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A qualitative comparative analysis of women's agency and adaptive capacity in climate change hotspots in Asia and Africa

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There is growing concern about sustainable and equitable adaptation in climate change hotspots, commonly understood as locations that concentrate high climatic variability, societal vulnerability and negative impacts on livelihood systems. Emphasizing gender within these debates highlights how demographic, socioeconomic and agro-ecological contexts mediate the experiences and outcomes of climate change. Drawing on data from 25 qualitative case studies across three hotspots in Africa and Asia, analysed using qualitative comparative analysis, we show how and in what ways women's agency, or the ability to make meaningful choices and strategic decisions, contributes to adaptation responses. We find that environmental stress is a key depressor of women's agency even when household structures and social norms are supportive or legal entitlements are available. These findings have implications for the effective implementation of multilateral agreements such as the United Nations Framework Convention on Climate Change, the Sendai Framework on Disaster Risk Reduction and the Sustainable Development Goals.

Sustainable, equitable and effective adaptation is critical in climate change hotspots, locations where climatic shifts, social structures and livelihood sensitivity converge to exacerbate vulnerability[1,2]. Entrenched social structures create power relations that shape women's and men's experiences of vulnerability through access to resources, divisions of work, and cultural norms around mobility and decision-making, all of which determine adaptive capacity[3–15]. Involving trade-offs at every level[6,16–19], these contextual factors not only shape vulnerabilities but also create possibilities for adaptation[20,21].

When examining gendered vulnerability and the way in which it is manifest in unequal patriarchal systems, women's agency has emerged as key to realizing adaptive capacity, but remains understudied[5]. Drawing on feminist arguments to move beyond simplistic framings of actors in terms of active or passive, victims or perpetrators[22–24], we conceptualize agency as the ability to make meaningful choices and strategic decisions[25]. It can take multiple forms, from bargaining and negotiation to subversion and resistance[21], varying across institutional sites and scales, and drawing differentially on available material or social resources[25]. Institutions, ranging from the micro (household) and meso (community) level to the more macro levels of markets and states[26], interact and intersect with each other, often intensifying or reproducing inequalities. The rules and norms they establish can be formal or informal, complementary or competing[27], giving specific meaning to particular activities, resources and relationships. In the context of climate action, while some research explores the role of social capital, especially women's groups, in supporting women's agency[28,29], a nuanced institutional analysis, linking women's agency and its implications for adaptive capacity, remains missing[5,30]. Driven by multiple factors across these institutions, acting in combination with each other[22], outcomes in terms of women's agency are not uniform across contexts.

Here we explore how women's agency contributes to adaptation responses in different climate hotspots. We use gender as an analytical framework, with its focus on power relations, to inform our theoretical conceptualization of the possible individual and relational conditions that combine to strengthen or depress women's agency. The evidence draws on 25 qualitative case studies (see Fig. 1, Table 1 and Supplementary Table 1 for details of cases) in three distinct agro-ecological regions: 14 in semi-arid regions, 6 in mountains and glacier-fed river basins and 5 in deltas. Predominant livelihoods are agriculture, livestock pastoralism and fishing, supplemented by wage labour, petty trade or business, and income from remittances. These areas face a range of environmental risks including droughts, floods, rainfall variability, land erosion and landslides, glacial lake outburst floods, heatwaves, salinity ingress, coastal erosion and cyclones, among others. As climate hotspots there is recognition that risk is related not only to climatic parameters but also socially differentiated and multiscalar vulnerability[2,3,22,31–35].

We use qualitative comparative analysis (QCA)[36–39] to assess the causation behind the diversity in women's agency as an 'outcome' due to varying influences of the contextual 'conditions' in climate change hotspots. QCA allows us to generalize to some extent our findings without ignoring the multiple cases' strong dependence on local context. This contributes to recent calls to synthesize the rapidly expanding climate adaptation knowledge basem, which remains fragmented and highly case-based, and thus less amenable to uptake in global and national policy and practice[40,41]. Through this analysis, we demonstrate multiple causal combinations of contextual 'conditions' that either strengthen or dampen women's agency, highlighting patterns that can suggest possible entry points for moving towards sustainable, equitable and effective adaptation.

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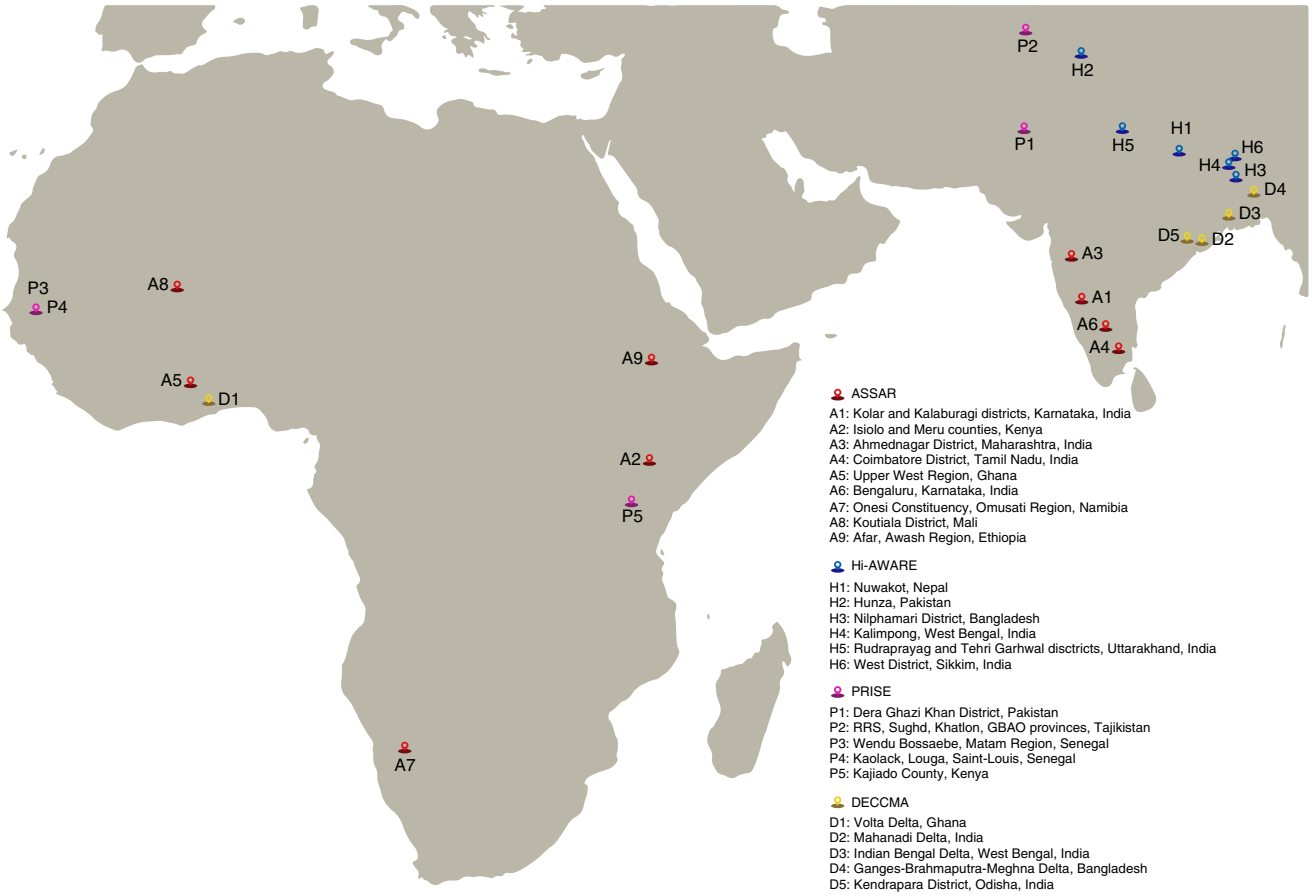

Fig. 1 | Location of 25 study sites across three climate hotspots in Africa and Asia. Case locations were chosen to understand the climate change impacts on vulnerable communities through four consortia working in three distinct agro-ecological regions: (1) semi-arid regions in Africa and parts of South and Central Asia, (2) deltas in Africa and South Asia and (3) glacier- and snowpack-dependent river basins in the Himalayas. The four consortia in the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) are ASSAR (Adaptation at Scale in Semi-Arid Regions), PRISE (Pathways to Resilience in Semi-arid Economies), DECCMA (Deltas, Vulnerability and Climate Change: Migration and Adaptation) and Hi-AWARE (Himalayan Adaptation, Water and Resilience Research on Glacier and Snowpack Dependent River Basins for Improving Livelihoods).

Environmental stressors negate women's agency

The QCA technique examines relations between set memberships of cases to identify combinations of causal factors (or conditions) resulting in a specific outcome[37–39]. In QCA terminology, 'outcome' is the phenomenon to be explained and typically cases are categorized as positive or negative based on the presence or absence of outcome. 'Conditions' are the possible explanatory factors determined from theory as well as the empirics of the cases under study. Drawing on theory[22,25,26], the Sustainable Development Goal 5 (on gender equality) targets and indicators[42] and our field insights, we initially identified seven conditions to explain women's agency, which was reduced to five through a process of aggregation (Supplementary Table 2). Aggregation rules—average of scores for equally important attributes, the minimum score if all attributes had to be present—were determined for the multiple attributes of the outcome and the conditions. To triangulate we relied on multiple sources of secondary data and in a few cases checks with field-based key informants (see Table 2 for definitions of outcomes and conditions and see Methods for further details on how we operationalized the QCA method).

Supplementary Table 3 presents the descriptive statistics that provide an overview of the dataset. On the outcome side (~womag, or women's agency), our set of 25 cases was characterized more by its absence than its presence—we therefore reframed our research question in terms of an enquiry into whether the conjunctural combination of five conditions can 'sufficiently' explain the negation of the outcome in our case studies. Furthermore, across 98% of the cases, the combined influence of stressed environmental conditions (envcon) and the interaction between mobility and women's working conditions (mobwom) explain the negation of women's agency as an outcome (Supplementary Table 4), and hence we interpret this as a commonality across hotspots. Using fsQCA software for the reduced form of the model ~womag = f(~matcon, ~hhcon, ~socstat), two causal pathways emerge (Fig. 2 and Table 3), pointing to combinations of conditions that depress women's agency.

Environmental degradation is common in all the climate hotspots with increasing rainfall variability and temperature extremes, land degradation and changing land use, soil salinization, waterlogging and water scarcity[43–45]. Given that most rural livelihoods are natural resource-dependent, climate variability and environmental degradation manifest adversely on livelihoods, with second- and third-order impacts on women's agency. For example, in case A1 (Kolar district, Karnataka, India), water scarcity is driving low agricultural returns and male outmigration. Whether as a regular livelihood strategy or in response to climate impacts, rural outmigration is highly gendered[21,19,46,47]. Men migrate out, looking for off-farm economic opportunities (A1, A7, D1, D5, H2, H5, P1, P2 and P3) or to access pastures for their livestock and cattle (A2, A9, P5 and P3). Although remittances contribute variously to incomes (from more than 50% in D4 to negligible sums in D2 and H3), male migration

Table 1 | Description of the 25 case studies

Code	Country	Livelihood	Risks	Sociocultural context
A1	India	Agriculture, livestock rearing, increasingly construction labour	Drought, water scarcity, poor credit access	Social stratification based on caste, religion (Muslim, Hindu)
A2	Kenya	Pastoralism, farming, petty trade, wage labour	Drought, water scarcity, poor credit access	Borana ethnic group, traditionally pastoralist
A3	India	Agriculture, wage labour	Drought, dry spells, water scarcity, price fluctuations	Social differentiation based on farmer categories and castes
A4	India	Non-timber forest products (NTFPs), agriculture	Irregular rainfall, market fluctuations	Social differentiation based on caste stratification within the tribals (locally called *kullam*)
A5	Ghana	Farming (crop and livestock)	Drought, floods, erratic rainfall, poor access to markets	Mostly peasant farmers, of Dagaaba ethnic group
A6	India	Transitioning from agriculture to construction labourers and other livelihoods such as petrol pump workers; shifts within agriculture from rainfed to irrigated and from subsistence to cash crops	Unplanned urbanization, water scarcity, lack of basic services	Primarily rural population where rapid urbanization is changing village boundaries and institutions (often shifts from *gram panchayat* to urban local body)
A7	Namibia	Subsistence farming (crop and livestock).	Drought, variable rainfall, flood	Socially differentiated by gender, ethnicity and income; rural farmers with a high population above 50 years of age
A8	Mali	Agriculture, livestock rearing, fishing, trade and handcraft; agriculture makes up 45% of gross domestic product	Uneven rainfall, land degradation, population growth and pressure and conflicts over natural resources	Gender division of tasks embedded in intra-household dynamics
A9	Ethiopia	Predominantly pastoralist and informal labour, some rainfed agro-pastoralism	Water scarcity, invasive species, livestock death	All Afar ethnicity
H1	Nepal	Farm-based livelihood in rainfed situation	Water scarcity, increased incidence of disease in cattle farming	Mixed caste groups affected by 2015 earthquake in Nepal
H2	Pakistan	Gender-based livelihood activities in flood-affected areas and their role in resilience to different climatic shocks	Land erosion and landslides, glacial lake outburst floods, floods, increasing rainfall variability, market access, rising temperature	Resilience of small land holder community, especially women
H3	Bangladesh	Agriculture, agriculture-based labourer	River bank erosion, flood, drought, higher poverty rate, no energy, bad road communication	Poor farm-based Muslim community
H4	India	Integrated farming practices in water-scarce situation	Water scarcity, increasing landslides	Mixed caste, ethnic and religious groups
H5	India	Agriculture, public and private service, remittance	Uncertainty of rainfall pattern, floods	Mixed caste groups
H6	India	Agro-pastoralism	Uncertainty in snowfall and changes in snow cover	Dokpa tribe—traditional livelihood system organized by customary institution named *dzumsa*
P1	Pakistan	Agriculture, daily wage (non-farm)	Floods, water scarcity, drought, heatwaves	Patriarchy, male outmigration, poverty rates, rural urban disparities
P2	Tajikistan	Agriculture, labour migration for various livelihood activities	Water stress, salinity, flooding, droughts	Poverty rates, vulnerability to climate change, receipt of remittances
P3	Senegal	Agriculture, migration	Droughts, extreme heat, wind	Socioeconomic disparities, receipt of remittances, garden farming, patriarchal culture
P4	Senegal	Small and medium sized enterprises	Droughts, extreme heat, wind	Poverty, low technical and financial capacity, poor access to credit, scarcity of raw materials, lack of real incentive
P5	Kenya	Livestock and pastoralism	Droughts, water scarcity, floods, extreme heat	Land tenure system, privatization
D1	Ghana	Small business, crop farming, fishing	Coastal erosion, flooding, drought, salinization, siltation	Sending and receiving areas for migrants, with predominantly rural–urban flows
D2	India	Construction, crop farming, other salaried employment, trading, small businesses	Monsoon flooding, tropical cyclones and erosion	Net outmigration

Continued

Table 1 | Description of the 25 case studies (Continued)

Code	Country	Livelihood	Risks	Sociocultural context
D3	India	Crop farming, small businesses, trading, construction	Cyclones, floods, waterlogging	Sending and receiving areas for migrants, with predominantly rural–urban flows
D4	Bangladesh	Crop farming, fishing, small businesses, salaried employment	Fluvio-tidal floods, tropical cyclones and storm surges, river bank erosion, salinity intrusion, arsenic contamination of shallow aquifers	Significant poverty, as well as severe development and urbanization pressure with the rapid expansion of the major cities (predominantly rural–urban migration flows)
D5	India	Small-scale rainfed agriculture (crops and livestock)	Severe coastal erosion from sea level rise and strong wind and tidal movements, salinization of agricultural land, inundation during storm surges	High levels of poverty and inequality, migration driven by environmental (including climate) stresses

and often risky informal sector activities (A2, P5, H1, H3 and P4). In the absence of supportive physical and social infrastructure, this can lead to additional burdens on women and families[19,48]. Most women across cases reported reduced leisure time, with negative consequences on their wellbeing, including the health and nutrition of themselves and their households[49].

A 41-year-old woman from case A3 (semi-arid South India) said 'It is so difficult to get labour to work on our farms, especially during harvest season and when they do come, they demand too much money for us to pay… I have started working more on the farm now, I do not have a choice. My husband goes for construction work in the neighbouring town and if I do not do agricultural work the crops will die'[50]. In the case of P1 (D.G. Khan, Pakistan), monsoon rains and floods destroyed the cotton crop and, as a young woman noted, 'Men can easily migrate for work whereas we have to stay here (at home) to take care of the family. After floods, my daily wage decreased from Rs. 200 ($1.62) per bale of cotton to Rs. 75 ($0.61)'. Similar testimonies emerged from the other sites.

With reduced male labour in the rural areas, feminization of agriculture was common but not always accompanied by higher women's agency. Agricultural decision-making continued to be in men's hands, with women remaining farm workers, or, at best, supervisors (A8, P2, P3, H5 and H2). In semi-arid Kenya (P5 and A2), when men moved away with livestock, women lost control over milk for consumption and sale, and had to work harder to provide nutritious food for their children. As a 22-year-old woman with two young children in A2 (Northern Kenya) noted, 'My husband is sometimes away for four to five days. I manage the shop, cook and look after the children. I have no help'[51]. Even in cases where women's involvement in household budget management increased, patriarchal societal structures made this appear as a burden rather than a source of empowerment or agency (D5, P2 and A1).

Next we turn to the distinctions between the two pathways. Pathway 1 suggests that the negation of women's agency is an institutional outcome where, although social capital and state interventions seem to be substituting for each other, they are unable to significantly improve women's agency. Pathway 2 demonstrates that, even if household conditions are positive, poor material conditions or poverty can negate women's agency.

Social capital and state support as institutional pathways

There is a stated commitment towards affirmative legislation and action for women's empowerment across contexts (Table 2). Yet, in the hotspots under study, men dominated the state-provided aid and relief facilities during floods or droughts, with women relying on their male relatives to fulfil their needs (D1, P1 and A2). Furthermore, while women may have statutory rights over land and property (A5, P4 and P5), state extension and financial services, or

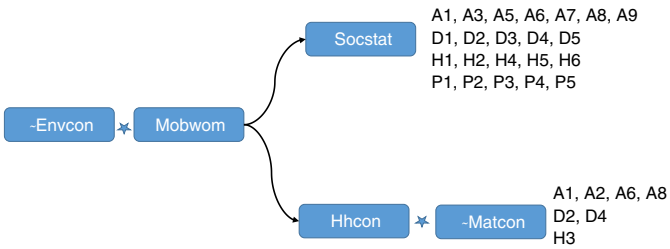

Fig. 2 | Causal pathways explaining variation in case studies. Two causal pathways describe the combination of conditions (indicated by blue stars) explaining the variation in the cases. Cases for each pathway are listed on the right side (see Table 1 and Supplementary Table 1 for case descriptions).

holds true for agricultural as well as pastoralist regions in Kenya, Pakistan, India and Nepal, where, despite constitutionally conferred powers, women often act only in line with male decisions or, at best, in consultation with men.

State intervention and social capital often substitute for each other, as illustrated in the case of Ethiopia (A9), where people seem to support each other more in the absence of state interventions, or Tajikistan (P2), where networks and associations, especially related to migrant households, support each other. In Ghana (A5), state interventions seemed to impede both the traditional cohesion within communities and women's ability to diversify into more lucrative livelihoods. Focusing on cash crops, and providing formal extension services, typically controlled by men, they strengthened cultural norms that excluded women[52].

Although community cohesion may be declining in the contexts of environmental stress, donor agencies and states seek to strengthen social capital through the organization of women's self-help groups (SHGs), providing them with financial and other livelihood support, including skill development. Common to all cases, and specifically D1 (Ghana), there is a strong argument in favour of SHGs to strengthen women's collective action and empowerment. However, despite their advantages, SHGs are often limited in number and lack the needed capacity, skills and opportunities to be effective and sustainable, especially where individual women and groups are dependent on natural resource systems for livelihood resources. Although membership to an SHG often acts positively for women's agency, it does not necessarily translate into decision-making authority outside the SHGs and within their homes (A3). This raises another important point, that women's agency in one institutional site may not necessarily transfer uncontested to another—it is contextual and socially embedded.

Table 2 | QCA outcome, conditions and attributes

Outcome/conditions	Definition in terms of attributes	References
Women's agency	This outcome is characterized by both material and social dimensions, reflecting over productive assets and income, alongside the decision-making voice in the household, in community institutions and in conflict resolution mechanisms.	21,24–27
Material conditions (matcon)	Multiple attributes—education, health status, food security, indebtedness and access to and ownership of assets—related to Sen's (1999) basic human capabilities capture dimensions of material poverty, livelihood resources and wellbeing freedoms at an individual level.	65
Mobility and migration (mobcon)	We specifically explore the implications of male absence from the home, as well as receipt of remittances by women, on enhancing their agency.	19,66–69
Climate change and environmental stress (~envcon)	For this condition we mainly considered how women in our case study locations experienced environmental stress in their everyday lives, in particular the incidence of extreme events and impact of natural resource degradation (the available literature largely shows these impacts to be negative).	70–72
Household structures (hhcon)	This includes headship, whether the household is nuclear, joint or extended and the spaces this offers women, cultural norms around mobility and the reporting of violence.	21,73,74
Social capital (socap)	This refers to community-level social capital and explores the membership in local institutions and networks, as well as the social relations that facilitate trust and reciprocity.	75
State intervention (statin)	This focuses on the enabling environment for gender equality and women's agency created by the State, and includes coverage by social protection programmes, the existence of a supportive legal framework, and access to information and basic services.	13
Women's work and labour (womwcon)	This condition is about women's engagement with labour markets, their working conditions in terms of time and effort spent, the nature of jobs and the ability to set up independent enterprises with remunerative returns.	14,76
'socap' OR 'statin' = socstat	In line with Sen's (2007) discussion of the relationships between formal and informal institutions, in the case of the hotspots studied, where formal channels/instruments of 'state interventions' are absent or insignificant in scale, 'social capital' steps in to substitute for this absence. To capture this relationship, we aggregate (using the OR operator) the membership scores of 'social capital' and 'state intervention' to generate a new condition.	27
'mobcon' OR 'womwcon' = 'mobwom'	Women often end up taking on additional work burdens, including traditionally male work, as their men migrate out in search of better and more secure work. Their heavy and often poor working conditions cancel out the benefits of male migration and remittances, if any.	17,77

Among the cases of equifinality (multiple combinations of conditions producing the same outcome as seen in A8, D2 and D4), the case of Mali (A8) is interesting, as the peculiarity of the household structure explains the trade-off between state support and social capital. In polygamous and multigenerational households, the status of women is not homogeneous but depends on their age and status. Senior women have more say in food decisions, while younger women provide the labour[53]. Positive social capital here reflects the position of senior rather than junior women. In the case of the Ganga-Brahmaputra delta in Bangladesh (D4), state interventions in terms of planned relocation negatively impacted women's agency. Jobs available in the export processing zones are preferentially accessed by men, who are able to commute to work or even stay away from home for long periods. Women bear the burden of working in the fields, following a shift from fishing, in addition to managing the household and families. Poverty here contributes to enhancing their vulnerability.

Household poverty as a depressor pathway

Across cultures, restrictions on women do exist, but they vary in nature and, in general, appear to be loosening in contexts of environmental stress, where household survival becomes a priority. In terms of women's mobility, more women are working outside their home, whether in factories, as in peri-urban Bangalore (A6), or in petty trade and the provision of domestic services, as in semi-arid northern Kenya (A2). There is a wide variation in household headship across the study sites, from 40% of the households being female-headed in Kenya (A2) to barely any in the Teesta floodplain areas of Bangladesh (H3). Household decision-making also presents mixed results across cases, often shaped by household type.

Table 3 | fsQCA results of the model

Combinations of conditions	Raw coverage	Consistency	Cases with greater than 0.5 membership
socstat	0.96	0.69	P4 (1,0), P3 (1,1), P2 (1,0.69), D5 (1,0.94), D3 (1,0.25) D4 (0.75,0.44), D2 (1,0.44), D1 (1,0.5), P5 (0.88,0.69), P1 (0.88,0.87), H6 (0.88,0.81), H5 (1,0.87), H4 (1,0.75), H2 (1,0.87), H1 (1,0.5), A9 (0.88,0.81), A8 (1,0.25), A7 (0.88,0.19), A5 (0.88,0.94), A3 (0.75,0.75), A1 (0.75,0.56), A6 (0.69,0.56)
hhcon* ~matcon	0.56	0.86	A1 (0.88,0.56), H3 (0.75,1), A6 (0.67,0.56), D2 (0.58,0.44), D4 (0.58,0.44), A2 (0.54,0.56), A8 (0.54,0.25)

Solution coverage, 0.98; solution consistency, 0.69. ~womag = f(~hhcon, ~matcon, ~socstat); frequency cutoff, 1; consistency cutoff, 0.9.

In polygamous multigenerational households, senior men make major decisions (A8); in multigenerational households in east Africa, mothers and daughters were building mutually supportive relationships (A2)[51]; in peri-urban Bangalore, increasing incidence of nuclear households was increasing women's voices (A6), with one young woman noting, 'Absolutely, the change in me happened because of my working. I did not know where to alight from the bus. Now I travel alone even changing two three buses'. What is clear is that, given the diversity of household types, it is hard to generalize on a particular type that could be considered more supportive of women's agency.

Despite overall positive household conditions, this pathway still results in a negation of women's agency owing to poor material conditions of the household, measured by the educational status of men and women, health conditions, food (in)security of the household (for example, A2), ownership of productive assets (H3, A5 and A8) and levels of indebtedness. In semi-arid Kenya (A2), female-headed households engage in trade in intoxicants such as *miraa*, for higher earnings to support the education of their children, but this exposes them to health risks, for example through engaging in sexual activities with their clients. Yet, as a 35-year-old woman reported, 'Despite our efforts, there is a high level of malnutrition here. We can't afford meat, we just eat rice and potatoes, but even for this, the quantity is not enough'. In Mali and Ghana, women farm on borrowed lands, which are insecure and not very fertile; they are hence hesitant to invest in such lands, reproducing a cycle of low productivity and food insecurity (A5 and A8)[52]. Indebtedness also determines material conditions, with levels varying across regions and cases, with high levels in semi-arid India (A1 and A6)[50,54], the Teesta floodplains (H3) and the delta regions (D2 and D4), but lower in semi-arid Africa (A2 and A8).

In all the cases represented in this pathway, household poverty and environmental stress seem to combine to suppress women's agency, even when favourable household norms are leading to improved participation of women in the workforce and voice in household decision-making. The everyday pressure of survival does not lead to improving the adaptive capacity of women and households or to build long-term resilience.

Contradictions

We identified three cases—H1, P4 and A7—all under pathway 1, responsible for producing 'contradictions' in our truth table (Supplementary Table 5) and therefore requiring explanation of what is unique to the women actors, the institutional landscape or the socio-ecological context that makes the same factor configuration produce a contradiction on the outcome side that is stronger women's agency. In these three cases, women's agency appears strong, related to the ability of women to make decisions and participate in economic activities unhindered by legal barriers and socio-cultural norms and rules of mobility, resource access and indeed gender divisions of labour. In the Nuwakot District of Nepal (H1), establishment of a cooperative provided opportunities to some women to purchase buffaloes and gain a steady income stream from the sale of milk. Not all women benefited; deep-rooted caste inequalities led to the exclusion of low caste women, despite formal attempts to include them. In Kenya (P5), alongside household structures providing them an enabling environment to engage in productive activities, and a supportive legal framework, opportunities for such productive engagement were higher in urban than rural contexts, and for middle-class rather than poorer households. In Namibia (A7), a strong legal and constitutional framework ensures pensions, social grants and state-sponsored relief to individual households, particularly those belonging to certain minority ethnic groups such as the Dhemba. A 67-year-old Dhemba woman confirmed, 'When I notice that the *mahangu* will not reach the next harvest, I start to supplement household food consumption with purchased maize meal using my social grant'[55]. Yet, with limited education and weak social support, women's inclusion in a range of arenas is depressed—migration and work in particular. The contradiction here is possibly arising because of state action's inability to make up for the inadequacies in social capital and community norms.

Implications for equitable adaptation

Our approach has allowed us to analyse and present complex causality in different climate hotspots, yet with an element of comparability and replicability that is necessary to generate insights into what is required to enable equitable adaptation, in our case with a specific emphasis on women's agency. To this extent, despite requiring several iterations, forcing us to rethink our assumptions, reflect continuously on our field insights and combine conditions that appeared to be substituting for each other, QCA provides a useful alternative to an exclusive reliance on big data, and the challenges it entails for a context-sensitive analysis.

What emerges is an acknowledgement that environmental stress can combine with other contextual conditions to act as a major depressor of women's agency, despite the existence of other enablers[56,57]. Importantly, social institutions and relations are central in shaping women's agency, but their role is often underplayed in discussions that view agency only as individual choice or freedom[21,58–60]. Even when household structures and social norms are supportive, or legal entitlements are available, environmental stress contributes to intensifying exclusionary mechanisms, leading to household strategies that place increasing responsibilities and burdens on women, especially those who are young, less educated and belong to lower classes, or marginal castes and ethnicities. Male migration does contribute to enhanced incomes, but the degree of such support is both uncertain and irregular. Confronted with issues of everyday survival, in the absence of supportive infrastructure and services, women often work harder, in poorer conditions and for lower wages across the hotspots studied, with negative wellbeing outcomes, seen particularly in the neglect of their health and nutrition. In a sense, women do have voice and

agency, yet this is not contributing to strengthening longer-term adaptive capacities[46,61–63].

The United Nations Framework Convention on Climate Change, through its Gender Action Plan and commitments to gender-responsive adaptation as outlined in the Paris Agreement, along with the Sendai Framework for Disaster Risk Reduction and the sustainable development goals, requires that we have empirical insights into what builds the adaptive capacity of women and men in order to support sustainable, equitable and effective adaptation. Our analysis suggests that some common conditions such as male migration and women's poor working conditions combine with either institutional failure, or poverty, to constrain women's agency. These barriers, if addressed in creative ways, could potentially strengthen adaptive capacities and enable more effective adaptation. First, effective social protection, such as the universal public distribution system (PDS) for cereals in India, or pensions and social grants in Namibia, can contribute to relieving immediate pressures on survival. Second, rather than creating competition among individuals and households, such universal benefits can support processes that strengthen collective action at the community level. This, however, cannot always be done on the 'cheap'; investments are needed to enable better and more sustainable management of resources. Women's SHGs are often presented as solutions, yet they are confronted by the lack of resources, skills and capacity to help their members effectively meet the challenges they confront[64]. Although not discussed in depth in this Article, competitive markets are clearly not working to strengthen women's agency; rather, they end up undervaluing and appropriating the labour of poor women, but equally men in contexts of migration. There appears to be a clear case for regulating labour markets to ensure decent work, whether for women or migrant men, but this is proving difficult in a globalized context.

Although there are some limitations of the post facto application of the QCA technique, for example, a low consistency score raising the issue of generalizability (see Methods), based on our theoretical insights and knowledge of the field contexts, we can say with some confidence that the emerging configurational combinations would, in a majority of cases, lead to the negation of women's agency as the outcome. There will always be exceptions, pointing to the need for further disaggregation and acknowledgement of differences among women, whether of caste, class or location. However, this method, like the assessments conducted by the Intergovernmental Panel on Climate Change or the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, contributes to the synthesis of case-based studies[40,41] necessary to inform policy messages. Our analysis highlights the need to move beyond stereotypes and simplistic framings and think creatively about a range of resources, opportunities and institutions that can create an enabling environment for women, and indeed men, to exercise agency for effective, equitable and sustainable adaptation.

Online content

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Methods

QCA. It is established from the relevant literature that women's agency ('womag') results from multiple factors depending on the socioeconomic, cultural, political and environmental context. The causal links are likely to be complex and varying as the context changes from case to case. Among the available methodologies for small-*n*, case-based comparative research, Ragin's[39] QCA was attractive to us because of the possibilities it offered to efficiently address the concerns of complex causality and the high context dependence of data. QCA is sensitive to case-specific complexity, while at the same time providing opportunity for limited generalization[38,39]. Because Ragin's seminal publication advocating the usefulness of QCA in social science research, application of QCA as an analytical technique has advanced to many disciplinary fields but not in any gender-relevant study until now, to the best of our knowledge.

Although QCA is both a research approach and an analytical technique[39,78], this study used the QCA as technique to analyse a 'given' set of 25 case studies drawn from larger research projects with their own objectives and methodologies that often varied from one project to another (Supplementary Table 1). Data collected for all the case studies conformed to the ethical guidelines and approvals of the respective institutions (both universities and research organizations) leading the data collection in those sites. Participants provided informed consent in all cases.

Most of the data for the case studies were already generated from primary field research at the time QCA was chosen to be applied; this naturally put constraints on the research design in terms of framing the hypothesis and formulation of the causal model. However, we felt that it still offered advantages in helping synthesize the concerns of complex causality and high context dependence of data in a systematic way. This is particularly useful when examining dynamics in social-ecological systems, because, while changes in environmental systems are often modelled, how changes in social systems feed back is not investigated as much. We hence sought to overcome this limitation by exhaustively using the empirical case data—both quantitative and qualitative—to not only discuss the QCA results but also to identify, using well-validated theoretical frameworks, critical cross-case patterns that the technique failed to capture.

QCA addresses complex causality by proposing the concept of 'multiple conjunctural causation'. This implies that the outcome is most often the result of conditions acting in combination, that there can be multiple combinations of conditions producing the same outcome ('equifinality'), and that a given individual condition can have varying impacts on the outcome depending on how it combines with other conditions relevant to the context[38,79–81]. Our definition of QCA outcome and causal conditions (Table 2) was guided by a theoretically informed conceptual framework, which, while capturing the interplay of individual and relational factors, across institutional scales and the environmental, livelihood and social dimensions of sustainability, highlights the complex relationships and trade-offs that women (and men) encounter across contexts and over time. First, field observations and interviews revealed the importance of material conditions ('matcon') for survival, with people across sites often risking their lives to ensure food security and resource control, apart from fulfilling their educational aspirations. Second, mobility and migration ('mobcon') visible across climate hotspots is itself a complex phenomenon, with variations in outcomes dependent on the type of migration, its duration, location and so on[66,67]. Third, given the location of the case studies, it was important to consider the impacts of environmental stress ('~envcon') on women's agency. Occurring at a macro level, this condition might be seen as more remote and less causally proximate than the others[82]; however, in our definition, we have mainly considered how women experience environmental stress in their everyday lives. The next four conditions focus on institutions—the household, the community, the state and markets—as central to shaping women's agency[26]. Sociocultural norms and practices across these institutions interact with and influence each other and the final outcome, as captured in the Organisation for Economic Co-operation and Development's construction of its Social Institutions and Gender Index[21,73]. As our focus is on how these institutions relate to women's agency, we do not differentiate between them as being more causally proximate or remote. Moreover, when from a preliminary analysis of the contextual information across cases some of the conditions were found to be substituting for each other in influencing the outcome, we aggregated (using the OR operator) the membership scores of the substitutes to generate new conditions such as 'socstat' and 'mobwom' (Table 2). The initial seven conditions were thus reduced to five conditions following the above aggregations.

Supplementary Table 3 provides the descriptive statistics that provide an overview of the data matrix presented in Supplementary Table 6, which presents our 25 case studies as rows and the five causal conditions along with the outcome as columns. On the outcome side, only one case (P4) scored 1.0, which puts it fully in the outcome set. Three cases (A7, A8 and D3) scored 0.75 or more, which makes them more in than out of the set members, four cases (H1, D1, D2 and D4) scored 0.5 or slightly higher values, putting them in the category of threshold cases, and the rest of the cases had outcome scores less than 0.5 (Supplementary Table 6). Hence, we reframed our research question in terms of an enquiry into whether the conjunctural combination of five conditions, including environmental stress (~envcon), material poverty (~matcon), household structures (~hhcon), the presence/absence of either social capital or state support (socstat) and the nature of either migration, mainly male or women's labour market experiences (mobwom) can 'sufficiently' explain the negation of the outcome (~womag) in our case studies.

Five-step QCA procedure. Our application of QCA followed a five-step procedure. To the extent possible we tried to adopt 'best practices' in the application of the technique, although there were constraints on account of the data and cases being a 'given'. Our approach to defining the outcome and identifying the conditions has already been already explained. To apply the QCA technique we began, in step 1, with the raw case data collected from primary field research and converted them into set membership scores ranging from 0 to 1 at the attribute level of both outcome and conditions using pre-defined criteria (Supplementary Table 2). We used a four-value fuzzy scale with scores 0 (fully 'out' of the set), 0.25 (more 'out' than 'in' the set), 0.75 (more 'in' than 'out' of the set) and 1 (fully 'in' the set). This scoring logic was based on the collective wisdom of the research team that between the two extremes of zero and full agency it is possible to further distinguish the presence of women's agency in either moderate or substantial degree. The fuzzy scale was applied by referring to a pre-defined set of criteria identified at the attribute level for the outcome as well as each of the conditions (Table 2). As required in QCA, we took care to 'speak to the data'[79] so that the set membership scores were appropriately calibrated to correctly capture the case site context. For this purpose, we developed thresholds (or anchor points), guided by in-depth case information combined with theory-based understanding of the relevant concepts[83]. For triangulation purpose, we relied on multiple sources of secondary data and occasional cross-checks with field-based key informants. Aggregation of the membership scores across multiple attributes of the outcome and conditions required that we identify the appropriate operators. For equally important attributes, we took an average of the scores; if all attributes had to be present for the case to be considered in the set, then we took the minimum of all the attribute scores. Guided by theory and also the case information we looked at aggregation across conditions. Thus, for example, and as already explained in the main text (Table 2), the two conditions 'socap' and 'statin' were combined to yield 'socstat'; similarly, 'mobcon' and 'womwcon' were aggregated as 'mobwom'.

Step 2 involved testing for necessary conditions, for which we used the XY plot feature in the open-source fsQCA software (Supplementary Table 4). A causal condition is identified as necessary when its set of cases contains the outcome set as a subset; alternatively, if the outcome set contains the condition set of cases as a subset, then it points to sufficiency of the condition[36,84]. Necessity of a condition (or combination) for an outcome does not rule out the possibility of the same condition (or combination) causing a completely different outcome, whereas sufficiency of a condition will not exclude other conditions resulting in the same outcome[39]. In terms of XY scores, for a condition to be necessary its consistency threshold should be high (X score > 0.9) and coverage not too low (Y score > 0.5)[85]. Consistency in QCA is linked to predictability, whereas coverage is akin to the notion of goodness-of-fit in econometrics. In our necessity analysis, going by theorized links with the revised outcome ('~womag'), we tested for the presence of environmental stress (~envcon) and the absence (or negation) of household and material conditions (~hhcon, ~matcon); for the remaining two conditions (socstat and mobwom), we tested for both their presence and absence. Besides ~envcon, the presence of 'socstat' and 'mobwom' were identified as necessary for the negated outcome to result. Guided by our understanding of the case contexts we chose to combine '~envcon' and 'mobwom' using the AND operator and found it to be a necessary configuration with very high consistency score. Excluding this configuration resulted in the reduced form of the model ~womag = f(~matcon, ~hhcon, ~socstat), which we took to the next stage for sufficiency analysis.

In step 3, application of the fsQCA software to the data matrix produced the 'truth table', which is a summary presentation of the distribution of cases across all possible combinations of the causal conditions leading to the outcome. With three causal conditions in our model, there were a total of eight (2^3) possible causal combinations, of which five combinations accounted for the 14 cases with outcome set membership score exceeding 0.5. Supplementary Table 5 presents the edited truth table, which contains only those causal combinations with at least one observable case as member in the outcome set (that is, the frequency cutoff is set to 1 under the number column) and a raw consistency value greater than or equal to 0.90. The combinations with no observable cases are termed logical remainders in QCA and are a result of limited diversity in the database. The fsQCA software produces three types of solution—complex, parsimonious and intermediate—based on the treatment of remainders as counterfactuals. In this study, we relied on the intermediate solution because, unlike the other two types of solution, it is based on theoretically informed assumptions linking the presence or absence of conditions to the outcome. Our assumption was that all the three causal conditions can be left marked 'present or absent' because of theoretical ambiguity in linking these to negated women's agency.

Before generating the solution, the issue of 'contradictions' present in the truth table was resolved in step 4. Contradictions are row configurations in the truth table causally linked to opposite outcomes. We used the method provided by Rubinson to identify the anomalous observations[86]. In our truth table, two rows exhibit such contradictions (rows 2 and 4, Supplementary Table 5). The combinational configuration represented by row 2, for example, has four cases, two revealing a positive outcome and two negative. Although a conservative approach

would suggest removing the rows of the truth table in which such contradictions occur, or revisiting the empirical data, we chose to resolve the issue by adopting the expansive solution that involves assigning the contradictory configurations a score of 1 (refs. [39,86]). Instead of ignoring the anomalies, we use it as an opportunity to reconsider both theory and our data to explore in greater depth causal complexity.

Finally, in step 5, we evaluated the fsQCA solution in terms of the consistency and coverage scores. The evaluation would have been enhanced by a second minimization of the opposite outcome value (womag), but this was not possible because of the limited number of cases with 'womag' outcome.

Limitations. One of the CARIAA consortia working in delta regions, DECCMA, mainly used quantitative surveys for data collection. Although the scoring of conditions was done to the extent possible using data for female-headed households in their sample or generating proxy indicators that could map onto the conditions, given the geographical and cultural diversity, there were clearly gaps in terms of data on context and social relations more broadly. Also missing were data from women in male-headed households. Furthermore, while the deltas in India, Bangladesh and Ghana (the sites for research) varied vastly, in terms of the survey scores there was very little variation. In one site, the Mahanadi Delta, it was interesting to find that the survey data scores did not correlate with the qualitative data from a smaller area within the same delta. In fact, when the case studies were completed and run through the QCA software, one case dropped out—the Mahanadi survey data. The qualitative Mahanadi data stayed in—immediately highlighting an inconsistency that can only be explained by the different ways in which scores were applied (to quantitative data for female-headed households, as opposed to a subjective scoring based on experience of women within all household types in the qualitative study) and the scales of data. Although a limitation in this dataset, this methodological diversity also offered us an interesting learning opportunity, especially around issues of validity.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are available from the corresponding author on reasonable request. No other article has been published from the QCA dataset, although there are articles in preparation from the larger research projects.

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Author contributions

N.R. led the theoretical conceptualization of the key arguments. A.M. led the analysis using QCA methodology. A.P. coordinated the process and review of literature. C.S. coordinated the case writing, contributed to the literature review and put together the supplementary material and references. A.Q. and P.P. contributed text on the two pathways. K.V. provided implications of the cases and comments on the text and structure, and C.B. provided critical comments.

Competing interests

The authors declare no competing interests.

Additional information

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☒	☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐ Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Primary data was collected using both survey and qualitative method as part of the lager research programme of the consortia.
Data analysis	fcQCA pre software was used for data analysis

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

Data available on request from the authors. The data that support the findings of this study are available from the corresponding author upon reasonable request. Relevant data is however included in the supplementary material. No other article has been published from the QCA data set, though there are articles in preparation from the larger consortia research.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Mixed methods were used, though the precise methods varied across the 25 case studies.
Research sample	Research samples mainly included rural men and women in the climatic hotspots across the countries studied.
Sampling strategy	Sample size varied depending on the method used and the purpose of the larger study. Once the hotspots were selected, a combination of random and purposive-stratified sampling was used.
Data collection	Pen and paper, and at times recorders, were used to record the data. In some instances, local translators were present alongside the researchers, while in the case of large-scale surveys as in DECCMA, local agencies were used to conduct the survey. Ethical approval was secured by all participating institutions for ensuring both confidentiality and anonymity to the participants.
Timing	The data was collected between the years 2015-18.
Data exclusions	The data used for this QCA analysis only included cases where a gender analysis was possible.
Non-participation	The consortia had several research strands as part of their research; not all of them took gender on board during the process of data collection or analysis. We therefore ended with 25 case studies.
Randomization	Some participants were randomly selected, but in other instances purposive sampling was used.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology
☒	☐ Animals and other organisms
☐	☒ Human research participants
☒	☐ Clinical data

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics	see above
Recruitment	In the case of surveys, household listing was first done, on the basis of which every nth household was selected. For the qualitative cases, recruitment was based on other characteristics of interest.
Ethics oversight	Each consortia had its own University/organisational ethics approval committee which approved the protocol.

Note that full information on the approval of the study protocol must also be provided in the manuscript.