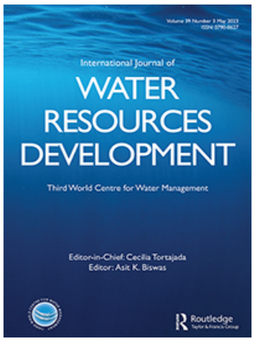

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Retrospective climate resilience assessment of semi-arid farming systems in India

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ABSTRACT
Semi-arid farming systems in India are facing an increasing frequency of climate change-induced extreme weather events. With the aim of improving their climate resilience, we retrospectively assess climate resilience in two case studies in Maharashtra, India. We considered a 15-year period and multiple interventions in both. The systems showed improved climate resilience when agricultural productivity-enhancing interventions were combined with those related to water management, soil health, livelihood diversification, and food and nutrition security. Further, we recommend embedding a monitoring, evaluation and learning component within the design of all interventions to help with adaptive decision-making.

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Climate change; resilience; semi-arid; water management; agriculture; India

Introduction

Indian agriculture has undergone major changes over the past four to five decades, from being subsistence oriented to market oriented (Joshi & Khadka, 2022). Despite early gains in farm productivity, the agricultural sector once again finds itself in need of transformative changes in the face of the increasing frequency of climate change-induced extreme weather events, which are depleting soil health and putting pressure on groundwater resources (Chand, 2022). Interventions aimed at agricultural development, particularly in rainfed and semi-arid areas in India, have had only limited success (NRAA, 2022; M. Shah et al., 2021a). The National Rainfed Area Authority (NRAA) argues that the 'Green Revolution' framework of intensification, which assumed adequate water availability even in drought-prone and resource-poor areas, has led to unsustainable cropping patterns, ecological degradation and malnutrition (NRAA, 2022). Influenced by markets and supply chain governance, cropping patterns have seen the rise of agricultural

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monocultures, leading to further vulnerability of agriculture to climate change (Bharucha et al., 2014; M. Shah et al., 2021a).

Watershed development has been a part of the national approach to improve agricultural productivity in semi-arid India for several decades (Gray & Srinidhi, 2013; S. H. Shah et al., 2021). Considering that the country's semi-arid regions are home to a majority of India's poor, watershed development interventions have also been a key strategy in reducing poverty and improving livelihoods (Wani et al., 2011). However, in many instances, despite the initial success of the watershed development, the over-exploitation of groundwater to support water-intensive cash crops has led to falling water tables in several districts and threatened the sustainability of the agricultural economy (Bharucha et al., 2014; Kerr et al., 2002; Samuel et al., 2007). Empirical studies assessing the impact of watershed development across several states in India show that a participatory approach to planning and implementation of projects has shown greater sustainability (Batchelor et al., 2003; Kolavalli & Kerr, 2002; Palanisami et al., 2009). In the face of an increasing frequency of extreme weather events, de Condappa et al. (2021) and Behera and France (2016) discuss the need for diversified and holistic solutions for the resilience of farming systems. As a response to the multiple challenges faced by rainfed and semi-arid areas in India, the Government of India has tasked the NRAA to revise the watershed development guidelines in the country with the aim of improving the ability of the farming systems to cope with evolving challenges, including building resilience to climate change (Aggarwal et al., 2022). However, even in agricultural programmes considering climate resilience, issues such as a 'narrow understanding of resilience' led to unsustainable outcomes and a lack of equity (Taylor & Bhasme, 2020). Considering the climate change projections over India and its increasing adaptation needs, Gajjar et al. (2019) specifically discuss the need for retrospective assessments of development strategies to improve future climate resilience.

The objective of our research is to retrospectively assess the contribution of agricultural development interventions to the climate resilience of farming systems in semi-arid India. We define an intervention as an activity or set of activities with a specific objective, for example, improving soil health or providing access to irrigation. We selected two farming systems as case studies: one where interventions were aimed at improving agricultural productivity and irrigation infrastructure, and another where interventions targeted the building of adaptive capacities, besides improving agricultural productivity. The assessment builds on a two-step process. First, we assess the climate resilience of the two farming systems using a holistic and participatory process that includes stakeholder interactions through village meetings and focus group discussions. Next, we perform a content analysis of the stakeholder interactions to draw insights about the contribution of specific interventions to its climate resilience.

Our research evaluates a broad range of interventions addressing the multiple challenges faced by farming systems in semi-arid India. We find that the climate resilience of farming systems improved when agricultural productivity-enhancing interventions were combined with those related to water management, soil health, livelihood diversification, and food and nutrition security, along with a focus on monitoring, evaluation, learning and adaptive decision-making. The findings help us in drafting policy recommendations for improving the climate resilience of farming systems. Our study also demonstrates a methodology for assessing a sequence of agriculture development interventions and comparing the climate resilience of case studies from different contexts. We believe that this study will be useful to researchers and policymakers engaged in agriculture, food security, sustainable livelihoods and water management in semi-arid areas, particularly in the context of climate change.

The remainder of the paper is structured as follows. Following this introduction, we discuss our methods, including a description of the case studies. The results of the climate resilience assessments and the analysis of interventions that contributed to climate resilience are then presented. The following section discusses the key findings of our research and provide policy recommendations. This is followed by the conclusions.

Methods

To retrospectively assess the contribution of agricultural development interventions to the climate resilience of farming systems in semi-arid India, we follow a two-step process. In the first step, we assess the climate resilience of the two farming systems using a holistic and participatory climate resilience assessment framework, called the Climate Resilience In Semi-arid India (CRISI) framework (Srinidhi et al., 2023). In the second step, we assess the contribution of the sequence of interventions on the climate resilience of each farming system. We discuss the choice of framework and methodology for both steps of our research, followed by a description of the case studies, data collection and data analysis.

Choice of framework and methodology

In the context of climate change, resilience is the capacity of a system to dynamically respond to, recover from and even thrive in changing climate conditions while continuing to maintain essential functions, identities and structures (Dixon & Stringer, 2015; Rockefeller Foundation, 2009). Studies focusing on assessing the climate resilience of farming systems suggest that to be able to provide useful information, frameworks should be context specific and consider multiple hazards and underlying socio-economic vulnerabilities (Dixon & Stringer, 2015; Laurien et al., 2022; Samuel et al., 2015). We apply the six-part CRISI framework owing to its holistic consideration of resilience, its ability to incorporate the views of diverse stakeholders, the usefulness of the information it provides for decision-makers and the fact that it has been tested in semi-arid India. The parts of the framework that cover the system description, challenges and system functions explain the specific resilience of the system, while the resilience attributes clarify the general resilience of the system (see Table A1 in the supplemental data online for an overview of the six parts of the CRISI framework). The use of 10 system functions and 16 resilience attributes in the CRISI framework can be time intensive (Srinidhi et al., 2023). To avoid respondent fatigue, we narrowed the list to four system functions and six resilience attributes based on stakeholder consultation. In doing so, we combined the crop and livestock-related functions of economic viability, food and nutrition security, and animal health and welfare (in the original CRISI framework; see Table A1 in the supplemental data online) as a single function of agriculture productivity (see Table A2 in the supplemental data online). Further details of the framework and indicators used in the local context are provided in Tables A1–A3 in the supplemental data online. The description of the case studies, the time period used in the assessment and the process of data collection are provided below.

To assess the contribution of interventions on the climate resilience of each farming system, we perform a content analysis of the discussions with stakeholders during our data-collection process. Content analysis is a widely used methodology for understanding the causes and effects of content in various disciplines of research (Krippendorff, 1989; Prasad, 2008). It is recommended not to use content analysis to test causal relationships between variables (Chadwick et al., 1984); therefore, we use it only to understand the contribution of interventions to resilience and not for attribution per se. In the second step, we first look at the aggregate scores of the system functions and resilience attributes as a proxy to indicate the overall resilience of the system. We then carry out a content analysis of the discussions with stakeholders and map the interventions to their contribution to a function and/or attribute (for more details, see below).

Case studies

The case studies are located in the semi-arid part of India (Figure 1) – an important criterion in their selection. From a holistic system's perspective, we considered all interventions influencing the resilience of the farming system in our assessments, including non-farm interventions such as the establishment of self-help groups and the promotion of alternate livelihoods. Based on discussions with the local communities in both villages, we selected a 15-year time span for the assessment, from the period before any watershed development activities (2007) to the current status (2021). The basis for the

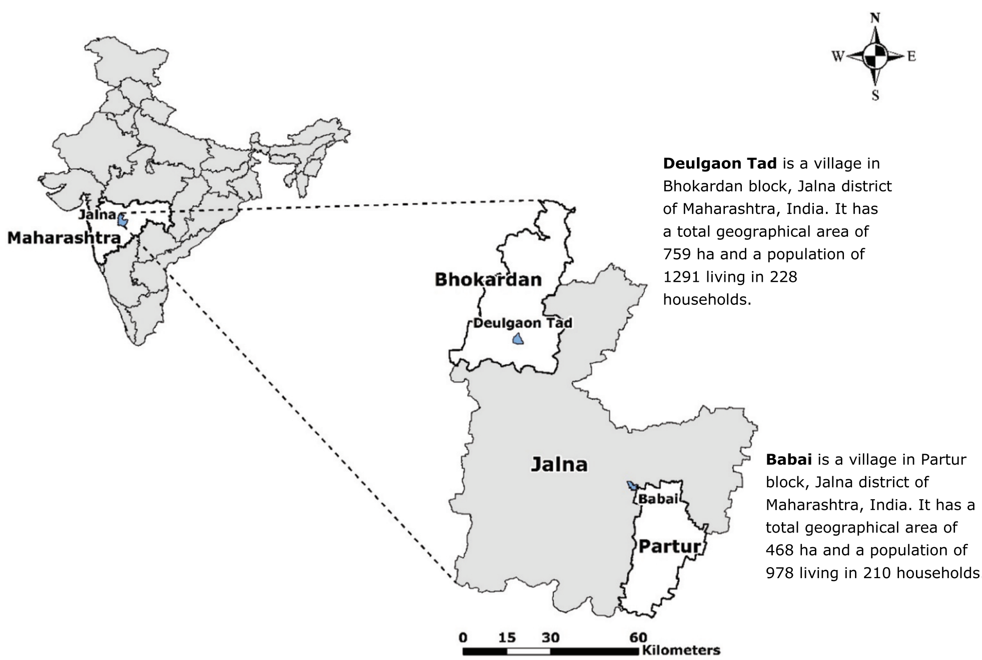

Figure 1. Map showing the selected case studies.

selection of this period was that interventions before 2007 were deemed to have less relevance to the current resilience of the system. Thus, data availability over this 15-year period was another important consideration in the selection of the case studies. Other similarities between the case studies were that neither had any unique characteristics in terms of caste and class demographics nor proximity to urban areas.

The case studies were, however, deliberately chosen for differences with regard to agricultural development interventions. The first case study, Babai, had a series of interventions primarily aimed at improving agricultural productivity and irrigation infrastructure. The second case study, Deulgaon Tad, had interventions basically aimed at building adaptive capacities in addition to improving agricultural productivity. Both case studies had additional interventions aimed at diversifying incomes. The two case studies also differ in terms of access to water, as noted in Table 3. The reason for the selection of case studies with different contexts and a different sequence of interventions was to be able to assess a wider range of strategies addressing the climate resilience of the farming system. Verbal consent was obtained from the local communities for the research.

Table 1 provides a timeline of interventions and related activities for each case study during the assessment period. In Babai, watershed development was implemented in the village from 2010 to 2015 under the Integrated Watershed Management Programme, which follows the common watershed development guidelines of the Government of India (NRAA, 2011). Self-help groups were introduced as a part of the watershed development programme, and they continued under the Maharashtra State Rural Livelihood Mission (MSRLM) from 2017 onwards. The MSRLM also promoted alternate farm and non-farm activities, such as training in food processing, handicrafts and tailoring. Irrigation infrastructure under the Maharashtra Dryland Agriculture Mission was a significant intervention between 2015 and 2017, under which pipes and micro-irrigation equipment were distributed to all farmers. Solar pumps under central and state government subsidies were also installed from 2016 onwards. Since 2017, a few private companies and banks have started distributing microfinance loans through joint-liability groups in the village.

As with Babai, the first major agricultural development intervention in our assessment period in Deulgaon Tad was also watershed development – between 2008 and 2014. This intervention was supported by the Government of India's National Rural Employment Guarantee Act. Under a unique public–private–community participation initiative, the Watershed Organization Trust (WOTR) – a non-governmental organization (NGO) based in Pune – provided technical assistance and capacity-building support for project planning and institution-building, such as supporting the creation of village development committees and self-help groups (WOTR, 2015a). Between 2015 and 2018, the local community in Deulgaon Tad, along with research and implementation staff from WOTR, initiated three action research projects based on their evolving climate and natural resource management challenges. The watershed development project endline assessment report and a climate vulnerability assessment study by WOTR provided inputs for designing these interventions (WOTR, 2015b). The climate-resilient agriculture intervention included activities such as promoting the use of organic inputs and providing the community with locale-specific weather and crop advisories through an application (app) called FarmPrecise (Gaikwad et al., 2019). The water stewardship intervention aimed to improve water-use efficiency, crop planning and equitable water governance in the village (D'Souza et al., 2019). In response to household food and nutrition security issues, the

Table 1. Timeline of interventions in Babai and Deulgaon Tad, 2007–21.

Intervention	Activities	Timeline 2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Babai																
Watershed development	Soil and water conservation, project management committee				■	■	■	■	■	■						
Self-help groups	Capacity-building, bank linkages					■	■	■	■	■		■	■	■	■	■
Irrigation infrastructure	Pipes, drips and sprinklers for micro-irrigation									■	■	■				
Microfinance	Joint liability groups and small loans											■	■			■
Solar pumps	Panel and pumpsets										■	■	■	■	■	■
Alternate livelihoods	Training on activities such as food processing, handicrafts, tailoring											■	■	■	■	■
Deulgaon Tad																
Watershed development	Soil and water conservation, village development committee		■	■	■	■	■	■	■							
Climate-resilient agriculture	Promotion of soil health, organic inputs, silage, agro-advisories									■	■	■	■	■	■	■
Self-help groups	Capacity-building, bank linkages		■	■	■	■	■	■	■	■						
Food and nutrition security	Kitchen gardens, multilayer farming, nutrition												■	■	■	■
Water stewardship	Water budgeting, crop planning, village water management teams										■	■	■	■	■	■
Farm ponds	Subsidies for 18 farm ponds											■	■	■	■	■
Farmer–producer organization	Infrastructure support, value-chain development, marketing											■	■	■	■	■

Note: Shaded cells indicate the duration for which financial or technical support was received for each intervention (as reported by the local community).

third action research project, which focused on setting up kitchen gardens, multilayer farming and nutritional advice to women, was initiated in 2018. To improve the economic viability and profitability from agriculture and allied livelihoods, a farmer–producer organization (FPO) was set up in 2019. All these new interventions were directed towards building adaptive capacities of the community and formation of community-based organizations (e.g., building capacities of the village water management teams). About 18 farm ponds have been constructed by farmers under the state government's *Magel Tyala Shettale* scheme since 2017. As in Babai, self-help groups were initiated in Deulgaon Tad during the watershed development project (2008–14), which continued under the MSRLM in 2015. However, unlike in Babai, the self-help groups in Deulgaon Tad have not been adequately linked with the promotion of alternate livelihoods. A few other government interventions in Deulgaon Tad involved the construction of some dugwells and deepening of the main drainage line. However, during our assessment, these interventions were found to benefit very few households and were not very significant for the resilience of the farming system; therefore, they have been excluded from the timeline shown in Table 1.

Data collection

Data were collected for both steps of our study between August and November 2021. In applying the CRISI framework, we followed a participatory rural appraisal process (Narayanasamy, 2009), which included semi-structured discussions with a multi-stakeholder group and focus group discussions with marginalized sections of the local community. To minimize the influence of the powerful sections in swaying the consensus of the local community (Cornwall & Pratt, 2011), we engaged marginalized sections in separate focus group discussions.

The first meeting was an introductory and rapport-building meeting in the village, where the purpose of the study was explained and consent was sought for documenting all the discussions and use in research. Prior communication about the meeting and an invitation to participate in it were sent to the village council and each of the hamlets in the village. The number of attendees in the first meeting was low, but as our rapport with the village community improved, we observed much higher participation in later meetings. While some attendees came for all the meetings, others joined in only for specific focus group discussions, and some did not return for the final plenary meeting. The number of attendees in each stakeholder meeting is shown in Table 2. During the first meeting, the list of all relevant stakeholders to be included in further assessment steps and the plan for focus group discussions were co-created with the community.

The second meeting was with a multi-stakeholder group that included two to three representatives of large farmers, small farmers, landless households, women, youth, representatives of the village council (*panchayat*) and representatives of other community-based organizations. The finalization of the timeline and selection of interventions for the assessment were done in a participatory manner during the first and second meetings. During the second meeting and the subsequent focus group discussions, we assessed parts 1–5 of the CRISI framework (see Table A1 in the supplemental data online). Parts 1, 2 and 4 of the CRISI framework that cover the system description challenges and resilience capacities included qualitative data. Parts 3 and 5 involved quantitative data by

Table 2. Timing and number of participants in data collection.

#	Stakeholder meetings and purpose	Type of data collected	No. of participants in Babai; timing	No. of participants in Deulgaon Tad; timing
1	Informal introductory meeting and seeking consent for study	Consent and list of all relevant stakeholders	7 participants August 2021 (1 day)	8 participants August 2021 (1 day)
2	Semi-structured discussions with multi-stakeholder group to go through CRISI parts 1–5[a]	Qualitative (system description, challenges, resilience capacities) Quantitative (performance of functions and attributes)	12 participants November 2021 (1 day)	22 participants October 2021 (1 day)
3	Focus group discussions with women, landless, marginalized sections (small farmers), and youth to go through CRISI parts 1–5[a]	Qualitative (system description, challenges, resilience capacities) Quantitative (performance of functions and attributes)	38 participants November 2021 (2 days)	66 participants October 2021 (2 days)
4	Plenary meeting with multi-stakeholder group to reflect on findings and improve accuracy of assessment (CRISI part 6)[a]	Qualitative data across all stages of CRISI application	12 participants November 2021 (1 day)	21 participants October 2021 (1 day)

Note: [a]The six parts of the Climate Resilience In Semi-arid India (CRISI) framework refer to: 1, System description; 2, Challenges; 3, System functions; 4, Resilience capacities; 5, Resilience attributes; and 6, Reflection. For a more complete description of each part, see Table A1 in the supplemental data online.

eliciting relative scoring of the system function indicators and resilience attributes on a scale of 1–5. Participants in the meetings were asked to give a score of 1 to the poorest form of the indicator or attribute they could imagine (e.g., relying on a single crop on a small piece of land, meaning poor profitability and diversity) and 5 to the best possible form of the attribute (e.g., multi-cropping and mixed crop and livestock system). In assessing the system functions and resilience attributes, we also evaluated their performance during a period with a climatic stress, identified as the drought year of 2012. While our focus was on assessing the climate resilience of the farming system, we accounted for multiple stresses and a wide range of interventions for a holistic understanding of the system dynamics. The objective of the focus group discussions was to ensure that the interests of these marginalized groups and issues around the local power dynamics are appropriately captured.

The final meeting was a plenary with all the stakeholders from the previous stage being invited. During this phase, the final assessment results, as well as opinions expressed in the focus group discussions, were discussed. This plenary meeting also covered part 6 of the CRISI framework (Reflection) and provided participants the opportunity to reflect on the accuracy of the assessment and the adequacy of the resilience-building measures. Quantitative data available at the village council and from project baseline and endline reports also contributed to all the steps of the assessment of the case study. An overview of the village-level meetings and data collected is provided in Table 2.

Data analysis

All the meetings were recorded and later transcribed by the two researchers involved in the fieldwork of the case studies. The researchers also took notes during the meetings, which were used to create analytical memos. The memos from each stage of the assessment were used to refine the questions and issues to be discussed in the subsequent stage. While the effort was to arrive at a consensus on various aspects of the assessment, differing opinions – especially from the marginalized sections of the group – were separately recorded and appropriately captured in the final scores with comments. Where there was a difference in opinion between groups on the scores of the system functions or resilience attributes, an average of the scores reported by the different groups (equally weighted and rounded off to the closest whole number) was used. Quantitative information gathered from the village council and project baseline and endline reports, such as demographic data, crop-sown statistics and geographical information system (GIS) maps showing land-use change, were referred to during the meetings to infuse more objectivity into the assessment of the earlier time period.

In step 2 of the research, we use the cumulative scores of the system function and resilience attributes (adding the scores reported in Table 3) as a proxy to demonstrate the overall resilience of the system. Although these scores are not necessarily additive, we suggest that the overall direction of change is illustrative of the dynamic changes in the resilience of the system. We also manually coded the transcribed notes in Microsoft Excel using a mix of deductive and inductive codes. The deductive codes were based on the parts of the CRISI framework (e.g., 'social organisation', a system function in part 3) and the interventions that the case study had been subjected to (e.g., 'WSD' for watershed development). We also generated some inductive codes, such as *wellbeing, trend* and *aspiration*, to reflect changes or issues that transcend specific interventions and their intended objectives. For instance, a quote about watershed development helping improve well water recharge through contour trenches was assigned the codes *WSD* for activity, *health of ecosystem* and *agricultural productivity* as functions it contributed to, and *ecological self-regulation* as an attribute that this activity contributed to. The coding was done by the researchers involved in the study. While referring to a specific quote within later sections of this paper, we use the following convention: <label for case study>-<label for meeting>-<serial number of quote>. Thus, CS1-FGW-2 refers to case study 1 (Babai), the focus group discussion that involved women (FGW) and the second quote recorded from the meeting. We use our coded Excel file to map the quotes from stakeholders to a specific intervention and the function/attribute the intervention contributes to. The quotations explicitly cited in this paper are listed in Table A6 in the supplemental data online (the complete coded files are available from the authors upon request). Based on this analysis, we were able to draw insights into the contribution of agricultural development interventions to the climate resilience of the two farming systems.

Results

Climate resilience of the two case studies

The results of the application of the CRISI framework to both case studies are summarized in Table 3. Considering that both case studies are located in semi-arid areas, access to a reliable source of water throughout the year is an important source of resilience. We find

Table 3. Climate resilience assessment results of Babai and Deulgaon Tad.

	CRISI framework	Babai				Deulgaon Tad			
1	System description	Babai is on the banks of the Dudhana River, which has water nearly all year round. A large check dam constructed across it in 1993 increased the water available for irrigation in the village, but causes the river to dry up in the peak summer months further downstream of the dam. Agriculture is characterized by cash crops such as sugarcane, cotton, soybean and horticulture, and some food crops such as wheat and sorghum. There is no dairy in the village, and few farmers own livestock. The *gram panchayat* (village council) is the main decision-making body				Deulgaon Tad has one stream flowing through the village, one pond and two small check dams. However, these are not perennial sources of water and dry up a few months after the end of the monsoon. Major crops are cotton, maize, wheat, sorghum, pearl millet (*bajra*), chickpea and vegetables. There is a dairy in the village, and a mixed crop–livestock system is prevalent. In addition to the village council, there is an active village development committee and a farmer–producer organization, which serve as decision-making forums			
2	Challenges	The predominance of cash crops and intensive use of chemical fertilizers are affecting soil health and increasing rates of groundwater pumping. The lack of integrated crop–livestock farming in the village means a lack of organic manure. Most interventions in recent years have benefitted large farmers: irrigation pipes, solar pumps, etc. There have been attempts at livelihood diversification and improving access to credit, but this has benefitted just a few households				Water is a limiting factor in crop choices. Increasing weather variability, particularly high-intensity rain in short spells, followed by long dry spells and rising summer temperatures, was another challenge cited. However, farmers felt that water budgeting and other interventions to improve soil health had made agriculture a little more resilient to rainfall fluctuations and reduced input costs. Landless households complain that their lack of opportunities arises from a lack of access to credit and support to expand alternate businesses.			
3	System functions	2007	2012	2021	Direction of change (2007– 21)	2007	2012	2021	Direction of change (2007– 21)
	Social organization	2	3	2	↔	2	4	3	↑
	Health of ecosystem	4	3	3	↓	2	2	3	↑
	Agricultural productivity	3	2	4	↑	2	2	3	↑
	Equity	3	3	3	↔	2	3	3	↑

(*Continued*)

Table 3. (Continued).

4	Resilience capacities	Evidence for resilience capacities	Direction of change (2007–21)	Evidence for resilience capacities	Direction of change (2007–21)
	Anticipation	The lack of community forums (other than the formal village council) to discuss risks and responses is an indicator of low anticipation. Earlier project management committees have ceased to exist	↓	In addition to the village council, the village development committee and the farmer–producer organization provide forums for discussing livelihood risks and responses	↑
	Robustness	Adequate water availability from the Dudhana River implies that agriculture in Babai has always been quite robust. Irrigation infrastructure has increased robustness	↑	Efficient water management and sustainable agriculture practices have helped improve agriculture productivity. Better maintenance of watershed structures by the village development committee also contributes to robustness	↑
	Adaptability	Limited evidence of adaptive decision-making. Livelihood diversification and micro-finance interventions have benefitted very few households	↔	Adaptive decision-making can be seen in the water budgeting and crop planning carried out based on actual rainfall. Voluntary actions by the community to maintain soil health were also seen	↑
	Transformability	Limited/no evidence contributing to the capacity of transformability was found. The need for urgent action in this regard can be seen in the community's aspirations for setting up agri-allied and non-agricultural businesses	↔	The farmer–producer organization is contributing to collaborative decision-making based on the empowerment of the local community, economies of scale and profitability. While still quite recent, the intervention shows promise of transformative action in value-chain enhancements	↑

(*Continued*)

Table 3. (Continued).

5	Resilience attributes	2007	2012	2021	Direction of change (2007– 21)	2007	2012	2021	Direction of change (2007– 21)
	Reasonable profitability	3	2	4	↑	2	2	3	↑
	Human capital-building	2	3	3	↑	2	3	4	↑
	Infrastructure and information for innovation	2	3	3	↑	1	2	3	↑
	Ecological self-regulation	4	3	2	↓	2	3	3	↑
	Functional diversity	2	2	2	↔	2	3	3	↑
	Governance arrangements that support transformation	2	2	2	↔	2	2	3	↑
6	Reflection	In this step, certain findings were common to both case studies. (1) While there were some differences in the scoring during the different FGDs, there was consensus on the overall direction of change between 2007 and 2021. (2) A bias towards interventions targeting mainly agriculture and a lack of livelihood diversification and access to credit emerge as key inadequacies of current resilience-building interventions. (3) The lack of access to climate information services and local weather-based agro-advisories was highlighted as another inadequacy							

Note: 'Direction of change' refers to the overall change between the start (2007) and end (2021) of the assessment. ↑, positive change; ↓, negative change; ↔, no change.

that access to water influences the cropping pattern and level of intensification in agriculture. Access to adequate water throughout the year and better soil in Babai are key to its resilience, while Deulgaon Tad demonstrates other forms of resilience, such as better social organization within the community and efficient management of limited resources (particularly water). We also find a greater degree of ownership and post-project sustainability of project interventions in Deulgaon Tad. Discussions with stakeholders in Deulgaon Tad showed that some of this sustainability can be attributed to the capacity-building of the local community and of the institutions that were set up. A short summary of the system description and challenges is provided in Table 3, and a more detailed version is presented in Tables A4 and A5 in the supplemental data online.

Contribution of interventions to climate resilience

The cumulative effects of the interventions in each case study on the system functions and attributes are shown in Figures 2 and 3, respectively. We use the aggregate scores of the system function and resilience attributes as a proxy to demonstrate the overall resilience of the system. These scores of the functions and attributes are shown in Table 3 and reflect the resilience of the system in 2007, 2012 (a drought year) and 2021. We also indicate the starting year of each intervention in Figures 2 and 3 for reference. Based on the coding of transcripts from all stakeholder meetings, the functions and attributes each intervention in Babai and Deulgaon Tad contributes to are shown in Tables 4 and 5, respectively. The coding also helps in understanding if the contribution towards a specific function or attribute is positive or negative/neutral.

Babai

With its better water resources, Babai had more resilience than did Deulgaon Tad in 2007. This can be seen in terms of both the performance of its system functions as well as its

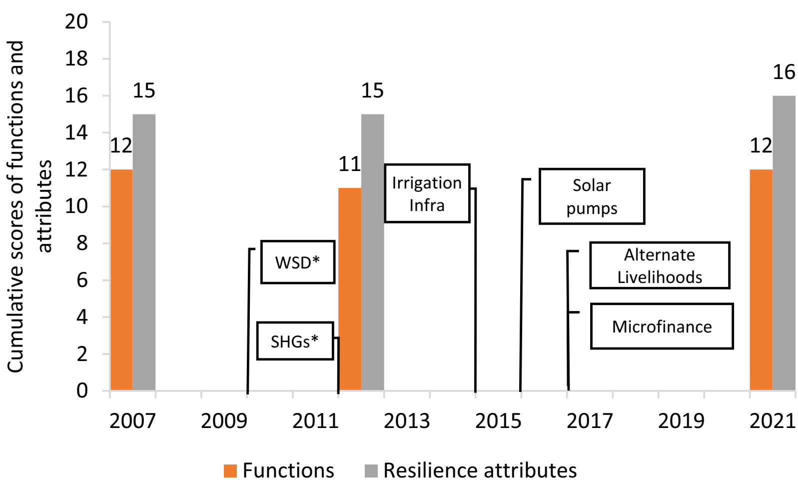

Figure 2. Cumulative effect of all the interventions on system functions and resilience attributes in 2007, 2012 and 2021 in Babai. Note: WSD, watershed development; SHG, self-help group.

Table 4. Contribution of interventions to a system function and/or attribute in Babai.

	Positive		Negative/neutral	
Interventions	Functions	Attributes	Functions	Attributes
Watershed development	Social organization Health of ecosystem Agricultural productivity Equity	Reasonable profitability Human capital-building Ecological self-regulation	Social organization Health of ecosystem Equity	Ecological self-regulation Functional diversity
Self-help groups	Social organization Equity	Reasonable profitability Human capital-building Functional diversity		
Irrigation infrastructure	Social organization Agricultural productivity Equity	Reasonable profitability Infrastructure and information for innovation Functional diversity	Social organization Health of ecosystem Equity	Ecological self-regulation Functional diversity
Microfinance	Equity	Functional diversity		
Solar pumps	Agricultural productivity	Infrastructure and information for innovation	Social organization Equity	
Alternate livelihoods	Equity	Reasonable profitability Human capital-building Functional diversity		

Note: Interventions such as watershed development and irrigation infrastructure included several activities each, from establishing physical assets to the formation of committees. Different aspects of the intervention can have a positive or a negative influence on the same function/attribute. For instance, the inclusion of all farmers within committees had a positive influence on the social organization function, while the exclusion of landless households had a negative influence on the same function.

general resilience attributes. However, there has been no substantial change in the overall resilience of Babai over the years. While there was a slight dip during the 2012 drought, the scores improved marginally, driven by the new irrigation infrastructure and some livelihood diversification.

Watershed development in Babai helped increase the cropping area and contributed to the expansion of water-intensive cash crops such as sugarcane, cotton, horticulture and floriculture (CS1-FGB-5). The irrigation infrastructure and solar pumps helped to draw additional groundwater to meet the needs of these crops. These interventions were followed by increases in agriculture productivity and reasonable profitability, but also led to decreases in health of ecosystem and ecological self-regulation (Table 3). The project management committees formed during the implementation of the watershed development and irrigation infrastructure interventions helped improve the functions of social organization for a while. However, this deteriorated after the completion of the projects, and the committees became defunct (CS1-MSG2-16 and CS1-MSG2-31). Furthermore, these interventions did not improve equity or governance issues as they did not benefit landless households in any way (CS1-MSG2-19). The work of the self-help groups and the alternate livelihoods interventions improved human capital-building and reasonable profitability (CS1-FGW-5 and CS1-FGW-6). The interventions also had a marginal influence on equity and functional diversity, as they focused on landless households, small farmers and women. However, these interventions have benefitted very few households (CS1-FGW-3) to date; therefore, we do not see any change in the overall score for equity or functional diversity in the village.

Table 4 shows that besides the initial watershed development intervention, none of the later interventions positively affected the health of ecosystem function or the ecological self-regulation attribute. Irrigation infrastructure had a negative impact on these aspects of resilience due to the over-intensification of agriculture, with the heavy use of chemical inputs that it entails (CS1-MSG2-11, CS1-MSG1-3). Irrigation infrastructure and solar pumps did not have a net positive influence on social organization and equity either, owing to their exclusion of landless households. The criteria to access subsidies for solar pumps exclude even small farmers (CS1-MSG2-1). The interventions in Babai had little or no influence on the governance arrangements supporting the transformation attribute.

Deulgaon Tad

Deulgaon Tad scored much lower than Babai did in 2007 in terms of both its system functions and resilience attributes in 2007 (Figure 3). Given this lower starting point, we see a rapid rise in terms of its specific and general resilience with the start of the watershed development interventions in 2008. The performance of system functions in 2012 might have been even higher, were it not for the drought. The improvement in its system functions slowed down in later years, as interventions continued to favour large farmers, and marginalized sections felt left out of decision-making processes (CS2-FGD-9). However, improvements were seen across all its general resilience attributes (Table 3), driven by the interventions that built adaptive capacities and agricultural productivity through better management of its natural resources.

As with Babai, Deulgaon Tad also saw an intensification of agriculture along with increased use of chemical fertilizers and pesticides and groundwater withdrawal soon after the completion of watershed development activities (CS2-MSG1-16). However, some key differences from Babai influenced how the farming system of Deulgaon Tad evolved in the following years. First, the watershed development intervention included setting up a village development committee, with representation of small farmers and other marginalized sections of the community (CS2-MSG1-56). The committee continued to be involved in later interventions introduced by the NGO WOTR. Improvement in social organization was, therefore, sustained even beyond the project period. The maintenance work done by the committee also ensured that the biophysical impacts of the watershed development work were sustained, thus improving health of ecosystem and ecological self-regulation (CS2-MSG1-61).

As opposed to Babai, the focus on health of ecosystem, social organization and ecological self-regulation in Deulgaon Tad continued even after the initial watershed development (Table 5). Later interventions of climate-resilient agriculture, water stewardship initiative, and food and nutrition security all had a strong focus on capacity-building through demonstrations and training programmes. These interventions also led to improvements in functional diversity, agricultural productivity, and reasonable profitability by promoting crop rotation, inter-cropping, mixed crop–livestock system and more efficient management of water resources (CS2-MSG1-11, CS2-FGD-5, CS2-FGY-6). Some interventions also contributed to the governance arrangements that support the transformation attribute. The village water management teams formed as a part of the water stewardship initiative (CS2-FGY-13) and the FPO contribute to

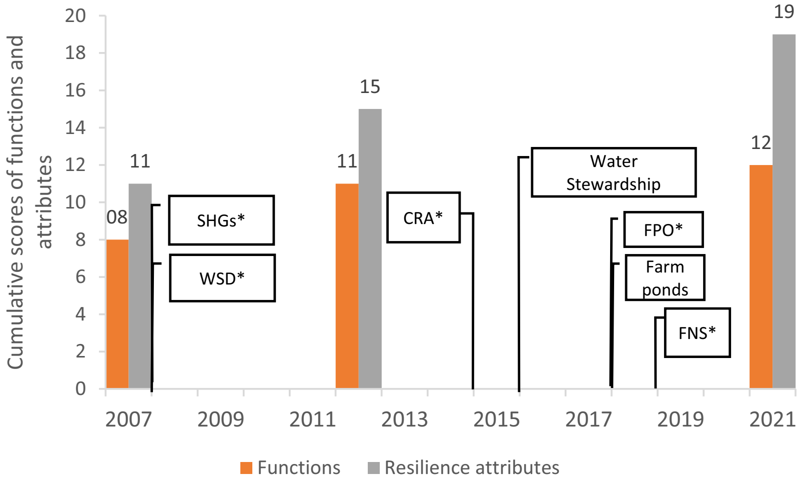

Figure 3. Cumulative effect of all the interventions on system functions and resilience attributes in 2007, 2012, and 2021 in Deulgaon Tad. Note: WSD, watershed development; SHG, self-help group; CRA, climate-resilient agriculture; FPO, farmer–producer organization; FNS, food and nutrition security.

Table 5. Contribution of interventions to a system function and/or attribute in Deulgaon Tad.

	Positive		Negative/neutral	
Interventions	Functions	Attributes	Functions	Attributes
Watershed development	Social organization Health of ecosystem Agricultural productivity Equity	Reasonable profitability Human capital-building Infrastructure and information for innovation Ecological self-regulation	Health of ecosystem	Ecological self-regulation
Self-help groups	Social organization Equity	Human capital-building		
Climate-resilient agriculture	Health of ecosystem Agricultural productivity	Reasonable profitability Human capital-building Infrastructure and information for innovation Ecological self-regulation Functional diversity		Infrastructure and information for innovation
Food and nutrition security	Agricultural productivity Equity	Human capital-building Functional diversity		
Water stewardship	Social organization Health of ecosystem Agricultural productivity Equity	Reasonable profitability Human capital-building Infrastructure and information for innovation Functional diversity Governance arrangements that support transformation		
Farm ponds	Agricultural productivity	Reasonable profitability Functional diversity	Health of ecosystem, Equity	Ecological self-regulation
Farmer-producer organization	Social organization Agricultural productivity	Reasonable profitability Governance arrangements that support transformation	Social organization Equity	

this attribute by providing a platform for discussing challenges and novel solutions (CS2-MSG2-5).

One of the key factors that contributed to the positive influence of interventions such as water stewardship initiative, climate-resilient agriculture, and food and nutrition security was that these were planned based on monitoring, evaluation, and learning by the NGO WOTR. The endline assessment of the earlier watershed development project and a vulnerability assessment done before designing the new interventions helped in making them better suited for the evolving needs of the community. Equity is an emerging concern, and there seems to be an urgent need for livelihood diversification, as expressed in the aspirations of the landless households (CS2-FGL-3) and youth (CS2-FGY-9). The same concern was discussed in the context of the FPO as well, where the key decision-makers were large farmers (CS2-FGY-10). There were also concerns around the emergence of plastic-lined farm ponds that have been used in the village since 2017 and their effect on groundwater (CS2-MSG1-52). These are often used to pump groundwater and store it on private land, particularly by large farmers, for use in drier months of the year (CS2-MSG1-49 and CS2-MSG1-50).

Discussion

The analysis of the two case studies showed that interventions focusing on improving productivity alone, such as watershed development and improving access to irrigation, had a limited impact on the overall resilience of the farming system. However, climate resilience indicators improved when these productivity-enhancing interventions were combined with those related to water management, soil health and livelihood diversification, together with an emphasis on monitoring, evaluation, learning and adaptive decision-making. We discuss these findings and also highlight implementation issues that warrant further attention. We believe these findings are relevant to policymakers at the state and national levels in India. We therefore provide a set of policy recommendations.

Insights from the two case studies

In both case studies, we observe that the initial watershed development interventions led to an intensification of agriculture and changing cropping patterns, which over time has led to dropping groundwater tables and deteriorating soil health. These findings reinforce the belief that agricultural development pathways in semi-arid areas have not met with much success. The bias of watershed development and allied agricultural interventions towards agricultural productivity while neglecting the development of adaptive capacities has been reported by several researchers (e.g., Bharucha et al., 2014; D'Souza et al., 2020; Singh, 2018). Highlighting patterns of social exclusion in watershed development, Kale (2020) pointed out the broader challenge of the lack of equity in agriculture-related interventions, where large farmers generally benefit the most. Prioritizing irrigation infrastructure without improving capacities for demand-side management, especially in resource-poor, rainfed and semi-arid regions, is short-sighted and worsens vulnerability to climate change in the long term (M. Shah et al., 2021b; Venkateswarlu & Shanker, 2012). However, this study showed that climate resilience indicators, especially those related to resilience attributes, were improved when climate-resilient agriculture, water stewardship initiative, and food and nutrition security interventions were introduced in Deulgaon Tad. A key focus of these interventions was building awareness and capacities of the local community to manage its own resources. The importance of community engagement and capacity-building in rural development and natural resource management are well established (e.g., Dyer et al., 2014; Murray & Dunn, 1995). Our findings show that these are equally important from a climate resilience point of view by enabling inclusive and adaptive decision-making. The water stewardship initiative and climate-resilient agriculture interventions helped the community undertake a water-budgeting exercise and crop planning based on actual rainfall for the given year. Community-based groups like village water management teams are then able to facilitate further discussions related to water-use efficiency planning and equitable groundwater governance. However, sustaining these initiatives beyond the period of a government or NGO-led project is likely to be a challenge.

The key to sustaining these initiatives lies in recognizing the economic benefits they yield, such as avoided crop losses and lower costs of external inputs, and perhaps even finding ways to strengthen such 'farmer-friendly' financial incentives (e.g., Siedenburg et al., 2012). Ensuring benefits from agricultural and rural development interventions for small and marginal farmers and landless households is another challenge that will need to be tackled. In both case studies, stakeholders did talk about prioritizing drinking water and water for livestock and ensuring that marginal communities receive wage benefits from labour activities related to the land- and water-related interventions to address equity issues. However, it was mentioned that any significant impact on improving the resilience of the small and marginal farmers and landless households would need a greater impetus to promote non-farm livelihoods.

Several studies discuss the need for livelihood diversification and non-farm livelihoods to improve the climate resilience of farming systems (e.g., Kumar et al., 2020; Mohammed et al., 2021; Mondal et al., 2016). A few non-farm livelihood promotion activities were carried out as a part of the comprehensive watershed development intervention in Deulgaon Tad, and some additional training and demonstration sessions were organized in Babai under the Maharashtra State Rural Livelihood Mission. However, these have benefitted very few households, and capacity-building for entrepreneurial activities and access to credit continue to be chief challenges in both case studies. Owing to the lack of attention to non-farm livelihoods, landless households, small farmers and women have not benefitted as much as large farmers have from all the agricultural development interventions. The lack of diversification has also translated into a greater sensitivity to changes in rainfall patterns and greater stress on the limited water resources in these semi-arid farming systems.

In an effort to improve the profitability of agriculture and financial incentives for managing the farming system, a FPO was set up in Deulgaon Tad in 2017. The FPO is already helping farmers get better rates for their produce, thereby contributing to profitability (CS2-FGD-22). There is also some evidence that the FPO can be encouraged to consider ecosystem health through its collective efforts. For instance, in 2021, the FPO was engaged in negotiations with the Jalna municipal corporation to source city compost at reasonable rates (CS2-MSG2-5). However, in the long term, whether such 'environmentally conscious' decision-making will always be a priority for the FPO is not clear. Moreover, the quotations from the youth (CS2-FGY-10) and marginalized sections (CS2-FGD-11) show that being inclusive in governance and decision-making is not always a priority for the FPO. Perhaps one way of ensuring checks and balances is to make the FPO answerable to the local *gram panchayats* for an appropriate form of a no-objection certificate when starting a new activity. Such checks may ensure some equity in the composition of the FPO, with small and marginal farmers also being included amongst the FPO's shareholders. Especially for sustainably managing socio-ecological systems, community engagement and inclusiveness must go beyond simply providing information to empower citizens to make their own decisions (Reed, 2008; Stringer et al., 2006).

Discussions in both case studies highlight the need for access to technology and information, especially short- and long-term climate forecasts and agriculture advisories based on these forecasts. Efforts to develop locale-specific, crop-specific, farmer-friendly advisories are beset by problems such as the technology itself and challenges of navigating institutional collaborations (Bendapudi et al., 2019; Lobo et al., 2017). The discussion in Deulgaon Tad showed that alongside these challenges, accounting for behavioural preferences of farmers is very important for greater uptake of such climate information services. It is also imperative to recognize the barriers for the poor and illiterate sections of the community for whom access to a smartphone itself is a barrier.

In our research, we selected two case studies with different contexts and a different history of interventions. While the benefit of such a choice is that it provides the opportunity to assess a wider range of strategies to address the climate resilience of the farming system, a drawback of this choice is the possibility of confounding factors influencing the results. A larger number of case studies with similar contexts and serving as a control for various external factors would have helped bring more generalizability to the conclusions. We believe that there is scope for more such studies on retrospective assessments to contribute to evidence-based policy. In terms of our content analysis, the coding of the transcripts was done by researchers, where a tag for the intervention and resilience function or attribute it contributed to was added next to the quotations from stakeholders. Care was taken to reduce any bias by triangulating the coding based on the notes from other focus group discussions and interviews that discussed the same topic. However, we acknowledge that this method is prone to researcher subjectivity and bias. The coding and tagging exercise is time-consuming and requires a nuanced understanding of different aspects of resilience. While getting involved in such an exercise may not be of interest to the local community, finding ways to incentivize them could yield more participatory research outcomes and co-produced knowledge.

Given the multiple challenges faced by farming systems in India, we believe that the time period considered in the study (15 years) and the assessment of multiple interventions (as opposed to just one intervention) contribute to the novelty of our research. Figures 2 and 3 provide a visual overview of the dynamic changes in the resilience of the system over a 15-year period. We believe that the focus on the overall direction of change, as opposed to the exact scores from the resilience assessments, means that this methodology is generic enough to be applied in other semi-arid farming systems in India or in other developing contexts. Tables 4 and 5 helped in clarifying both the positive and negative contributions of the interventions on different system functions and resilience attributes, providing a nuanced understanding of factors contributing to the resilience of the farming systems. This was also useful to understand the synergies and trade-offs between interventions by assessing the possibility of any negative influence of one intervention being compensated by another. For instance, the hesitation of the local community to trust weather-based agro-advisories (climate-resilient agriculture intervention) could be overcome by synergistic messages around appropriate crop choices and efficient water use (water stewardship intervention). Table 5 also shows that gains from the water stewardship and climate-resilient agriculture interventions could be undone by a large increase in the number of farm ponds. While farm ponds bring in better profitability for some farmers, there are trade-offs in terms of their negative impacts on health of ecosystem and equity through inefficient groundwater use and capture by a few large farmers.

Several studies have highlighted that no single set of interventions will be appropriate in all situations, underscoring the need to consider multidisciplinary and multi-stakeholder interventions for a more effective response to climate change (Denton et al., 2014; Schipper et al., 2022; Stringer et al., 2020). To help incorporate longer time frames, uncertainties, multiple and contested options, and different stakeholder views into planning, a pathways approach to understanding development and climate action has been gaining traction (Haasnoot et al., 2013; Leal Filho et al., 2021; Werners et al., 2021a). Fazey et al. (2016, p. 29) suggest the use of a pathways lens 'to understand the actual, but different routes taken in the past by different social groups (e.g., households, communities)' and discuss the usefulness of such retrospective assessments to plan interventions in the present and to respond to future changes. In this regard, we believe that our research contributes to the understanding of climate-resilient development pathways (Stringer et al., 2022; Werners et al., 2021a) for semi-arid farming systems, especially in terms of assessing the multiple risks, the cumulative effect of a wide range of interventions, and highlighting the importance of monitoring, evaluation, learning and adaptive decision-making. However, co-creating climate-resilient development pathways in complex multi-stakeholder environments requires further research, especially where decisions on the timing and sequence of interventions need to be made in contested spaces (Bosomworth et al., 2017; Werners et al., 2021b).

Improving the climate resilience of semi-arid farming systems in India: policy recommendations

Based on the insights from the two case studies and supporting evidence from the literature discussed above, we make the following five policy recommendations regarding interventions for improving climate resilience in semi-arid India.

Agricultural development interventions should consider ecosystem health, adaptive capacities and governance arrangements

The case studies assessed showed that a focus on agricultural productivity at the cost of ecosystem health reduced the system's resilience. Moreover, interventions that did not have provisions for effective social organization, governance arrangements or adaptive capacity-building lacked sustainability. The three elements of ecosystem health, adaptive capacities and governance are part of an ecosystem-based approach to climate change adaptation (Bertram et al., 2017; de Condappa et al., 2021; Vignola et al., 2015), which is gaining traction and would be very relevant for semi-arid regions in India. Accordingly, we suggest that the national watershed development guidelines need to be revised. With the elements of an ecosystem-based approach in place, the guidelines should include activities related to water stewardship, climate-resilient agriculture, food and nutrition security, soil health, biodiversity conservation, and inclusive governance mechanisms.

FPOs should be promoted to improve profitability and empowered decision-making

The FPO in Deulgaon Tad contributed to collaborative decision-making based on the empowerment of the local community, economies of scale and profitability. Given the dominance of smallholder farmers in semi-arid areas, we believe such action would be critical for increasing the adaptive capacity of farmers and agriculture's viability amidst future climate change and market uncertainty stresses. This is reflected in the Government of India's policy on promoting 10,000 FPOs across the country (GoI, 2021). However, the sustainability of these FPOs is challenged by issues such as understanding the complexity of domestic and international markets; getting the right human resources; access to loans; and capacity-building for operational issues such as technical support for post-harvest processing, book-keeping, managing debt and rotation of funds, especially in the early years of establishment (Chintala & Mani, 2022; Tagat & Tagat, 2016). Considering the diverse range of expertise that FPOs require, we recommend that the programme to promote FPOs in the country includes a detailed model for capacity-building that brings together agriculture experts, NGOs, financial institutions and private enterprises with experience in marketing and business operations.

Access to climate information services should be improved

Farmers in neither case study found the current sources of climate data or weather-based agro-advisories very useful. Reasons for the lack of usefulness included not being user-friendly and the need for a high literacy level and expensive smartphones. However, amidst the increasing frequency of weather variability being experienced, farmers do perceive a need for such information. Therefore, we recommend that app developers focus on providing more user-friendly solutions that are co-created with the involvement of the local community. We also recommend that agriculture extension officers and NGOs explore innovative ways of information dissemination, where language, literacy or access to a smartphone do not pose a barrier.

Income sources should be diversified with a focus on non-agrarian livelihoods

Both the case studies showed that most of the interventions did not benefit the marginalized groups of the community, especially landless households and women. Improved access to credit and support for establishing non-farm livelihoods was an often-repeated demand from these groups. Promoting such non-farm livelihoods can have multiple benefits of improving equity and functional diversity in the system and reducing the sensitivity to weather variations and climate change. A recent draft policy document on rainfed agricultural policy by the Ministry of Agriculture, unfortunately, does not include an action plan for livelihood diversification and has a very small section that addresses the needs of 'vulnerable and disadvantaged groups' (NRAA, 2022, pp. 27, 28). In this regard, we recommend that agriculture and rural development policies for semi-arid and other rainfed areas give adequate weightage to non-farm livelihoods, integrating access to credit, training on entrepreneurship skills, and advisory services (similar to agriculture extension services).

A monitoring, evaluation and learning component should be embedded within all interventions

While monitoring and impact assessment at the end of interventions took place in both case studies, Deulgaon Tad also showed evidence of 'learning' in the design of the new interventions. Based on project endline assessment and a climate vulnerability assessment study, new action research interventions were implemented here, ultimately leading to greater resilience. Therefore, we recommend embedding monitoring, evaluation and learning within the design of all agriculture and rural development interventions, which would help farming systems adaptively respond to both external (e.g., climate change) and internal (e.g., changing aspiration, soil health) challenges.

Conclusions

The overall objective of our research was to assess the contribution of agricultural development interventions to the climate resilience of farming systems in semi-arid India. To do this, we first assessed the climate resilience of two case studies: one where interventions targeted improving agricultural productivity and irrigation infrastructure, and another where interventions targeted the building of adaptive capacities in addition to improving agricultural productivity. Following this, we performed a content analysis of stakeholder interactions to draw insights about the contribution of interventions to its climate resilience.

We found that interventions that focused on improving productivity alone had a limited impact on the overall resilience of the farming system. However, improvements in the climate resilience indicators were seen when these productivity-enhancing interventions were combined with those related to water management, soil health, livelihood diversification, and food and nutrition security, in concert with monitoring, evaluation, learning and adaptive decision-making. The lopsided focus on agriculture has also meant a greater sensitivity to changes in rainfall patterns and greater stress on the limited water resources in these semi-arid farming systems. While interventions such as water stewardship, climate-resilient agriculture and promoting FPO can ensure better management of natural resources and better economic returns, addressing equity issues to reduce the vulnerability to climate change would require stronger initiatives to improve non-farm livelihoods. We also found that the time period of 15 years considered in the study and the assessment of multiple interventions enabled a more holistic assessment of climate resilience that took into account multiple challenges, such as access to water, soil health and equity issues. This approach is also helpful in considering synergies and trade-offs between interventions by assessing both the positive and negative contributions of the interventions on different system functions and resilience attributes, providing a nuanced understanding of the contributors to the resilience of the farming systems.

We also make the following policy recommendations in this study: (1) agricultural development interventions should be planned considering ecosystem health, adaptive capacities and governance arrangements; (2) FPOs should be promoted to improve profitability and empowered decision-making; (3) access to climate information services should be facilitated; (4) income sources should be diversified with a focus on non-agrarian livelihoods; and (5) a monitoring, evaluation and learning component should be embedded within all interventions. These recommendations can support the ongoing efforts of the National Rainfed Area Authority (NRAA) and the Government of India to enhance the ability of farming systems to cope with evolving challenges, including building resilience to climate change (Aggarwal et al., 2022).

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Disclosure statement

No potential conflict of interest was reported by the authors.

CRediT author statement

A.S.: conceptualization, methodology, investigation, formal analysis, writing – original draft, reviewing and editing. S.E.W.: supervision, conceptualization. D.Da.: investigation and data curation. M.D'S.: supervision. F.Lu.: supervision. M.P.M.M.: supervision, methodology, writing – review and editing.

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