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Adapting to Climate Change in Vulnerable Areas: Farmers' Perceptions in the Punjab, Pakistan

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Abstract: Climate variability and change pose a substantial threat to agricultural practices and livelihoods in the Punjab province of Pakistan, a region of agricultural significance in South Asia. In particular, farmers residing in vulnerable parts of Punjab will be affected by a combination of high exposure to the impacts of climate events, the innate sensitivity of agricultural systems, and constraints on farmers' adaptive capacity. The situation requires closer engagement with vulnerable farming communities of Punjab to assess their vulnerability and build their capacity for adaptation actions. Through qualitative analysis of semi-structured interviews with farmers from four highly vulnerable districts of Punjab (Rajanpur, Muzaffargarh, Chakwal, Dera Ghazi Khan), we explored farmers' perceptions of climate change, their adaptation strategies, and enablers and limitations on adaptation options imposed by the enabling environment. We found issues around water governance, knowledge exchange, and market arrangements for crops as key limitations to farmers' local adaptation action in highly resource-constrained settings. Moreover, the results indicated the need to address equity issues for small-scale compared to large-scale farmers. Farmers valued their experience-based local knowledge and peer-to-peer sharing networks as pivotal resources in pursuit of their practice-based learning. The research findings highlighted the necessity of directed institutional assistance to empower adaptation by vulnerable small-scale farmers. This study emphasizes the critical significance of the enabling environment that facilitates vulnerable farmers to implement adaptation strategies, thereby promoting the adoption of Vulnerable-Smart Agriculture.

Keywords: agriculture; climate change; vulnerability; farmers' perceptions; punjab

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1. Introduction

Climate change is considered the greatest threat to humanity due to its far-reaching adverse impacts for societies globally [1,2]. However, the impacts of climate change are dissimilar across geographical [3], social [4], and cultural [5] contexts. Less economically developed countries and climate-sensitive sectors of the economy such as agriculture are likely to be most severely affected [6]. Climate change effects on agriculture result from a range of often interconnected factors including higher temperatures, variable precipitation, and extreme climatic events such as heat waves, floods, and droughts [7,8]. In addition, climatic changes have a major impact on livelihoods that are constructed on the use of natural resources and rely on climate stability, such as crop production [9–11]. Furthermore, while farmers from the developing world play a significant role in global agricultural production [12], many are already suffering from poverty and food insecurity [13], a situation that is aggravated by a changing and uncertain climate.

The adaptation of farmers to increased climatic variability and change is essential for their food and livelihood security [14] with a distinction made in the literature between short-term coping, adaptation for system resilience, and transformative adaptation [15]. Coping includes short-term strategies and actions undertaken within existing institutional settings, whereas adaptation for resilience is associated with incremental changes and

long-term strategic actions that may require institutional change [15–17]. In contrast, transformative adaptation refers to responses and strategies that alter permanently and drastically the structures or functioning of systems [16,17].

Farmers in the developing world employ a range of coping and adaptation strategies in response to climate variability and change [14,18]. For instance, farmers in Africa incorporated coping measures in their livelihood strategies in response to climate variability such as selling household assets including livestock, migration of entire households, and changing diets [14]. Studies on farmers in Asia reported a number of adaptation strategies in irrigation and water management (e.g., [19,20]); farm management through tree planting (e.g., [21]); and in financial management by relying on non-farm activities to generate extra income (e.g., [22,23]). Farmers in Bangladesh, Pakistan, Thailand, and India practice mixed cropping as a strategy to adapt to multiyear persistent drought, changes in temperature, and altered rainfall patterns to minimize the risks associated with variations in productivity and income loss [19,22–24]. For instance, recent studies have found that changing fertilizer use and adjusting cultivation dates are commonly adopted strategies to mitigate the effects of climate change on crop production in Pakistan [25–27]. Also, one of the most common adaptation strategies in crop management by farmers in Asia is to diversify crops [18]. These types of strategies are employed universally by vulnerable farmers in situations where resource access is inadequate and institutional support is limited [18,24,28].

Pakistan, a developing country in South Asia, is one of the most vulnerable to the impacts of climate change [29]. Livelihoods in Pakistan, particularly in the Punjab province (the location of this study), are highly sensitive to climate change due to the region's dominance as a major agricultural producer [30] and the sensitivity of agriculture to climatic changes [31]. Punjab province has and will likely continue to experience severe effects of climate change including drought and flooding [32–34]. For instance, direct losses from floods over the last decade in Pakistan were estimated to exceed USD 18 billion [35,36]. Recently, 'super' flooding events in 2022 affected 33 million people, caused significant human and livestock losses, displacements of settlements, and loss of livelihoods, and badly affected 3.6 million hectares of crops [37].

A top–down vulnerability assessment to climatic changes of Punjab province [38] based on available secondary data showed districts within the province varied in their vulnerability and generic capacity for adaptation. This assessment found highly vulnerable districts in south and north Punjab owing to a combination of high exposure to the impacts of climate events and relatively low objective adaptive capacity defined by [39] as available resources. This situation points toward the need for closer engagement with district stakeholders to better understand the vulnerability of farming communities in these locations [40].

In response to a growing need for agricultural systems to adapt and improve their resilience to the threats posed by climate change, the concept of climate-smart agriculture (CSA) has gained considerable attention due to its potential to address key challenges, including to food security, through climate change mitigation and adaptation [41,42]. CSA, although subject to criticism because of ambiguities in its conceptual scope and institutional mechanisms [43], requires sustainably increased agricultural productivity to support equitable increases in income, food security, and development [42,44]. Moreover, it aims to foster agricultural innovations that adapt and build resilience to climate change [44]. Despite the potential benefits CSA could offer, its wide adoption by farmers is associated with many challenges [41,45]. CSA has been criticised for targeting the commercial production of high-value water-intensive commodities rather than the small-scale production of local food [46]. Notably, less attention has been paid in the CSA literature to understanding the situation of vulnerable farmers, which is often overlooked and thus requires rethinking CSA approaches [47,48].

Vulnerable-Smart Agriculture (VSA) is a newer concept that seeks to address some of the shortcomings of CSA by designing VSA strategies using locally available resources with a particular focus on vulnerable farmers [47]. VSA thinking requires the inclusion

of the concept of vulnerability into CSA and highlights the necessity for prompt interventions to fortify the adaptive capacity of those most vulnerable to the impacts of climate change [47,49]. VSA's premise rests on the assumption that substantial alterations to farming systems are feasible solely through the active participation of farmers in devising and overseeing any agenda for change [47,50]. Within VSA's perspective, prioritizing sustainable livelihoods is fundamental for augmenting food production and adapting to the impacts of climate change [51]. Hence, VSA aims to comprehend the coping mechanisms employed by vulnerable farmers, along with the obstacles they encounter in adapting to climate change and enhancing their livelihoods [47,52].

Effective adaptation to climate change requires an enabling environment that builds the adaptive capacity of vulnerable farming communities and seeks to minimize their vulnerability [53,54]. The term 'enabling environment' refers to the set of conditions within which farmers operate that supports them in efforts to enhance their capacity to adapt and to pursue sustainable livelihoods [53]. An enabling environment therefore includes factors such as access to information, markets, governance, local infrastructure, and the availability of credit. While resources are important to adaptation, these may not be deployed effectively without enabling policies in an appropriate institutional environment [54], where 'institutions' refers to public and private organisations. Government, as a key institution, can play a significant role in adaptation management [54,55].

It is widely recognized that adaptation policy needs to create supportive conditions that not only provide guidance to decision makers in planning and executing adaptation interventions but also enable farming communities to adapt to climatic changes [44,56,57]. Governments through effective policies and plans can support adaptation actions through the production and dissemination of information about climatic changes, their impacts, and how to adapt to changes [56]. Public policy intervention may also be justified to improve the equity and efficiency of resource allocation [44]. Moreover, actors may be unable or unwilling to take adaptation actions on their own, even when adaptation measures are in their best interests, thus requiring government intervention [56]. The governments of Pakistan and Punjab province have recognised the potential of policy interventions to influence adaptation action and have developed various policies and plans such as the National Climate Change Policy 2012 [38] to deal with the adverse effects of climatic change.

Despite the significance of the enabling environment and its potential influence on the adoption of Vulnerable-Smart Agriculture, knowledge is limited about how farmers from vulnerable areas of Punjab (as 'canaries in the coalmine') are responding to changes in climate. Also, in a developing country context, the extent to which formal, often top–down, policy and planning arrangements for climate change are achieving their objectives is understudied [58]. In this study, we use and expand on the concept of VSA to explore the enabling environment of farmers in highly vulnerable areas of Punjab identified through top–down vulnerability assessment [38] to explore farmers' perceptions of climatic changes, their adaptation actions, and enablers and constraints to local-scale adaptation to inform the future development of adaptation policy for VSA practices.

2. Methods

2.1. Framework

Ref. [47] provide a conceptual model of VSA structures and a framework for use in this study to assess the situation of farmers in highly vulnerable areas of Punjab province. The framework focuses on small-scale farmers and emphasises the identification of the livelihood resources and coping strategies they utilise in response to climate change impacts. The framework also seeks to aid the understanding of how small-scale farmers predict upcoming climate change events, such as droughts, how farmers adapt to these incidents by implementing appropriate interventions, and the barriers they face in doing so.

Although livelihoods and coping strategies have critical significance for vulnerable farmers, more importantly, an effective enabling environment allows farmers to access available resources and creates supportive conditions for the effective utilization of them

for adaptation, which is fundamental to adaptive capacity [15] (Bene et al., 2018). Recently, authors have elaborated on the shortcomings of first-generation (capital deficit) capacity assessments, suggesting refinements in second- (capacity mobilisation) and third-generation (capacity transfer) assessments [59–61]. However, qualitative studies of capital deficits remain a useful first step in understanding adaptive capacity in a developing-world context (e.g., [62]) and can shed light on elements of subjective adaptive capacity (cognitive processes associated with farmers' appraisal of risk and adaptation actions, [39]). Building on the work of [47], this study emphasises the significance of an enabling environment for vulnerable farmers for pursuing their local adaptation interventions.

2.2. Study Area

The study was carried out in the Punjab province of Pakistan. Punjab is the largest province by population and the second largest province in terms of area, covering 205,344 square kilometres (sq.km) [30]. Punjab accommodates over 50% of the population of Pakistan and produces over 60% of national agricultural commodities [30,63]. Administratively, the Punjab province is divided into 36 districts comprising both rain-fed areas, called '*barrani*', and irrigated areas. Irrigated areas are supplied with water from a canal-based irrigation system, while *barrani* areas are rainfall-dependent. The annual mean precipitation ranges from >800 mm in the northern part to <300 mm in the southern part of Punjab [64].

The Rajanpur, Dera Ghazi Khan, Muzaffargarh, and Chakwal districts of the Punjab province were chosen for this study (Figure 1) due to their agricultural significance and based on the construction of an index of vulnerability and related mapping of exposure, sensitivity, and adaptive capacity, i.e., the components of vulnerability [65], identified through vulnerability assessment [38]. The selected vulnerable districts were all highly exposed and sensitive with low adaptive capacity. This qualitative study builds from the authors' previous quantitative analysis that identified hotspot districts of vulnerability [38].

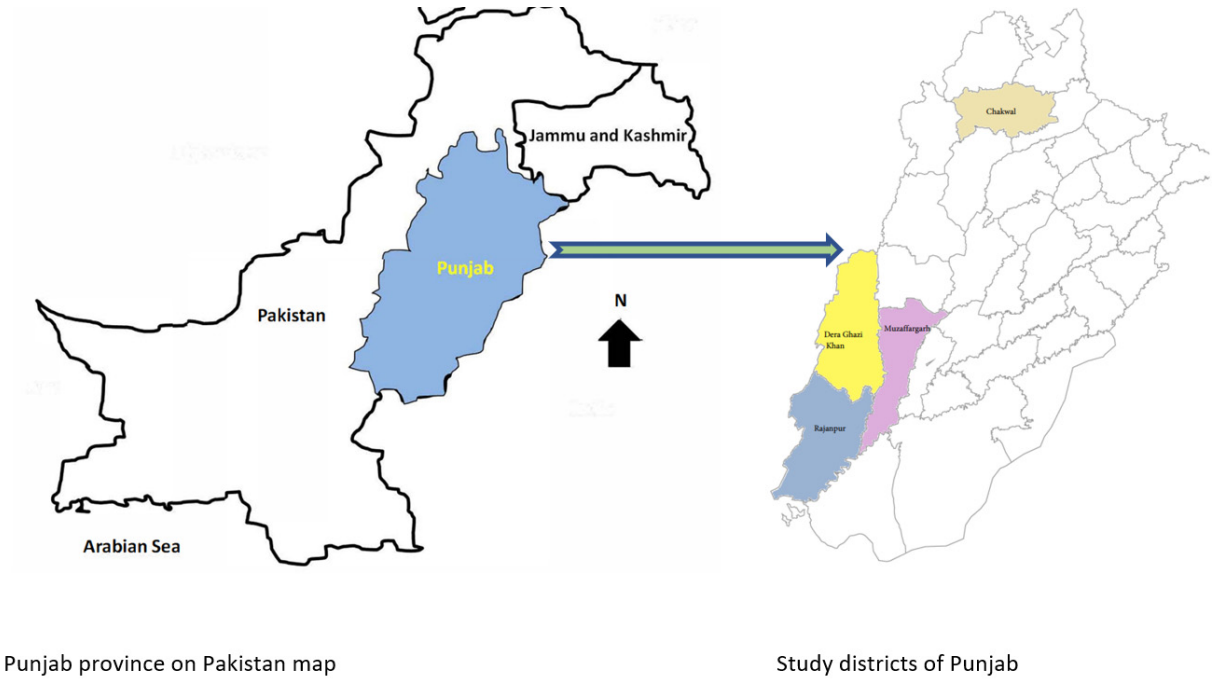

Figure 1. Study districts of Punjab province. Source: author.

These districts have importance for the production of major crops including cash crops (i.e., cotton, sugarcane) and food crops (i.e., wheat, rice, maize) [30]. In Punjab, cotton is mostly produced in the Rajanpur, Dera Ghazi Khan, Bahawalpur, and Muzaffargarh districts. Pakistan is the 4th largest cotton producer in the world, and cotton has been

described as the lifeline of Pakistani economy [66]. The cotton crop value chain in Pakistan employs more than 50% of total industrial labour and accounts for more than 60% of total exports in the form of textile products [67]. Similarly, the Chakwal district is an important area for wheat production among the rain-fed farming areas of Punjab, which are mostly concentrated in the Rawalpindi division [30]. The Chakwal district is considered the most rain-dependent district of the arid zone of Punjab and makes up 33% of the total cultivated area of the Rawalpindi division [68].

2.3. Data Collection and Analysis

Primary data for this study were collected through face-to-face semi-structured interviews with farmers from the selected districts. Formal permission was obtained from the department of Directorate General Agriculture, Extension and Adaptive Research (AED), Government of Punjab (GoP), to conduct this study. Interviews with farmers were conducted between January and March 2019. Farmers associated with major crops (wheat, rice, cotton, sugarcane, maize) were selected from the records of field staff of the AED department in each study district. Due to budget and security limitations, district locations with access difficulties (i.e., tribal areas of Rajanpur and Dera Gahzi Khan districts) were excluded from this study. Each of the study districts' key characteristics, i.e., area, major crops, farmers interviewed, average annual rainfall distribution, soil texture, and agro-ecological zone, are listed in Table 1.

Table 1. Study areas' characteristics.

District Name	Area (sq.Km)	Major Crops	Farmers Interviewed	Average Annual Rainfall Distribution (mm)	Soil Texture	Agro-Ecological Zones (AEZs)
Rajanpur	12,318	Cotton, wheat, sugarcane, rice, and maize	5	83–218	Mix of clay loam, clay, loam, and sandy-loam	AEZ III—cotton and sugarcane; AEZ VI—mix cropping
Chakwal	6524	Wheat and maize	3	543–1107	Loam and sandy-loam	AEZ XIII—medium rainfall; XIV—high rainfall
Muzaffargarh	8249	Sugarcane, wheat, cotton, rice, and maize	5	83–218	Mix of sandy-loam, loam, and clay	AEZ VI—mix cropping
Dera Ghazi Khan	11,922	Sugarcane, cotton, wheat, rice, and maize	5	83–218	Mix of sandy-loam, loam, and clay	AEZ VI—mix cropping

Source: Government of Punjab [69]; study data: Food and Agriculture Organisation [70].

In total, 18 interviews were conducted with farmers at their farms and, on occasions, at field days held near their farms organised by the Agriculture Extension Department. The information from all farmer interviewees is presented in Table 2.

Before conducting the interviews, informed consent was obtained from all participants in line with research ethics approval guidelines. For less literate participants, the consent form was translated into the local language and read aloud, and verbal consent to proceed was obtained. For literate participants, written consent was obtained. Interviews were conducted in the local language, Urdu (by the lead author of this study), to ensure the understanding of participants, audio recorded, and transcribed into English. Participants were de-identified prior to analysis, and responses were coded according to F1 (farmer 1), F2 (farmer 2), etc. Data analysis of interview transcripts involved coding and identification of emergent themes using NVivo analysis software [71,72]. Data analysis adopted an

inductive approach to qualitative coding [73] to allow the recurrent narratives to emerge from the data through two coding cycles [74,75].

Table 2. Farmers interviewed details.

Sr. No.	Farmer Crops Produce	Livestock Possession	Farmer Gender	Household Female Participation in Agriculture (Y/N)
F1	Wheat, sugarcane, and cotton	Buffalos and cows	Male (M)	N
F2	Wheat, sugarcane, cotton, and rice	No (N)	M	N
F3	Wheat and cotton	Buffalos and cows	M	N
F4	Wheat, sugarcane, and cotton	Goats	M	Yes (Y)
F5	Wheat, sugarcane, and cotton	Goats	M	Y
F6	Cotton and maize	Buffalos, cows, and goats	M	N
F7	Wheat, cotton, rice, and sugarcane	Cows and buffalos	M	N
F8	Wheat, rice, and sugarcane	Cows and buffalos	M	N
F9	Wheat and rice	N	M	N
F10	Wheat, cotton, and fruits	N	M	N
F11	Wheat, rice, and cotton	N	M	Y
F12	Wheat and rice	Cows and goats	M	Y
F13	Wheat and rice (also formerly cotton grower)	Cows and goats	M	Y
F14	Wheat, rice, and cotton	Cows and buffalos	M	Y
F15	Wheat and rice	Cows and goats	M	N
F16	Wheat	Cows and buffalos	M	N
F17	Wheat, vegetables, and fodder	Cows	M	N
F18	Wheat, maize, and pulses crops	Buffalos, cows, and a few goats	M	Y

Our research adopted semi-structured interviews (SSIs) for data collection. SSIs offer a nuanced understanding of participants' perspectives, allowing for in-depth exploration of the subject matter [76]. We aimed to uncover rich qualitative insights into the experiences and perceptions of farmers in vulnerable districts. In this context, the focus is on depth rather than breadth with the aim of achieving thematic saturation [77]. The qualitative nature of our approach enables us to delve deeply into the complexities of farmers' experiences and perceptions, capturing nuanced insights. We adhered to the established criteria for quality in qualitative research such as credibility and confirmability [78,79]. In addition, we presented other markers that indicate quality in qualitative research including research context, theoretical underpinnings, the methods of data collection and analysis, gaining consent, and protecting participant identity [79], and in line with ethics approval guidelines. The use of open-ended questions minimizes the risk of loaded questions and allows participants to provide detailed and candid responses based on their own experiences and perspectives. Additionally, efforts were made to ensure the confidentiality and anonymity of participants, thereby mitigating concerns about response bias. Also, efforts were made to engage with potential participants and address any concerns they may have had about participating in this study prior to and post-interview.

3. Results

3.1. Farmers' Perceptions of Climate Change and Adaptation Action

Farmers reported high exposure to climate variability, climate change, and climate-induced weather extremes. The following quotes were typical of the responses of experienced farmers:

> "I am over 60 years old now. I have noticed temperature rise in my lifetime. In my younger age, winters were quite longer but it is not the case now. Drought conditions here are very common. More rains were [common] in my early years but rains have reduced too much now except some unexpected heavy wild rainfall events". **F13**

> "I have observed the duration of summers have stretched and winters have shortened. There were more rain spells 30 years ago than now in our area. I have seen nine worst floods in my lifetime here in my area". **F4**

Reports of rises in mean temperatures over periods spanning up to 50 years were common. Farmers associated temperature changes with an extension of summer conditions and a reduced duration of winter. Farmers also reported declining trends in the amount of rainfall observed as more intense rainfall events interspersed with frequent drought conditions, decreasing rainfall effectiveness. Moreover, farmers from southern Punjab districts reported frequent large flooding events.

Interviewees acknowledged adaptation as a key strategy to respond to their increased exposure to changed seasonal weather conditions. Although farmers pointed toward the need for planned adaptation measures, such as the use of drought-tolerant crop varieties in response to long-term changes in rainfall patterns, their adoption of such interventions as part of agronomic practice was seldom reported. Instead, farmers most often reported short-term strategies to cope with seasonal weather variations. These strategies included changes in planting and harvest dates and alterations in crop water management primarily in response to variations in the onset or duration of the growing season or in-season heat waves.

3.2. Factors Affecting Farmers' Adaptive Capacity

Farmers spoke not only of their exposure but also about factors limiting their capacity to adapt that included biophysical, economic, and social aspects.

3.2.1. Biophysical Aspects

Farmers identified a range of issues around water availability for cropping, including insufficient irrigation water, rainfall variability, excessive flood waters, and the use of groundwater to supplement crop water needs in irrigation and rain-fed areas. Typically, water availability for irrigation was a critical factor cited as limiting farmers' capacity to pursue changes in cropping practices. For instance, a farmer stated the following:

> "I think initial division of irrigation water was okay but due to acute shortage, farmers like me do not get enough water according to our needs. I have to use tube well water for crops although underground water is of poor quality and [this] brackish water causing salts on land but we have no choice except to use it for crops". **F14**

Almost all farmers interviewed reported issues with low water inflows in the rivers that led to the availability of water for irrigation being inadequate for crop water requirements. They perceived that canal water shortages were due to a combination of changing climatic conditions and management of water storage in existing dams. Farmers viewed shortages in irrigation water as the cause of limitations to crop yields, which they considered far below the potential crop productivity of these districts were adequate supplies made available for agriculture. Farmers also reported frequent water 'wastage' as excessive flood waters due to the inability of dams to store these waters for use in agriculture.

To overcome issues with water supply and meet crop water demand, farmers reported supplementing irrigation water supplies through tube wells. However, the excessive use of groundwater resources had led to a significant lowering of groundwater tables and increased extraction efforts, potentially endangering aquifers. In addition, they noted the appearance of 'scaling' and soil salinity associated with poor groundwater quality. Farmers also highlighted the significant financial impacts on crop water management through the high cost of electricity for pumping from tube wells compared to canal water irrigation. They reported that farmers with greater financial resources were better able to manage for water scarcity than less wealthy farmers.

3.2.2. Economic Aspects

In addition to biophysical factors, interviewees identified several economic aspects restricting their capacity. For example, farmers stated the following:

> "I feel that crop farming is not as beneficial for us and mostly we are doing it to fulfil our passion and as we cannot do anything other than that. Our costs on crops are mostly more than what we get in return. We do not have the opportunity of getting some better [irrigation] set ups than what we have [now]". **F3**

> "Benefits are either taken by industrialists or middlemen, no benefits passed on to farmers for their hard work who remain deprived. Many tenant farmers I know quit even when standing crops of sugarcane were ready [for harvest] and offered landlords to take control of their lands with crops to harvest and sell themselves, considering this was not viable to them". **F7**

Interviewees mentioned declining terms of trade for farmers as a critical constraint to adaptation, making it difficult to continue cropping in the study locations of Punjab. They reported that the prices of various farm inputs, such as fertilizers, seeds, pesticides, and electricity, had increased, but returns on cropping had risen slowly, remained static, or declined, resulting in their finances becoming 'squeezed'. Farmers also reported that they were not receiving reasonable returns on their harvested crops due to various market-related barriers. They indicated that either markets for crops were not available locally or were distant from their farms. Farmers of the Rajanpur district revealed that there was no market for major crops in the entire district, while farmers of the DGK, Muzaffargarh, and Chakwal districts indicated that markets were very far away with poor road conditions. Farmers who attempted to access more distant markets reported additional costs of transportation due to damage and increased maintenance to vehicles from deteriorated road conditions. Where farmers were unable to access markets, they were obliged to sell their harvested crops to 'middlemen' who act as marketing agents between farmers and central markets. However, farmers noted that these middlemen buy their harvested crops at low prices usually in instalments, making multiple trips to markets, and include many unrelated deductions, which further reduce farmers' returns.

Although farmers found cropping less financially attractive, they reported being motivated to continue for a range of other reasons such as means of survival, passion, continuation of their forefathers' profession, and lack of other livelihood options. In particular, the identity and culture of farmers who were landowners appeared more strongly bound to cropping than tenant farmers. In contrast to landowner farmers, in poor seasons, many tenant farmers had reportedly preferred to abandon standing crops or hand-over crops to landlords as a coping strategy to limit losses. Although most of the farmers considered it necessary to supplement their cropping income with other means, they reported a lack of livelihood opportunities available to them in their districts as alternatives to crop farming. For example, a respondent from Rajanpur identified limited industrial activity in their district as a major barrier to diversifying non-farm income. However, farmers noted some opportunities for diversification within agriculture through livestock; cattle farming is becoming a profitable addition for those farmers who can afford to keep livestock at their farms.

3.2.3. Social Aspects

In addition to biophysical and economic aspects, farmers identified several social barriers to adaptation. Farmers identified the potential of local knowledge networks (formal and informal) to contribute to district social and human capital in support of adaptation. For example, farmers reported the following:

> "Since most of the farmers, 90% or so, are illiterate in villages, if they get educated then they could better understand, learn and act. I think education could play a major part here [. . .] Farmers come together on occasions of happiness and sorrow [and] discuss with each other how was the crop this time, what were the problems faced and how they had dealt with those. Farmers learn from each other's experiences". **F13**

> "We do exchange things with other farmers. I feel this is very good. I have three tractors and mostly those are working on others farmer's fields. I do not charge rent from other farmers. They fill their own fuel in my tractors and use them in their fields when needed". **F2**

Farmers from south Punjab indicated that low rates of literacy in their districts may limit adaptive changes in farm practices. They recognized the importance of knowledge acquired formally through education institutions and through dissemination via agricultural extension services. Some farmers reported that the district extension service approached farmers through meetings with field extension staff and arranged training sessions with small farmer groups. However, most of the farmers reported limited access to extension services in their districts. Some farmers also pointed towards the lack of 'practical' knowledge in extension service information as a barrier to its local utility.

In addition to extension services, farmers reported the significance for adaptation of their local knowledge and sharing through informal knowledge networks. They considered their knowledge of local conditions, practical experience, and informal knowledge networks to be key resources to their practice-based learning. Most of the farmers reported informal peer-to-peer sharing networks of importance that included both local and extended networks. In addition to their own experiences, farmers reported benefiting from the experiences of other local farmers, not limited only to their own districts. Farmers mentioned several local-scale settings for their sharing of knowledge and information such as occasion-based social gatherings like weddings and meeting points in villages called *derra*, which are places where farmers of the villages share their experiences in frequent meetings. In addition to knowledge exchange, all the interviewed farmers reported good cooperation with other fellow farmers. They identified several avenues for cooperation that included the sharing of agricultural machinery and farm inputs. Notably, farmers reported excellent cooperation when other farmers were in crises. For example, a farmer from the Rajanpur district noted that all farmers' associations cooperate with each other and strive for the wellbeing of farmers. While local networks were most frequently cited as significant, some farmers highlighted the importance of extended networks encompassing other districts. For example, a farmer reported experiencing benefits through cooperation with farmers in other districts of Punjab:

> "Last year I had brought quality seed of cotton crop from my friend who lives in another district. . . . . .I tried that seed; found very good results and I had got increased income from my cotton crop in accordance with my expectation. In my area, such better quality of seed is not available". **F6**

3.3. Farmers' Perspectives on Policy and Planning

Farmers held strong opinions on formal policies and plans that aim to address climate change (such as national and provincial adaptation measures) and how well these initiatives were delivering intended outcomes and meeting farmers' needs at a local level. Policy-related constraints included a lack of local consultation about needs, inconsistencies in

planning policies, limited attention to support for farm-scale action, and greater equity in policies.

3.3.1. Local Consultation about Needs

In relation to a lack of consultation with farmers about their needs in policies and plans, a farmer discussed policy initiatives on the provision of subsidized farm inputs:

> "We are bound to use high rates of electricity for agriculture use. There is reduced electricity tariff for agriculture use but the problem is to be able to get this, [to obtain access] we are required to pay for costly transformers and agriculture meter feasibility costs by our own means, which we cannot afford so cannot take the benefit of subsidized rates. We are doing agriculture on a self-help basis". **F17**

The Government of Punjab (GoP) has taken policy initiatives at the provincial scale aiming to provide subsidies on various farm inputs such as electricity and fertilisers to reduce the effects of high costs to farmers of production inputs. For instance, study respondents noted the policy initiative to provide electricity to farmers on a reduced tariff for agriculture use in Punjab. However, not all farmers were able to benefit from these reductions due to many miscellaneous upfront costs associated with electricity connection to farms, which they were unable to afford. For example, farmers from the Muzaffargarh district reported that only a few farmers in their villages were accessing subsidized electricity connection, which allowed them to pump irrigation water, operate their tube wells, and thereby maximize their crop yields and avoid the use of high-cost (fossil-based) fuels. They were of the view that where farmers were unable to access electricity, they were bound to use diesel-driven pumps for water extraction, even though high prices made diesel affordability equally difficult for many farmers.

In addition to farm inputs, most of the farmers reported a lack of consultation in other policy initiatives such as the provision of agriculture loans and crop buying. A farmer stated the following:

> "Getting agricultural loans is a very difficult, complicated and tiring process. Farmers only get into the process of obtaining a loan when he has nothing else to do [. . .] The wheat crop announced price by the government is high but we are bound to sell to middle men, [because] the government does not buy directly from us. I feel that the government departments have lots of their own projects and do not have time to engage in crop buying from farmers". **F4**

Almost all the farmers interviewed in this study reported that the loan process was overly complex and difficult to follow and that the loan approval process involving extensive documentation was time-consuming and required numerous visits to the bank over a span of many months. Farmers also reported that the loan conditions were very onerous with very high rates of interest. Farmers expressed reservations that the time commitments would impinge on their essential farm management activities. Many farmers were reportedly unable to pay back loans on time and complicated loan conditions that included interest penalties for late payments often saw debts multiplying.

On the issue of crop marketing, farmers reported a lack of engagement with government policymakers. Some farmers noted that the national government sets the price for wheat crops for all provinces at a much higher level than the regular market price, which farmers considered beneficial to them. However, they reported a range of issues impeding their access to the official support price that included the inability of individual farmers to afford the appropriate bagging of crops, labour requirements, and transport arrangements to access government buying centres.

3.3.2. Planning and Consistency in Policies

In addition to a lack of engagement, farmers reported aspects of a lack of planning and inconsistency in policy processes. For instance, a farmer stated the following:

> "There are many things which we feel are needed but we cannot afford to adopt. Like drip irrigation, and solar tube wells we cannot afford. I know tunnel farming can be very useful in winter but it will cost me a lot. Government policies for drip irrigation, tunnel farming are there but [only] some farmers can take advantage of that, I do not fulfill government criteria to take benefit of this". **F17**

Farmers identified a range of policy initiatives formulated by the government of Punjab at a provincial scale aiming to benefit farmers at a district scale. However, they noted that policy measures were constrained by a lack of planning. Farmers found that uniform policy measures could not be made accessible to all Punjab farmers, and the full benefits of such theoretically promising policy initiatives were not reaching all farmers at a district scale where they could have the greatest impact. For example, farmers found that policy support for the adoption of drip irrigation and solar-powered tube wells was a useful measure introduced by the Punjab Government to address the farm water shortages and to replace high-cost diesel-driven tube wells. However, policy-related bottlenecks and a lack of financial resources to support the policy were reportedly hampering access to measures that might lead to improved climate adaptation. Likewise, other farmers reported that they were excluded from the policy initiatives because they failed to meet a minimum land-holding threshold established as a criterion for access under the policy. In addition, farmers identified the need to plan policy initiatives to respond effectively to crop failure. Many farmers reported that their crops had failed many times in the past due to a range of factors such as heat waves, pest attacks, frequent drought conditions, and floods. However, they found that the compensation on offer was either missing or very poor compared to the magnitude of their losses. Some farmers suggested the need for effective and systematic policy responses to crop failures such as the availability of insurance for crop loss.

A lack of consistency in policies and plans developed by government at a national and provincial scale was viewed by farmers as a further impediment to adaptation. Many farmers identified a range of inconsistent policies and plans that included subsidies on farm inputs, programs to improve crop varieties, assistance for technology adoption, and the provision of loans. Farmers viewed inconsistency as due to changes in leadership of federal and provincial governments which resulted in 'policy churn'. Farmers found that some revised policies were beneficial to them, but they were uncertain about their continuity in light of ongoing changes in central governments. Farmers suggested that frequent changes to plans and policies meant that they seldom remained in place long enough to achieve their goals. For example, a farmer stated the following:

> "There was an earlier government policy to give new variety of seeds to some selected farmers of the area through balloting. These farmers share these seeds with other farmers. Such good seed policy has now stopped with the change of new government [. . .] There were government schemes for giving loans on low interest rates from banks and subsidies on fertilizer to farmers, but now with new policies these steps withheld. I think farmers are not doing planning because government does not have plans for farmers". **F3**

3.3.3. Effects of Farm Scale

Farmers noted that they currently receive support, formal knowledge, and information from government departments at a provincial and district scale. However, they found that the provision of support from these levels of government was not meeting their requirements. While there were often high levels of activity from government functionaries through meetings and the development of plans for agriculture, they viewed these actions as ineffective because they did not result in any noticeable change in their districts or villages. Many farmers identified shortages of agriculture extension service staff to effectively cover whole districts as a barrier to improved access to knowledge. They suggested that extension service teams at a district scale need to be strengthened and required to focus their activities at a finer scale. They suggested that the employment of additional field staff, combined with the availability of down-scaled meteorological information, would ensure

the dissemination of relevant information to support local adaptation action by farmers. For example, a farmer stated the following:

> "Timely meteorological information should be provided to us so that we can make adjustments. The climatic forecasts are for the whole region but not specifically for my area so what is the use for me. Seeds needs to be of better quality. I don't know where the problem is, we had seen good quality imported seeds in 1970's which mostly give better production but I have not seen such seeds again in my area and local seeds now are not of good quality. If [farmers] use fertilisers and seeds but do not find timely water for land then all this goes in vain. If they [government] focus on these absolute necessary things, then we can adapt to climatic changes in a better way. Things could be improved if farmers' problems were solved at their [local] level". **F10**

In addition to enhanced extension services, farmers suggested that the establishment of government crop buying centres at locations more accessible to their farms (e.g., within tehsil areas) would reduce the current high levels of logistics-related expenses. Moreover, informants reported that farmers were lacking access to costly agriculture-related machinery (e.g., tractors) and technology (e.g., laser land levellers). Some farmers suggested that support from government for the provision of agriculture machinery and technology on reasonable rents at a local tehsil scale would help to alleviate this constraint.

> "At district level many meetings and gatherings occur regarding agriculture but I do not see practical outcomes of those on ground for the betterment of farmers and agriculture in my area. I think if practical actions are to be taken to address farmers' needs and to focus agriculture at union council level then this will likely produce good effects on local agriculture [. . .] Extension staff try in their capacity to approach farmers but district level field staff is very limited. There is a need for field staff even at each tehsil level to better assist us". **F4**

3.3.4. Equity in Policies

Farmers observed that inequity existed in some government policies where they discriminated against small-scale farmers. For instance, farmers stated the following:

> "Government policies also need to be developed for small [scale] farmers instead of focusing on large [scale] farmers only which already are not in as much need. There should be more support from government departments especially for poor farmers. Large farmers usually get support from all, but poor farmers do not get the same support. Loans should be given to needy small farmers instead of large farmers only". **F11**

> "Farmers who have direct connections with politicians or other influential persons utilise their powers to open canals to benefit farmers. As a large farmer, I do not sell my crops to middlemen and directly deliver my harvested crops by utilising my own links [. . .] Farmers whose lands are situated at the canal head or middle, although not enough, usually receive far better canal water [access] as compared to farmers who are at the tail of canal who receive almost negligible share". **F7**

Many farmers identified inequality in policies in addition to the general biophysical and economic resource constraints referred to earlier. For instance, they reported that farmers at the tail-end of irrigation canals were in a disadvantaged position as they seldom received their full irrigation water allocation compared to head-end farmers. Farmers were of the view that most of the irrigated water was removed from canals before it reached the tail-end of the system either as losses, through water sales, or consumption.

Several aspects of discrimination against smaller-scale farmers were reported, including more limited access to irrigation water from canals, access to poorer quality of seeds, limited access to loans, and greater difficulty in negotiating sales of crops due to lack of appropriate storage. Farmers were of the view that influential large producers were more

likely to secure agricultural loans and higher-quality seeds. They noted that they rarely observed higher-quality seeds in the open markets.

Small-scale farmers considered that although they were affected by climate variability and seasonal conditions, they had limited means to deal with the impacts, and discrimination simply increased their sensitivity compared to larger-scale more influential farmers. Some interviewees perceived that the influence of these large-scale farmers may be due to their possible connections with national- and provincial-scale politicians and other influential persons through utilising their power relations. Many farmers interviewed were of the view that these large influential farmers have more flexibility than small-scale farmers to secure agricultural loans and in canal water management, receive higher quotas in wheat crop selling processes managed by institutions, and were better able to store crops and then sell in batches at better market prices rather than selling their entire crop at once at relatively low rates.

4. Discussion

Climate change threatens the food and income security of millions of vulnerable farmers in developing countries because of the primacy of agriculture [80]. This challenge is particularly acute in South Asian countries like Pakistan, which are home to the world's largest number of poor smallholder farmers [81]. By focusing on vulnerability, in addition to the resources needed to promote change, the socio-economic, institutional, political, and cultural factors, collectively known as the enabling environment, which support farmers' adaptation responses to climate hazards, can be explored [53,82].

In this study, we examined how farmers in selected vulnerable districts of the Punjab province [38] perceive their vulnerability to climate change, adaptation responses, and constraints to local-scale adaptation. We found farmers' ability to adapt is constrained by the available resources and various aspects of the enabling environment set by existing government arrangements. Farmers viewed government support as inadequate and poorly matched to their needs owing to a focus on a top–down policy agenda that failed to incorporate bottom–up need assessments. Farmers called for greater engagement with local government on climate change as the most accessible formal institution. The following discussion places our findings on Punjab farmers' perceptions of climate change and their capacity for adaptation in the context of the South Asian region and of specific constraints imposed by their enabling environment at the district scale.

4.1. Farmers' Perceptions of Climate Change

Farmers' perceptions of the hazards of climate variability and change drive their need to adapt (e.g., [83]) and influence the implementation of adaptation measures [84,85]. In this study, farmers agreed that the climate was changing in vulnerable districts of Punjab, and they recognized the need to respond. Farmers' observations of rising temperatures and increasingly variable rainfall as interfering with local crop production were consistent with the available scientific evidence. Long-term climate monitoring data for Punjab (1967–2017) show an increasing trend of mean annual temperature [64], and prolonged dry spells have been observed for the analysis period (1980–2010) in southern Punjab [63]. To support local adaptation action, farmers saw a need to improve the provision of seasonal weather forecasts calling for greater availability of down-scaled meteorological information that is locally relevant, useful, and timely for agriculture. However, many factors determine the potential benefits that farmers gain from access to meteorological services, including the scale of farmers' operations, the reach of the information services into remote areas, the timeliness of communication about the agricultural calendar, and the dissemination of information in a form that farmers can understand and use in their decision-making [11,86,87]. Other studies have indicated that in addition to short-term meteorological information for seasonal decision-making, long-term (seasons to decades) down-scaled climate projections are critical for farmers' adaptation planning [88–90]. Ref. [89] suggested that strengthening the evidence base through farmer engagement would improve user-tailored climate ser-

vices as decision-support tools to transform climate information into relevant, salient, and usable advisory services for vulnerable communities.

4.2. Farmers' Adaptation Strategies

The responses of farmers to climate change can range across a spectrum of change to reduce vulnerability and enhance their resilience [15]. The spectrum of change refers to the degree of departure from the status quo that different types of responses to climate change entail, ranging from coping, which maintains the existing system functions and structures, to incremental changes, which modify them within certain limits, to system transformation, which fundamentally alters them in pursuit of a new system state [15,91]. We found that, in our study, farmers largely adopted coping and incremental changes mainly in response to drought. Farmers adopted coping strategies such as changing planting dates, fertilizer application, and alterations in crop water management as short-term and reactive responses to climate shocks, e.g., heat waves, to maintain the existing livelihood system.

In addition, we found the adoption of incremental changes (e.g., crop diversification) as moderate and proactive adjustments to the existing livelihood system that aim to improve the efficiency or effectiveness of the current practices without altering the fundamental structure or function [16,17] (Kates et al., 2012; Bene et al., 2016). Further, farmers reported incorporating livestock into cropping systems as a useful adaptation strategy. Livestock form a valuable asset that hedges farmers against poor cropping seasons through livelihood diversification and provides farm households with better food dietary diversity and food security outcomes [92,93]. Farmers adopted practice changes as coping strategies, incremental changes, or a mix of both. However, the key distinction between coping and incremental change depends on whether farmers revert to previous practices after the climatic event. Other studies identified these adaptation strategies as commonly adopted measures in response to climatic changes in Pakistan because they are easy to implement and relatively low-cost [94–96]. In particular, crop diversification was found in many studies as a common adaptation measure to minimize the losses incurred by the failure of a single crop due to extreme climatic conditions [25,96–98].

Actions taken by farmers strive to address aspects of underlying vulnerability, and this is consistent with the idea that climate change is an amplifier of existing vulnerability and a multiplier of threats [99]. For instance, changing planting dates, adjustment to water management, fertilizer application, and crop diversification are practice changes that can address aspects of low productivity, soil degradation, and water scarcity that make farmers more vulnerable and exposed to climatic changes. These changes also show that the adaptation strategies of farmers are not only influenced by the nature and magnitude of climate risks but also by the underlying factors that shape their vulnerability and exposure to those risks. Notably, climate change magnifies existing vulnerability by increasing the frequency, intensity, and duration of climatic stressors that affect the livelihood systems of farmers (e.g., [100]). Thus, climate change interacts with other drivers of change and creates new challenges for farmers. Changes to practices help farmers survive the immediate crisis and enhance their productivity and resilience in the face of climatic changes. However, they can also have limitations or trade-offs in the long term. For instance, changing planting dates can reduce exposure to climatic stress but can also affect crop yield (e.g., [101]). Likewise, fertilizer application can increase soil fertility, but the inefficient use of fertilizers can cause environmental problems and can hinder the sustainable development of agriculture (e.g., [102]). Such changes, therefore, are not always effective or sufficient for adapting to climate change in the long term. Moreover, coping strategies are more likely to be used by poorer farmers who have limited access to resources and opportunities [72].

4.3. Farmers' Enabling Environment

In addition to the changes already adopted by farmers, they also identified several potential practice changes that they thought were needed (e.g., drought-tolerant crop vari-

eties and advanced water conservation practices) to support adaptation but appeared to be currently beyond their capacity because they require an enabling environment that facilitates change. In this section, we discuss changes to irrigation, crop market arrangements, and knowledge dissemination identified as critically needed by farmers and subject to the complex nature of the enabling environment.

4.3.1. Water Governance

The supply of irrigation water was identified by farmers as a key enabler of adaptation to a changing climate, as adequate supplies of water contributed to the natural capital base required for the growth of their crops [103]. However, under the current management of the irrigation water supply, farmers reported being highly constrained in their ability to use water effectively to respond to increased seasonal variation in rainfall. Farmers identified issues around the amount, access, and distribution of irrigation water as key constraining factors of concern under current water governance arrangements that restricted their farm planning. They reported that the irrigation water supplies were generally far less than their crop needs and frequently unreliable, findings that are in line with earlier studies from Pakistan (e.g., [104]). Furthermore, ref. [105] found that the availability of water resources was a significant determinant of adaptation planning and identified a lack of water resources as a key barrier to adaptation in the rice-growing zone of Pakistan.

Constraints imposed by the governance of irrigation water on adaptation by farmers appear to be widespread throughout Asia with studies from Bangladesh [106], India [107,108], and Nepal [109] reporting similar findings. While farmers often described the establishment of government water initiatives to support adaptation, their ability to exploit these opportunities was often hampered by poor policy design or implementation that did not account for farmers' resource-constrained settings. For example, drip irrigation has been promoted by government to improve the water use efficiency of irrigated crop production and with the potential to transform the agricultural landscape of Punjab [110,111]. Ref. [110] suggested that a lack of adoption was related to knowledge deficits about the benefits and limited experience with drip technology. However, most farmers in the current study appeared to be aware of the adaptation benefits of drip irrigation with adoption reportedly limited by the financial capacity to purchase equipment (also documented by [112]), particularly where the security of access and supply of irrigation water were uncertain. Consequently, to ensure crop water requirements, farmers turned to potentially maladaptive practices such as the use of often poor-quality groundwater extracted from tube wells with potential adverse implications for sustainability. The excessive use of groundwater in Pakistan is degrading land and lowering groundwater levels [113].

In India, groundwater resources are also rapidly depleting due to their consumptive use in agriculture [46]. However, to address the rising physical and economic scarcity of water, India is focusing on a switch from augmenting irrigation water supply to managing demand (e.g., incentives to farmers to reduce groundwater extraction, [114]), improving irrigation efficiency [46], and promoting water-saving cultivation practices for staples [115]. Likewise, the critical need for the demand management of water resources has also been emphasized in studies from Pakistan, including the minimization of losses from water courses and, at the field level, the replacement of inefficient flood irrigation practices and promotion of drought-tolerant crop varieties to reduce irrigation requirements (e.g., [111]).

4.3.2. Market Arrangements of Crops

Appropriate market arrangements of crops have implications for farmers' physical and financial capital because they can affect the accessibility and affordability of inputs and outputs that farmers need to produce and sell their crops [116,117]. Better market arrangements can help farmers to lower their transaction costs, reduce their risks, increase their income or savings, and raise their capacity to adapt to climate change [118,119].

However, under current market arrangements, the farmers interviewed reported issues around market access (such as the logistics of crop transport and availability of

quality seeds) constraining their capacity to adapt. They reported that their market access is severely hindered by poor road infrastructure and high transportation costs. Limited market access constrains farmers' enabling environment because it affects income, profitability, competitiveness, and capacity to take adaptation initiatives [120]. It limits farmers' exposure to diverse markets, income opportunities, and incentives to adopt improved technologies and practices [121]. Farmers with higher and more stable incomes can afford to invest in adaptation measures that require upfront costs or have delayed returns [122]. Notably, gaps in market access also affect the success and continuity of the farmers' adopted practice changes, limiting the shift from coping strategies to incremental changes. For example, the enabling environment in our case fails to provide reliable market arrangements for quality seeds of better-adapted (drought-tolerant) crop varieties despite farmers' willingness to adopt such changed practices.

Constrained market access can also affect farmers' bargaining power and competitiveness, which are important factors underpinning profitability and sustainability under climate change (e.g., [123]). Small-scale farmers reported their limited bargaining power to influence market prices as they are largely 'price takers'. Farmers with greater bargaining power can negotiate better prices and terms with buyers, suppliers, and intermediaries and reduce their transaction costs and risks [124]. Moreover, market access can affect farmers' incentives and motivation to adopt improved technologies and practices, which are important drivers of their productivity and efficiency under climate change [125]. Therefore, gaps in market access requiring institutional interventions constrain farmers' enabling environment for climate change adaptation by limiting their incentives to adopt improved practices, bargaining power, and income opportunities. Our findings are in line with other studies on South Asia. For example, ref. [126] found that poor market facilities and road connectivity reduced farmers' adoption of climate-smart agricultural practices. Also, ref. [127] found that market accessibility factors of road infrastructure and transportation costs significantly affect the small farming household food security in rural Pakistan. Similarly, ref. [128] reported that a lack of market access hindered farmers' ability to switch to more profitable and climate-resilient crops in Nepal. In our study, farmers found these critical constraints adding to existing declining terms of trade, a problem common to agriculture globally (e.g., [42,129]).

Economic policy interventions by the GoP, such as subsidies on farm inputs, crop support prices, and credit schemes in collaboration with financial institutions, have been established to incentivize improvements to the infrastructure of rural communities [130] that might also enhance climate change adaptation [131]. However, this study found that government financial support is not contributing effectively to the enabling environment for adaptation, as farmers find these financial schemes difficult to access due to onerous loan conditions and administrative complexities. Farmers reported that high upfront costs on subsidized farm inputs and the eligibility criteria of agricultural loans or repayment terms (such as high interest rates) discourage many farmers from applying for or benefiting from financial support. Also, farmers found that support price schemes that guarantee minimum prices for farmers' crops through direct purchases by the government have limited coverage or effectiveness. These constraints reflect the cost of agricultural finance, and initial investments to access subsidies (such as solar power for irrigation) tend to be higher than the returns on investment for many small-scale farmers. High interest rates on loans may also reflect the high risk or low profitability of agriculture in some areas or seasons, likely to be exacerbated under climate change. Additionally, a lack of competition in the rural credit market may allow lenders to charge exorbitant rates or fees. Agriculture loans with short repayment periods, rigid schedules, or penalties may not suit the cash flow or risk profile of farmers. Our findings on the lack of access to credit for farmers are consistent with other studies on Pakistan (e.g., [25,132]). In addition, farmers reported various administrative complexities such as the procedures and application requirements for receiving agricultural loans and subsidies involving eligibility criteria, lengthy processes, multiple agencies, and cumbersome paperwork. Such complexities can further increase

the transaction costs and delays or create uncertainties for farmers seeking government financial support (e.g., [133]).

4.3.3. Knowledge Exchange

Knowledge exchange as a process of sharing and learning can enhance farmers' ability to adapt to climatic changes by providing them with access to different sources of information and experiences [134,135]. Effective knowledge exchange between actors can facilitate the adoption of more sustainable and resilient practices and foster innovation and collaboration [136]. Actors in farmer knowledge networks can include formal (e.g., government extension officers, NGO development practitioners) and informal (peer-to-peer and 'model' farmers) institutions that together shape the enabling environment for knowledge exchange [137,138]. However, our findings indicate that farmers were afforded little opportunity to exchange knowledge with formal government actors, resulting in policy interventions on climate change that failed to address local needs and undermined farmers' adaptation actions. We found top–down policy development created a mismatch between farmers' preferences, realities, and the practices prescribed for adaptation. Also, farmers reported limited opportunity to voice their concerns or influence the policies that affected their livelihoods, which are essential for fostering learning and innovation for adaptation and are key features of knowledge exchange (e.g., [139]). In this study, farmers described diverse and complex local conditions that fit poorly with the standards and regulations imposed on agriculture by government. Moreover, farmers had limited opportunities to affect these policies as they lacked representation, consultation, feedback, or accountability mechanisms. As a result, farmers may lose trust in participating in institutional decision-making processes, feeling excluded and marginalized. Knowledge exchange requires mutual trust and dialogue among actors, which are undermined by a lack of representation (e.g., [134,140,141]).

Farmers reported seeking greater engagement with local (district) government to communicate issues around climate change because they want to have more influence in policy planning processes that affect them. Globally, responsibility for action on climate change adaptation has devolved to local governments in the face of often ineffective national responses (e.g., [142]) because, for communities, local government is more accessible (e.g., [143]) and because it is a "key moderating force between high level adaptation plans and how they are put into action" [144]. Closer engagement with local government may empower farmers' voices by giving them more information, choices, or opportunities. Also, the engagement of stakeholders is the basis of participatory processes, and better engagement can build more cooperation with stakeholders in agriculture and environmental management [145,146]. Cooperation is essential for effective knowledge exchange as it can help improve the quality and effectiveness of decision-making and practice, as well as foster collaboration and innovation among different actors [140]. However, for local government to assume an expanded role in farmer engagement and adaptation planning, it may require additional resources, which in the Global South may be scarce [143].

Notwithstanding resource constraints, local knowledge acquired by farmers can help local governments understand their needs and preferences, design more appropriate and effective policies and services, and foster collaboration and innovation. Farmers reported the importance of their local practice and experience-based knowledge to promote the drive to adopt new practices. Farmers acquire local knowledge through their interaction with their environment and their community (e.g., [135]). It is context-specific, dynamic, and diverse. Local knowledge can help farmers adapt to changing conditions and improve their productivity and sustainability. With the likely exacerbation of climatic impacts that challenge the limits of current adaptation strategies (e.g., [147]), the enormous store of farmers' experience-based knowledge can be useful for knowledge exchange with the formal institutions that shape the enabling environment in which adaptive strategies are developed [135,148,149]. However, knowledge exchange is most effective when there is

a two-way dialogue that facilitates the co-design of interventions among stakeholders (e.g., [134,150]).

The imperative for differentiated public policies for marginalized groups such as small-scale farmers, family farming, and less favoured groups deserves significant emphasis [151,152]. It becomes evident that a one-size-fits-all approach is not sufficient to address the diverse needs and challenges faced by these stakeholders. For instance, Brazil serves as a notable example with its specific policies tailored to family farming and less favoured groups [152,153]. Family farming, characterized by its small-scale operations, serves an important role in food production, rural livelihoods, and sustainable agriculture [152]. Brazil's commitment to family farming is reflected in initiatives such as the National Program for Strengthening Family Agriculture (PRONAF), which provides crucial financial support, technical assistance, and market access to small-scale farmers [153]. This empowers them to enhance their productivity and livelihoods. Additionally, programs like the Food Acquisition Program (PAA) create valuable market opportunities for family farmers while addressing broader food security concerns [154] (Perin et al., 2022). In light of distinct challenges faced by small-scale farmers in Punjab, tailored public policies are indispensable for effectively supporting small-scale farmers within the agricultural sector, as evidenced by this study. Differentiated public policies are pivotal in fostering resilience, promoting equitable access to resources, and achieving sustainable agricultural development.

Farmers called for equitable policies and plans that enable all farmers to access the same opportunities for local adaptation action. We found that small-scale farmers encountered various forms of inequity compared to large-scale influential farmers, which adversely affected their livelihoods and adaptive capacity for climate change. These inequity issues intersect with key aspects of the enabling environment discussed earlier. For instance, in areas with insufficient irrigation water supply, the unequal allocation of irrigation water—i.e., who receives what share and at what cost—exacerbates the farmers' vulnerability, with small-scale farmers often bearing the brunt (e.g., [104]). The study findings illuminate the intricate interplay between agricultural productivity, energy access, and water resource management within the context of the Food–Energy–Water (FEW) nexus (e.g., [155]). The significant financial strain imposed by the high cost of electricity for water pumping, as highlighted by farmers, not only underscores the energy requirements of agricultural practices but also the pivotal role of water in sustaining food production. The disparity in access to affordable electricity exacerbates existing socio-economic inequalities, limiting the capacity of resource-constrained farmers to adapt to changing climate conditions. Furthermore, the reliance on fossil fuel-powered pumps in areas lacking electricity infrastructure not only amplifies production costs but also contributes to environmental degradation and carbon emissions. Integrating the essence of the FEW nexus into policy formulation is essential for fostering synergies across these interconnected systems and promoting sustainable resource management practices. By adopting a holistic approach that recognizes the intrinsic linkages between food, energy, and water security, policymakers can develop strategies that enhance resilience to climate variability and promote equitable access to essential resources. Also, the eligibility criteria for accessing agricultural loans and subsidies often exclude or discourage small-scale farmers from applying for or benefiting from these initiatives. For example, loans and subsidies require upfront costs, collateral or guarantors, formal land titles, or bank accounts that many smallholder or marginal farmers may not have. Studies have shown that unequal and restrictive governance structures can severely limit entitlements to the key resources needed to respond and adapt to climate-related threats [156–158] (McGray et al., 2007, Masters and Duff 2011; Thomas et al., 2019). In addition, small-scale farmers face exploitation by middlemen who act as intermediaries between farmers and markets. Farmers reported that middlemen charge exorbitant fees for their services or extract a substantial portion of the profits from the sales of small-scale farmers, who already have limited resources to access markets. Such monopoly situations, resulting from limited market diversity and competition and the increased role of intermediaries, diminish the bargaining power of small-scale farmers when it comes to negotiating

the prices of their farm products (e.g., [159]). Moreover, extension services also tend to favour large-scale wealthier farmers given the skewed nature of distribution in favour of resource-rich farmers (e.g., [96,160,161]). Accordingly, small-scale farmers face heightened vulnerability because of their limited access to resources and government support services, with the reduced returns from sales of agricultural produce further diminishing their ability to invest in technology improvement or adaptation practices.

5. Conclusions

This research conducted in vulnerable districts of the Punjab province highlighted the profound impact of climate change on farmers, revealing their heightened exposure to climatic variability and extreme events. This study aimed to gather bottom–up evidence to inform policy and enhance the enabling environment for adaptation strategies. Despite recognizing the urgency to adapt, farmers' responses predominantly relied on short-term coping strategies and incremental adjustments. A significant finding was the existence of an inadequate enabling environment for adaptation coupled with limitations in accessing crucial resources critical for broader adaptation. Insufficient government support aligned with farmers' needs, combined with inequitable market practices, exacerbated the vulnerability of small-scale farmers. The crucial role of irrigation water in climate adaptation was evident, yet its inequitable distribution and access constrained effective farm planning. Addressing these disparities in water governance emerged as a critical step toward fostering resilience in agriculture. Notably, the lack of knowledge exchange between farmers and formal government bodies hindered effective policy implementation. Creating an enabling environment that fosters communication and actively integrates farmers into policy planning processes emerged as essential for the effective implementation of adaptation strategies. Climate change is an ongoing, dynamic process that continuously influences the vulnerability and adaptation needs of communities. To address this limitation, future research can adopt a longitudinal perspective to examine the evolving dynamics of climate change impacts, vulnerability, and adaptation strategies to capture the changing nature of climate vulnerability and adaptation requirements.

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