accessibility

	Low	Medium	High	Don't know
Crop loss	○	○	○	○
Percentage of drought-resistance crop varieties cultivated	○	○	○	○
Percentage of farmers who use different types of crops	○	○	○	○
Percentage of area protected and designated for the conservation of biodiversity	○	○	○	○
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	○	○	○	○
Crop water use efficiency (WUE)	○	○	○	○
Degree of land degradation and desertification	○	○	○	○

	Low	Medium	High	Don't know
Land rights clearly defined (yes/no)	○	○	○	○
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	○	○	○	○
Technical assistance from local entities (e.g., cooperatives/NGO/government)	○	○	○	○
Percentage of farmers with crop, livestock, or drought insurance	○	○	○	○
Water use rights clearly defined	○	○	○	○
Availability of drought prediction and warning systems or climatic predictions	○	○	○	○
Produce storage and transportation capacity	○	○	○	○
Access to energy	○	○	○	○

	Low	Medium	High	Don't know
Prevalence of conflict/insecurity	○	○	○	○
Percentage of the population without access to (improved) sanitation	○	○	○	○
Gender inequality	○	○	○	○
Percentage of the rural population	○	○	○	○
Unemployment rate and/or proportion of formal work	○	○	○	○
Percentage of population ages 15-64	○	○	○	○
Percentage of population displaced internally or transboundary	○	○	○	○
Presence of drivers of migration and displacement	○	○	○	○

	Low	Medium	High	Don't know
Poverty Rate	○	○	○	○

Data Accessibility

	Low	Medium	High	Don't know
Food source reliability and diversity	○	○	○	○
Level of public participation in local policy	○	○	○	○
Participation in farming cooperatives or associations	○	○	○	○
Percentage of the population employed in farms	○	○	○	○
Access to financing and credit	○	○	○	○
Ratio of annual withdrawals to available water	○	○	○	○
Water quality	○	○	○	○

	Low	Medium	High	Don't know
Groundwater level/sources	○	○	○	○
Integrated land and water management policies	○	○	○	○
Percentage of retained renewable water	○	○	○	○
Total dam capacity	○	○	○	○

Data Objectivity:

Please rate the following indicators in terms of **data objectivity as described below.**

Option	Definition
Low	A subjective measure that requires expert judgment to evaluate the indicator.
Medium	Requires some degree of expert judgment to interpret quantitative or qualitative data.
High	An objective measure is based on quantifiable, impartial, and recorded data.

Data Objectivity

	Low	Medium	High	Don't Know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	○	○	○	○
Crop loss	○	○		○
○ Percentage of drought-resistance crop varieties cultivated	○	○		○
○ Percentage of farmers who use different types of crops	○	○		○
○ Percentage of area protected and designated for the conservation of biodiversity	○	○	○	○
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	○	○	○	○

Data Objectivity

	Low	Medium	High	Don't Know
Crop water use efficiency (WUE)	○	○	○	○
Degree of land degradation and desertification	○	○	○	○

	Low	Medium	High	Don't Know
Land rights clearly defined (yes/no)	○	○	○	○
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	○	○	○	○
Technical assistance from local entities (e.g., cooperatives/NGO/government)	○	○		○
○ Percentage of farmers with crop, livestock, or drought insurance	○	○		○
○ Water use rights clearly defined	○	○		○
○ Availability of drought prediction and warning systems or climatic predictions	○	○		○
○ Produce storage and transportation capacity	○	○		○
○ Access to energy	○	○	○	○

	Low	Medium	High	Don't Know
Prevalence of conflict/insecurity	○	○		○
○ Percentage of the population without access to (improved) sanitation	○	○		○
○ Gender inequality	○	○		○
○ Percentage of the rural population	○	○		○
○ Unemployment rate and/or proportion of formal work	○	○		○
○ Percentage of population ages 15-64	○	○		○
○ Percentage of population displaced internally or transboundary	○	○		○
○ Presence of drivers of migration and displacement	○	○	○	○

	Low	Medium	High	Don't Know
Poverty Rate	○	○		○
○ Food source reliability and diversity	○	○		○
○ Level of public participation in local policy	○	○		○
○ Participation in farming cooperatives or associations	○	○	○	○
Percentage of the population employed in farms	○	○	○	○
Access to financing and credit	○	○	○	○

Data Objectivity

	Low	Medium	High	Don't Know
Ratio of annual withdrawals to available water	○	○	○	○
Water quality	○	○	○	○

	Low	Medium	High	Don't Know
Groundwater level/sources	○	○		○
○ Integrated land and water management policies	○	○		○
○ Percentage of retained renewable water	○	○		○
○ Total dam capacity	○	○	○	○

Data Consistency over Temporal Scales:

Is the data for the indicator **available consistently over different temporal scales** to be used in a drought resilience index for **small to medium size farms**?

Option	Definition
Low	The indicator data is collected in an ad-hoc manner, limiting the ability to monitor and compare the indicator over different temporal scales.
Medium	The indicator data is collected periodically but not frequently enough for comparing the indicator in different temporal scales.
High	The indicator data is collected regularly and available over different time scales, allowing for monitoring and comparing the indicator over different temporal scales.

Data Temporal Consistency

	Low	Medium	High	Don't know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	○	○	○	○
Crop loss	○	○	○	○
Percentage of drought-resistance crop varieties cultivated	○	○	○	○
Percentage of farmers who use different types of crops	○	○	○	○
Percentage of area protected and designated for the conservation of biodiversity	○	○	○	○
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	○	○	○	○
Crop water use efficiency (WUE)	○	○	○	○

Data Temporal Consistency

	Low	Medium	High	Don't know
Degree of land degradation and desertification	○	○	○	○

	Low	Medium	High	Don't know
Land rights clearly defined (yes/no)	○	○	○	○
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	○	○	○	○
Technical assistance from local entities (e.g., cooperatives/NGO/government)	○	○	○	○
Percentage of farmers with crop, livestock, or drought insurance	○	○	○	○
Water use rights clearly defined	○	○	○	○
Availability of drought prediction and warning systems or climatic predictions	○	○	○	○
Produce storage and transportation capacity	○	○	○	○
Access to energy	○	○	○	○

	Low	Medium	High	Don't know
Prevalence of conflict/insecurity	○	○	○	○
Percentage of the population without access to (improved) sanitation	○	○	○	○
Gender inequality	○	○	○	○
Percentage of the rural population	○	○	○	○
Unemployment rate and/or proportion of formal work	○	○	○	○
Percentage of population ages 15-64	○	○	○	○
Percentage of population displaced internally or transboundary	○	○	○	○
Presence of drivers of migration and displacement	○	○	○	○

	Low	Medium	High	Don't know
Poverty Rate	○	○	○	○
Food source reliability and diversity	○	○	○	○
Level of public participation in local policy	○	○	○	○
Participation in farming cooperatives or associations	○	○	○	○
Percentage of the population employed in farms	○	○	○	○
Access to financing and credit	○	○	○	○
Ratio of annual withdrawals to available water	○	○	○	○

Data Temporal Consistency

	Low	Medium	High	Don't know
Water quality	○	○	○	○

	Low	Medium	High	Don't know
Groundwater level/sources	○	○	○	○
Integrated land and water management policies	○	○	○	○
Percentage of retained renewable water	○	○	○	○
Total dam capacity	○	○	○	○

Data Availability at Regional and Local Scales:

Is data for the indicator **available at regional and local scales level**? (Select all that apply)

Option	Definition
Local Level	The indicator data is available at the local level (e.g., municipality, town, village) and can be aggregated and compared across **different geographical areas.**
Regional Level	The indicator data is available at regional or sub-national spatial scales (regional) and can be aggregated and compared across **only regional levels.**

	Local	Regional	Don't know
Percentage of the contribution of crop and livestock production in the income of smallholder farming	☐	☐	☐
Crop loss	☐	☐	☐
Percentage of drought-resistance crop varieties cultivated	☐	☐	☐
Percentage of farmers who use different types of crops	☐	☐	☐
Percentage of area protected and designated for the conservation of biodiversity	☐	☐	☐
Use of agricultural inputs (e.g., insecticides, pesticides, fertilizer, machinery)	☐	☐	☐
Crop water use efficiency (WUE)	☐	☐	☐
Degree of land degradation and desertification	☐	☐	☐

	Local	Regional	Don't know
Land rights clearly defined (yes/no)	☐	☐	☐
Existence of drought management policies (mitigation/adaptation/prevention/preparedness)	☐	☐	☐

	Local	Regional	Don't know
Technical assistance from local entities (e.g., cooperatives/NGO/government)	☐	☐	☐
Percentage of farmers with crop, livestock, or drought insurance	☐	☐	☐
Water use rights clearly defined	☐	☐	☐
Availability of drought prediction and warning systems or climatic predictions	☐	☐	☐
Produce storage and transportation capacity	☐	☐	☐
Access to energy	☐	☐	☐

	Local	Regional	Don't know
Prevalence of conflict/insecurity	☐	☐	☐
Percentage of the population without access to (improved) sanitation	☐	☐	☐
Gender inequality	☐	☐	☐
Percentage of the rural population	☐	☐	☐
Unemployment rate and/or proportion of formal work	☐	☐	☐
Percentage of population ages 15-64	☐	☐	☐
Percentage of population displaced internally or transboundary	☐	☐	☐
Presence of drivers of migration and displacement	☐	☐	☐

	Local	Regional	Don't know
Poverty Rate	☐	☐	☐
Food source reliability and diversity	☐	☐	☐
Level of public participation in local policy	☐	☐	☐
Participation in farming cooperatives or associations	☐	☐	☐
Percentage of the population employed in farms	☐	☐	☐
Access to financing and credit	☐	☐	☐
Ratio of annual withdrawals to available water	☐	☐	☐
Water quality	☐	☐	☐

	Local	Regional	Don't know
Groundwater level/sources	☐	☐	☐
Integrated land and water management policies	☐	☐	☐
Percentage of retained renewable water	☐	☐	☐

	Local	Regional	Don't know
Total dam capacity	☐	☐	☐

Demographics

Gender: How do you identify?

- ○ Female
- ○ Non-binary
- ○ Male
- ○ Prefer not to say
- ○ Prefer to self describe, below

What type of institution do you (primarily) work for (choose one):

- ○ Academic/University/Research Institution
- ○ Government
- ○ International Organization
- ○ NGO
- ○ Consultancy
- ○ Industry/Private Sector
- ○ Other (please specify)

Do you have expertise in any of the following areas? (please choose as many as are applicable)?

- ☐ Agricultural Sciences
- ☐ Anthropology and Development
- ☐ Climate Change
- ☐ Climate Science/Services
- ☐ Drought Hazard and Disaster Risk Assessment
- ☐ Economics (water, environmental)
- ☐ Environmental Sciences
- ☐ Geography
- ☐ Health
- ☐ Hydrology
- ☐ Interdisciplinary
- ☐ Sociology
- ☐ Soil and Water Conservation
- ☐ Water Resource Managment
- ☐ Data and Information science
- ☐ Other (please specify)

Do you have expertise in any of the following sectors? (please choose as many as are applicable)?

- [ ] Agriculture sector
- [ ] Water sector
- [ ] Energy Sector
- [ ] Water Energy Food Nexus

If you have Disaster Risk/Resilience expertise how would you rate your level of expertise?

- ○ Not knowledgeable
- ○ Fairly knowledgeable
- ○ Knowledgeable
- ○ Highly knowledgeable
- ○ Fully profocient

Years of experience working on drought:

- ○ 1-2
- ○ 3-5
- ○ 6-10
- ○ 10+
- ○ No Previous Experience

Years of experience working on vulnerability and risk:

- ○ 1-2
- ○ 3-5
- ○ 6-10
- ○ 10+
- ○ No Previous Experience

Geographic focus of work (select all that apply):

- [ ] Asia
- [ ] Africa
- [ ] Europe
- [ ] North America
- [ ] South America
- [ ] Global
- [ ] General/Theoretical

Please provide your First Name, Last Name, and email if you are willing to participate in a drought resilience **online workshop in Spring 2023** and/or the 2nd round of this survey.

The online workshop will focus on identifying the relationships among the indicators.
As an expression of our appreciation for your time, online workshop participants will be compensated with a $20 digital gift card unless they decide to decline.

In the 2nd round of this survey, we will send the summary results of the survey and ask you to review the drought vulnerability and resilience indicators again.

Please indicate your decisions (select all that apply).

- [ ] I would like to participate in the online workshop
- [ ] I would like to receive the 2nd round of the survey
- [ ] I decline to participate in the online workshop

First Name

Last Name

Email

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Enhancing drought resilience and vulnerability assessment in small farms: A global expert survey on multidimensional indicators

Sass, Karina Simone; Batalini de Macedo, Marina; Benso, Marcos Roberto; Shrimpton, Elisabeth; Balta-Ozkan, Nazmiye ...

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