Farming Practices and Water Management Strategies in Akole, Ahmednagar, India: A Response to Water Availability

Safira Asy Syifa – 1323725

May 2025

FSE80436 MSc Thesis FSE

MSc Resilient Farming and Food Systems

Farming Systems Ecology Group

Department of Plant Science

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Examiner: Dr Roos de Adelhart Toorop

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Department of Plant Science

Wageningen University

Droevendaalsesteeg 1, 6708 PB, Wageningen, The Netherlands

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ABSTRACT

aAkole, Ahmednagar, Maharashtra, India faces significant farming challenges due to heavy monsoon rainfall, severe summer droughts, and rocky-hilly terrain. The reliance of farmers on a rainfed system presents a challenge, and the application of water management interventions like farm ponds supported by subsidies and training are crucial to addressing water availability issues. This study interviewed seven farmers; in three villages (Murshet, Pendshet and Chichondi); four with and three without access to water interventions such as farm ponds, subsidies, and training; alongside four experts to understand local water management issues. The aim of the study was to understand farming practices and water management strategies that allow farmers to cope with drought situations in Akole tehsil (sub-district). The study used Fuzzy Cognitive Maps (FCM) with help of the Mental Modeler software to analyze the current knowledge of farmers and experts. Findings show that most farmers own smallholding land sizes, with rice being the main crop during the kharif season (monsoon) and drought-tolerant crops like wheat and pulses cultivated during dry seasons. Water interventions have improved farming opportunities and crop diversification for farmers with access (WI). In contrast, those without interventions (NI) remain with conventional rainfed with limited options. Social factors, such as land size and social status, significantly influence intervention access. Limited technical knowledge, high costs of implementation of farm ponds, and market-driven pressures are challenges farmers face. Further research is needed to understand the complex system in Akole, such as promoting good agricultural practices, like reduced tillage and mulching with plant residue, improvement in policy on market price, and developing a typology of farmers. Water is crucial in shaping farming practices in Akole. It affects farmers' livelihoods, and implementing water interventions is a good approach to help farmers improve their farming activities and address the unpredictability of the changing climates.

1. INTRODUCTION

1.1. Context Background

Water is an essential aspect of human life (FAO, 2020; D'Odorico et al., 2020), serving various purposes such as drinking, washing, and other daily activities. Moreover, it is a valuable and essential component for food production and agriculture (Knorr and Augustin, 2023; Perli et al., 2019). Crop water requirement adjusts with water available on the field, it leads to crop yield (OECD, 2014), preventing pests and diseases (Sreeni and Vasudeva, 2024) also to improve farmer's livelihood (Desai et al., 2012). However, challenges arise due to climate change, which has limited water resources and become a major obstacle to agricultural sustainability.

In agriculture, around 60% of the water withdrawn is ultimately consumed through processes such as evaporation and transpiration (Molden et al., 2011) However, the source of consumed water varies considerably. In regions facing water scarcity, the consumption relative to the total withdrawn can be higher. Water has been a crucial element in the development of farming in India (Perlin et al., 2019). Nearly two-thirds of agricultural land in this country relies on rainfed farming (Hobbs and Osmanzai, 2011; ICRISAT, 2022). According to Matham et al. (2024), the majority of farmers who use this system are smallholder and marginalized farmers who rely on agriculture for their livelihood.

The rainfed system is often related to cultivating rice, and this crop is essential in the country (Negi et al., 2025). Approximately 2,500 liters per kilogram of water are used to grow grains (Pfister et al., 2011), of which rice is particularly included. In unmanaged rainfed systems, especially in areas where high evaporation or poor drainage occurred, accumulation of salts occurred due to waterlogging and evaporation. The continuous cultivation can aggravate salinization and result in soil degradation (Rao et al., 2015; Wu et al., 2009). Salinity, which typically occurs in the lower layer of soil, prevents roots from absorbing essential nutrients and water (Foster et al., 2018; Dinneny, 2025), thereby affecting plant productivity (Sreeni and Vasudeva, 2024) and how farmer selecting crops for their farming activity. Therefore, the rainfed system seems inefficient in semi-arid regions (Pulido-Bosch et al., 2018).

Rainfed systems are strongly affected by climate change which alters rainfall patterns, increases extreme weather frequency, and reduces groundwater recharge (Ma et al., 2007; Kang et al., 2009; Nichols, 2016; OECD, 2014). This uncertainty and unpredictability initially due to erratic rainfall patterns and prolonged droughts can lead to reduced food production (Knorr and Augustin, 2023). High evaporation rates due to high temperatures is also significantly challenging the system and therefore threatening water available on farmers' fields and further threatens the stability of smallholder farming (Hellin et al., 2023) through unavailable water in the field for crop production, particularly in drought-prone areas such as Maharashtra (Kuchimanchi et al., 2019).

1.2. Problem Statement

Maharashtra is known as a drought-prone area, and it is most impacted by the limited amount of water during the dry season (BAIF, 2023). According to Rahase et al. (2023), Akole, which is situated in a hilly region, has an annual high rainfall in the Ahmednagar district, with 40 rainy days, making it the highest in the district and prone to soil erosion. However, the tehsil (sub-district) also experiences long dry spells, which cause heavy crop yield losses. September is the wettest month in the region. In the northern part of Maharashtra, specifically Akole, farmers experienced both situations of heavy rainfall and drought (Sasane, 2016) lead to water scarcity.

Farmers in Akole still rely on more conventional water management, such as rainfed, gravity-based systems, or no saving at all. With the current system and changes in precipitation, farmers have experienced a limited water supply, resulting in a significant reduction in their agricultural productivity (BAIF, 2023). The lack of water results in lower crop yields. Moreover, limited access to new knowledge has become another crucial factor in facing water scarcity. Due to a lack of knowledge, farmers were unable to adopt new methods of water management (Lamm, et al., 2017). Therefore, they choose to leave their fields or land barren during the post-monsoon seasons (zaid and rabi) (Hobbs and Osmanzai, 2011), which leads to a reduction of their agricultural productivity.

Addressing these issues requires sustainable water management strategies. Implementing water interventions to improve water use efficiency and support farmers in adapting to changing climate conditions is needed (Sanga and Koli, 2023). Interventions refer to specific actions, implementation of technologies, or policies to manage water practices and improve outcomes related to water availability, efficiency and agricultural productivity. These can range from the adoption of new irrigation techniques (Dhawan, 2017) to the implementation of water conservation policies and the introduction of knowledge-sharing initiatives (Maggioni, 2014). According to Matham, et al. (2024), the Participatory Watershed Development Programme, which addressing drought conditions and incline groundwater in rainfed systems for agricultural purposes, is the most widely used intervention in India.

In Akole, a watershed project has been introduced for two years with the sacrifice of a minimum amount of farmers' land, such as a farm pond, for common use, such as the development of a Gabion Wall (BAIF, 2023). Unlike conventional irrigation or conventional water management that can reduce water resources (Amalia, et al., 2020), several techniques implemented can improve water availability. Such rainwater harvesting, drip irrigation, watershed management, and agroecological practices can be implemented. Some of these methods increase the amount of water irrigation and others allow for more efficient and affordable water use in the area (BAIF, 2023; O'Leary, et al., 2011; Hobbs and Osmanzai, 2011). Sustainable water management emphasizes long-term water conservation. It ensures that agricultural production in the region remains viable even in water-scarce conditions (Zhang, et al., 2021).

1.3. Objectives and Research Questions

The main objective of this research is to understand farming practices and water management strategies that allow farmers to cope with drought situations in Akole, Ahmednagar, Maharashtra, India. The sub-objectives are:

1. To understand the water management strategies and adaptation strategies employed by farmers and to identify the influencing factors behind the practices.
2. To analyze the differences and challenges in water management strategies used by farmers with and without interventions in addressing water scarcity and availability.

After building the objectives of this research, we found some interesting questions which we conducted as research questions.

1. What farming practices do farmers employ to adapt to water availability and what are the influencing factors?
2. What water management strategies do farmers use, especially farmers without intervention (NI), and the impacts of implementing interventions in addressing water scarcity?
3. What are the key differences and the challenges farmers face in water strategies between the two groups?

2. METHODOLOGY

2.1. Research Context

The research was conducted in the CGIAR initiative on Nature Positive Solutions. This project is active in five different countries. One of the countries is India, where the project is located in two different clusters: Akole, Ahmednagar, and Nandurbar, all of which are located in the state of Maharashtra. The sub-district is known as rich in biodiversity as it is part of the Western Ghat. Therefore, it has many traditional agricultural knowledge systems (BAIF, 2023) that need to be preserved. The project aims to strike a balance between the need for high food production and environmental preservation, particularly by enhancing soil moisture and groundwater recharge (Bahera, et al., 2025). Besides, the project works to mitigate greenhouse gas emissions and to reach net-zero emissions in the future. Additionally, this initiative has the objective of increasing profits for smallholder farmers who contribute to the agrifood system. The project in India is a collaboration between CGIAR and the Indian Council of Agricultural Research (ICAR) and BAIF Development Research Foundation (BAIF). In the research conducted in this thesis, the main focus is centered on the problem of water shortages which are a major problem in the Akole.

2.2. Study Area

This research focuses on Akole Tehsil, Ahmednagar district, Maharashtra state (Figure 1). Maharashtra is located in Western India and encompasses diverse climatic zones. The state has several districts, and Ahmednagar is one district spans 5.6% of Maharashtra's total area and is situated between latitudes of 18.2°N to 19.9°N and longitudes of 73.9°E to 75.5°E, consisting of 14 tehsils (sub-districts) with 1602 villages. The district has various climatic conditions, but it is generally hot and dry, while the western part of the district is cooler and drier due to hilly terrain. The eastern part of the district is hot and dry, making the district experience drought-prone areas with uneven rainfall distribution.

Akole tehsil is located in the western hilly region, with the highest surface at 5427 feet on Kalsubai mountain and contains 191 villages. Akole tehsil has two different zones: the Transition Zone (receiving 700-1250 mm rainfall) and the Hilly Zone (1250-3250 mm rainfall), especially during the southwest monsoon season (Ahmednagar.org, n.d.; Gadekar Janardhan, 2021; Kharde, *et al*., 2022).

This study focused on three villages: Chichondi, Murshet, and Pendshet. The selection of villages was based on different levels of landscape. Amongst three villages, Pendshet is located closer to Kalsubai Mountain and has an average elevation of 873 meters above sea level. At the same time, Chichondi and Murshet are located between 741-781 meters above sea level (topographic-map.com, n.d.).

Regarding the cropping patterns, farmers in the three villages, grow a wide variety of crops and have different cropping sequences through the seasons. However, rice was the most common crop, grown primarily during the kharif season (monsoon) with the rainfed system. Besides rice, farmers cultivated millet, which requires less water or can be intercropped with rice. During the rabi season (winter), the crops grown were more varied, consisting of wheat, millet, and pulses. The crops grown during rabi were resistant to dryness as they mostly relied on soil moisture.

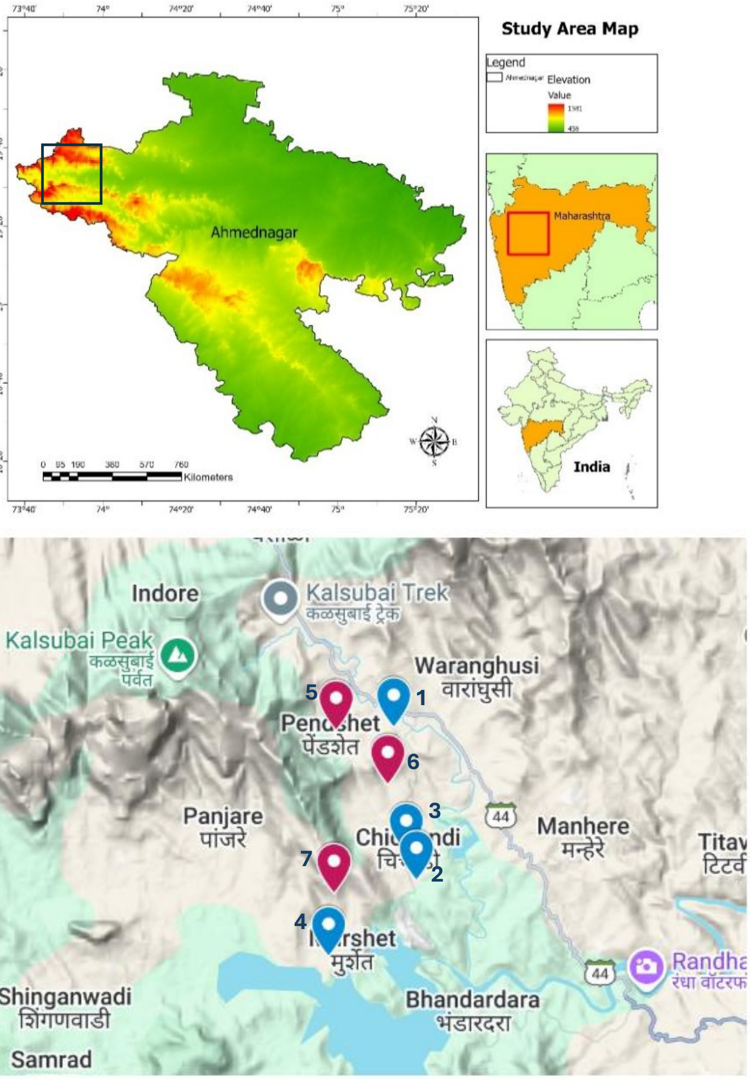

Figure 1. Location of the district of Ahmednagar in India (top) and of the seven farmers that were interviewed as part of a thesis (bottom; blue pin: farmer with interventions and red pin: farmers without interventions)

Akole experiences high annual rainfall; however, only 80% of it is retained, with the remaining 20% lost to evapotranspiration and infiltration, resulting in specific hydrogeological challenges for water management. The soil in the sub-district consists of shallow black and red sandy soils in a hilly terrain area. Soil types contribute to high infiltration and limited surface runoff. The limited adoption of rainwater harvesting techniques among farmers further hinders efforts to improve water availability for irrigating crops (Behera, et al., 2025).

2.3. Climate Condition

The monsoon season typically occurs from June to late October or early in November. Figure 2 shows the annual rainfall pattern and the average temperature from 2020 until 2024 in Akole tehsil. The average annual rainfall recorded was 920 mm (from 2020-2024). Temperature throughout the year has remained relatively stable, the annual average in 5 years was 24.4°C, with the highest temperatures always in June or early monsoon and drops when the monsoon comes to an end. The rainfall fluctuated and was recorded in the Ahmednagar district. It was clear that most farmers were cultivating their rice production during those months due to high amount of water available during the season.

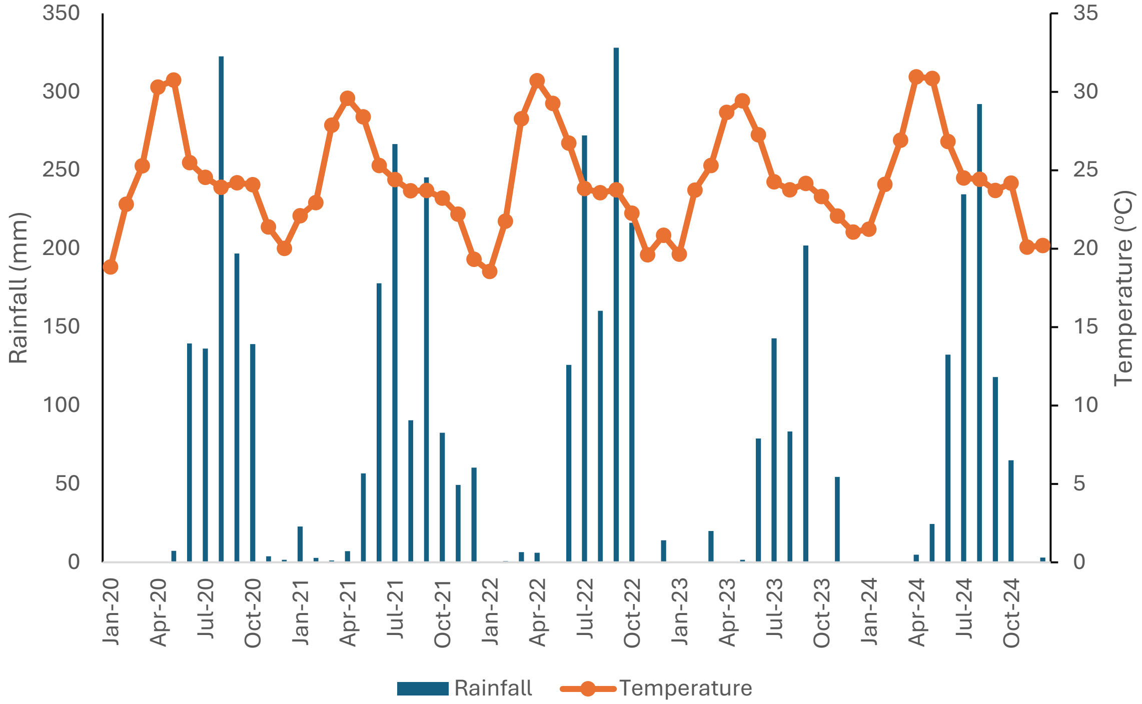

Figure 2. Rainfall pattern in Ahmednagar district from 2019-2024 (June-September) (Source: https://maharain.maharashtra.gov.in and https://power.larc.nasa.gov/data-access-viewer/)

2.4. Data Collection

Data collected to analyze farmers' adaptation strategies toward water scarcity. This study employed a mixed-methods data collection approach, utilizing both qualitative and semi-quantitative methodologies. Collected data through primary and complementary secondary data. The fieldwork was conducted from November 16 to December 20, 2024, and data collection continued until February 2025 through online interviews with experts.

2.4.1. Farmers' Selection

The research selected seven farmers as participants. The seven farmers were divided into two groups: with interventions (WI) and without interventions (NI). Farmers who receive interventions typically have greater access to water, gained through training from organizations and subsidies to implement these interventions on their fields. The interventions mentioned include farm ponds, gabion walls, farm field bunds, and other rainwater harvesting techniques. The second group consisted of farmers without interventions. This group is relatively vulnerable due to a lack of access to water and often relies on rainfall to grow their crops. Some of the farmers in this group had wells that were passed down by their ancestors. However, it was not efficient enough to irrigate their fields.

2.4.2. Questionnaire and Interview

A questionnaire was used to gain information from farmers in Akole. Due to limited literacy and understanding, farmers were given a questionnaire with multiple-choice questions to help them answer the questions. The questionnaire employed a semi-structured approach, as it was conducted in conjunction with an interview. A local translator, who spoke Marathi (a local language), assisted with the interview and survey among the farmers.

The questionnaire was conducted and divided into several topics, including the demographics of farmers (Appendix 1). It was then divided into several subtopics: the crops they cultivate, their adaptability to water scarcity, challenges, and their history before interventions were applied (for groups with interventions), as well as their future wishes regarding their farming practices and systems. This approach helped answer Research Questions 1 to 3.

2.4.3. Experts Interviews

After interviewing farmers in the region, we interviewed four experts: a water civil engineer, a researcher in biodiversity, a researcher in water management, and a field extension worker who works directly with farmers in Akole. The interviews covered farmers' understanding of the challenges they faced during the implementation of water interventions, the work they have done, and their knowledge of the area context. The whole information helped structure the research on refining the Akole area and how farmers faced the problems based on the experts' experience. This approach helped answer all research questions.

2.4.4. Observation and Participatory Field Mapping

Observation and participatory field mapping were also conducted during the data collection. The approach was conducted together during a survey and interview with farmers. Farmers were asked to draw their field on a piece of paper and indicate in which areas it is scarce and the source of water. Additionally, they helped in indicating which crops were cultivated in each season. The approach helped in answering Research Questions 1 and 2.

2.4.5. Baseline Data

Baseline data, consisting of general information from 102 farmers in Akole across 10 villages (a scope study project of NPS), were collected by BAIF. The data was used to put the results of interviews and questionnaires in a broader context.

2.5. Analyzing Data

2.5.1. Qualitative Analysis

After the interview with the farmers, the data was transcribed with the help of Microsoft Word. The recording generated several passages, and each answer was combined with the corresponding answers from the questionnaire. Thematic analysis was conducted by manual coding. This code was then used as a variable or concept to generate cognitive maps (similar to fuzzy cognitive maps) for the two groups of farmers (WI and NI) and the experts. The results of the interviews were used as quotations to support the findings.

2.5.2. Semi-Quantitative Analysis

Fuzzy Cognitive Mapping (FCM) is used to complement the qualitative findings and to support the research questions. In this research, there were three different models built to analyze the results after interviewing both farmers and experts. According to Barbrook-Johnson (2022), FCM has two approaches: causal and dynamic. Both methods use numerical values to measure factors or concepts. The causal mapping approach helps people examine the certainty of each concept's relationships and whether a one-factor change would lead to another. While dynamic is more about measuring the weight of each relationship with further synthesis analysis, and a more dynamic process of building the map through scenarios. The maps were drawn using a mind-mapping application called Miro.

In this research, a causal approach was employed to highlight the key differences factors influencing farmers adaptive in certain conditions caused by the interventions. Causal relationships between key factors are identified through transcribing and coding the interviews. The next step was to give a value to the concepts. The number of each measurement is shown in Table 1. The number represents the strength and impact of each factor on the others.

Table 1. Value of the connections on the map

Symbol	Value
+++	1
++	0.66
+	0.33
-	-0.33
--	-0.66
---	-1

The Mental Modeler software was used to help with the analysis and identify the adaptive management of identifying problems and solutions before the implementation of models; also understanding current system thinking to have better decision-making (Gray, et al., 2012). Mental Modeler calculates indicators to characterize the role of concepts in the cognitive maps (in-degree, out-degree, and centrality) and identifies three types of concepts (driver, ordinary or receiver). The concepts were categorized by in-degree; degree to which the concept is influenced by other concepts, sum of incoming influences) and out-degree concept; degree of influence that a concept has on other concepts in the system, sum of outgoing influences, and the centrality concept is the sum of in-degree and out-degree.

Driver concepts tend to influence or initiate or a caused of other concepts, but are not influenced by other factors. In contrast, the receiver is a factor or concept that results from or is the effect of other factors. An ordinary concept is both influence by and influencing other concepts (Gray, et al., 2012; Gray, et al., 2014).

3. RESULTS

3.1. Cropping Patterns and Seasonal Strategies

Farmers in Akole follow a seasonal cropping calendar shaped by water availability. All farmers cultivated rice during kharif season, also indicated as the major crop in the region with 23.3% (Table 2), a water-intensive crop aligned with monsoon rainfall. However, the interviewed farmers mostly cultivate rice-wheat pattern throughout the cultivation seasons. An expert also mentioned that during the kharif season, *"Akole is a wet and humid area, that is the reason most farmers cultivate rice, as it is suitable within the region."* Wheat is the dominant crop during rabi, mostly grown using soil moisture. Also mentioned by all farmers, *"after rice, we cultivate wheat using soil moisture. It is less water-intensive"*.

Other crops, including pulses, groundnut, and millets, are also cultivated. The selection of crops is not only based on similarity in water needs but also to support household nutrition. One of the farmers also mentioned their strategy during the interview, *"When water is limited, we choose drought-resistant crops like chickpeas. It is easy to cultivate because it doesn't need much water"* (Farmer NI01). Another reason is that *"Due to limited yield produced, we use it for home consumption. Besides, it is very nutritious to consume"* (Farmer NI03).

Most farmers with interventions (WI) can continue farming in the zaid (summer) season, cultivating crops other than those mentioned and expanding to high-value fruits such as strawberries and watermelons. These cropping choices demonstrate that diversification is closely linked to access to water infrastructure and available water during dry periods, filling in the gap of the cultivational season in Akole (Appendix 3).

Table 2. Cropping patterns of farmers in Akole district

Cropping Pattern	Total Farmers	Percentage (%)	Interviewed Farmer Placement
Rice	24	23.30	-
Rice, Wheat	14	13.59	All, specifically NI01
Rice, Wheat, Lentil/Chickpea/Hyacinth Bean/Bean	13	12.62	WI01, WI04, NI03
Rice, Wheat, Millet	11	10.68	WI03, NI02
Rice, Millet	10	9.71	-
Rice, Lentil/Chickpea/Hyacinth Bean/Bean	5	4.85	NI01
Rice, Wheat, Groundnut	4	3.88	WI01, WI02, WI03, WI04
Rice, Lentil/Chickpea/Hyacinth Bean/Bean, Groundnut	1	0.97	WI01, WI02
Rice, Maize, Groundnut	1	0.97	WI04

Note: The data consists of 102 farmers, based on baseline data.

3.2. Water Sources and Access

Rainfall is the primary water source for all farmers, especially during kharif season (Table *3*). Farmers with interventions (WI) supported by the implementation of farm ponds for collecting rainwater and owning a solar pump or electric pump through a subsidy, as well as functional wells. In contrast, farmers without interventions (NI) rely mostly on rainwater in kharif and on more conventional methods for water management, as shown in Table *3* counted 43.12%. Moreover, farmers also accessed water resources from wells; however, these wells were frequently silted with soil and unable to provide water on demand for agricultural purposes due to limitations in the groundwater level. Many farmers in this group report limited or unreliable access to water infrastructure, and some opt to barren their land when the summer (zaid) season is coming.

Table 3 Farmers' water source for irrigation in 10 villages.

Water Source	Frequency	Percentage (%)	Interviewed Farmer Placement
Rainfall without irrigation	47	43.12	NI01, NI02, NI03
Well	31	28.44	NI01, WI01, WI02,
River	12	11.01	-
Dam	9	8.26	WI02, WI04, NI02
Rainwater with irrigation	6	5.50	WI01, WI02, WI03, WI04
Pond	4	3.67	WI01, WI02, WI03, WI04

Group WI farmers report more consistent water use, enabled by interventions. In contrast, NI practices are more reactive to rainfall variability. However, one farmer in NI is more equivalent to gaining access through joining a collective group, as explained: *"I had access to the dam (through the collective group) and used a pipeline. However, today I am not able to get water from there due to limited water and my farm's location, which is far from the dam,"* Farmer NI02.

3.3. Farmer Profiles and Land Characteristics

Farmers with interventions (WI) typically have larger and more accessible land, increasing their eligibility for government or NGO support. They are not solely dependent on rainfall and have mitigated concerns about water scarcity by utilizing farm ponds, which they manage effectively following expert training, and with the help of a subsidy. In contrast, farmers without interventions (NI) tend to own smaller or fragmented parcels of land and face difficulties in applying for subsidies and other interventions. Additionally, land topography, particularly rocky soil, poses challenges for some of these farmers, especially in regions where constructing farm ponds is not feasible.

The average farm size among surveyed farmers was 2.57 hectares (Figure *3*). The seven farmers interviewed primarily represented the dominant smaller landholding categories in Akole, typically less than 4 hectares, with an average holding of 2.27 hectares (Table 4; Figure *3*). Interviews revealed that farming in Akole tehsil is largely a family-based system with passed-down land. Family involvement significantly influences crop selection and farming practices, as illustrated by the quote: *"My parents are still involved in the selection of crops. Therefore, I cannot cultivate strawberries (because they are still involved in crop selection)"* –Farmer WI01. This quote represents that despite owning sufficient land size and water availability, the decision still relies on the family.

The data in the Table 4 and Appendix 2 indicates a potential link between water access and land size. Agriculture served as the primary income for most interviewed farmers. However, two individuals supplemented their income with off-farm occupations, which enhanced their ability to secure water resources and mitigate water scarcity. The average age of farmers was 44 years, with no significant difference in farming experience between the groups. While age and experience did not show a direct correlation, educational background and family involvement appear to play a role in shaping farming practices.

Table 4. Profile of seven farmers (the interviewed farmers

Variables	With Interventions (WI)				Without Interventions (NI)		
	WI01	**WI02**	**WI03**	**WI04**	**NI01**	**NI02**	**NI03**
Age	40	60	45	27	37	39	57
Farming Experiences	<5 years	>30 years	11-30 years	5-10 years	11-30 years	11-30 years	>30 years
Education	College	Primary	Secondary	College	College	Secondary	Primary
Land size (hectare)	2.02	4.05	1.21	5.26	1.21	1.42	0.71
Land size during rabi/zaid (hectare)	1.21	2.02	1.01	1.01	0.2	0.2	-
Income	50,000	500,000	50,000	250,000	40,000	50,000	20,000

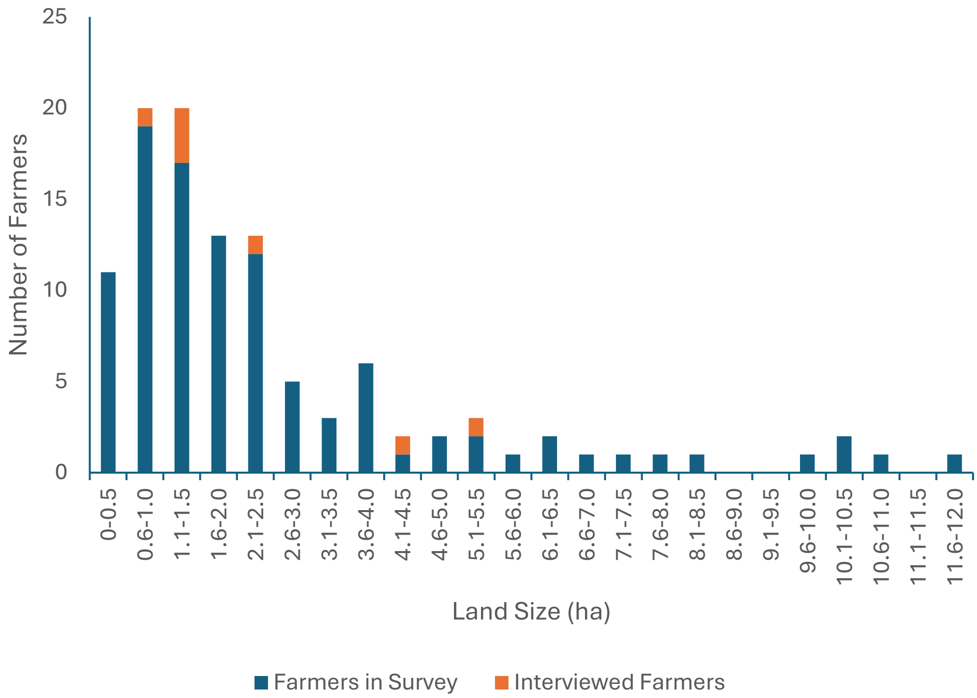

Figure 3. Distribution of land area per farm in the survey of 102 farmers and the interviewed farmers in Akole tehsil.

3.4. Farmers' Challenges in Water Access and Management

Farmers identified the high implementation cost of interventions as a major challenge. This was further emphasized by an expert interview, which highlighted the potential for significant ongoing maintenance costs for water storage solutions. While three WI farmers received government and NGO subsidies covering up to 20% of costs. Interestingly, one WI farmer, despite being part of the same intervention group (with a farm pond and NGO training), did not receive a subsidy. He initially gained water access during the summer through a collective group with permission to draw from a nearby dam. However, the declining membership of this collective, with most farmers ceasing their subscription to the local water agency, has increased this particular farmer's water-related expenses. In contrast, three farmers in the without interventions (NI) also explicitly cited the high cost of accessing water as a major obstacle. The expert interview also pointed to the important role of NGOs in facilitating implementation and mitigating these challenges in broader watershed projects. Additionally, a significant issue was the limited knowledge of farmers. It leads to the continued use of conventional and outdated practices that are inadequate for current environmental changes. Further see Appendix 6.

3.5. Cognitive Maps and Perceived Influences

Farmers' perceptions of water management were captured using Fuzzy Cognitive Mapping (FCM). While group WI showed a strong link between Water Availability, Water Management, and Crop Choice and Diversification, group NI seems to have different drivers, although both groups have almost similar concepts (Figure 4 and Figure 5). NI prioritized Crop Yield and Rainfall (Table 5). The complexity scores between the two maps show no significant difference; however, they were slightly higher for Group NI. This suggests that NI requires farmers to consider more variables and face greater uncertainty. Table 5 presents a comparative summary of central concepts across both groups.

Table 5 Fuzzy cognitive mapping analysis degrees and differences

Type	Top Concepts –With Intervention (WI)	Top Concepts –Without Intervention (NI)	Differences
Centrality	Water Availability, Rainfall, Crop Choice & Diversification	Rainfall, Water Availability, Crop Choice & Diversification	Same concepts, different in priority.
Outdegree	Water Availability, Rainfall, Crop Yield	Rainfall, Summer, Water Availability	WI focuses on resource use, while NI focuses on natural seasonal conditions.
Indegree	Crop Choice & Diversification, Water Availability, Water Management	Crop Choice & Diversification, Water Availability, Crop Yield	WI includes water management; NI on crop yield as an outcome.
Complexity	0.15	0.17	NI has slightly more complex, more varied practices.

The expert cognitive map (Appendix 4, Figure 8) incorporates broader systemic concepts, such as Climate Change, Water Use Efficiency, Resiliency, and the implementation of drip irrigation, which are part of the interventions. These reflect a long-term perspective on sustainability and adaptive capacity that was less visible in farmer maps, especially for those farmers without interventions (NI). The comparison highlights how interventions are not just technical fixes but are part of building long-term resilience and efficiency in water-scarce farming systems.

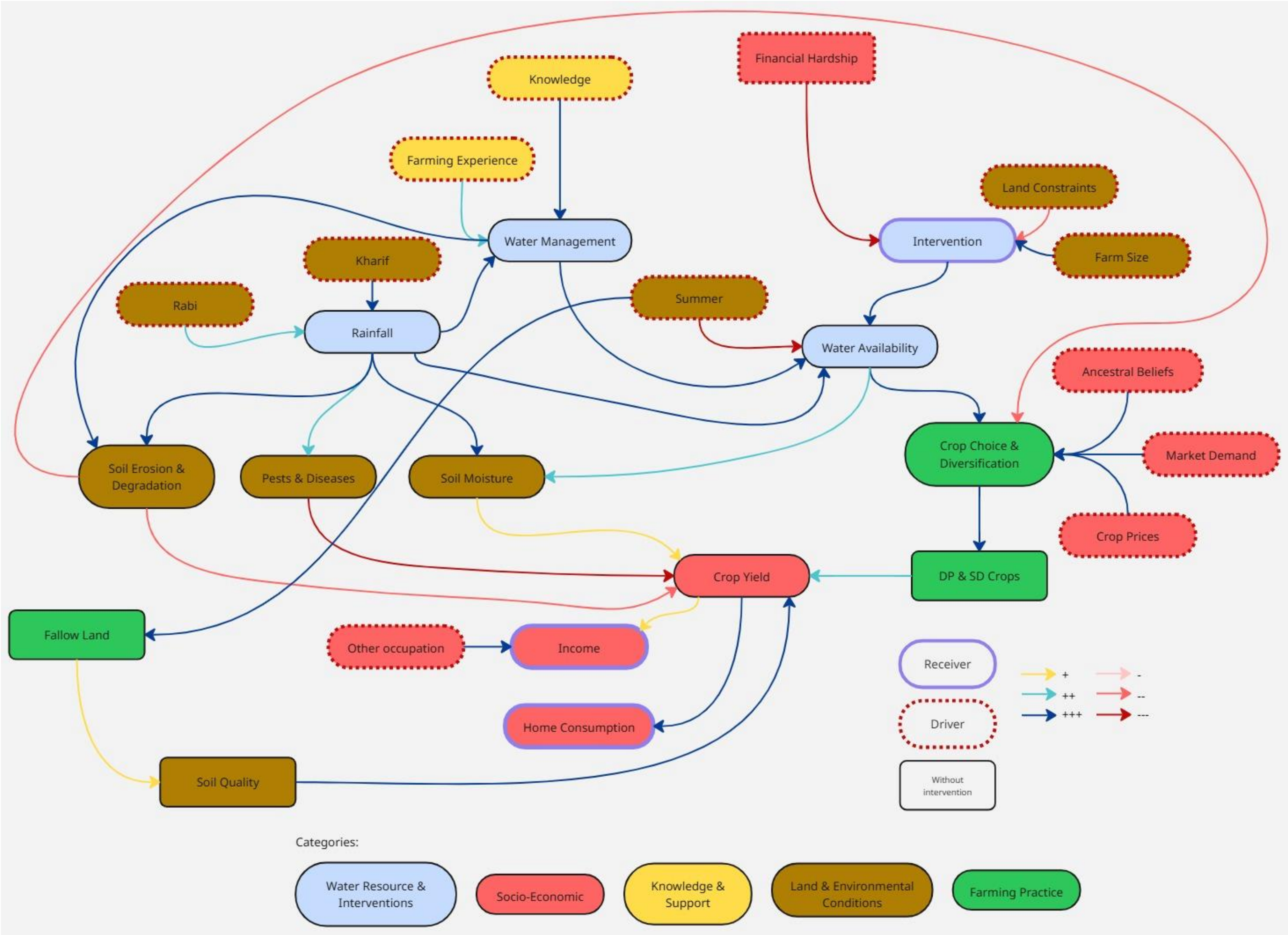

Figure 4. Fuzzy cognitive mapping farmers without interventions (NI)

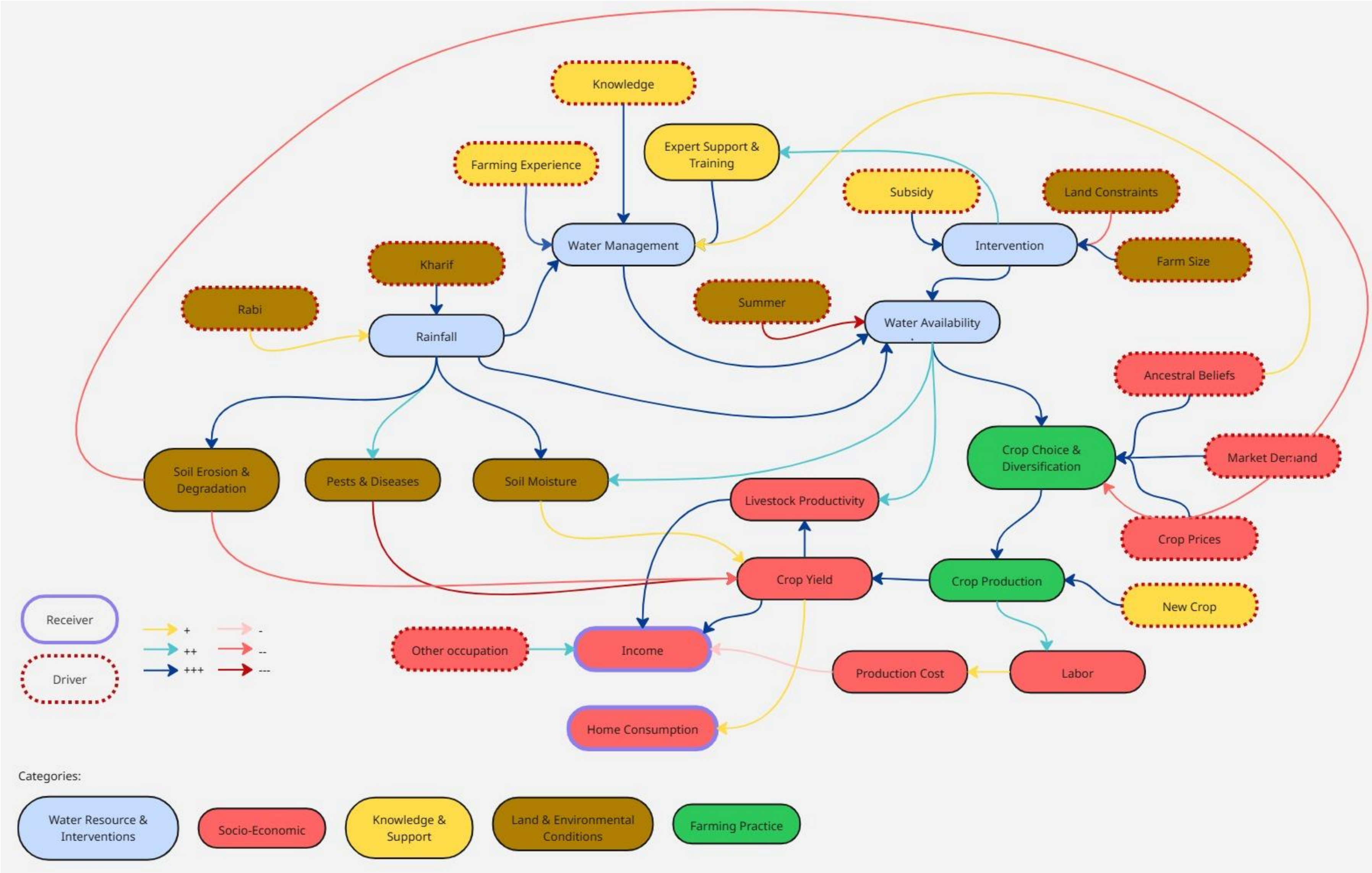

Figure 5. Fuzzy cognitive mapping of farmers with interventions (WI)

4. DISCUSSION

4.1. Cropping Patterns, Farming Practices and Water Adaptation Strategies

Farmers in Akole commonly grow rice during kharif season, aligning with the region's limited rainfall and hilly terrain. Rice requires a high demand for water, which is suitable for the season, while other seasons offer minimal access to water. Although local rice varieties exist, most farmers opt for dominant commercial types due to market demand, high-yield varieties due to their economic returns, leading to a decline in some local cultivation varieties. The expert has mentioned this, *"reduction in diversity of varieties of crops led by mechanisms of commercial demand on the market"*. Wheat is the main rabi crop, cultivated using residual soil moisture—a strategy shaped by limited irrigation options and water available in the field. A statement by Zachariah et al. (2020) mentioned that crop selection is linked with environmental factors, particularly water, to farmers' decisions, especially in semi-arid regions. As the area is in rocky-hilly terrain, it limits crop diversity. This statement is supported by Sreeni and Vasudevan (2024), highlighting some varieties adapting to the climate, soil, and water availability.

Farmers without interventions (NI) mainly rely on traditional methods like soil moisture to grow wheat and other waterless crops. This approach reflects their dependency on rainfall, as also seen in Table 5, where Rainfall, Summer, and Water Availability rank among the top influencing factors. The method is widely used due to its accessibility and low cost, offering various agronomic benefits. However, with uncertain rainfall and climate conditions, these practices may lead to lower yields, as supported by Saidy et al. (2008) and Whitmore (2009). Although soil moisture reliance promotes deeper root growth in crops, it can lead to lower yields due to limited and improper irrigation and nutrient availability. This suggests that, in the absence of adequate infrastructure, soil moisture alone may not support optimal crop performance, especially in increasingly erratic rainfall.

In addition to soil moisture, NI farmers maintain traditional soil bunds to reduce the impact of heavy rainfall during the kharif season on soil erosion. However, these structures are often insufficient to conserve water for the longer term, contributing to subsequent water scarcity during the post-monsoon period (Bekele et al., 2018). Some farmers have established a collective group to manage water access, as demonstrated by Farmer NI02 and WI04 (Table *4*). However, this arrangement appears to be fragile. The unpredictable rainfall and dependence on unmanaged water infrastructure highlight significant inefficiencies, which diminish the group's capacity due to a lack of structured management. This observation is further supported by Bassi et al. (2014), who emphasize the broader unsustainability of relying exclusively on self-organized, informal water management systems in regions experiencing dynamic environmental conditions. Another relatable strategy chosen by farmers is barren land as a default. Although this reduces income and yield, it is a low-risk way to preserve soil quality and moisture. According to O'Leary (2011), it improves soil quality and is relatively efficient in improving next season's yields.

4.2. The Intervention Impacts

Water interventions, like farm ponds, have significantly improved farming conditions for WI farmers (with intervention farmers). By capturing rainfall during kharif, these structures reduce soil erosion, enhance water availability and enable irrigation in the dry rabi and zaid seasons. this aligns with findings from Rao et al. (2017), who highlighted farm ponds' role in recharging groundwater and stabilizing farming systems. As also supported by the Water Researcher and Civil Engineer, *"the implementation of* *watershed project, like farm pond and Gabion Wall, will not only benefit one farmers, but also target the entire or the whole farmers in the impacted area"*.

Training and subsidies provided by NGOs and the government were crucial for successful implementation. These subsidies not only made the infrastructure financially accessible but also shaped how effectively farmers could use them afterward. Training sessions equipped farmers with practical knowledge on water-efficient practices, crop diversification and maintenance of the ponds. This encouraged structured water management and confident decision-making. As Das (2013) emphasizes, combining farm pond and irrigation with farmer education significantly increases productivity and sustainability.

One key outcome of improved water access through the implementation of interventions was diversifying crops. As also mentioned by Garg et al (2021), water availability broadens farming opportunities, in this case, of introducing a new crop. Farmers began cultivating high-value crops such as strawberries and watermelons, which would not be possible without reliable off-season water. The intervention helped lower the perceived risks of trying unfamiliar crops. Farmers mentioned that this support gave them confidence beyond subsistence crops. This diversification, in turn, improved better livelihoods. It also indirectly supported livestock improvement productivity. Access to water in the field has reduced the need for farmers to travel outside to feed their livestock, saving time and effort. The increased availability of water boosts the role of livestock, serving not just as a resource but also as a crucial element in enhancing farmers' yields.

4.3. Factors Influencing Farmers Practices

Despite the positive impacts of water interventions, not all farmers have equal access. Factors such as land quality, farm location and social status influence eligibility, with better-connected or wealthier farmers more likely to qualify for support schemes (Jha and Gupta, 2021). As a result, smallholder farmers with limited resources were often excluded, reinforcing inequality in access to innovation and external support. Knowledge from previous generations also shape adaptation strategies. Many farmers follow practices passed down from older generations. This could lead to reluctance as farmers prioritize tested over unfamiliar changes, which is supported by Misquitta and Birkenholts (2021). Those with less education or farming experience may adopt traditional methods without fully understanding their limitations, making them more vulnerable. In this context, the role of extension workers becomes crucial in bridging knowledge gaps.

Education and farming experience further influence farmers' responses to water-related challenges. While the formal education level and years of experience between both WI and NI farmers do not differ significantly, the application of these attributes varies. For example, Farmer NI02, who despite only graduating up to secondary school, has higher farming experience, was able to independently find a solution to access water from the dam by joining a collective group and using an old pipeline, to water his field during the summer. This action demonstrated awareness and initiative, despite the efforts were still constrained by factors beyond his control, such as low volume of water, farm location and purchasing power—which connects with good management and leadership and cooperation amongst members (Matham, 2024), supported by balanced local management and policy by the local government.

4.4. Farmers Perceived and Challenges

With interventions farmers (WI) has the privilege of accessing interventions and more structured water management. As shown in Table 5 and the result of complexity, despite being insignificantly different, shows that NI farmers are more complex. Reflecting on how they perceived and faced greater vulnerability and lack access to reliable water, often consider a broader range of factors when adapting their strategies. It is covered by Sanga and Koli (2023) and Eakin et al (2015), a group of farmers who experience a lack of available water or are more vulnerable tend to have a higher desire to cope with the issue and think about different factors such as environment, social, and technical.

Another difference in deciding on crops. Although market demand and pricing are both influencing the group (WI and NI), however, they acted differently. WI farmers with the support provided by the government and NGO are more confident in diversifying their crops beyond staples like rice and wheat. As one of the primary solutions to the water and climate change issues, the activity not only helps people enhance their standard of living but also helps to increase regional variety. In contrast, NI farmers tend to stick with familiar and widely grown crops, limiting their ability to diversify due to both risk and lack of water access. This reflects a constraint on their freedom to choose more profitable components in crops or livestock. Also supported by the Mohanty et al. (2016).

Those differences are also supported by challenges like the high cost of interventions, such as the farm pond. The subsidy was the only reason that afford water infrastructure. Dismiss of them, NI groups struggle to improve their water availability. Aligning with Sanga and Koli's (2023) statement, which mentioned that limited financial resources and poverty often become inhibitors to adopting sustainable water management. Watershed projects by implementing sustainable water management will be a good choice to help farmers reduce their challenge to get access to water.

Another challenge is lack of modern technical knowledge, especially for NI, leading to a continued reliance on less effective traditional methods like stone and soil bunding, rainfed systems and unproductive wells. This contrasts with WI's access to and knowledge gained from modern interventions such as farm ponds. The limited adoption of more efficient techniques in NI is hindered by limited access to information due to uneven electricity and remote locations of their field. Additionally, number of older farmers hinder to a new adoption of water management techniques in NI (Bahinipati and Viswanatha, 2016), underscoring the need for youth engagement.

4.5. Limitations and Recommendations

Most farmers interviewed were unable to provide precise land sizes, especially for their rainfed and irrigated land. All the information was based on estimation rather than real measurements. The lack of readily available land documentation hindered data validation during the survey. Another limitation in this research was the limited time spent in Akole and the limited number of farmers who participated in the research. The fieldwork overlapped with the farmers' agenda with festivals and pre-cultivation of the rabi season, making it difficult to collect data, especially to seemingly see their perspective on the issue. One of the initial methodologies, the Focus Group Discussion, was unable to be conducted due to the same reason, and it would also be interesting to explore this approach further. Understanding farmers' network represents a compelling direction for future research, potentially revealing key insights into their collaborative behaviors related to water and crop production. Youth involvement in farming activities is a big suggestion to see how youth impact the innovation of addressing water scarcity and how it will change farming in Akole. Understanding social status and developing a typology of farmers will be a valuable input to understand the findings and further the adaptation of farmers based on socio-economic, resource endowment, risk perception, and farming systems (Alvarez, et al., 2018). In the next research, good collaboration between researchers, extension workers, and farmers is crucial to having a proper interview place and time for data collection. Conducting data collection during the summer is also recommended. Farmers have fewer farming activities, which may enrich the information for research, according to farmer and translator insights.

5. CONCLUSIONS

This study explored how smallholder farmers in Akole adapt to water scarcity and manage their cropping strategies under varying levels of support. The findings highlight that rainfall remains the dominant water source, but its seasonality and unpredictability force farmers to adapt differently. Those with access to interventions such as farm ponds and training benefit from improved water availability, greater cropping diversity and enhanced productivity during the rabi and zaid seasons (a dry seasons). In contrast, farmers without interventions (NI) are more vulnerable. They rely on traditional and outdated knowledge, cultivate drought-tolerant crops like pulses and millet, and often fallow land during dry periods. While crop selection acts as a key adaptation strategy, limited access to modern water infrastructure and institutional support can create a gap in resilience and livelihood as an outcomes.

The study underscores the importance of strengthening farmer support systems, including targeted subsidies, technical training and the promotion of sustainable practices such as remaining residual crops as a mulching and reduced tillage practices (O'Leary, et al., 2011; Ndlovu and Mathe, 2020). Addressing inequality in access to interventions, especially among tribal and marginalized farmers, remains a policy priority. In short, water issue is a key challenge for farmers in Akole. It affects farmers' lives and well-being. Implementing water interventions, although still limited, is a good approach to helping farmers in their farming activities. It also helps mitigate climate change that affects rainfall patterns, which indirectly influence farmers' farming activity in the future. Despite the limitations, this research enhances the author's understanding of the complex issues that farmers in Akole face regarding water-related concerns and their crop productivity.

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APPENDIX

Appendix 1. Questionnaire

Tick the multiple answer beside the question (v)

Date (dd/mm/yyyy)	:	
Name of Farmer	:	
Time Interviewing	:	
District	:	
Village	:	
Latitude	:	
Longitude	:	
Elevation (meters)	:	

Farmer’s Information						
Gender	:	Female	Male			
Age of respondent	:					
Years of farming experience	:	< 5 years	5-10 years	11-30 years	>30 years	
Education level of respondent	:	No education	Primary	Secondary	Tertiary	College
Number of household members	:					
Number of persons working on farm	:					
Aprox. Total combined working hours available per year (for all individuals)	:					
Mobile phone number of respondent	:					
Source of income	:	Agriculture ( ) Off-farm ( ) Other, _____				
If the answer is off-farm, in which sector?	:					
How much do you earn? (range)	:					
Land size (ha)	:					
Area cultivated with irrigation (ha)	:					
Area cultivated without irrigation (ha)	:					
Land ownership	:	Owner of land ( ) Rented ( ) Other, _____				
If the land is rented, how much do you rent?	:					
For how long do you rent the land?	:					
What is your primary water source?	:	Rainfall ( ) Spring ( ) River/stream/dam ( ) Groundwater ( ) Farm Pond ( ) No source ( ) Other, _____				
Group A (Farmers with Water Intervention)						
What type of water intervention/water storage do you have? (Select all that apply)	:	Rainwater harvesting ( ) Water pond/tank ( ) Recharge shaft ( ) Nala bund ( ) Farm bunding ( ) Drip irrigation ( ) Other, ______				
Since when do you have that intervention/water storage?	:					
How often do you use the stored water during kharif?	:	Daily ( ) Weekly ( ) Biweekly ( ) Monthly ( ) Never ( )				

How often do you use the stored water during rabi and summer?	:	Daily ( ) Weekly ( ) Biweekly ( ) Monthly ( ) Other, ______
How much duration do you use to irrigate your crop during kharif?	:	
How much duration do you use to irrigate your crop during rabi and summer?	:	
How do you decide how much water to use per season?	:	Crop population Crop types
Does the water storage you have sufficient for your crop production?	:	Yes ( ) No ( )
If not, what would be the reason for the insufficient?	:	
What farming practices were you using before the water intervention strategies were introduced?	:	
What crops did you grow before the intervention?	:	Kharif: Rabi: Summer:
How did you decide on cropping patterns?	:	Based on rainfall/water available ( ) Market demand or price of crops ( ) Traditional practices or advice from elders ( ) Seed and inputs availability ( ) Other, ____
How did you manage water availability before the intervention?	:	Rely on rainfall ( ) Used stored rainwater ( ) Shallow wells ( ) Cultivated only drought-resistant crops ( ) Other, _____
What farming practices are you using after the intervention?	:	
Have you introduced new crops or changed cropping patterns after the intervention? If yes, which one and why?	:	Kharif: Rabi: Summer:
What differences have you observed in your crop production since the intervention on your farm? (Select all that apply)	:	Increase crop yield ( ) Increase income ( ) Reduce pests and diseases ( ) Reduce crop failure risk ( ) Improved water efficiency in irrigation ( ) Reduced dependency on rainfall ( ) No significant difference ( ) Other, _____

If your answer is increasing crop yield, how would you describe the change in your crop yield?	:	Significantly increase ( ) Slightly increase ( ) No change ( )
If your answer is increasing income, what are the main source of income after water intervention?	:	Crop yield ( ) Expansion of cropping area ( ) Buy more livestock ( ) Livestock productivity ( ) Reduce production costs ( ) Buy more facilities for farming ( ) Other, ____
Which season do you think the intervention has impacted your yield?	:	Kharif | Rabi | Summer
What challenges do you still face despite having water storage?	:	High-cost maintenance ( ) Increased pests and diseases ( ) Nothing ( ) Other, _____
Group B (Farmers without intervention)		
How do you manage water during rabi and summer season?	:	Rainfall ( ) Water from pond/tank ( ) Plant drought-resistant crop ( ) Reduce the number of crops ( ) Leave the land barren ( ) Cover crop and/or mulching ( ) Join community water ( ) Other, _____
What is the reason to implement this water management? (based on your answer)	:	
How many months of the year do you have enough water for farming?	:	
Do you plant millet during rabi/summer?	:	Yes ( ) No ( )
What is the role of millet during those seasons relating to water availability?	:	
What other crops do you grow during those seasons (rabi & summer)? (Select all that apply)	:	Maize ( ) Wheat ( ) Vegetables ( ) Groundnut ( ) Beans ( ) Other, _____
What would be the reason to choose this crop? (select all that apply)	:	Improved production during that season ( ) Need less water ( ) Improved soil structure ( ) Increased income ( ) It has high nutrition ( ) Other, ____
What crop(s) do you grow during kharif? (select all that apply)	:	Rice ( ) Maize ( ) Vegetables ( ) Other, _____

What challenges do you face due to lack of water?	:	Reducing yield ( ) Income losses ( ) Soil degradation ( ) Pest and diseases outbreak ( ) Other, ____
Have you considered adopting new water-saving techniques? Why?	:	Yes ( ) No ( ) Reason: _____
If water interventions were available, how do you think it would help? (select all that apply)	:	Improved crop yield ( ) Improved cropping pattern ( ) Reduce irrigation costs ( ) Better soil health ( ) Other, ____
Are there any reasons why you are still not implementing the intervention?	:	
For farmer(s) who adopt barren land		
What changes have you noticed after leaving the land barren during the dry season?	:	Soil quality improved ( ) Weeds or pests decreased ( ) Nothing happens to land ( ) Other, ____
What benefits do you get from leaving the land barren?	:	Soil recovery ( ) Reducing labor ( ) Saving water from critical uses ( ) Reducing input cost ( ) No benefit ( ) Other, ____
Do you see barren land as a strategy to manage water scarcity? Why?	:	Yes, it helps conserve water ( ) No, it is just a necessity due to a lack of options ( )
Have you seen other farmers using their barren land differently? If yes, what practices have they adopted?	:	

Appendix 2. Farm Characteristics

Table 6. Farmers characteristics in three different villages in Akole, Maharashtra, India.

Variable	Farmer- 1	2	3	4	5	6	7
Farmers Code	**WI01**	**WI02**	**WI03**	**WI04**	**NI01**	**NI02**	**NI03**
Village	**Pendshet**	**Chichondi**	**Chichondi**	**Murshet**	**Pendshet**	**Chichondi**	**Murshet**
	With Intervention				*Without Intervention*		
Age	40	60	45	27	37	39	57
Years of farming	<5 years	>30 years	11-30 years	5-10 years	11-30 years	11-30 years	>30 years
Gender	Male	Male	Female	Male	Male	Male	Male
Educational background	College	Primary	Secondary	College	College	Secondary	Primary
Type of water intervention	Farm pond, subsidy, training	Farm pond; gabion wall structure; dam, subsidy, training	Farm pond, subsidy, training	Dam; farm pond, training	-	-	-
Subsidy of water intervention	NGO	NGO; Government	NGO	-	-	-	-
No Household	6	8	4	22	8	8	7
No person working on farm	4	6	2	15	5	2	4
Land size (hectare)	2.02	4.05	1.21	5.26	1.21	1.42	0.71
Rainfed land during kharif (hectare)	2.02*	4.05*	1.01*	5.26*	0.81*	0.61*	0.61*
Irrigated land during rabi/summer (hectare)	1.21*	2.02*	1.01*	1.01*	0.2	0.2	-
Income/year (Rupees)	50,000	500,000	50,000	250,000	40,000	50,000	20,000
Source of income	Agriculture and work with NGO	Agriculture	Agriculture	Agriculture and work with NGO	Agriculture	Agriculture	Agriculture and daily wages
Source of water	Rainfall; groundwater; farm pond	Rainfall; groundwater; dam; farm pond	Rainfall; groundwater; farm pond	Rainfall; dam; farm pond	Rainfall; groundwater with pump	Rainfall: received water from the	Rainfall

						dam not frequently	
Crop during monsoon/kharif	Rice	Rice	Rice	Rice	Rice	Rice	Rice
Crop during winter/rabi	Wheat; chickpea; pea	Wheat; strawberry; chickpea	Wheat	Wheat; maize; hyacinth bean; groundnut	Wheat/chickpea	Wheat	Wheat and chickpea
Crop during summer/zaid	Groundnut	Groundnut; sorghum; pearl millet; watermelon**	Pearl millet or groundnut	Groundnut; cowpea; maize	-	Vegetables*** and pearl millet***	-
Have livestock?	Yes	No, but once a year, he rented other farmers' livestock	Yes	Yes	Yes	Yes	Yes

Note: *the size of rainfed and irrigated land might potentially inaccurate the interpretation should be carefully taken, **cultivated in the former and the next year after and ***home-consumption/livestock feed.

Appendix 3. Cropping Calendar & Water Availability in Akole

Figure 6 illustrates the annual cropping calendar observed among the seven interviewed farmers, representing both intervention and non-intervention groups. The calendar reveals a dynamic cropping pattern that extends across different months of the year. Notably, the presence of interventions in Akole appears to correlate with a more intensive use of the agricultural seasons, enabling the cultivation of various crops throughout the year. This suggests an enhanced crop productivity and diversification within the region, particularly evident in the three surveyed villages. The calendar provides visual evidence supporting the notion that improved water access and availability are indeed key factors driving crop diversification in Akole.

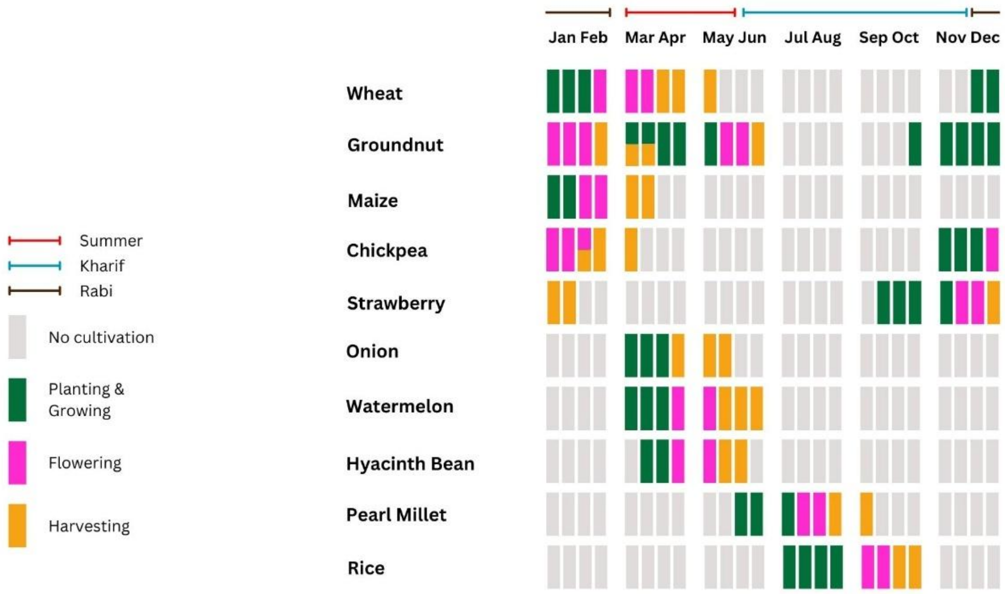

Figure 6. Cropping calendar of 7 farmers in Akole

The groundwater table is influenced by rainfall. Rainfall usually occurs in the period of June to September, which is called the monsoon season. It will decrease from October and cause the drought or summer season in May. Figure 7 shows that 102 farmers from the survey by the organization agreed with the statement that the driest month is May. It is also quoted by a farmer that we interviewed, *"One of the challenges is soil degradation, especially in May, as this is the hottest month in our area, which limits the availability of water and impacts soil"*.

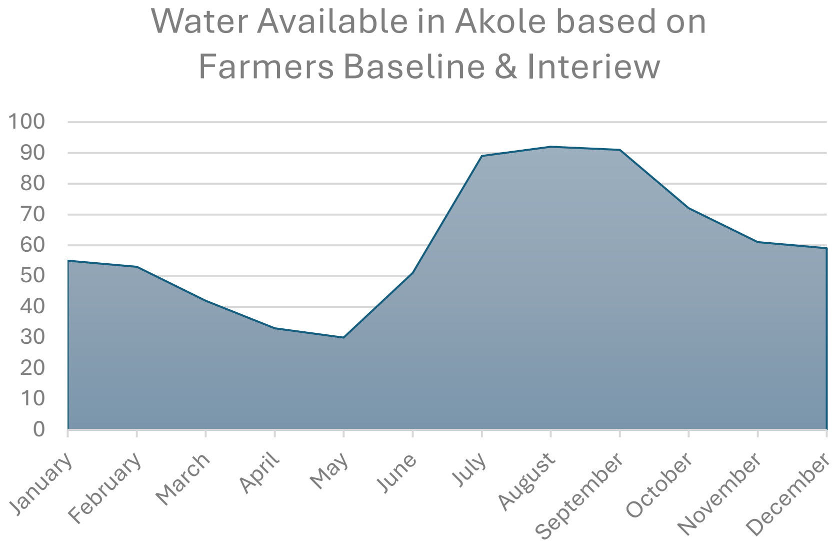

Figure 7. Water available in Akole district amongst 102 farmers from the baseline and interview data

Appendix 4. Fuzzy Cognitive Mapping

Appendix 4.1. Expert FCM

Figure 8 informed by expert interviews in Akole, illustrates the perceived connections between implementing water interventions and various influencing factors. Experts envision that interventions, like the farm ponds discussed, can enhance water availability, especially with drip irrigation. However, they recognize existing challenges such as difficult terrain ("Land Constraints") and financial limitations ("Financial Hardship") that farmers face, mirroring the passage's points about the impracticality of drip irrigation due to water and electricity scarcity.

Despite these hurdles, experts anticipate positive long-term outcomes. Improved water access is expected to drive crop diversification, leading to better yields, increased income, and greater resilience, while also reducing soil erosion. The diagram also incorporates socio-economic factors like knowledge and support, as well as environmental influences like climate change. Notably, it includes "Ancestral Beliefs" as a factor that could both inform and potentially limit crop choices, and highlights "Market Demand" as a key driver in crop selection, aligning with the passage's discussion on market influences.

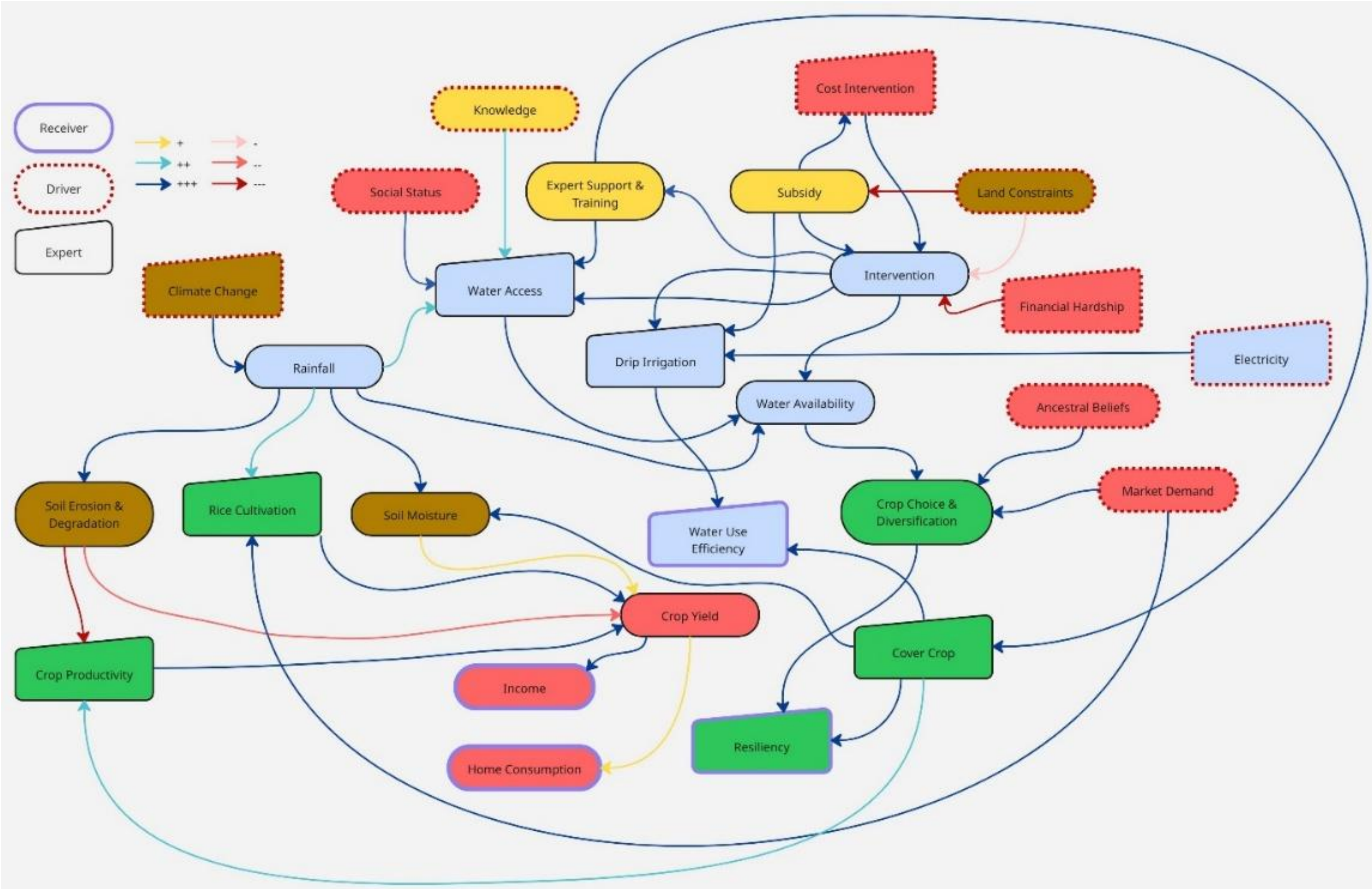

Figure 8. Diagram from experts about water interventions in Akole

Appendix 4.2. FCM Matrices

Table 7 presents the metrics of the FCMs of the three groups. The group of Experts had the largest numbers of total connections, density, connections per concept, number of receiver and ordinary components, and a higher score of complexity of the model. The group of farmers with interventions (WI) had the largest number of total concepts, number of driver (transmitter) concepts and number of ordinary components. The group of farmers without interventions (NI) does not have higher results when compared to other groups. However, the complexity of map is higher than WI and both groups have the same number of receiver components. The density between WI and NI shows the same result and relatively lesser than Experts.

Table 7. Metrices of all Fuzzy Cognitive Mapping (FCM)

Metrices	Farmers with interventions (WI)	Farmers without interventions (NI)	Experts
Total Number of Concepts	**29**	26	27
Total Number of Connections	39	32	**41**
Density	0.05	0.05	**0.06**
Connections per Concept	1.35	1.23	**1.52**
No of Transmitter Components	**13**	12	9
No of Receiver Components	2	2	**4**
No of Ordinary Components	**14**	12	**14**
Complexity Score	0.15	0.17	**0.44**

Appendix 4.3. Centrality

From Table 8, farmers with interventions (WI) highly considered Water Availability and followed by Rainfall. The Intervention ranks sixth but has relatively higher consideration in its strategies. Water Management is ranked fifth suggesting some awareness of managing the water they have, but it is still secondary to the primary concern of getting enough water. Different from farmers without interventions (NI), which highly considered Rainfall and Water Availability. In this group, the unpredictability of rainfall will directly affect water available on their farm as they dependent to the rainfall. Intervention is ranked fifth, interpreting as a concept that they consider as a potential solution gaining water access. Water Management is ranked sixth make it less central compared to WI. The experts see Intervention as the most central concept when discussing water availability. It shows that their focus on the implementation and the impact of the interventions. Drip Irrigation is ranked fifth which indicating that they focus on water efficiency and targeted water methods as a key intervention especially in crop production.

Table 8. The centrality of each group mapping

Ranking	Farmers with interventions (WI)	Farmers without interventions (NI)	Experts
1	Water Availability	Rainfall	Intervention
2	Rainfall	Water Availability	Water Access
3	Crop Choice & Diversification	Crop Choice & Diversification	Rainfall
4	Crop Yield	Crop Yield	Crop Yield
5	Water Management	Intervention	Drip Irrigation
6	Intervention	Water Management	Crop Choice & Diversification
7	Crop Production	Soil Erosion & Degradation	Cover Crops
8	Livestock Productivity	Summer	Subsidy

Appendix 4.4. In-Degree

Table 9 shows in-degree of the FCM concepts of the three groups. Farmers with and without interventions (WI and NI, respectively) have similar high indegree in Crop Choice and Diversification and followed by Water Availability. Both concepts are influenced by the same drivers: Water Availability, Ancestral Knowledge, Market Demand, Crop Prices and Soil Erosion & Degradation. The difference lies in the rank of the Intervention concept. Farmers with interventions puts this concept in sixth rank and farmers without interventions makes it the fourth consideration. The concept shows different way of farmers see the intervention. For farmers with interventions, who are able to have intervention impact on driving other factors, but for farmers without interventions, there is no intervention applied, which reflects their current struggles with water availability and other factors, and a desire to have water interventions as a solution. Experts show totally different ranks, with Water Access having a high indegree which indicates that experts see it as a result of multiple factors. Intervention was ranked third which indicates that experts see that implementing intervention requires different factors.

Table 9. The Indegree of each mapping

Ranking	Farmers with interventions (WI)	Farmers without interventions (NI)	Experts
1	Crop Choice & Diversification	Crop Choice & Diversification	Water Access
2	Water Availability	Water Availability	Crop Yield
3	Water Management	Crop Yield	Intervention
4	Crop Yield	Intervention	Drip Irrigation
5	Income	Water Management	Water Availability
6	Intervention	Soil Moisture	Crop Choice & Diversification
7	Crop Production	Rainfall	Water Use Efficiency
8	Livestock Productivity	Income	Resiliency

Appendix 4.5. Out-Degree

All groups identify Rainfall as a high out-degree (Table 10). This indicates that rainfall patterns significantly influence their actions and choices. The out-degree represents actions, practices, and choices that farmers perceive as influencing other factors. However, farmers with interventions see Water Availability as a second higher concept. Intervention is ranked fifth, indicating that this group may not see the intervention while they already have sufficient water on their field. In farmers without interventions (NI), Summer is second, highlighting that the challenges and conditions of the summer season will drive many of their adaptation strategies and farming practices. Water Availability ranked after Summer, which indicates the impact of the season and constant struggle that farmers faced in shaping their decisions. Experts considered Cover Crops as a potential concept to influence water availability. This was followed by Subsidy, Intervention, and Drip Irrigation, which are three concepts of the interventions to improve water access and water availability on farmers' fields.

Table 10. The outdegree of each mapping

Ranking	Farmers with interventions (WI)	Farmers without interventions (NI)	Experts
1	Rainfall	Rainfall	Rainfall
2	Water Availability	Summer	Cover Crops
3	Crop Yield	Water Availability	Subsidy
4	Crop Production	Crop Yield	Intervention
5	Intervention	Soil Erosion & Degradation	Drip Irrigation
6	Ancestral Beliefs	Occupation	Market Demand

7	Soil Erosion & Degradation	Market Demand	Expert Support & Training
8	Expert Support & Training	Crop Price	Crop Choice & Diversification

Appendix 5. Farm Pond for Rainwater Harvesting

Implementing farm ponds provides an opportunity for farmers to adopt rainwater harvesting, a novel strategy to tackle water scarcity during the rabi and zaid seasons in semi-arid hilly areas with uneven electricity. The higher elevation of farm ponds allows for gravity-based irrigation (Cai, X., et al., 2012), minimizing electricity use. Water interventions on farms improve irrigation efficiency, enabling cultivation outside the monsoon, which experts agree enhances diversity, yield, and food security. Additionally, these ponds prevent soil erosion, improving soil quality by capturing runoff. Garg (2021) notes these interventions saved 100 mm of water compared to the 150 mm lost previously. Garg, K., et al. (2018) found groundwater table improvements led to crop intensification and higher rural income. Farmers' crop selection is also driven by market demand and pricing (Zachariah, M., et al., 2020), highlighting the need for fair regulation to support farmers with limited water access. These water-saving interventions can improve their well-being and allow them to benefit from the watershed project's impacts over the next 3-5 years.

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Appendix 6. Challenges faced by Farmers

The expert also pointed out that a key challenge of intervention is relying on the maintenance of the infrastructure of interventions. For example, recharge shafts and lined farm ponds present a significant potential challenge to farmers in terms of their financial ability to adopt these solutions, which would be a burden on low-income farmers. The expert then stressed the importance of NGOs, and also the government, in facilitating the successful implementation of the whole watershed project. It aims to enhance water availability across the community, thereby mitigating high individual costs.

Table *11*. Challenges faced by farmers towards water availability

Farmers	Most Challenging
WI01	**Cost of intervention**
WI02	Uneven rainfall
WI03	-
WI04	**Cost of intervention**; social and cultural challenges
NI01	Lack of technical knowledge
NI02	**Cost of intervention**; lack of income
NI03	**Cost of intervention**; lack of income

Appendix 7. Comparison of Farmers With Interventions and Without Interventions

Table *12* presents an overall comparison between the two groups of farmers across five categories: water management, crop choices, soil and land conditions, economic impact and knowledge and decision-making regarding water availability. In crop choices, farmers with interventions are usually influenced by market demands and crop prices rather than by water availability. This suggests that interventions allow for a range of factors to guide crop selection. In comparison, farmers had less freedom in choosing the crops, as it is primarily driven by rainwater. In turn, forcing them to focus on drought-resistant crops like chickpeas and pearl millet, crops which people can find easily on the market and affect their profitability. The lack of irrigation and water limited their ability to apply multi-seasonal cropping patterns. Although NI were in a less favorable situation due to constraints such as financial hardship and limited land size, they still found ways to adapt and conserve water, using it efficiently.

Table 12. Comparison between farmers with and without interventions

Factor	With Interventions (WI)	Without Intervention (NI)
Water Management	Improved, have structured systems for irrigate crops, have water storage for limited-water seasons.	Limited, rely primarily on rainfall.
Crop Choices	Diversified and expand. Usually select market-oriented crops.	Restricted to drought-resistant crops. Limited choice.
Soil Conditions	Improved soil moisture and quality—impacts on better yield and healthy soil.	Degraded, prone to erosion—related to lack of nutrients.
Impact on the Economy	It assists farmers in improving their income, diversified economy (e.g. livestock and new crops), then improve their livelihood.	Relatively lower income due to lower yield and use as home-consumption (due to limited amount of yield).
Knowledge and Decision Making	Collaborating knowledge from different sources (market and ancestral knowledge).	Limited to traditional non-improved knowledge.

Appendix 8. Farmers' Plotting System (Group with Interventions)

From Table *13* to Table *16*, display the cropping plots that the farmer used during all seasons. All plots are used for cultivating rice during the kharif season. They did not have uneasy access to water during this season. They also did not experience soil erosion due to heavy rainfall because they have water intervention through soil and water conservation with the help of NGO and/or the government. In Table 13, plots 3 and 4 belong to leguminous crops in the rabi and zaid seasons. Potential reasons might be a limitation in labor and resources needed. *"The implementation of water intervention in our field has increased our income and introduced new crops like groundnut. However, we also experienced increased labor needs for cultivating"*. From this statement, farmers still find their strategy to maintain their income and be productive during the summer season. Therefore, only plots 3 and 4 were selected to be grown with groundnut, as in the previous season, they had been cultivated with chickpea and other peas.

Table 13. Farmer WI01 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	Wheat	-	Close to farm pond, (28 x 18 x 3) meter
2		Wheat	-	

3		Chickpea and peas	Groundnut	-
4		Chickpea and peas	Groundnut	-
5		Wheat	-	Close to bore well, with 56 ft depth and 20 ft width
6		Wheat	-	

The same reason also belongs to Farmer WI02 (Table 14). Labor is one of the impacts they experience with implementing water intervention (farm pond). Besides, it had only been 2 years since they received a subsidy and developed water storage. This reason indicates that farmers are still transitioning by improving their cultivation, especially during summer or the zaid season. Choosing the right crops, such as groundnut, sorghum, and pearl millet, is their own strategy to keep productive. The improvement in cultivating non-local crops, such as strawberries and watermelon, indicates their ability to improve by having sufficient water availability in their field.

Table 14. Farmer WI02 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	-	-	There is a well with a solar pump. Volume: 53 x 53 x 50 ft with pipeline crossing to the other farmlands.
2		-	-	
3		-	Groundnut	
4		-	-	
5		-	-	
6		Strawberry	-	In between plots 6 and 9, there is a farm pond: 30 x 30 x 3 meter
7		-	Watermelon	
8		Chickpea	-	
9	-	-	-	
10	Rice	Wheat	-	Pipeline access from plot number 1, the pipe is located under the road.
11		-	Groundnut	
12		-	Sorghum	
13		-		
14		Wheat	Pearl millet	
15	-	-	-	
16	Rice	-	-	

Table 15 and Table 16 show two farmers plotting over the crops they cultivated during the year. farmer WI03 utilizes all plots except plot 4 and 7 due to the land condition iare not suitable for cultivation. During summer farmer cultivate drought-tolerant crops such as pearl millet and groundnut. There is also a small area grows vegetables due to improved land after intervention. One plot (plot 7) remains uncultivated due to stones, therefore, farmer utilizes it as a farm pond location.

Farmer WI04 cultivated the whole plots during kharif with rice and relying the water from rainfall. Rabi shows diverse cropping with varieties of crops. During summer the cropping pattern is limited with the same choice as Farmer WI03. Both farmres adapt their crop choices and plot usage to the different seasons. WI03 appears to have more summer cultivation potentially due to a water intervention, while WI04 shows intercropping as a strategy in the drier season.

Table 15. Farmer WI03 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	Wheat	-	There is a bore well with solar panels in between plots 1, 2 and 3.
2		-	Pearl Millet	
3		-	Groundnut	
4	-	-	-	A small amount is used to cultivate vegetables for home consumption.
5	Rice	-	Groundnut	It was a scarce land before the intervention.
6		-	Pearl Millet	
7	-	-	-	Full of stone, however, an intervention of a farm pond was built in this area. volume: (26 x 29 x 15) meter.

Table 16. Farmer WI04 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	Pearl Millet	-	
2		Wheat	-	
3		Chickpea	-	
4		Pearl Millet	Groundnut, cowpea and maize	
5		Hyacinth	-	
6		Wheat	-	

Appendix 9. Farmers' Plotting System (Group without Interventions)

Table 17 has 3 plots with rice becoming the main and the only crop in kharif. In the rabi season, farmers mentioned that they prefer to cultivate either wheat or chickpea, because they are common crops in that season. *"Like any other farmers, we also cultivate wheat this season because it requires less water, which is suitable during rabi"*. There is no crops in summer as it is related to water available on his land. He mentioned that he has an old well from his ancestor, however, the well has not yet functioned well. *"I have an old well, but it silted with soil and there the water is not available"*.

Table 17. Farmer NI01 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	Wheat/chickpea	-	An old well situated in this plot with water pump to transfer water during rabi.
2		-	-	
3		-	-	

Farmer NI02 (Table 18), cultivates in 10 plots, but not the whole plots can be cultivated. Rice is grown in kharif in all plots, except plots 3 and 7 due to land topography. However plot 7 is used for cultivating pearl millet during summer season and later the land is used for doing rab or burning the plant residue, therefore the land gain nutrient and will be used for other crops, especially for rice seedlings. Due to limited water he also can only cultivate wheat in one plot which has larger size compared to other plots and high soil moisture.

Table 18. Farmer NI02 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	-	-	
2		Wheat	-	the size is larger compare to other plots.
3	-	-	-	
4	Rice	-	-	He usually does rab/burn plant residue in this plot.
5		-	-	
6		-	Vegetables	
7	-	-	Pearl Millet	He usually does rab/burn plant residue in this plot.
8	Rice (partial)	-	-	
9		-	-	
10		-	-	

In Table 19, farmer is also cultivating rice in kharif—as this crop is the most suitable during the season. However, the land he owns experiences soil erosion due to heavy rainfall. The most impacted plots are 3 and 4, therefore, he uses the plot in a small portion to cultivate rice. Chickpea is chosen to grow in plot 4 (the damaged plot), the reason is unknown. However, chickpea can act to absorp nitrogen, therefore improve soil function (reference). Plots 1 and 2 are the most scarce especially during non-mosnoon seasons. The amount of water in both plots are very limited, which made a farmer choose to not grow anything in these plots—also applied in all plots, as he does not have any water storage and receives interventions.

Table 19. Farmer NI03 plotting plan during the seasons

Plot	Kharif	Rabi	Summer	Note
1	Rice	Wheat	-	It has high water scarcity during the non-monsoon season.
2			-	
3		-	-	It impacts soil erosion from the hill due to heavy rainfall. Only small portion can be used.
4		Chickpea	-	
5		-	-	
6		Chickpea	-	