frontiers | Frontiers in Climate

TYPE Original Research
PUBLISHED 25 July 2024
DOI 10.3389/fclim.2024.1418015

OPEN ACCESS

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RECEIVED 15 April 2024
ACCEPTED 11 July 2024
PUBLISHED 25 July 2024

CITATION
Segnon AC, Magassa M, Obossou EAR, Partey ST, Houessionon P and Zougmoré RB (2024) Gender vulnerability assessment to inform gender-sensitive adaptation action: a case study in semi-arid areas of Mali.
Front. Clim. 6:1418015.
doi: 10.3389/fclim.2024.1418015

Gender vulnerability assessment to inform gender-sensitive adaptation action: a case study in semi-arid areas of Mali

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Understanding the gender dimensions of vulnerability to climate change is crucial for designing effective gender-transformative climate actions. This is particularly crucial in the semi-arid regions of West Africa, a climate change "hotspot" where high dependence on climate-sensitive livelihoods and limited adaptive capacity make agriculture and livelihoods highly vulnerable. In this study we combined semi-structured interviews and focus group discussions with a systematic literature review to analyze gendered household vulnerability to climate change in Cinzana, a semi-arid area of Mali, and identify entry points for gender-transformative adaptation actions. The Livelihood Vulnerability assessment indicated that female-headed households were more vulnerable than male-headed households. Differential socio-demographic profiles, livelihood strategies, social networks, water and food and agricultural production systems were key drivers of the gendered vulnerability patterns. A systematic review of drivers of gendered vulnerability in Mali illustrated how socio-cultural norms and roles assigned to women, and limited women access to and control over productive resources and adaptation technologies make women more vulnerable to climatic and non-climatic risks. We highlight the need of gender transformative approaches to address the structural gender inequality and reduce vulnerability of female-headed households. We outline three pathways for reducing female-headed households' vulnerability to climate change, including the promotion of gender-smart extension and climate advisory services and empowering women.

KEYWORDS

gender, livelihood vulnerability, vulnerability assessment, social inclusion, semi-arid regions, adaptation, climate change, Mali

1 Introduction

With a long history of prolonged and severe drought but also a bleaker future in terms of projections, semi-arid regions of West Africa are one of the most exposed and vulnerable regions in the world (Gutiérrez et al., 2021; Segnon et al., 2021; Carr et al., 2022; Trisos et al., 2022; Bezner Kerr et al., 2022a; Zougmoré et al., 2023). Thus, limiting global warming to 1.5°C becomes particularly imperative to substantially reduce damages to economies, agriculture, human health, and ecosystems in semi-arid regions of West Africa and more broadly in Africa (Trisos et al., 2022; Bezner Kerr et al., 2022a).

While climatic factors are key driving forces of vulnerability in semi-arid areas of West Africa, they are often intertwined with multiple non-climatic drivers (Nyantakyi-Frimpong and Bezner-Kerr, 2015; Ahmed et al., 2016; Räsänen et al., 2016; Schmitt Olabisi et al., 2018; Huet et al., 2020; Segnon et al., 2021; Bezner Kerr et al., 2022b). Non-climate drivers are factors, agents or processes not linked to or outside to the climate or the climate system that influences human or natural systems (IPCC, 2022). Non-climatic drivers often include socio-economic, political, institutional and policy factors and processes that shape or drive differential vulnerability (Ahmed et al., 2016; Räsänen et al., 2016; Segnon et al., 2021; Bezner Kerr et al., 2022b). Recent empirical literature from semi-arid regions of Mali, a hotspot of climate change exposure and climate impacts illustrated the interplay between climatic and non-climatic stressors shaping differential household vulnerability (Segnon et al., 2021). Farm households faced a diversity of risks both climatic and non-climatic in nature operating and interacting at the same time (Schmitt Olabisi et al., 2018; Huet et al., 2020; Sanga et al., 2021; Segnon et al., 2021). Drought and climate variability but also labor availability, hazards related to human and animal health are of highest concern (Huet et al., 2020; Sanga et al., 2021; Segnon et al., 2021).

Human vulnerability is often situated within and results from the interaction between climate change and existing social and gender inequalities (Ahmed et al., 2016; Call and Sellers, 2019; Huyer et al., 2021; Awiti, 2022; Bezner Kerr et al., 2022b). In semi-arid zones of West Africa, the negative impacts of climate change are experienced differently across social groups and a growing body of literature has established the links between gender (in)equality and climate change impacts on human livelihoods (Ahmed et al., 2016; Call and Sellers, 2019; Huyer and Partey, 2020; Huyer et al., 2021, 2024; Awiti, 2022; Khoza et al., 2022; Roy et al., 2022; Elias et al., 2024). The socio-cultural contexts in which climate shocks occur strongly influence how the impacts are experienced and addressed by the various social groups. For instance, women and men farmers experience climate change differently based on their roles, rights, and opportunities, which also depend on variables including gender norms, socio-cultural contexts, religion, ethnicity (Ahmed et al., 2016; Huyer et al., 2021, 2024; Tantoh et al., 2021; Elias et al., 2024). These factors often explain gender gaps in access to and control over key resources that also define the vulnerability and adaptive capacity of men and women to respond to climate risks (Huyer et al., 2021, 2024; Tantoh et al., 2021; Elias et al., 2024). Strengthening adaptive capacity of women and other socially-differentiated groups requires both understanding and addressing these gender gaps, which can also improve livelihood and development outcomes, including poverty, food insecurity, and inequality.

This study echoes the growing literature advocating for gender-sensitive approach in planning, implementation and monitoring of climate actions (Huyer et al., 2021, 2024; Khoza et al., 2022; Elias et al., 2024). A gender-sensitive approach is crucial to address gender gaps in agriculture and food systems. Indeed, a gender-blind approach to climate actions in agriculture and food systems can exacerbate existing inequalities and power relations governing women's opportunity and ability to benefit from both adaptation and mitigation interventions (Huyer et al., 2021, 2024; Elias et al., 2024). A gender-sensitive approach helps understand the intricacies of how gender influences vulnerability to climate change and the ability of men and women to cope with and adapt to climate variability and change, thereby facilitating actions that recognize and integrate the different vulnerabilities, knowledge, priorities and roles of men and women. The paper illustrates how integrating vulnerability assessment and analysis of its drivers can help identify entry points for gender-sensitive adaptation actions, using a case from semi-arid areas of Mali. While acknowledging the dynamic, complex and context-specific nature of gendered livelihood vulnerability, we argue that many of the gender inequalities embedded in local agriculture and food system contexts are likely to persist if not addressed systemically through gender-sensitive adaptation across scales. Combining semi-structured interviews and focus group discussions with a systematic literature review (Figure 1), the study analyzed women- and men-headed household vulnerability to climate change in Cinzana, a semi-arid area of Mali, and explored the factors contributing to differential vulnerability of male and female head households. It also outlined and discussed entry points for gender-sensitive adaptation actions.

2 Materials and methods

This paper employs a two-stage methodology (Figure 1). Firstly, it uses primary empirical data from two villages in Cinzana, a semi-arid area of Mali to provide a local understanding of gendered livelihood vulnerability to climate change. Secondly, the findings of the empirical investigation of gendered livelihood vulnerability are situated within a broader context of gendered vulnerabilities in Mali resulting from a systematic literature review. The combination of empirical research with a systematic review provides a robust and comprehensive approach to investigating complex issues such as climate change in local contexts. This approach further allows for the triangulation of data with existing sources, thus providing a more complete picture of the state of knowledge on the gender dimensions of vulnerabilities in the context of semi-arid areas of Mali.

2.1 Study area

The study was carried out in the Cinzana Climate-Smart Village (CSV) site in Segou region, Mali. The Cinzana CSV is approximately 30 km x 30 km and comprises 48 villages. It is one of the intervention sites of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).[1] This study area belongs to Sahelian agro-ecological zone and characterized by a semi-arid climate and a high inter-annual and intra-seasonal variability of annual rainfall (Segnon, 2019). Two villages, Tongo and Ngakoro, were randomly selected for the study (Figure 2).

1 https://ccafs.cgiar.org/mali

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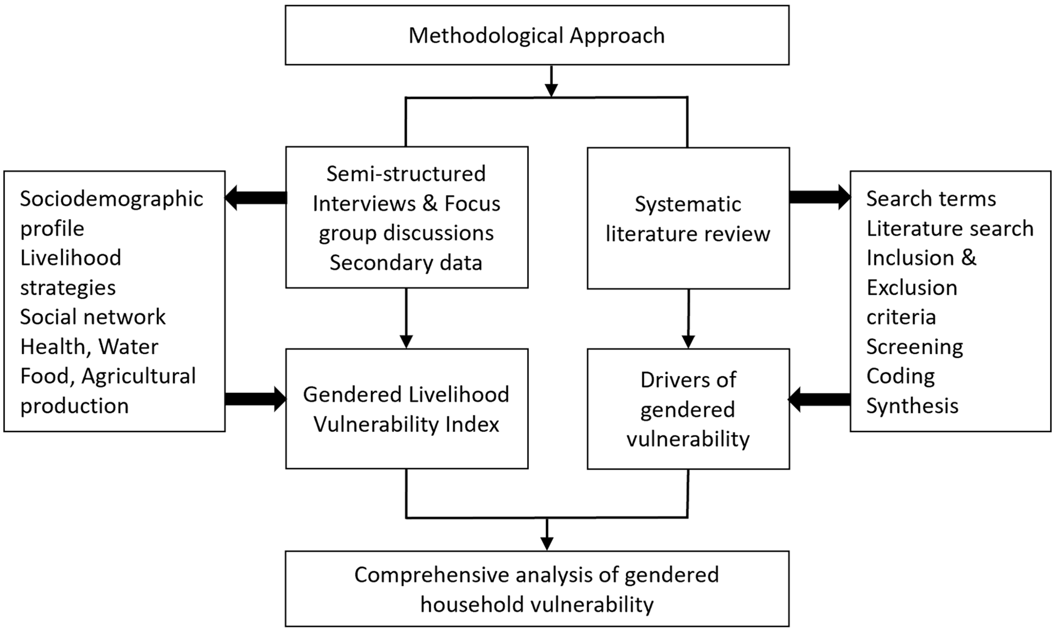

FIGURE 1
Methodological approach.

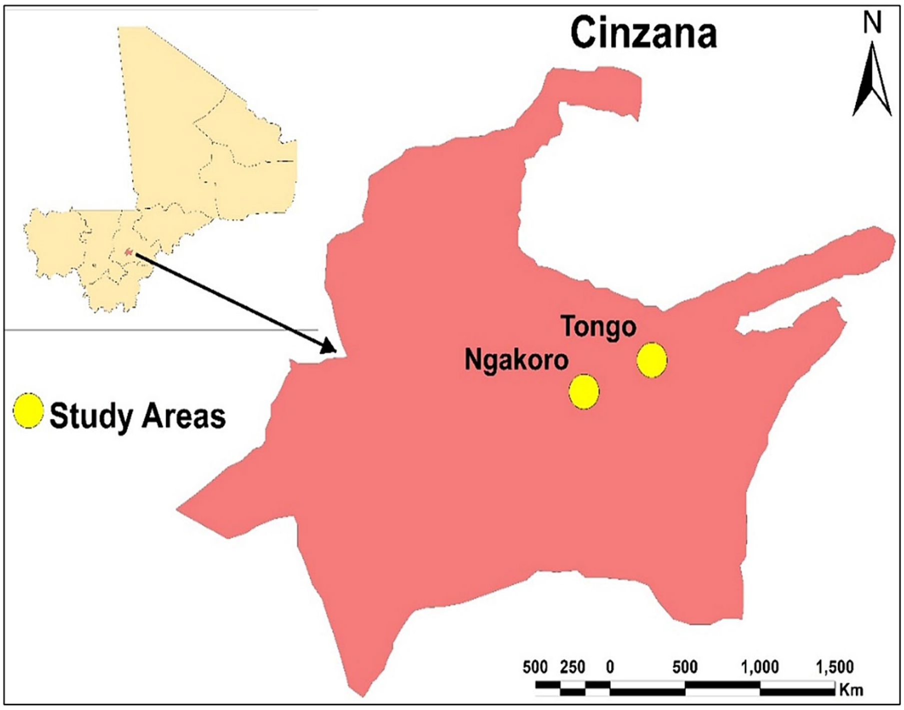

FIGURE 2
Location of the study area.

2.2 Livelihood vulnerability assessment

While acknowledging the diversity of framework, approaches, methods and tools for assessing vulnerability (Hinkel, 2011; Reed et al., 2013; Tonmoy et al., 2014; Vincent and Cull, 2014; Kok et al., 2016; Crane et al., 2017; Gerlitz et al., 2017; Ford et al., 2018; Estoque et al., 2023), we adapted the Livelihood Vulnerability Index (LVI; Hahn et al., 2009) to assess vulnerability to climate change of female and male headed households. Developed based on the Sustainable Livelihood (SL) framework, the LVI offers a pragmatic and flexible tool for vulnerability assessment and has been widely used in the literature (Hahn et al., 2009; Reed et al., 2013; Gerlitz et al., 2017; Segnon et al., 2021).

The LVI consists of seven major components—natural disasters and climate variability, the socio-demographic characteristics of households, livelihood strategies, social networks, current health, food and water resource characteristics—and provides an understanding of specific drivers of vulnerability to climate change and variability (Hahn et al., 2009). In light of the recent IPCC's transition from vulnerability-centered framework to risk-centered assessment framework, where vulnerability is conceptualized as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (Ishtiaque et al., 2022; Estoque et al., 2023), we modified the original LVI by excluding the component of natural disasters and climate variability from our vulnerability assessment. While hazard has long been analyzed as one of the dimensions of vulnerability, the new IPCC risk framework clearly incorporates hazard as a component of risk. We have excluded the component of natural disasters and climate variability from our assessment of vulnerability to reflect this recent development in the conceptualization of vulnerability. In addition, given that livelihoods in the study area are mainly linked to agriculture, we have added a component (agricultural production systems). Finally, we included seven major components including socio-demographic profile, livelihood strategies, social networks, health, food, water, and agricultural production systems. Each of the seven components of the LVI is composed of several indicators (Supplementary material 1).

We used a mixed methods approach combining quantitative data collected through semi-structured interviews and qualitative data from focus group discussions. We conducted semi-structured interviews with 233 household heads (180 male-headed households and 53 female-headed households) selected in the Cinzana CSV. Prior informed consents were obtained from the participants before the start of each interview. Participants were informed of the context and objectives of the study. The interviews lasted between 20 and 60 min and were conducted in the local language (Bambara), the most common language in the study area. The information collected included socio-demographic profiles, livelihood strategies, social relationships, health, food, water, and agricultural production system. Each of these sections reflects one of the main components of the LVI used in this study. In addition, we conducted four FGDs, two per village, to complement the data collected in the semi-structured interviews by probing respondents' perceptions of climate change and its impacts on their livelihoods. Each village, separate FGDs were held with men (10 participants in each village) and women (10 participants in each village). We used descriptive statistics to compute the LVI, based on the data generated from the semi-structured interviews, while content analysis was employed to analyze the information from the focus group discussions.

Before generating the LVI, data were normalized (Equation 1) as the sub-components were measured on different scales (e.g., percentage, indices, ratios, or count). The following equation was used for normalization:

$$\text{Index}_S = \frac{S - S_{\min}}{S_{\max} - S_{\min}} \tag{1}$$

Where S is the main subcomponent and $S_{\min}$ and $S_{\max}$ are the minimum and maximum sub-component values, respectively, for the entire sample. The balanced average weighting approach was used, which gives each sub-component equal importance. This approach is the most widely used in composite indicator assessments, which improves comparability (Hahn et al., 2009).

After normalizing the data, the sub-components by the gender of the household head were averaged to calculate the respective major components (Equation 2).

$$M_s = \frac{\sum_{i=1}^{n} index_{norm^i}}{n} \tag{2}$$

Where M_s represents the respective major component for each gender category, n is the number of sub-components, $index_{norm^i}$ represents the normalized values of the sub-components of the respective major component.

$$LVI = \frac{\sum_{i=1}^{n} w_{M_i} M_{di}}{\sum_{i=1}^{n} w_{M_i}} \tag{3}$$

Where LVI_{F_g} is the contributing factor (F) to the overall LVI (Equation 3) per gender of the household head g, Mdi is the major component for the gender of the household head g indexed by i, WMi is the weight of each major component, and n is the number of major components in each contributing factor. The LVI is scaled from 0 (least vulnerable) to 1 (most vulnerable).

2.3 Systematic scoping review

To better understand the drivers of gendered livelihood vulnerability, we complemented our case study with a systematic review of drivers of gendered vulnerability in Mali. We searched the relevant publications in English and French available up to 2023 in SCOPUS and Web of Science (WoS), two academic databases commonly used for systematic review. Using various keyword and search terms related to climate change, vulnerability, gender and Mali. We used synonyms and Boolean operators to capture comprehensive literature results (Supplementary material 2), we obtained 374 articles. After removing duplicates, we retrieved 153 articles. After screening of titles and abstracts for eligibility following inclusion and exclusion criteria (country of publication, type of literature, study design, and report results on the vulnerability component), we excluded 129 articles. The full text screening of the remaining publications retained 19 research

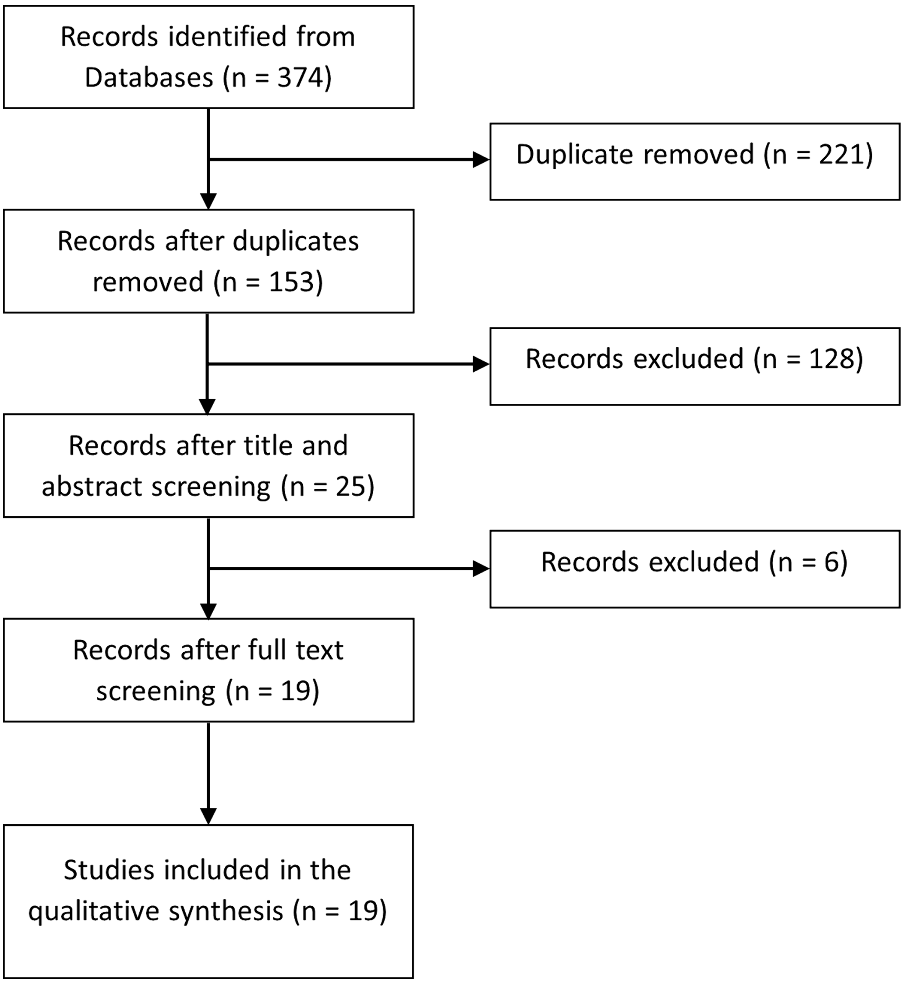

FIGURE 3
PRISMA diagram of the screening process.

articles (Figure 3) for the qualitative synthesis (Supplementary material 3). The relevant publications were coded for climate change impacts, vulnerability dimensions and gender-related vulnerability factors using Microsoft Excel. Data extracted were analyzed through content analysis.

3 Results

3.1 Gendered livelihood vulnerability to climate change

The LVI for female-headed households is 0.470, while the LVI for male-headed households is 0.432. This indicates that both types of households were vulnerable to climate change. However, female-headed households were more vulnerable than male-headed households (Table 1). Female-headed households were more vulnerable than male-headed households in terms of socio-demographic profile, social networks, livelihood opportunities, access to natural resources including water, and food and patterns agricultural production systems (Figure 4).

We found significant differences between the vulnerability indices of female-headed and male-headed households for the components of socio-demographic profile (0.672 and 0.627), livelihood strategies (0.570 and 0.531), and social network (0.506 and 0.406). The results indicate that female-headed households are more vulnerable than male-headed households for all three components. Majority of female-headed households had lower incomes, fewer crop and livestock adaptation practices, less diversified agriculture, and limited access to both formal and informal financial support, government support, and information and communication technology (ICT) tools compared to male-headed households. Moreover, female headed households had limited access to ICT tools such as radio (41.8%) and mobile phones (37.34%) compared to 15.1 and 13.19% of male headed households (Table 1).

Female-headed households were found to be more vulnerable to food insecurity (FI = 0.294) compared to male-headed households (FI = 0.278). A higher percentage of female-headed households (76.5%) relied solely on farm production as their primary source of food compared to male-headed households (54.9%). Approximately 20% of all households were food insufficient year-round with an average of 2 months per year. About 30.7% of households headed by men had storage facilities for harvested agricultural products, compared to 17.7% of households headed by women. The index for water showed negligible disparities (WI = 0.372 for female-headed

TABLE 1 Livelihood vulnerability index for female- and male-headed households.

Major components	Indicators	Major components values	
		Female-headed households	Male-headed households
Socio-demographic profile	Dependency ratio	0.172	0.183
	School attendance	0.843	0.886
	Household income level	1.000	0.813
	SDI	**0.672**	**0.627**
Livelihood strategies	Outside employment	0.824	0.824
	Dependency on agriculture for income	0.804	0.852
	Agricultural diversity index	0.41	0.35
	Crops-based adaptation index	0.111	0.089
	Livestock-based adaptation index	0.430	0.302
	Receiving remittances	0.843	0.769
	LSI	**0.570**	**0.531**
Social networks	Household assistance	0.314	0.293
	Household borrowing/loaning	0.484	0.375
	Government Assistance	0.922	0.907
	Cooperative membership	0.451	0.357
	Household ownership of a radio	0.412	0.374
	Household head mobile phone ownership	0.451	0.132
	SNI	**0.506**	**0.406**
Health	Household-Health Center distance	0.316	0.333
	Illness of a household member	0.275	0.324
	Malaria exposure and prevention index	0.895	0.894
	HI	**0.495**	**0.517**
Food	Agriculture as a main source of food	0.765	0.549
	Food self-sufficiency	0.196	0.209
	Crop harvest saving	0.176	0.307
	Crop seeds saving	0.039	0.045
	FI	**0.294**	**0.278**
Water	Water conflict	0.216	0.148
	Natural source of water usage	1.000	1.000
	Household-Water source distance	0.233	0.235
	Water availability at their main source all year round	0.039	0.099
	WI	**0.372**	**0.371**
Agricultural production system	Crop diversity index	0.463	0.268
	Livestock diversity index	0.394	0.242
	Land ownership	0.079	0.173
	Livestock feeding	0.524	0.528
	Farm Equipment	0.253	0.162
	APSI	**0.343**	**0.275**
Overall LVI		**0.465**	**0.429**

households and WI = 0.371 for male-headed households). However, water-related conflicts were reported by a higher proportion of female-headed households (21.6%) than male-headed households (14.84%). Both male and female-headed households heavily rely on water from hand-dug wells or rainwater for domestic activities. In terms of agricultural production systems, female-headed households were more vulnerable (0.343) than male-headed households (0.275) due to their lack of land ownership. On average, male-headed households own more than twice as much agricultural land as female-headed households (11.2 ha compared to 5.1 ha). Female-headed

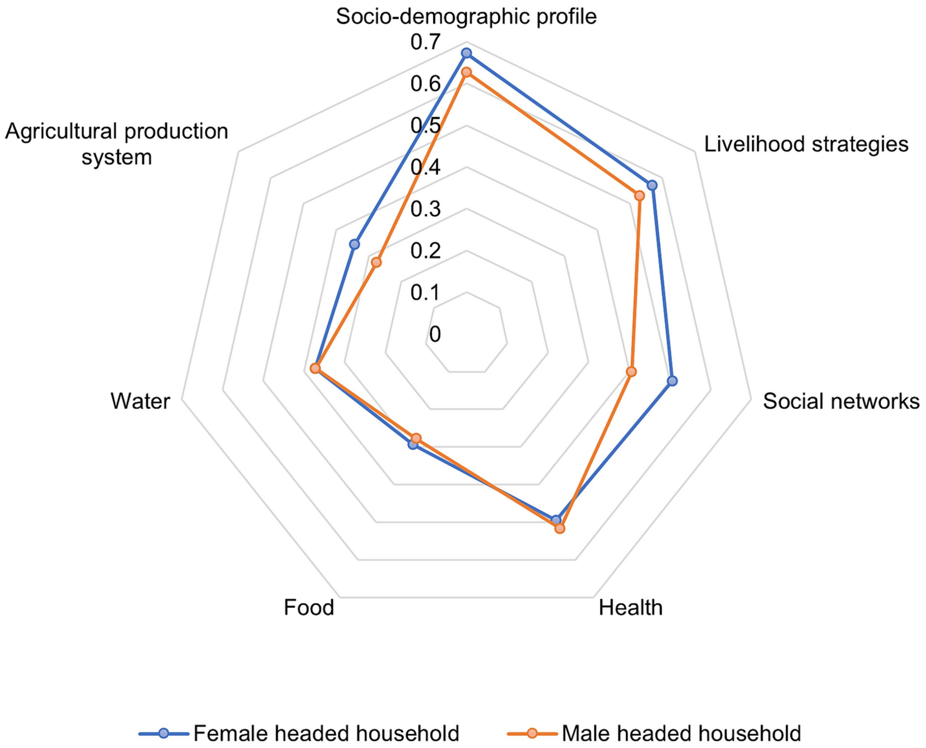

FIGURE 4
Vulnerability spider diagram of the major components of the LVI for female- and male-headed households.

households own fewer basic farm tools, including draft animals, than male-headed households, which is the second reason for the inequality in agricultural productivity.

3.2 Drivers of gendered livelihood vulnerability

Based on qualitative content analysis the relevant papers (Figure 3), we identified three categories of factors that drive gendered vulnerability in Mali: (i) socio-cultural roles, rules and norms assigned to and restricting women livelihoods, and women's limited access to (ii) productive resources, and to (iii) adaptation technologies.

3.2.1 Socio-cultural norms affecting women livelihoods

In Mali, women are responsible for most household tasks, including cooking, collecting water and fuel wood, and caretaking (Djoudi and Brockhaus, 2011; Becerra et al., 2016; Rogé et al., 2017; Carr and Onzere, 2018; Rivers III et al., 2018; Sanga et al., 2021; Wood et al., 2021). Women are already socially burdened with the responsibility of managing household food and water resources (Djoudi and Brockhaus, 2011; Lecoutere et al., 2023). In times of drought and water scarcity, they must walk long distances to fetch water (Wood et al., 2021). In the northern part of Mali, where women involved in livestock production already face high climate risks (Lecoutere et al., 2023), as men increasingly migrate to cities to cope with the impacts of climate change, traditionally male activities (such as small ruminant herding) are being added to women's workload (Djoudi and Brockhaus, 2011). Similarly in southern part of the country, women are increasingly taking more agricultural tasks, including those traditionally performed by men, in addition to household chores as men increasingly migrate (Rogé et al., 2017; Carr and Onzere, 2018; Rivers III et al., 2018; Sanga et al., 2021; Segnon et al., 2021; Wood et al., 2021). While migration can be an important livelihood diversification and risk management strategy for households, including climatic risks, under certain circumstances, migration can increase vulnerability and reduce adaptive capacity for those left behind, especially women (Maharjan et al., 2020; Segnon et al., 2022; Singh et al., 2022). Although changes in forest biomass and biodiversity have the potential to increase fuelwood availability and provide social and economic opportunities for vulnerable groups, especially women and youth through the creation of rural wood fuel markets, limited access to natural resources, and unequal power structures and relationships between women and men at household and community levels can limit women's ability to exploit the potential of forest resources (Djoudi and Brockhaus, 2011; Sanogo et al., 2017; Gautier et al., 2020).

3.2.2 Women have limited access and control over resources

A substantial body of literature suggests that there are gender inequalities in access to and control over productive resources in Mali, including land, water, equipment, agricultural inputs, climate information, and extension services (Djoudi and Brockhaus, 2011; Rogé et al., 2017; Carr and Onzere, 2018; Rivers III et al., 2018; Waldman and Richardson, 2018; Diarra et al., 2021; Sanga et al., 2021; Wood et al., 2021). Often, men hold the power to decide about agricultural strategies that could help in mitigating food production challenges in the face of climate stressors (Carr and Onzere, 2018;

Wood et al., 2021). On the other hand, women have limited opportunities to make independent decisions about rainfed agriculture, and may cultivate particular crops or varieties in responses to social challenges such as constraints over land tenure, rather than the challenges posed by climate change (Wood et al., 2021).

Access to extension and training programs, labor opportunities, financial resources, productive land, and animal manure is restricted for women (Djoudi and Brockhaus, 2011; Diarra et al., 2021; Sanga et al., 2021; Singbo et al., 2021). As results, male farmers are more likely to receive climate information services, including early warnings, compared to female farmers (Sanogo et al., 2017). Gendered differences in access to climate information may be attributed to variations in social distance to central nodes, or differences in the transmission of information between central nodes and networks of men and women due to varying degrees of frictions (Beaman and Dillon, 2018). Furthermore, women have limited access to formal groups and networks, both within and outside communities (Huet et al., 2020). In addition, the gendered social norms have contributed to greater ownership of draft animals and farm equipment among men compared to women (Carr and Onzere, 2018; Huet et al., 2020; Diarra et al., 2021). Male farmers who possess these assets can swiftly react to climate change and variability, while female farmers without them have to wait until they can borrow or lease the necessary resources before planting (Carr and Onzere, 2018). These structural disadvantages further widened the gender productivity gap (Singbo et al., 2021).

3.2.3 Women limited access to adaptation technologies

There is a differential capacity to use adaptation technologies between male and female farmers, with women having limited adaptative capacity (Djoudi and Brockhaus, 2011; Carr and Onzere, 2018; Waldman and Richardson, 2018; Sanga et al., 2021; Wood et al., 2021). Women farmers are reported to be more likely to plant short-duration crop varieties to cope with late planting and labor unavailability (Rogé et al., 2017; Diarra et al., 2021; Sanga et al., 2021). Women's ability to adapt to drought events through the use of irrigation infrastructure is limited (Rogé et al., 2017). Furthermore, women have lower adoption rates of climate-smart agriculture (CSA) technologies and other agronomic practices than men (Christie et al., 2015; Sanogo et al., 2023). In addition, women have not extensively embraced improved agricultural technologies such as improved crop varieties, soil and water conservation practices due to their high costs, skill requirements, and labor (Diarra et al., 2021). On the other hand, membership in microfinance groups can potentially increase their ability to diversify production and access cutting-edge technologies such as improved crop varieties (Sanga et al., 2021). A promising solution to overcoming gender-related barriers to resource sharing, including customary land, involves promoting perennial crops. The cultivation of such crops requires less labor, saves seeds, and enhances food security at the household level over time and space (Rogé et al., 2017; Waldman and Richardson, 2018).

4 Discussion and conclusion

In this paper, we illustrated how socio-cultural roles, rules and norms assigned to and restricting women livelihoods, and women's limited access to productive resources, and to adaptation technologies result in and reinforce vulnerability of women-headed households. We showed how gender roles and responsibilities, as well as inequalities in access to and power over productive resources, embedded in the local gender context, widen vulnerability gaps between female- and male-headed households. Addressing these vulnerability gaps therefore requires addressing the root causes of gender inequalities. We discussed pathways to reduce women's vulnerability to climate change and variability in Mali.

4.1 Making climate information and advisory services gender-responsive

Climate information and advisory services are crucial in enabling farmers to manage climate-related risks and to better anticipate and prepare for climate hazards. Yet women-headed households in Mali face greater difficulties than men in accessing and using climate information. Unless women are intentionally involved in the design and development of agricultural technologies, specifically climate information systems, there is a risk of them being excluded from reaping the benefits (Mapedza et al., 2023). Gender-sensitive extension and advisory services need to be designed and implemented to effectively address the specific needs, interests and concerns of women and men. Gender-sensitive extension and advisory services have the potential to consider the socio-cultural realities of communities and the extension organizations implementing them, enabling gender-equitable and empowering agricultural extension (Ogato et al., 2009; Jafry and Sulaiman, 2013). Furthermore, gender gaps in access to digital tools and devices have increased the vulnerability of female-headed households to climate change and variability (Huyer et al., 2024). Women-headed households have less access to ICT tools such as radios and telephones (Zougmoré and Partey, 2022). In the absence of these tools, they face heightened potential for losing significant information, including climate information and early warnings (Partey et al., 2018; Zougmoré and Partey, 2022). Outreach approaches based on ICTs, including radio, television, mobile phones and social media, need to be integrated into mechanisms to increase women's access to climate information and technologies (Heywood and Ivey, 2022).

4.2 Promoting gender-smart land reforms

While climate-smart agriculture has potential to reduce vulnerability to climate change through a wide range of gender-responsive technologies and practices, barriers related to land access and ownership prevent women from fully benefiting from CSA technologies (Totin et al., 2018, 2021; Roy et al., 2022; Huyer et al., 2024). As illustrated in this study, women in Mali have limited access to land, yet equitable access to land plays an important role in addressing gender inequality and women's vulnerability to climate change (Nnoko-Mewanu et al., 2021). Land reforms can promote socially efficient land allocation and enable women to adopt CSA on a large scale (Rampa et al., 2020). Additionally, land reform is crucial to sustain the livelihoods of female-headed households (Totin et al., 2021).

4.3 Empowering women through income generating activities

Inequalities in income and access to finance widen the vulnerability gap between female- and male-headed households (Balikoowa et al., 2019; Basiru et al., 2022; Huyer et al., 2024). Enhancing financial capacity is crucial for effectively enhancing adaptive capacity of female-headed households to respond to climate change and variability (Witinok-Huber et al., 2021). To increase female-headed household income, there is a need for agricultural diversification and diversifying livelihood strategies (Michler and Josephson, 2017; Bellon et al., 2020; Mulwa and Visser, 2020; Roy et al., 2022; Magesa et al., 2023). Indeed, female-headed households have a lower agriculture diversity index and fewer livelihood strategies to cope with climate change and variability compared to their male-headed counterparts. Several CSA technologies, climate-resilient soil and water conservation, rainwater harvesting, crop diversification, and climate information are available as potential adaptation options (Roy et al., 2022; Segnon et al., 2022). However, implementing these strategies would require a high investment on the farm (Belay et al., 2017; Ogada et al., 2020). Targeting programs that support women and households headed by females via income-generating activities can increase their earnings and decrease their susceptibility.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements. The studies were conducted in accordance with the local legislation and institutional requirements. The aim of the study was clearly explained to the administrative authorities at district and village level. Permission was obtained from the chief of each village before conducting the focus group discussion and the survey. Participants were included in the survey after obtaining their verbal prior informed consent. Participants had the opportunity to stop participating in the research at any time of their choice.

Author contributions

AS: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Investigation. MM: Conceptualization, Data curation, Formal analysis, Writing – original draft. EO: Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. SP: Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing – original draft. PH: Data curation, Resources, Supervision, Validation, Writing – review & editing. RZ: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This paper was developed as part of the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) project, funded by the International Development Association (IDA) of the World Bank. The data supporting the analysis was collected with the support of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from the CGIAR Fund Donors and through several bilateral funding agreements (the CGIAR Fund Council, Australia-ACIAR, European Union, International Fund for Agricultural Development-IFAD, Ireland, New Zealand, Netherlands, Switzerland, USAID, United Kingdom, and Thailand). For details, please visit https://ccafs.cgiar.org/donors.

Acknowledgments

The authors are grateful to all the farmers interviewed during this work for their time and willingness to share their knowledge. We gratefully acknowledge the support and facilitation of Siaka Dembele during the data collection.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2024.1418015/full#supplementary-material

References

Ahmed, A., Lawson, E. T., Mensah, A., Gordon, C., and Padgham, J. (2016). Adaptation to climate change or non-climatic stressors in semi-arid regions? Evidence of gender differentiation in three agrarian districts of Ghana. *Environ. Dev.* 20, 45–58. doi: 10.1016/j.envdev.2016.08.002

Awiti, A. O. (2022). Climate change and gender in Africa: a review of impact and gender-responsive solutions. *Front. Clim.* 4:895950. doi: 10.3389/fclim.2022.895950

Balikoowa, K., Nabanoga, G., Tumusiime, D. M., and Mbogga, M. S. (2019). Gender differentiated vulnerability to climate change in eastern Uganda. *Clim. Dev.* 11, 839–849. doi: 10.1080/17565529.2019.1580555

Basiru, A. O., Oladoye, A. O., Adekoya, O. O., Akomolede, L. A., Oeba, V. O., Awodutire, O. O., et al. (2022). Livelihood vulnerability index: gender dimension to climate change and variability in REDD + piloted sites, Cross River state, Nigeria. *Landscape* 11:1240. doi: 10.3390/land11081240

Beaman, L., and Dillon, A. (2018). Diffusion of agricultural information within social networks: evidence on gender inequalities from Mali. *J. Dev. Econ.* 133, 147–161. doi: 10.1016/j.jdeveco.2018.01.009

Becerra, S., Saqalli, M., Gangneron, F., and Dia, A. H. (2016). Everyday vulnerabilities and "social dispositions" in the Malian Sahel, an indication for evaluating future adaptability to water crises? *Reg. Environ. Chang.* 16, 1253–1265. doi: 10.1007/s10113-015-0845-7

Belay, A., Recha, J. W., Woldeamanuel, T., and Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the central Rift Valley of Ethiopia. *Agric. Food Secur.* 6:24. doi: 10.1186/s40066-017-0100-1

Bellon, M. R., Kotu, B. H., Azzarri, C., and Caracciolo, F. (2020). To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. *World Dev.* 125:104682. doi: 10.1016/j.worlddev.2019.104682

Bezner Kerr, R., Hasegawa, T., Lasco, R., Bhatt, I., Deryng, D., Farrell, A., et al. (2022a). "Food, fibre, and other ecosystem products" in Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. eds. H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck and A. Alegríaet al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press), 713–906.

Bezner Kerr, R., Naess, L. O., Allen-O'Neil, B., Totin, E., Nyantakyi-Frimpong, H., Risvoll, C., et al. (2022b). Interplays between changing biophysical and social dynamics under climate change: implications for limits to sustainable adaptation in food systems. *Glob. Chang. Biol.* 28, 3580–3604. doi: 10.1111/gcb.16124

Call, M., and Sellers, S. (2019). How does gendered vulnerability shape the adoption and impact of sustainable livelihood interventions in an era of global climate change? *Environ. Res. Lett.* 14:083005. doi: 10.1088/1748-9326/ab2f57

Carr, T. W., Mkuhlani, S., Segnon, A. C., Ali, Z., Zougmoré, R., Dangour, A. D., et al. (2022). Climate change impacts and adaptation strategies for crops in West Africa: a systematic review. *Environ. Res. Lett.* 17:053001. doi: 10.1088/1748-9326/ac61c8

Carr, E. R., and Onzere, S. N. (2018). Really effective (for 15% of the men): lessons in understanding and addressing user needs in climate services from Mali. *Clim. Risk Manag.* 22, 82–95. doi: 10.1016/j.crm.2017.03.002

Christie, M. E., Van Houweling, E., and Zseleczky, L. (2015). Mapping gendered pest management knowledge, practices, and pesticide exposure pathways in Ghana and Mali. *Agric. Hum. Values* 32, 761–775. doi: 10.1007/s10460-015-9590-2

Crane, T. A., Delaney, A., Tamás, P. A., Chesterman, S., and Ericksen, P. (2017). A systematic review of local vulnerability to climate change in developing country agriculture. *Wiley Interdiscip. Rev. Clim. Chang.* 8:e464. doi: 10.1002/wcc.464

Diarra, F. B., Ouédraogo, M., Zougmoré, R. B., Partey, S. T., Houessionon, P., and Mensah, A. (2021). Are perception and adaptation to climate variability and change of cowpea growers in Mali gender differentiated? *Environ. Dev. Sustain.* 23, 13854–13870. doi: 10.1007/s10668-021-01242-1

Djoudi, H., and Brockhaus, M. (2011). Is adaptation to climate change gender neutral? Lessons from communities dependent on livestock and forests in northern Mali. *Int. For. Rev.* 13, 123–135. doi: 10.1505/146554811797406606

Elias, M., Zaremba, H., Tavenner, K., Ragasa, C., Paez Valencia, A. M., Choudhury, A., et al. (2024). Towards gender equality in forestry, livestock, fisheries and aquaculture. *Glob. Food Secur.* 41:100761. doi: 10.1016/j.gfs.2024.100761

Estoque, R. C., Ishtiaque, A., Parajuli, J., Athukorala, D., Rabby, Y. W., and Ooba, M. (2023). Has the IPCC's revised vulnerability concept been well adopted? *Ambio* 52, 376–389. doi: 10.1007/s13280-022-01806-z

Ford, J. D., Pearce, T., McDowell, G., Berrang-Ford, L., Sayles, J. S., and Belfer, E. (2018). Vulnerability and its discontents: the past, present, and future of climate change vulnerability research. *Clim. Chang.* 151, 189–203. doi: 10.1007/s10584-018-2304-1

Gautier, D., Dessard, H., Djoudi, H., Gazull, L., and Soumaré, M. (2020). Savannah gendered transition: how woodlands dynamics and changes in fuelwood delivery influence economic autonomy in Mali. *Environ. Dev. Sustain.* 22, 3097–3117. doi: 10.1007/s10668-019-00336-1

Gerlitz, J.-Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S., and Jha, S. K. (2017). The multidimensional livelihood vulnerability index – an instrument to measure livelihood vulnerability to change in the Hindu Kush Himalayas. *Clim. Dev.* 9, 124–140. doi: 10.1080/17565529.2016.1145099

Gutiérrez, J. M., Jones, R. G., Narisma, G. T., Alves, L. M., Amjad, M., Gorodetskaya, I. V., et al. (2021). "Atlas" in Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. eds. V. Masson-Delmotte, P. Zhai, A. Pirani, S. Connors, C. Péan and S. Bergeret al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press), 1927–2058.

Hahn, M. B., Riederer, A. M., and Foster, S. O. (2009). The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change—a case study in Mozambique. *Glob. Environ. Chang.* 19, 74–88. doi: 10.1016/j.gloenvcha.2008.11.002

Heywood, E., and Ivey, B. (2022). Radio as an empowering environment: how does radio broadcasting in Mali represent women's "web of relations"? *Fem. Media Stud.* 22, 1050–1066. doi: 10.1080/14680777.2021.1877768

Hinkel, J. (2011). "Indicators of vulnerability and adaptive capacity": towards a clarification of the science–policy interface. *Glob. Environ. Chang.* 21, 198–208. doi: 10.1016/j.gloenvcha.2010.08.002

Huet, E. K., Adam, M., Giller, K. E., and Descheemaeker, K. (2020). Diversity in perception and management of farming risks in southern Mali. *Agric. Syst.* 184:102905. doi: 10.1016/j.agsy.2020.102905

Huyer, S., Loboguerrero, A. M., Chanana, N., and Spellman, O. (2024). From gender gaps to gender-transformative climate-smart agriculture. *Curr. Opin. Environ. Sustain.* 67:101415. doi: 10.1016/j.cosust.2024.101415

Huyer, S., and Partey, S. (2020). Weathering the storm or storming the norms? Moving gender equality forward in climate-resilient agriculture. *Clim. Chang.* 158, 1–12. doi: 10.1007/s10584-019-02612-5

Huyer, S., Simelton, E., Chanana, N., Mulema, A. A., and Marty, E. (2021). Expanding opportunities: a framework for gender and socially-inclusive climate resilient agriculture. *Front. Clim.* 3:718240. doi: 10.3389/fclim.2021.718240

IPCC (2022). "Annex II: glossary" in Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. eds. H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck and A. Alegríaet al. (Cambridge, UK and New York, NY, USA: Cambridge University Press), 2897–2930.

Ishtiaque, A., Estoque, R. C., Eakin, H., Parajuli, J., and Rabby, Y. W. (2022). IPCC's current conceptualization of 'vulnerability' needs more clarification for climate change vulnerability assessments. *J. Environ. Manag.* 303:114246. doi: 10.1016/j.jenvman.2021.114246

Jafry, T., and Sulaiman, V. R. (2013). Gender-sensitive approaches to extension Programme design. *J. Agric. Educ. Ext.* 19, 469–485. doi: 10.1080/1389224X.2013.817345

Khoza, S., van Niekerk, D., and Nemakonde, L. D. (2022). Gendered vulnerability and inequality: understanding drivers of climate-smart agriculture dis- and nonadoption among smallholder farmers in Malawi and Zambia. *Ecol. Soc.* 27:19. doi: 10.5751/ES-13480-270419

Kok, M., Lüdeke, M., Lucas, P., Sterzel, T., Walther, C., Janssen, P., et al. (2016). A new method for analysing socio-ecological patterns of vulnerability. *Reg. Environ. Chang.* 16, 229–243. doi: 10.1007/s10113-014-0746-1

Lecoutere, E., Mishra, A., Singaraju, N., Koo, J., Azzarri, C., Chanana, N., et al. (2023). Where women in Agri-food systems are at highest climate risk: a methodology for mapping climate–agriculture–gender inequality hotspots. *Front. Sustain. Food Syst.* 7:1197809. doi: 10.3389/fsufs.2023.1197809

Magesa, B. A., Mohan, G., Matsuda, H., Melts, I., Kefi, M., and Fukushi, K. (2023). Understanding the farmers' choices and adoption of adaptation strategies, and plans to climate change impact in Africa: a systematic review. *Clim. Serv.* 30:100362. doi: 10.1016/j.cliser.2023.100362

Maharjan, A., de Campos, R. S., Singh, C., Das, S., Srinivas, A., Bhuiyan, M. R. A., et al. (2020). Migration and household adaptation in climate-sensitive hotspots in South Asia. *Curr. Clim. Chang. Rep.* 6, 1–16. doi: 10.1007/s40641-020-00153-z

Mapedza, E., Huyer, S., Chanana, N., Rose, A., Jacobs-Mata, I., Mudege, N. N., et al. (2023). Framework for incorporating gender equality and social inclusion (GESI) elements in climate information services (CIS). *Sustain. For.* 15:190. doi: 10.3390/su15010190

Michler, J. D., and Josephson, A. L. (2017). To specialize or diversify: agricultural diversity and poverty dynamics in Ethiopia. *World Dev.* 89, 214–226. doi: 10.1016/j.worlddev.2016.08.011

Mulwa, C. K., and Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Dev.* 129:104906. doi: 10.1016/j.worlddev.2020.104906

Nnoko-Mewanu, J., Téllez-Chávez, L., and Rall, K. (2021). Protect rights and advance gender equality to mitigate climate change. *Nat. Clim. Chang.* 11, 368–370. doi: 10.1038/s41558-021-01043-4

Nyantakyi-Frimpong, H., and Bezner-Kerr, R. (2015). The relative importance of climate change in the context of multiple stressors in semi-arid Ghana. *Glob. Environ. Chang.* 32, 40–56. doi: 10.1016/j.gloenvcha.2015.03.003

Ogada, M. J., Rao, E. J. O., Radeny, M., Recha, J. W., and Solomon, D. (2020). Climate-smart agriculture, household income and asset accumulation among smallholder farmers in the Nyando basin of Kenya. *World Dev. Perspect.* 18:100203. doi: 10.1016/j.wdp.2020.100203

Ogato, G. S., Boon, E. K., and Subramani, J. (2009). Improving access to productive resources and agricultural services through gender empowerment: a case study of three rural communities in Ambo District, Ethiopia. *J. Hum. Ecol.* 27, 85–100. doi: 10.1080/09709274.2009.11906196

Partey, S. T., Dakorah, A. D., Zougmoré, R. B., Ouédraogo, M., Nyasimi, M., Nikoi, G. K., et al. (2018). Gender and climate risk management: evidence of climate information use in Ghana. *Clim. Chang.* 158, 61–75. doi: 10.1007/s10584-018-2239-6

Rampa, A., Gadanakis, Y., and Rose, G. (2020). Land reform in the era of global warming—can land reforms help agriculture be climate-smart? *Landscape* 9:471. doi: 10.3390/land9120471

Räsänen, A., Juhola, S., Nygren, A., Käkönen, M., Kallio, M., Monge Monge, A., et al. (2016). Climate change, multiple stressors and human vulnerability: a systematic review. *Reg. Environ. Chang.* 16, 2291–2302. doi: 10.1007/s10113-016-0974-7

Reed, M. S., Podesta, G., Fazey, I., Geeson, N., Hessel, R., Hubacek, K., et al. (2013). Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options. *Ecol. Econ.* 94, 66–77. doi: 10.1016/j.ecolecon.2013.07.007

Rivers, L. III, Sanga, U., Sidibe, A., Wood, A., Paudel, R., Marquart-Pyatt, S. T., et al. (2018). Mental models of food security in rural Mali. *Environ. Syst. Decis.* 38, 33–51. doi: 10.1007/s10669-017-9669-y

Rogé, P., Diarisso, T., Diallo, F., Boiré, Y., Goïta, D., Peter, B., et al. (2017). Perennial grain crops in the west Soudanian savanna of Mali: perspectives from agroecology and gendered spaces. *Int. J. Agric. Sustain.* 15, 555–574. doi: 10.1080/14735903.2017.1372850

Roy, J., Prakash, A., Some, S., Singh, C., Bezner Kerr, R., Caretta, M. A., et al. (2022). Synergies and trade-offs between climate change adaptation options and gender equality: a review of the global literature. *Humanit. Soc. Sci. Commun.* 9:251. doi: 10.1057/s41599-022-01266-6

Sanga, U., Sidibé, A., and Olabisi, L. S. (2021). Dynamic pathways of barriers and opportunities for food security and climate adaptation in southern Mali. *World Dev.* 148:105663. doi: 10.1016/j.worlddev.2021.105663

Sanogo, K., Binam, J., Bayala, J., Villamor, G. B., Kalinganire, A., and Dodiomon, S. (2017). Farmers' perceptions of climate change impacts on ecosystem services delivery of parklands in southern Mali. *Agrofor. Syst.* 91, 345–361. doi: 10.1007/s10457-016-9933-z

Sanogo, K., Touré, I., Arinloye, D.-D. A. A., Dossou-Yovo, E. R., and Bayala, J. (2023). Factors affecting the adoption of climate-smart agriculture technologies in rice farming systems in Mali, West Africa. *Smart Agric. Technol* 5:100283. doi: 10.1016/j.atech.2023.100283

Schmitt Olabisi, L., Liverpool-Tasie, S., Rivers, L., Ligmann-Zielinska, A., Du, J., Denny, R., et al. (2018). Using participatory modeling processes to identify sources of climate risk in West Africa. *Environ. Syst. Decis.* 38, 23–32. doi: 10.1007/s10669-017-9653-6

Segnon, A. C. (2019). Exploring agrobiodiversity-based climate change adaptation in semi-arid areas of West Africa: A case study in Mali. Accra: University of Ghana.

Segnon, A. C., Totin, E., Zougmoré, R. B., Lokossou, J. C., Thompson-Hall, M., Ofori, B. O., et al. (2021). Differential household vulnerability to climatic and non-climatic stressors in semi-arid areas of Mali, West Africa. *Clim. Dev.* 13, 697–712. doi: 10.1080/17565529.2020.1855097

Segnon, A. C., Zougmoré, R. B., Green, R., Ali, Z., Carr, T. W., Houessionon, P., et al. (2022). Climate change adaptation options to inform planning of agriculture and food systems in the Gambia: a systematic approach for stocktaking. *Front. Sustain. Food Syst.* 6:834867. doi: 10.3389/fsufs.2022.834867

Singbo, A., Njuguna-Mungai, E., Yila, J. O., Sissoko, K., and Tabo, R. (2021). Examining the gender productivity gap among farm households in Mali. *J. Afr. Econ.* 30, 251–284. doi: 10.1093/jae/ejaa008

Singh, C., Iyer, S., New, M. G., Few, R., Kuchimanchi, B., Segnon, A. C., et al. (2022). Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Clim. Dev.* 14, 650–664. doi: 10.1080/17565529.2021.1964937

Tantoh, H. B., McKay, T. T. J. M., Donkor, F. E., and Simatele, M. D. (2021). Gender roles, implications for water, land, and food security in a changing climate: a systematic review. *Front. Sustain. Food Syst.* 5:707835. doi: 10.3389/fsufs.2021.707835

Tonmoy, F. N., El-Zein, A., and Hinkel, J. (2014). Assessment of vulnerability to climate change using indicators: a meta-analysis of the literature. *Wiley Interdiscip. Rev. Clim. Chang.* 5, 775–792. doi: 10.1002/wcc.314

Totin, E., Segnon, A. C., Roncoli, C., Thompson-Hall, M., Sidibé, A., and Carr, E. R. (2021). Property rights and wrongs: land reforms for sustainable food production in rural Mali. *Land Use Policy* 109:105610. doi: 10.1016/j.landusepol.2021.105610

Totin, E., Segnon, A. C., Schut, M., Affognon, H., Zougmoré, R. B., Rosenstock, T., et al. (2018). Institutional perspectives of climate-smart agriculture: a systematic literature review. *Sustain. For.* 10:1990. doi: 10.3390/su10061990

Trisos, C. H., Adelekan, I., Totin, E., Ayanlade, A., Efitre, J., and Gemeda, A., et al. (2022). "Africa," in Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change, eds. H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck and A. Alegríaet al. (Cambridge, United Kingdom and New York, NY, USA,: Cambridge University Press).

Vincent, K., and Cull, T. (2014). Using indicators to assess climate change vulnerabilities: are there lessons to learn for emerging loss and damage debates? Geogr. *Compass* 8, 1–12. doi: 10.1111/gec3.12105

Waldman, K. B., and Richardson, R. B. (2018). Confronting tradeoffs between agricultural ecosystem services and adaptation to climate change in Mali. *Ecol. Econ.* 150, 184–193. doi: 10.1016/j.ecolecon.2018.04.003

Witinok-Huber, R., Radil, S., Sarathchandra, D., and Nyaplue-Daywhea, C. (2021). Gender, place, and agricultural extension: a mixed-methods approach to understand farmer needs in Liberia. *J. Agric. Educ. Ext.* 27, 553–572. doi: 10.1080/1389224X.2021.1880453

Wood, A. L., Rivers, L., Sidibé, A., and Ligmann-Zielinska, A. (2021). Decision-making capacity to address climate-induced food insecurity within women-led groups in southern Mali. *Clim. Chang.* 164:30. doi: 10.1007/s10584-021-03003-5

Zougmoré, R. B., and Partey, S. T. (2022). Gender perspectives of ICT utilization in agriculture and climate response in West Africa: a review. *Sustain. For.* 14:12240. doi: 10.3390/su141912240

Zougmoré, R., Segnon, A. C., and Thornton, P. (2023). Harnessing indigenous knowledge and practices for effective adaptation in the Sahel. *Curr. Opin. Environ. Sustain.* 65:101389. doi: 10.1016/j.cosust.2023.101389