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Exploring Agriculture Sector Vulnerability to Climate Change at District Level in Pakistan

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under the supervision of Associate Professor Brent Jacobs and Associate Professor Dana Cordell

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, *Faisal Nadeem*, declare that this thesis is submitted in fulfilment of the requirements for the award of *Doctor of Philosophy*, in *the Institute for Sustainable Futures* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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List of Abbreviations

ADB- Asian Development Bank

AED- Directorate General Agriculture, Extension and Adaptive Research

CSA- Climate-Smart Agriculture

DGK- Dera Ghazi Khan

DFID- Department for International Development

EPA- Environment Protection Agency

FAO- Food and Agricultural Organization of the United Nations

FICCP- Framework for Implementation of Climate Change Policy

GHG- Greenhouse Gas

GIS- Geographical Information System

GoP- Government of Punjab

GO- Government Officials

IPCC- Intergovernmental Panel on Climate Change

NAPAs- National Adaptation Programmes of Action

LDCs- Least Developed Countries

NCCP- National Climate Change Policy

NDC- Nationally Determined Contributions

NEP- National Environmental Policy

NGO- Non-government Organisations

PBS- Pakistan Bureau of Statistics

PCCA- Pakistan Climate Change Act

PC- Planning Commission

PCCP- Punjab Climate Change Policy

PEPA- Pakistan Environmental Protection Act

RCP- Representative Concentration Pathway

RLF- Rural Livelihoods Framework

TFCC- Task Force on Climate Change

UIB- Upper Indus Basin

UNFCCC- United Nations Framework Convention on Climate Change

UNDP- United Nations Development Programme

VSA- Vulnerable-Smart Agriculture

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Abstract

Punjab, Pakistan is a region of agricultural significance in South Asia where farm practices and livelihoods are threatened by the effects of climate variability and change. This study used a mixed-methods approach (quantitative and qualitative methodologies) to explore the vulnerability of agriculture to climate change at the district scale in Punjab. Using available secondary data sources, indices of vulnerability and its components (exposure, sensitivity, and adaptive capacity) were developed to delineate, through geospatial mapping, districts of Punjab most vulnerable to climate change. Semi-structured interviews were then conducted with farmers and government officials in four districts identified as highly vulnerable (Rajanpur, Muzaffargarh, Chakwal, Dera Ghazi Khan) to understand participants' perceptions of climate change, barriers and enablers of adaptation, and interactions among adaptation actors. Small-scale farmers reported constraints on their capacity to adapt due to limited resources (water governance, knowledge exchange, and market arrangements) and insufficient institutional support for adaptation action. Farmers frequently called for assistance from local government. However, engagement with district-level government officials revealed the local institutional capacity to establish an enabling environment for adaptation to be heavily constrained by inadequate, cross-scale governance arrangements and limited opportunities for input to policy planning. This necessitates a flexible approach to enhance the enabling environment for adaptation across diverse local contexts. Engaging stakeholders in co-design of strategies has the potential to prioritize climate-smart options, and knowledge co-production can encourage mutual learning through knowledge exchange to understand actors' needs and influence decision-making. The findings indicated that targeted institutional support to empower adaptation by vulnerable small-scale farmers was critical. However, the formulation and delivery of this support required better coordination across levels of government, devolution of responsibility and resources for adaptation to district scale, and incorporation of contextually-relevant (bottom-up) information on farmers' vulnerability in the formulation of top-down climate change policies and programs.

Chapter One: Introduction

1.1 Rationale

This thesis explores agriculture sector vulnerability to climate change at district level in Punjab, Pakistan. The research seeks to align with the current climate change policy landscape in Pakistan (described in background section 1.2), to fill knowledge gaps (detailed in Chapter 2), and to highlight the need to bolster research capacities in Pakistan in conducting assessments of climate change. Although the climate change policy landscape in Pakistan is evolving, existing high-level policy documents and national adaptation plans are unlikely to create an enabling environment to appropriately address issues of local (district scale) adaptation. The deficiency arises as policies appear to be largely uninformed by vulnerability assessments, geospatial mapping and bottom-up engagement crucial for understanding the geographical nuances of vulnerable areas. While current high-level policy documents illustrate the government's commitment to addressing climate change, they predominantly reflect global mitigation policies and encourage the development of national-level adaptation plans, which may not necessarily support local-level adaptation efforts of stakeholders, i.e. farmers in this study. This inclination aligns with the policy responses commonly observed in many developing nations (Holler et al., 2020). Despite shortcomings, the current policies, such as *National Climate Change Policy* (NCCP 2012), do emphasise the need to enhance various aspects of research capacity, including climate vulnerability assessments and geospatial analyses. These enhancements are widely accepted initial approaches to address climate change because they have the potential to facilitate bottom-up adaptation by shaping local adaptation plans and measures in accordance with local needs (Malone & Engle, 2011; Patt & Klein, 2012; Asfaw et al., 2021). A review of the literature on Pakistan's vulnerability (Chapter 2) indicated a limited focus on assessing agricultural vulnerability to climate change, despite the importance of agriculture to the Pakistan economy. Additionally, previous attempts to map vulnerability demonstrated limited efforts in identifying areas sensitive to climate change at provincial scale (Nadeem et al., 2022). Further, qualitative studies aimed at gathering bottom-up information from key stakeholders in vulnerable districts of Punjab province, regarded as Pakistan's 'food basket', are scarce.

Therefore, considering the critical significance of agriculture in Pakistan and its sensitivity to climate variations (see section 1.2.1), and in keeping with the current policy settings (section 1.2.3), this thesis seeks to address the need for action at the policy-science interface to initiate climate change vulnerability assessments for Pakistan's agricultural sector. Within the evolving climate change policy environment in Pakistan, this thesis focuses on providing evidence to support adaptation in the agriculture sector in Punjab province.

1.2 Background

The following sections provide an overview of the agricultural landscape in Pakistan and Punjab (Section 1.2.1), offering reasons for the focus on farmers within the study, and establishing the groundwork for the subsequent detailed analyses in the Literature Review.

Section 1.2.2 elucidates the comprehensive nature of the concept of an enabling environment for climate change adaptation, encompassing both policy and broader contextual factors. Specifically, it will delve into the critical role of policies as an integral component of the enabling environment that shapes the landscape for effective adaptation strategies.

Section 1.2.3 sheds light on the evolving policy landscape within Pakistan, delving into the state of high-level policy documents and national adaptation plans. This subsection aims to delineate the challenges and opportunities inherent in the current policy landscape, specifically in addressing local adaptation issues. Understanding these nuances is essential for formulating effective adaptation strategies within Pakistan.

1.2.1 Agriculture in Pakistan: a contextual overview

Pakistan is a densely populated, agrarian, developing country in South Asia and is considered one of the most vulnerable countries to the impacts of climate change in global and local studies (Brooks et al., 2005; Barr et al., 2010; TFCC 2010; NDC 2021; Eckstein et al., 2021). The country is particularly vulnerable to climate change due to its strong dependence on agriculture, which is recognised to be highly climate-sensitive and significantly exposed to climate risks (Maharjan & Joshi, 2013; IPCC 2022). Pakistan's economy is heavily dependent on agriculture, and the agriculture sector directly or indirectly supports most of the population (GoP 2022). Agriculture employs around 44% of the labour force, and accounts for more than 60% of foreign exchange earnings (PBS 2023). Although Pakistan is a vulnerable country in regards to climate change, it is also critically important as a food bowl for South Asia, and within Pakistan, Punjab province acts as a food bowl for the nation. In Pakistan, Punjab province holds a leading role in producing agricultural commodities, particularly in the critically important major crops sub-sector, including wheat, rice, maize, cotton, and sugarcane. It contributes over 60% to the overall national agricultural production and accounts for 74% of the total cereal production at the national level (PBS 2023). The vast majority (around 86%) of farmers in Pakistan possess small landholdings (Ahmad et al., 2023). The livelihoods of these small-scale farmers heavily rely on agriculture which is highly susceptible to the impacts of climate change (Howden et al., 2007). Smallholder farmers in developing countries including Pakistan make a significant contribution to global food security (Azadi et al., 2023) and are among those who will suffer the most from climate change impacts (Lasco et al., 2011). The Literature Review (Sections 2.1, 2.2, and 2.3) analyses, in finer detail, the causes and effects of agricultural vulnerability to climate change in Pakistan and the Punjab. This includes historical climatic changes, as well as future climate projections. Furthermore, it examines the profound impacts of climate variability and change on the major crop subsector. The convergence of high population and high food demand is a pressing concern, particularly in the context of future climate change. Ongoing and future climatic changes will likely amplify the existing vulnerability of Pakistan.

1.2.2 Enabling environment for climate change adaptation

Effective adaptation to climate change necessitates the establishment of conducive conditions that empower actors to enhance their resilience while reducing their exposure to risks (Bantayan et al., 2018). The enabling environment denotes the collection of conditions and support mechanisms surrounding adaptation actors, pivotal in augmenting their ability to adapt and sustain their livelihoods in a changing climate (Bapna et al., 2008; Lewis & Rudnick, 2019). This encompasses elements such as effective policies, information, governance mechanisms, infrastructure, and accessible credit options. It is important to emphasise that without supportive policies operating within an enabling institutional setting, the utilization of resources available to adaptation actors, such as farmers, might be constrained, limiting actions to adapt. Significantly, government entities undertake a substantial role in leading adaptation management, shaping policies, and fostering an institutional environment that propels successful climate change adaptation efforts (Bantayan et al., 2018; Rahman et al., 2021). Policy plays a crucial role in fostering an environment conducive to effective decision-making and implementation of measures aimed at helping actors adjust to the challenges posed by changing climatic conditions (Hallegatte et al., 2011; Ampaire et al., 2017). It provides the legal and institutional framework necessary to guide actions and decisions. Effective policies set objectives, allocate resources and mandate actions that promote resilience-building measures and adaptation strategies (Bapna et al., 2008). They ensure coherence across sectors, provide regulatory support, and create an atmosphere conducive to implementing adaptive measures. Furthermore, public policy interventions become necessary to ensure fairness and efficiency in the distribution of resources (Hallegatte et al., 2011; Head, 2022).

1.2.3 Government policy context for adaptation

Recognizing the importance of addressing the climate change problem and agricultural vulnerability, including ongoing and likely impacts of climate change on agriculture, and future climate projections, the national Government of Pakistan has formulated policies and plans. The national Government of Pakistan formulated and approved its first *National Climate Change Policy* in 2012 (NCCP 2012). Although *Pakistan Environmental Protection Act* (PEPA) was in effect since 1997 (PEPA 1997), it did not specifically address climate change and the focus of PEPA remained mainly on other aspects of the environment including pollution prevention, initial environmental assessments, the establishment of federal environmental protection bodies and environmental tribunals. Later, the National Environmental Policy (NEP) was approved in 2005 (NEP 2005). National Environmental Policy indicates that the Pakistan Government may devise a national climate change policy, which subsequently came into effect in 2012. However, the first attempt at national legislation on climate change was drafted in 2017 as the '*Pakistan Climate Change Act* (PCCA)' (PCCA 2017).

The National Climate Change Policy (NCCP) was developed in 2012 with the goal of mainstreaming climate change in all sectors of the economy and to steer Pakistan towards resilient climate development (NCCP 2012). The document provides broad policy measures for both climate change mitigation and adaptation for key sectors including agriculture and livestock, health, energy, transport, forestry, and industries. This national level policy document within the adaptation domain indicates general policy measures for the agriculture and livestock sector under sub-areas of research, technology, risk management, and general management.

The Framework for Implementation of Climate Change Policy (2014-2030) was prepared by the Government of Pakistan in 2013 (FICCP 2013). This document outlines the roadmap for implementing the National Climate Change Policy (NCCP). Aligned with the NCCP's directives, it details a comprehensive array of mitigation and adaptation strategies tailored for key sectors identified within the policy. Action strategies are categorised by implementation time frames: priority actions (to be executed within 2 years), short term (5 years), medium term (10 years), and long term (20 years). However, the framework lacks clarity in assigning explicit roles and responsibilities to relevant organizations. Notably, it does not specify how effective coordination among these entities will be ensured, particularly in terms of institutional authority.

'*Vision 2030*' prepared by Planning Commission of Pakistan is a broad national planning document for the country (PC 2007). '*Vision 2030*' emphasises that a 'resource crunch' will be aggravated by looming climate change impacts and Pakistan must prepare to adapt to the coming climate changes and mitigate their negative impacts.

At the provincial level, The Government of Punjab developed *Punjab Climate Change Policy* (PCCP 2017), which briefly outlines general mitigation and adaptation policy measures for sectors of Punjab similar to the NCCP (2012). Adaptation policy measures, however, are not separately stated from mitigation measures. The policy document for PCCP (2017) does not provide any reference to specific climate change adaptation plans for sensitive or exposed areas of Punjab.

All of these policy documents emphasise the need for enhancing research capacity to develop appropriate adaptation plans and measures. For instance, *National Climate Change Policy* (2012) and *Framework for Implementation of Climate Change Policy* (2013) highlights policy measures that include:

- Establishment of climate change units in agriculture research organizations to devise adaptive strategies for impacts of climate change on agriculture.
- Development of a proper risk management system to safeguard against extreme climate events such as floods and droughts.
- Identification of the drought vulnerable agricultural areas that are prone to increasing heat and drought-related failures of crops.
- Development of capacity for Geographical Information System (GIS) techniques to facilitate research work on climate change impact assessments.

The *Pakistan Climate Change Act* (2017) also highlights the need to prepare provincial and local adaptation action plans and coordinate the conduct of research on current and emerging issues of climate change, in particular, through assessments of climate change. The *Punjab Climate Change Policy* (2017) emphasises the need for developing capacity, capability, and competence in many areas including vulnerability assessments for effective implementation of this policy.

The Government of Pakistan has focused on national climate action through its Nationally Determined Contributions (NDC 2021). Within this NDC, distinct strategies have been outlined to address both mitigation and adaptation measures. The mitigation initiatives primarily aim to curtail greenhouse gas emissions by endorsing renewable energy in energy generation, investing in nature-based solutions, and implementing afforestation programs. These measures are geared towards reducing the nation's carbon footprint. Alongside, adaptation strategies focus on conserving biodiversity by protecting rare fauna and flora, which helps ecosystems adapt to changing climates. Additionally, the government aims to create green jobs and promote eco-tourism by emphasizing less carbon-intensive industries. These adaptation efforts are designed to enhance resilience to the impacts of climate change.

The landscape of high-level policy documents in Pakistan reflects the government's dedication to addressing climate change, primarily centred around global mitigation strategies. These policies advocate for the development and enhancement of national-level adaptation plans, demonstrating a concerted effort to tackle the consequences of a changing climate. Yet, the predominant focus on national-scale strategies poses a challenge in translating these directives into actionable measures at the local level and potentially hindering robust support for grassroots adaptation efforts. This emphasis on national adaptation plans might overshadow the unique vulnerabilities and adaptation needs of diverse local communities within Pakistan. Addressing adaptation at local levels, which requires a context-specific approach, demands greater attention. Despite these challenges and policy inclinations, it is important to recognise the proactive stance within these policies toward augmenting research capacity related to adaptation initiatives. Notably, the policies underscore the critical need to strengthen research mechanisms, advocating for comprehensive climate vulnerability assessments and geospatial analyses. This emphasis on research signifies a pivotal recognition of the necessity to equip decision-makers and planners with nuanced insights into the intricate dynamics of climate vulnerabilities, thereby laying a foundation for informed and effective adaptation strategies.

1.3 Research objectives

My research endeavours to achieve four specific objectives:

1. Develop an index of climate change vulnerability, and its components, for the major crops subsector of agriculture at the district scale in Punjab province.
2. Visualise vulnerability through mapping and utilise these maps to inform engagement with vulnerable farming communities.
3. Collect and analyse bottom-up information related to climate adaptation from relevant key stakeholders (i.e. farmers and government decision-makers) in vulnerable districts of Punjab to better understand the likely responses to climate change.
4. Assist in identifying adaptation priorities and the development of informed policy to support adaptation.

1.4 Research questions

Given the importance of agriculture and farmers to the Pakistan economy, the importance of institutions (particularly government) in establishing an environment that enables effective adaptation and the current high-level policy context for climate change in Pakistan, this thesis asks three research questions:

RQ1: Using available data, can an index of vulnerability be constructed and mapped that identifies the most climate change vulnerable districts for the major crop subsector of Punjab province?

RQ 2: For selected districts of Punjab identified through vulnerability mapping, what constrains and enables adaptation to climate change from farmers' perspectives?

RQ 3: What constraints are faced by district-scale government officials in supporting farmers' adaptation in vulnerable districts of Punjab?

The research questions divided the thesis into two interrelated components: quantitative assessment using GIS mapping of available secondary data, addressed through RQ 1, and qualitative assessment through analysis of semi-structured interviews with farmers and government officials, addressed through RQ 2 and RQ 3.

1.5 Research contribution

This research aims to contribute to knowledge for climate change adaptation by addressing several key areas, as outlined in the Rationale (section 1.1). It provides much-needed information on the vulnerability of the agriculture sector in Pakistan. It also seeks to bridge the gap between top-down processes and bottom-up information, facilitating more effective policy formulation. Furthermore, the research aims to identify critical gaps in adaptive capacity and adaptation actions within the agricultural sector that require attention. It develops examples of good practice in vulnerability assessment that can guide other regions in Pakistan, allowing refinement for their specific contexts.

1.6 Thesis structure

The thesis structure is sketched in Figure 1.1. It is composed of nine chapters, structured as follows.

Chapter 1 In the introductory chapter, the research context and rationale are laid out, offering a brief glimpse into the study's goals, significance, research questions, and outlining the structure of the thesis.

Chapter 2 presents a review of literature that explains three key research themes: climate change, vulnerability assessment, and agriculture. Firstly, it explores the climate change problem, responses to climate change, the emergence of adaptation in climate change discourse, and climate change in Pakistan and Punjab province. Secondly, it reviews the significance of climate change for agriculture, its vulnerability to climate change in the context of Pakistan and Punjab, and the impacts of climatic changes on the major crops subsector of agriculture. Thirdly, it examines complexity in conceptualisations and interpretations of vulnerability, the elements that comprise vulnerability and the relationships between them, and approaches to the assessment and mapping of vulnerability. The chapter reviews the emerging literature at the intersection of these three key research themes.

Chapter 3 explores the fundamental underpinnings of my research. It explains the Rural Livelihood Framework (RLF) by providing a tapestry of livelihoods capitals. Additionally, it describes the evolution from Climate-Smart Agriculture (CSA) to Vulnerable-Smart Agriculture (VSA) thinking, presenting the building blocks of the VSA model as outlined in the literature.

Chapter 4 describes the research design and details the study sites. This chapter also discusses the methods used and ethical considerations of the research.

Chapter 5 is a published journal article presenting the findings on quantitative vulnerability assessment, mapping and correlation analysis in response to RQ1. It discusses the findings of the chapter and its implications for climate change adaptation.

Chapter 6 is a published journal article presenting empirical findings on qualitative engagement with farmers from vulnerable districts of Punjab province identified through mapping (Chapter 5) in response to RQ2. It probes the factors that limit or facilitate farmers' ability to adapt to climate change.

Chapter 7 explores qualitative engagement with district government officials in vulnerable Punjab districts, presenting empirical findings in response to RQ3. This chapter focuses on the challenges encountered by district-level government officials in creating an enabling environment for adaptation as they endeavour to assist the adaptation of farmers within the vulnerable Punjab regions.

Chapter 8 synthesises and discusses the thesis findings (from Chapters 5, 6 and 7). This overarching discussion delves into the diverse vulnerabilities of the Punjab and the specific adaptations observed in the empirical evidence. It presents a revised conceptual model of VSA augmented through identification and incorporation of enhancements in VSA thinking from empirical findings of this study. Additionally, it highlights the alignment of my preceding chapters with this revised model. Furthermore, the discussion emphasises the transformative potential of participatory approaches in understanding contextual realities of farmers and effectively shaping strategies for climate change adaptation through the establishment of a supportive enabling environment.

Chapter 9 encapsulates key conclusions, highlights the significance of my research, addresses the research inquiries along with their implications and limitations, and proposes potential directions for future investigation.

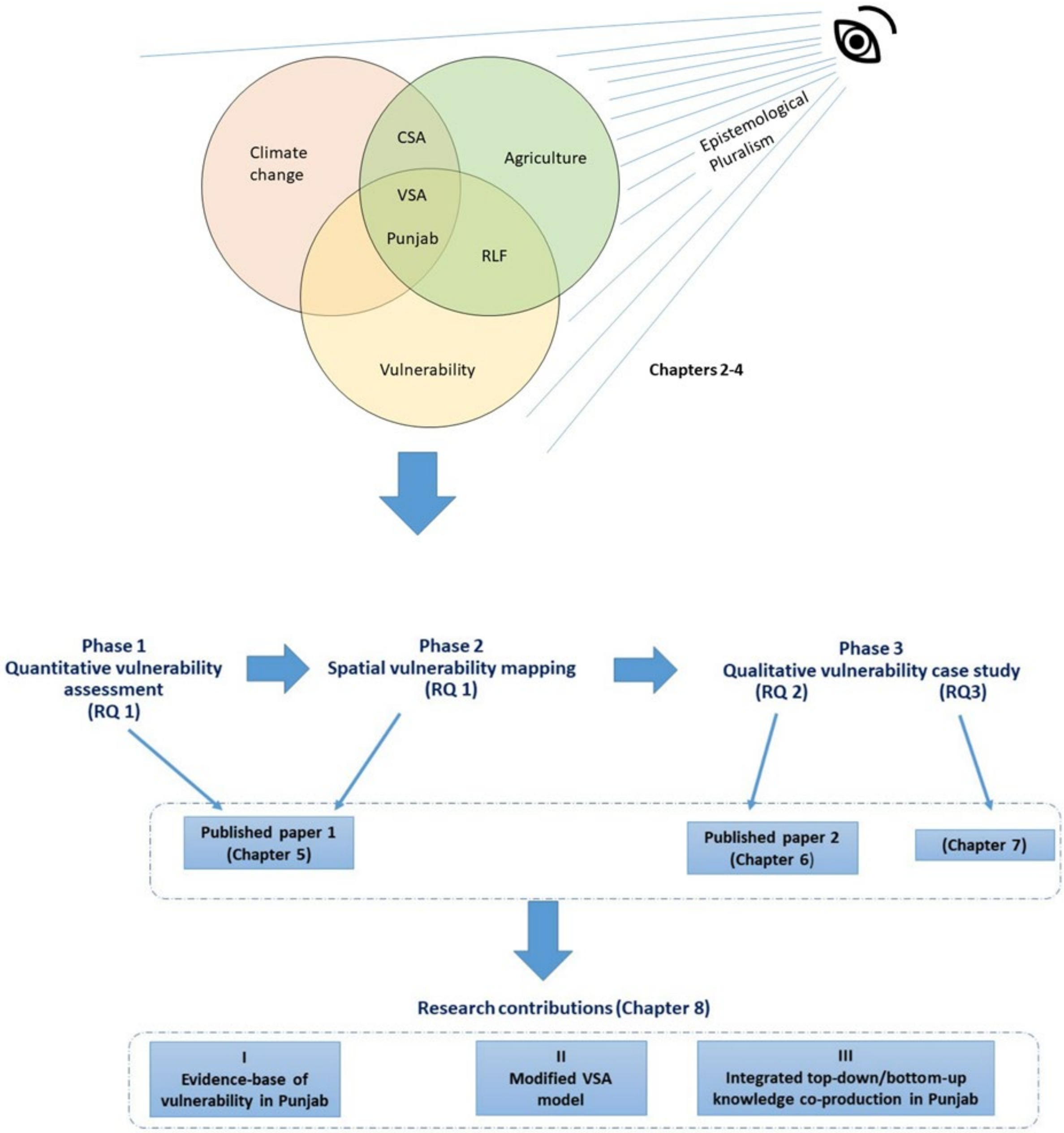


Figure 1.1: Thesis structure

Chapter Two: Literature Review

In this chapter, I review the scholarly literature pertaining to the three central themes of this research: climate change, agriculture, and vulnerability assessment. Through this exploration, I identify a notable gap in the literature that emerges at the intersection of these themes, particularly within the context of Pakistan's Punjab province and its economically crucial agricultural sector focusing on major crops i.e., wheat, rice, maize, cotton, and sugarcane.

2.1 Climate change

In this section, I explore the complex issue of climate change and its impact on Pakistan. I begin by examining the global climate change problem and the diverse responses it has elicited, with a focus on the emergent discourse surrounding adaptation. I examine the significance of adaptation in addressing climate challenges, highlighting its importance for societal resilience. Drawing upon climate change observations specific to Pakistan and future projections, I aim to provide concise insights into current trends and potential future scenarios.

2.1.1 Climate change problem

Climate change stands as one of the most formidable challenges of our era, causing devastating impacts that affect all global systems (Lawrence et al., 2020; Kumar et al., 2021; Zhou et al., 2023). The pervasive effects of climate change span impacts from altering weather patterns to exacerbating natural disasters (IPCC 2022). Yet, what makes the issue of climate change even more intricate is the lack of uniformity of impacts across regions, which manifest in diverse ways across the planet (Thornton et al., 2014, Eriksen et al., 2020). This spatial variation in climate change impacts underscores the complexity of the issue, with some areas experiencing intensified heatwaves, while others grapple with amplified precipitation variability, erratic weather patterns, or heightened frequency of extreme climatic events. This uneven distribution of impacts presents unique challenges and vulnerabilities for different geographical locations, sectors of economies, and communities (Dorkenoo et al., 2022). Notably, the agricultural sector emerges as particularly susceptible to the multifaceted impacts of climate change (Bilali, 2020; Sivakumar, 2021). Agriculture, inherently reliant on stable environmental conditions, experiences increased incidence of floods and droughts (Howden et al., 2007). These erratic weather patterns disrupt crop cycles, soil fertility, and water availability, leading to diminished yields, compromised food security and economic instability, and heighten the vulnerability of farming communities (IPCC 2022). The sensitivity of agriculture to these shifts underscores the urgency to comprehend, mitigate, and adapt to the evolving climate dynamics, demanding innovative approaches and robust strategies to ensure the resilience of agricultural systems in the face of an increasingly volatile climate.

2.1.2 Responses to climate change

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was established, as a framework for international cooperation on climate change to limit the rise of average global temperature and resulting impacts. UNFCCC recognises two main classes of response to climate change: mitigation and adaptation. Mitigation refers to those actions tailored to reduce emissions of greenhouse gases to achieve the stabilization of their concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC 1992; Huq & Reid, 2004; IPCC 2014).

The other principal response strategy to climate change is adaptation. A range of definitions of adaptation are found in climate change literature with some variations around a common theme. IPCC defines adaptation to climate change as adjustments in natural or human systems in response to actual or expected climate change stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC 2007). In response to climate change, different views among countries of global North and South contribute to challenges in international climate policy on how best to address climate change. In the global North, mitigation is more closely associated with the developed industrial countries that are the major contributors of GHG emissions (Dechezleprêtre et al., 2011). In contrast, for the global South developing countries whose contribution to GHG emissions is relatively less, adaptation is more closely linked with their development (Islam & Winkel, 2017). These countries need to adapt to reduce vulnerability to the impacts of the climate, and to enhance the resilience of systems to combat climate shocks and adversities (Arouri et al., 2015; Raj et al., 2022).

2.1.3 Emergence of adaptation in climate change discourse

In the early years of international response to climate change before the establishment of UNFCCC, adaptation received less attention than mitigation. The focus remained on mitigation with the need to reduce greenhouse gas emissions and to stabilise atmospheric concentrations. Adaptation has steadily risen on global policy agendas over the past decades. Adaptation to climate change formally gained due consideration later than mitigation, and scientific as well as political attention started to shift towards the recognition that climate was now changing and there was a need to adapt to the already unavoidable impacts (Huq & Reid 2004; McCarthy et al., 2001). In the later assessment reports, IPCC further emphasised the need for adaptation as necessary to address the impacts resulting from global warming, which are already unavoidable due to previous emissions (IPCC 2007). Growing global recognition of the need for adaptation also has been prominently highlighted in the Paris Agreement 2015, and in the recent contribution to sixth IPCC assessment report in addition to the earlier fourth and fifth IPCC assessment reports (UNFCCC 2015; IPCC 2007; IPCC 2014; IPCC 2022). For instance, the Paris Agreement (Article 7) emphasises adaptation and urges the parties to engage in adaptation planning processes including integrating adaptation into related environmental policies, climate change vulnerability assessments and implementation of adaptation actions in combating adverse impacts of climate change (UNFCC 2015).

2.1.4 Significance of adaptation

The significance of adaptation to climate change is understandable no matter what climate change policies are in place because a certain amount of change has already occurred within the climate system and that change will likely accelerate in the future (Patt & Klein, 2012; Zhou et al., 2023). In recent decades, climatic impacts and extreme events have increased in ways consistent with modelling projections showing that climate change is already happening (Ridder et al., 2022). Therefore, even if the concerted efforts to reduce global GHG emissions were to be attained, the climate system will continue to change which will cause ongoing damage if action is not taken to develop the capacity to adapt, and reduce current and future vulnerability to climate change (Haq & Reed, 2004; IPCC 2022). Adaptation to climate change offers many benefits including sustained or increased agricultural production, protection of livelihoods, increased environmental services and reduced vulnerability to extreme events (Smit & Pilifosova, 2003; Patt & Klein, 2012; Schoenefeld et al., 2022). In agriculture, adaptation by farmers can enhance food security, wellbeing and contribute to attaining sustainable livelihoods (Raj et al., 2022).

Prioritisation of adaptation as an urgent and important policy response is also associated with the time lag required for global mitigation efforts to reduce GHG emissions, and often involves complicated and protracted international negotiations (Anderson et al., 2020). Thus, slow progress on reducing GHG emissions globally potentially causes concerns for policy decision makers of developing nations who have limited capacity to be proactive on the devastating impacts of climatic adversities. Consequently, to assist and prioritise adaption efforts many of the world's poorest and least developed countries (LDCs) have been encouraged to prepare

National Adaptation Programmes of Action (NAPAs) with the support of UNFCCC through the Least Developed Countries (LDCs) Fund (UNFCCC 2022).

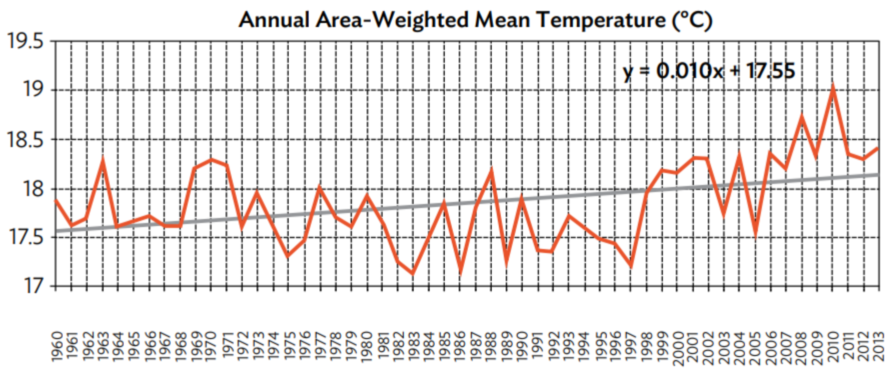
2.1.5 Climate change observations in Pakistan

Pakistan is one of the most vulnerable countries to the impacts of climate change (Eckstein et al. 2021) and has limited capacity to cope with climatic adversities (Brooks et al., 2005; Barr et al., 2010; TFCC 2010; NDC 2021). A report by a task force on climate change (TFCC 2010) identified Pakistan as particularly vulnerable because:

"*It generally has a warm climate; it lies in a world region where the temperature increases are expected to be higher than the global averages; its land area is mostly arid and semi-arid (about 60 per cent of the area receives less than 250 mm of rainfall per year, and 24 per cent receives between 250-500 mm); its rivers are predominantly fed by the Hindu Kush-Karakoram-Himalayan glaciers which are reported to be receding rapidly due to global warming; its economy is largely agrarian and hence highly climate-sensitive; and because the country faces increasingly larger risks of variability in monsoon rains, large floods and extended droughts*" (TFCC 2010 pg.1).

A significant warming trend in the annual mean temperature has been observed in Pakistan (Figure 2.1). According to an Asian Development Bank (ADB) report, the annual mean temperature in Pakistan has increased by 0.5°C in the last 50 years and the number of heat wave days per year has increased nearly fivefold in the past three decades (ADB 2017).

The report also indicated the historical high variability in annual precipitation in Pakistan. Furthermore, Pakistan has been grappling with a recurrent and challenging history of devastating floods, presenting a persistent issue for its human settlements. The recurring climate extremes have led to significant loss and damage in Pakistan (ADB 2017). The frequency and intensity of monsoon floods have increased over time, occurring almost annually since 2003 with varying degrees of severity. However, the mega-flood of 2010 stands out as a devastating event. It resulted in the displacement of approximately 20 million people and inflicted direct and indirect economic losses amounting to around US$ 10.5 billion, exclusive of restoration costs (WB, ADB, GoP 2010). More recently, the 2022 monsoon rains followed by devastating flooding were unprecedented in the history of Pakistan and had overwhelming impacts on the lives and livelihoods of the people, particularly the rural population and those relying on agriculture. This flooding affected 33 million people, displaced around 7.6 million people, and resulted in significant loss of lives and critical agricultural infrastructure, severely affecting 3.6 million hectares of crop areas, grain storage, and livestock (GoP 2022; Valavanidis, 2022). Total damages and losses were estimated at US$ 30.13 billion (GoP 2022).



Notes: red line = area-weighted mean temperature of Pakistan, black line = linear trend (rate of change = 0.01°C), Total Change = 0.54°C).

Figure 2.1: Pakistan annual area-weighted mean temperature from 1960-2013 (ADB 2017)

2.1.6 Future climate projections

The climate projections for Pakistan depict an alarming scenario regarding shifting climate trends. The projected increase in annual mean temperature in Pakistan by the century's end ranges from 3°C to 5°C under a central global emissions scenario (ADB 2017). However, under an elevated global emissions scenario, this rise could potentially escalate to between 4°C and 6°C (ADB 2017). In addition, substantial fluctuations in average annual precipitation are anticipated. Owing to substantial latitudinal variations, projections indicate that the northern glaciated areas are anticipated to witness a rise in mean annual temperature ranging between 3°C to 4°C, while an increase of 2°C to 3°C is likely for southern Pakistan by the 2080s under the high-emission Representative Concentration Pathway (RCP) 8.5 scenario (Iqbal & Zahid, 2014). A recent study by Ali et al. (2021), projected an even higher increase of 2.6°C in temperature across Pakistan under a moderate RCP 4.5 scenario by the end of the 21st century, which goes up to 5.1°C in the case of high emission RCP 8.5 scenario. Notably, these temperature escalations are particularly pronounced in glaciated and monsoon-influenced areas, as well as in the irrigated plains of Punjab province.

2.2 Agriculture

In the following sections, I explore the profound implications of climate change on agriculture in Pakistan. I begin by examining its overarching significance, followed by a focus on the importance of the Punjab province within Pakistan's agriculture. Subsequently, I explore the specific impacts of climate change on major crops.

2.2.1 Significance of climate change for Pakistan agriculture

Pakistan is particularly vulnerable to climate change due to its strong dependence on agriculture, which is recognised to be climate sensitive (Maharjan & Joshi, 2013; IPCC 2022). The total geographical area of Pakistan is 79.6 million hectares, of which 22 million hectares are used for crop production and most of this cultivated land is irrigated, which encompasses about 19 million hectares (Ahmad et al., 2015; PBS 2023). The agriculture sector is one of the largest sectors of the economy of Pakistan and provides food to the fast-growing population of the country (PBS 2023). Pakistan's economy is heavily dependent on agriculture, and the agriculture sector directly or indirectly supports most of the population (GoP 2022). Pakistan is amongst the world's top ten producers of wheat, cotton and sugarcane, and is ranked 10th in rice production (FAO 2022). Despite significant agricultural production, the country is still facing high levels of food insecurity. Around 40 million people (20.3% of Pakistan population) are food insecure, and one-fourth of the country's population is living below the national poverty line (WFP 2022). As a heavily populated, lower middle-income, developing nation, the convergence of high population and high food demand is a pressing concern, particularly in the context of ongoing and future climate change. With the large and growing population of the country, there is an inherent need for a constant and substantial supply of food to ensure food security for its citizens. However, this situation becomes significantly more complex due to the substantial impacts of climate change on agriculture. Therefore, ongoing climatic changes will likely amplify the existing vulnerability of Pakistan.

2.2.2 Punjab importance of agriculture

Although Pakistan is a vulnerable country in regard to climate change, it is also critically important as a food bowl for South Asia, and within Pakistan, the Punjab province acts as a food bowl for the nation. Punjab has a leading role in producing agricultural commodities in Pakistan. It contributes over 60% in overall national agricultural production and 74% to total cereal production at the national level (PBS 2023). Punjab makes a major contribution to the critically important major crops sub-sector of agriculture i.e., wheat, rice, maize, cotton, and sugarcane. These staple food and cash crops are a dominant part of the cropping sector in Punjab and share 75% of the total cropped area of the province (GoP 2022; PBS 2023). According to the Food and Agriculture Organization (FAO), Pakistan is the eighth-largest wheat producer in the world and the third-largest in Asia (FAO 2022). Notably, these statistics emphasise that Punjab province alone contributes a substantial 75 percent of the country's overall wheat production, emphasizing its vital role in ensuring the nation's food security (PBS 2023). Punjab province is critically important in Pakistan’s agriculture not only as a key source of food and livelihoods for the growing population of the country but is also responsible for major exports to other countries, thereby contributing to regional food security. In Basmati rice, Pakistan annually exports around 25% of world trade (Rehman et al., 2015). The province of Punjab, which accounts for more than 60 percent of the nation's total rice production, exclusively produces 100 percent of the Basmati rice in Pakistan due to its unique environment (Akhter & Haider, 2020). Similarly, Pakistan is the world’s 4th largest cotton producer and cotton has a critical role in Pakistan’s economy (Abbas, 2020). The Punjab province produces 80% of the national cotton crop (Zulfiqar et al., 2017). 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 (Abbas & Waheed 2017).

2.2.3 Climate change impacts on major crops

Multiple forecasts suggest that future climatic changes in Pakistan are anticipated to result in a decline in crop yields, particularly affecting wheat, rice, and cotton (Sultana et al., 2009; Siddiqui et al., 2012; Tariq et al., 2014; Ahmed et al., 2016; Alvar- Beltrán et al., 2021; Azmat et al., 2021). Under both RCP 4.5 and RCP 8.5 emission scenarios, the major crops (wheat, rice, and cotton) in Pakistan are projected to be exposed to temperatures above a critical threshold for growth, negatively impacting their yields, resulting in reduced farm income and an increased demand for water (Mahmood et al., 2021). The study also highlighted that irrigation will be essential to meet the elevated water requirements for these crops to maintain productivity per hectare. Climate change potential impacts on agricultural production are shown in Figure 2.2. Studies have investigated the potential impacts of climate change on agricultural productivity and the anticipated consequences on major crops in Punjab are concerning. For instance, research indicates an expected reduction in rice yield ranging between 15.2% and 17.2%, while projections suggest a potential decrease in wheat yield by an average of 14% in the rice-wheat cropping system of Punjab (Ahmad et al., 2015). For cotton, research indicates a substantial decline in yields, ranging from 7% to as much as 42% (Ahmad et al., 2023) under climate change. These declines are anticipated to significantly reduce net farm revenues across Pakistan.

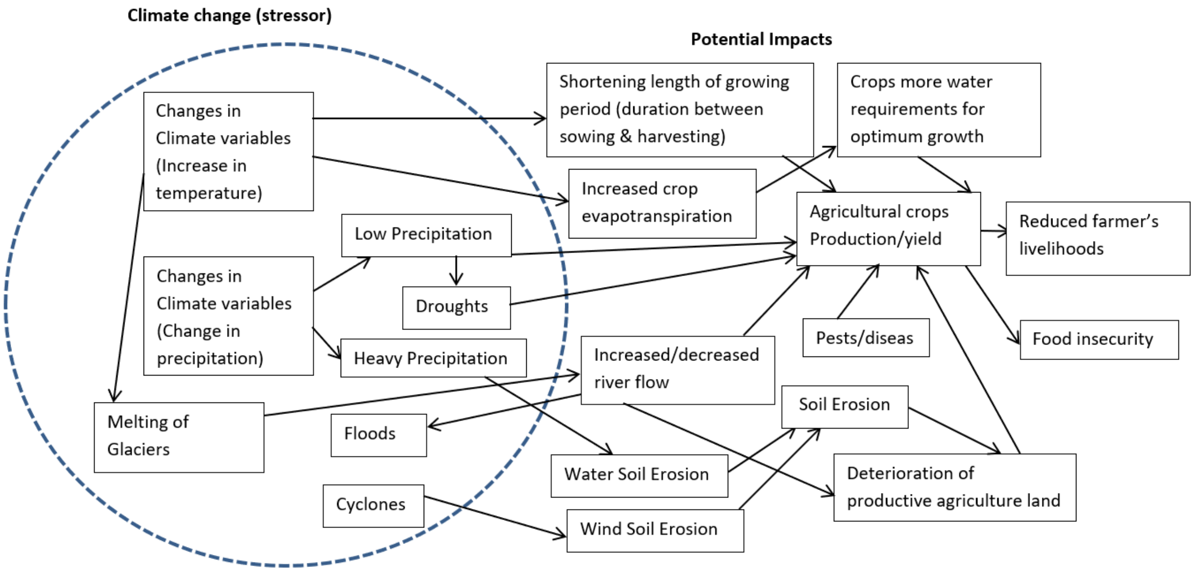


Figure 2.2: Climate change potential impacts on agricultural production

Source: Author

Khan et al. (2020) and Ali et al. (2021) reported significant losses due to changing temperature and rainfall patterns, impacting both summer and winter crops in Pakistan. For example, Khan et al. (2020) projected climate change-induced loss of US$ 19.5 billion in wheat and rice crop production for Pakistan by 2050, impacting the nation's Gross Domestic Product (GDP) and triggering commodity price hikes. This decline in crop productivity not only affects the agriculture sector but has a cascading effect on other sectors, posing a significant challenge to the livelihood of the whole country. Similarly, economic analysis reveals a substantial impact on farm incomes due to rising temperatures, with simulated increases of 69% in farm poverty due to a 27% reduction in net returns within the current cotton-wheat cropping system in the country under climate change (Ahmad et al., 2023). These findings unequivocally indicate that climate change poses a significant threat to future crop production and farm returns in Punjab province, with smallholder farmers likely to bear the brunt of these impacts. Smallholder farmers are likely to bear the brunt of various challenges due to their vulnerability to, environmental economic and social factors (FAO 2018; Awazi et al., 2020). Smallholder farmers often depend on rain-fed agriculture, making them highly susceptible to environmental changes (Niles and Salerno, 2018). Many smallholder farmers, especially in developing countries, have limited access to crucial resources including financial services, technologies and farm inputs (Rurinda et al., 2014; Lewis et al., 2018; Serdeczny et al., 2016; Otto et al., 2017; Awazi et al., 2020). In many regions, smallholder farmers live at or near the poverty line and do not have secure land rights, which limits their ability to invest in long-term improvements (Deressa et al., 2009; Awazi et al., 2022).

Some farming systems are particularly vulnerable to climate changes. In the arid to semi-arid climate of the Punjab, where rainfall is generally scarce and erratic, agricultural activities could encounter significant challenges due to water scarcity in the face of shifting climate patterns. Shahid and Rahman (2021) pointed towards an anticipated rise in drought conditions in the Lower Indus Basin, encompassing mostly the plains of Punjab and Sindh provinces. Moreover, they indicated unpredictable upstream water supply due to the changing climatic conditions in the Upper Indus Basin (UIB). Likewise, Hasson et al. (2019) projected rising uncertainty in the availability of water annually, particularly under scenarios of 1.5ºC and 2.0ºC temperature increases. Notably, a recent study highlighted a potential decrease in rainfall ranging between 33% to 52% during the cotton growing season and 36% to 42% during the wheat growing season, especially under hot and dry conditions (Ahmad et al., 2023). Of significant concern is the predicted alterations in spatial and temporal river water flows, resulting from variations in snowmelt and precipitation patterns. These alterations may desynchronise with the prevailing agricultural calendar and cropping patterns within the country (Hasson et al., 2019). In the arid to semi-arid climate of Punjab and Pakistan more generally, agriculture heavily relies on irrigation. Fluctuations in surface irrigation supply may significantly impact irrigated arable land in Pakistan, which contributes 90% of the nation's total agricultural output (Qureshi & Ashraf 2019).

2.3 Vulnerability

In this section, I explore the intricate nature of defining and interpreting vulnerability, examining the components that contribute to it and their interrelationships, as well as the importance of conducting vulnerability assessments to understand impacts and potential responses to climate change.

2.3.1 Complexity in vulnerability interpretations

The concept of vulnerability has been widely used in interdisciplinary literature. Various researchers use the term vulnerability in different ways depending upon their particular focus areas, such as natural hazards, public health, food security and climate change (Füssel & Klein, 2006; Cordell & Neset, 2014; Nunes et al., 2021). Similarly, Adger (2006) demonstrates the use of vulnerability terminology in many disciplines including anthropology, economics, ecological and environmental science. These different interpretations relate to the underlying causes of vulnerability that require different kinds of knowledge for the formulation of strategies to reduce vulnerability (O'Brien et al., 2007). A wide variation in conceptualization and operationalization presents the study of vulnerability as one of the most complex and challenging areas of research (Schipper & Burton, 2009; Gumel 2022).

2.3.2 What does vulnerability mean?

The term vulnerability has been used increasingly in literature in multiple ways to define the concept. Despite collective research experience on the concept, vulnerability means different things for different people (Cutter, 1996; Patt & Klein, 2012; Kasperson et al., 2022). Perspectives on vulnerability based on risk-hazard research broadly defined vulnerability as the potential for loss due to hazard as a cause of harm (Cutter, 1996). For example, Burton et al. (1978) and Gabor and Griffith (1980) are among the earliest studies on vulnerability in the hazard and risk literature. Another tradition of vulnerability research focuses on effects, such as hunger and famine rather than being centred on causes (Patt & Klein, 2012). Sen (1981) and Downing (1991) provide examples of this conception of vulnerability. Vulnerability is a widely used term in climate change literature. Despite diversity, the literature describes two key conceptualisations: *end-point* and *starting-point* vulnerability. O'Brien et al. (2007) interpret the *end-point* conceptualisation as potential net impacts of climate change on a particular exposure unit, which can be biophysical or social, after feasible adaptation is considered. This conceptualisation combines information on potential biophysical climate impacts with information on the socio-economic capacity to cope and adapt (Kelly & Adger, 2000; O' Brien et al., 2007). In contrast, the *starting-point* (or 'wounded soldier') conceptualisation considers vulnerability as the current inability to cope with multiple external drivers of vulnerability including social, economic, political and institutional conditions before the consideration of specific impacts of climate change (O'Brien et al., 2007; Schipper & Burton, 2009). There are, however, additional alternative conceptualisations of vulnerability that are considered neither better nor worse than those identified above (Schipper & Burton, 2009; Gumel, 2022).

Besides the potential impact of climate change, the vulnerability of a system at any geographical location also depends on its capacity to adapt to the change (Barr et al., 2010; Kasperson et al., 2022). Therefore, the concept of vulnerability adopted in this research facilitates the inclusion of capacity to adapt as a dimension along with potential impact, as conceptualised by IPCC's model (Figure 2.3). Vulnerability is defined by the IPCC in the context of climate change as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy et al., 2001 pg. 995). The original definitions of the vulnerability concept and components of vulnerability appear to be less complicated as defined by the IPCC and early researchers. However, over time researchers in the climate change literature have expanded the complexity of these definitions.

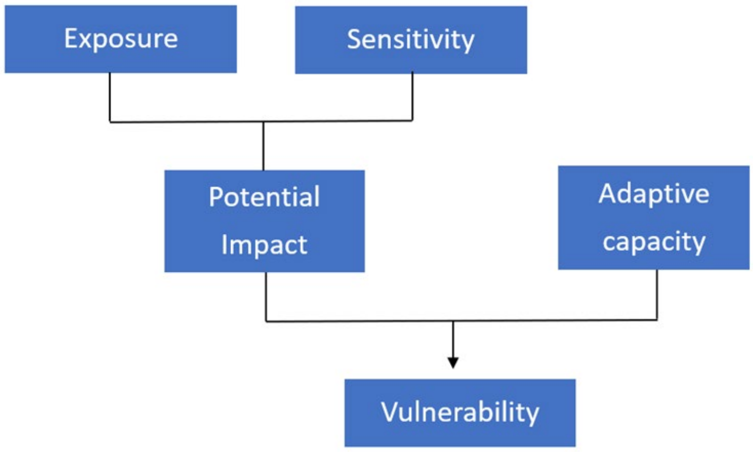


Figure 2.3: Vulnerability to climate change (Allen, 2005)

How vulnerability to climate change is conceptualised is important because it has the potential to alter and improve the understanding of the implications of a changing climate (Adger et al., 2007). Despite the variety of disciplinary interpretations, there is increasing consensus that vulnerability includes exposure, sensitivity and adaptive capacity as critical elements.

2.3.3 Elements of Vulnerability

Exposure:

Exposure is one of the elements of vulnerability and is considered as an entry point for the concept (Smit & Wandel, 2006). Exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations" (McCarthy et al., 2001 pg. 987). Adger (2006) further explains that exposure is not only the extent to which a system is exposed to climate variations and climate extremes but can also include duration, frequency, and magnitude of these variations.

Sensitivity:

Sensitivity is the second key element of vulnerability and is the propensity for exposure to result in harm (Jacobs et al., 2014). Sensitivity is defined by the IPCC as the degree to which a system is affected by climate change stimuli directly or indirectly (IPCC 2007). Sensitivity is visualised as an internal element of a system and is directly associated with vulnerability. The vulnerability of a particular system increases as the sensitivity of the system to perturbation increases. Gallopín (2006) distinguishes sensitivity from exposure as an attribute of a system that exists before the perturbation and separates it from exposure. Sensitivity can be seen as the responsiveness of the system to climate (Schipper & Burton, 2009). A more sensitive system is more responsive to climate and can be significantly affected by minor changes in climate (Abbass et al., 2022).

Adaptive Capacity:

Adaptive capacity is a central element of vulnerability conceptualization. Adaptive capacity in the context of climate change is defined as "the ability of a system to adjust to climate change including climate variability and extremes to moderate potential damages, to take advantages of opportunities, or to cope with the consequences" (McCarthy et al., 2001 pg. 982). Adaptation is the manifestation of adaptive capacity (Smit & Wandel, 2006). Coping ability and adaptive capacity are mentioned in the climate literature as closely related concepts. However, many authors distinguish between these. Smit and Wandel (2006) and Pelling (2010) differentiate coping capacity as short-term ability to survive, while adaptive capacity is viewed as longer-term or more 'sustainable' adjustments. Adaptive capacity is often seen as inversely associated with vulnerability (Pelling, 2010). In other words, an increase in adaptive capacity of any system of focus has the relative potential to reduce vulnerability, which has placed the enhancement of adaptive capacity at the centre of adaptation research.

2.3.4 Understanding vulnerability interrelations

While defining vulnerability and elements of vulnerability is essential, it appears to be even more important to understand conceptual links between these concepts. For example, a system may be exposed but may not be sensitive to a specific disturbance, and vice versa. Exposure and sensitivity are considered as directly associated with vulnerability. However, Fellmann (2012) argues that although a system may be very sensitive and highly exposed to any stress or shock, it cannot be said that system is definitively vulnerable without consideration of the capacity to adapt. Adaptive capacity has a significant position in reducing vulnerability by moderating exposure and sensitivity as depicted in Figure 2.4.

With the presence of high adaptive capacity, a system that is both sensitive and exposed may have a less than anticipated level of vulnerability. Therefore, adaptive capacity is considered as having a substantial impact on vulnerability through modulating exposure and sensitivity (Gallopin, 2006; Fellmann, 2012; Gumel, 2022).

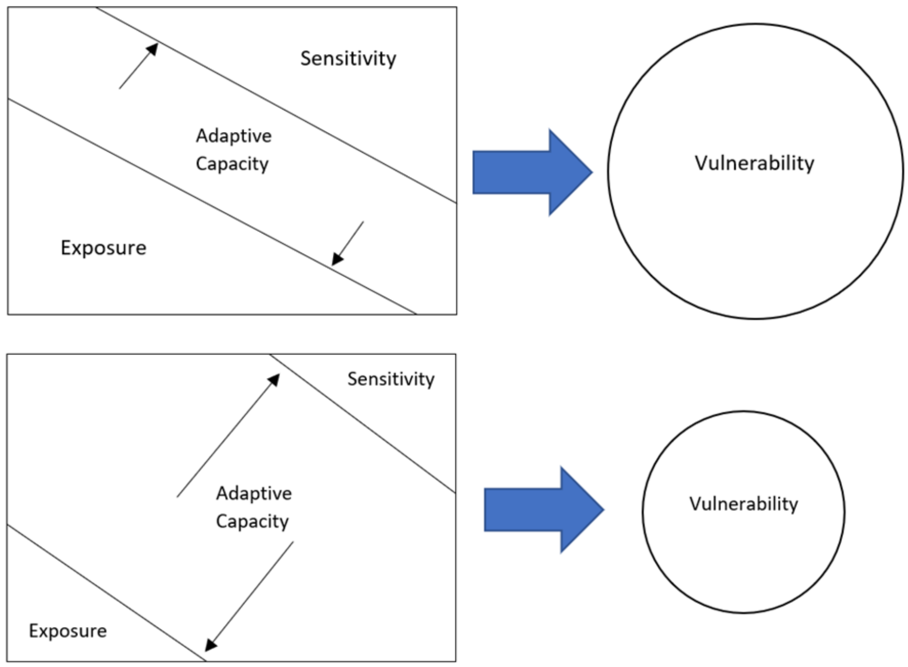


Figure 2.4: Role of adaptive capacity in impacting vulnerability (Engle, 2011)

2.3.5 Why assess vulnerability?

Vulnerability assessment is a complex and widely used method in climate change research. Vulnerability assessments can be undertaken for different reasons including to improve adaptation for ongoing or anticipated changes, to frame a climate change mitigation problem, to address social injustice, and to conduct scientific research (Patt & Klein, 2012; Birkmann et al., 2022). Patt and Klein (2012) further add that, in reality, the need for vulnerability assessments may not be limited to one reason and can be undertaken for multiple reasons, as boundaries between different reasons are likely to be blurred. Undertaking vulnerability assessments to climate change has the potential to provide multiple benefits. Vulnerability assessments can have many aims including facilitation of adaptation planning, identification of vulnerability hot spots, to begin a dialogue with stakeholders about climate change and vulnerability issues and improving basic scientific understanding (Jacobs et al., 2014; Malone & Engle, 2011). Patt and Klein (2012) differentiate the range of vulnerability assessments aiming to facilitate adaptation as usually driven by policy needs rather than scientific curiosity.

The key motivation in undertaking vulnerability assessment for this research is to support adaptation processes and to contribute incremental inputs into climate change policy processes in Pakistan. Preston et al. (2011) suggest that understanding of the positive outcomes of vulnerability assessments is challenging due to a high degree of spatial heterogeneity associated with physical and socioeconomic elements of vulnerability, and better communication of this complexity is an important aspect. Similarly, Kelly and Adger (2000) indicate that the process of adaptation is facilitated through actions aimed at reducing vulnerability, and they demonstrate that vulnerability is intrinsically linked to the process of adaptation.

2.3.6 How vulnerability is assessed?

The study of vulnerability to climate change is a rising area of attention in global research. The increasing attention on adaptation has also placed vulnerability as an essential concept in climate change research. Assessing vulnerability to climate change is important as it serves as a connection between climate change impacts and adaptation. Vulnerability can be assessed in several ways including modelling, index-based approaches using secondary data, approaches using questionnaire surveys, participatory approaches to collect primary data, and by a combination of different methods using both primary and secondary data (Malone & Engle, 2011; Patt & Klein, 2012; Gumel, 2022). There is considerable diversity in methodologies and a growing number of assessments of vulnerability are detailed in the literature (Patt & Klein, 2012; Wickramasinghe et al., 2021). Considering the breadth of vulnerability research, the examples from the literature on global vulnerability assessments to climate change shown in Table 2.1 do not intend to deliver a full range of all methods and the ways by which vulnerability can be assessed. However, these global vulnerability assessments provide some good examples of vulnerability research approaches that could inform this research in Pakistan.

Table 2.1 shows examples of global vulnerability assessments to climate change drawn from a collection of 29 global studies, of which 15 were conducted at local scale, 10 at provincial scale and 4 were national studies.

Table 2.1: Global examples from vulnerability assessments drawn from climate change literature

Study location	Scale	Focus	Method	Reference
Australia	National	Agriculture	Bio-economic modelling and an index-based approach to mapping	(Nelson et al., 2010)

Australia	Local	Bushfire	Secondary data sources with an expert judgment for vulnerability indicators with vulnerability maps	(Preston et al., 2009)
Bangladesh	Local	Coastal region climate vulnerability	PCA, spatial maps	(Uddin et al., 2019)
China	Provincial	Agriculture	Index approach with crop yield simulation model and weights by analytical hierarchy process (AHP)	(Li et al., 2015)
China	Provincial	maize production	Biophysical modelling	(Wang et al., 2011)
Ghana	Local	Flood	Vulnerability index by household survey and interviews	(Yankson et al., 2017)
Ghana	Local	Drought	Household livelihood index through quantitative and qualitative participatory methods such as focus group discussions, questionnaire surveys, and key informant interviews	(Antwi-Agyei et al., 2013)
India	provincial	agriculture drought	Index method based on secondary data and weights by variance approach with mapping	(Murthy et al., 2015)
	Provincial	crop yield	Wheat crop simulation model	(Attri & Rathore, 2003)
	National	natural and climate-induced disasters.	Index approach and weights by analytical hierarchy process (AHP) with mapping	(Chakraborty & Joshi, 2016)
	Local	agricultural household economy	Statistical ordinary least square (OLS) regression and ordered logit regression models	(Narayanan & Sahu, 2016)
	provincial	Agriculture	Index approach and weights based on the proportion of land with mapping	(Varadan & Kumar, 2015)
	Local	Drought	Index method with household questionnaire surveys and participatory rural appraisal (PRA) in the form of focus	(Jamir et al., 2013)

			group discussions and semi-structured interviews	
	Local	Agriculture	Interviews with participatory mapping	(Goswami et al., 2012)
	Provincial	agriculture, water, and forest	Index approach and principal component analysis (PCA) with mapping	(Ravindranath et al., 2011)
	Local	mountain ecosystems vulnerability	Climate vulnerability index method and Interviews	(Pandey et al., 2017)
	Provincial	high altitude mountain regions agriculture	Index based method and weights through AHP with mapping	(Shukla et al., 2016)
	Local	flood	Index method with household surveys and participatory rural appraisal (PRA)	(Chaliha et al., 2012)
	Local	coastal, sea level rise	Index approach and weights by AHP with mapping	(Mahapatra et al., 2015)
	National	agriculture, economic globalization.	Index approach and climate model scenario with mapping	(O'Brien et al., 2004)
	Local	socio-environmental vulnerability	Spatial Social Vulnerability Index (SSEVI), PCA and Questionnaire-based households Survey	(Gupta et al., 2020)
Indonesia	Local	Urbanization	Index method with focus group discussions	(Handayani et al., 2017)
Iran	Provincial	Smallholder farmers, climate change	Descriptive-analytical approach, correlation analysis, spatial maps, survey	(Jamshidi et al., 2019)
Philippine	Local	agriculture, typhoon Santi	Index method with focus group discussions	(Ezra, 2016)
Romania	Provincial	Drought	Socio-economic vulnerability index by quantitative method with mapping	(Dumitraşcu et al., 2017)
South Africa	Provincial	Farming	Index method with principal component analysis (PCA)	(Gbetibouo & Ringler, 2009)
Sri Lanka	National	agriculture, climate change, droughts, floods, landslides, cyclones	Composite vulnerability index and mapping	(Wickramasinghe et al., 2021)
Uganda	Local	rural subsistence farming	Semi-structured and guided interviews	(Cooper & Wheeler, 2017)

Vietnam	Local	Social	Social vulnerability index by mixed method approach, i.e., questionnaire survey, in-depth interview and focus group discussions	(Nguyen et al., 2017)

Table 2.1 shows many examples of the use of an index-based approach at provincial, national and local scales (e.g. O'Brien et al., 2004; Nelson et al., 2010; Ravindranath et al., 2011; Ezra, 2016; Mahapatra et al., 2015; Murthy et al., 2015; Gupta et al., 2020; Wickramasinghe et al., 2021). Examples of local vulnerability assessment studies indicate the use of quantitative, qualitative, or mixed methods approaches. For example, Nguyen et al. (2017) is a local city-scale study of central coastal Vietnam focusing on social vulnerability assessment to climate change using a mixed method approach. The study develops a Social Vulnerability Index (SVI) through a combination of qualitative and quantitative methods. The study used qualitative participatory methods, i.e., focus group discussions, in-depth interviews based on local environmental professionals and community members to identify elements of social vulnerability. The study further used quantitative methods, i.e., a household questionnaire survey to obtain primary data about those elements from selected households and applied statistical analysis to the data. The study results indicate that SVI scores can differentiate vulnerability among a range of communities.

Other provincial and national scale examples of global vulnerability assessments to climate change used a different combination of methods, including index-based and modelling approaches. For example, a provincial study by Gbetibouo and Ringler (2009) used an index-based approach with a focus on agriculture in South Africa. The study used secondary data sources for developing vulnerability indices. It used principal component analysis for allocation of weights to respective indicators. The findings of the study show that the geographical regions most exposed to climate change and extreme events do not always coincide with the most vulnerable populations. Similarly, Nelson et al. (2010) provides an example of a national-scale study of climate change vulnerability of Australian rural communities using bio-economic modelling with an index-based approach. The findings of this study show that hazard or impact modelling should be integrated with holistic measures of adaptive capacity.

Many of the local-scale vulnerability assessments shown in Table 2.1 include use of participatory approaches (e.g., Chaliha et al., 2012; Nguyen et al., 2017; Yankson et al., 2017).

There is a range of participatory methods available for eliciting information often from rural communities in village settings, including group discussions, timelines, and transect walks (Ellis, 2000; Chandra, 2010). Although useful for qualitative prioritization or ordinary ranking of variables, literature indicates limitations concerning such data collection exercises. Ellis (2000) emphasise that such participatory exercises can project a preferred image of the community or village that may not relate to the underlying reality of people's lives and the overall picture emerging from such communications may mask local differentiation.

Table 2.1 includes also examples of vulnerability studies from India, a neighbouring country to Pakistan, with a similar context. Before the 1947 partition, both India and Pakistan were administered jointly under British rule and thus have many similarities including climate characteristics and strong dependence on agriculture. A brief collection of 14 examples from Indian vulnerability assessments to climate change is shown in Table 2.1: seven were local-scale, five provincial-scale and two were national studies. For example, Jamir et al. (2013) assessed local scale vulnerability to drought using an index-based approach. They collected primary data from five villages through household questionnaires and participatory rural appraisal (PRA) in the form of focus group discussions and semi-structured interviews supplemented by secondary data sources. The findings of this study revealed that biophysical characteristics contributed most to overall vulnerability of the villages.

Ravindranath et al. (2011) provides an example of provincial-scale vulnerability assessment to climate change. They used a composite index approach by developing separate indices for agriculture, water and forest sectors in Northeast India. The study used secondary data sources for quantification of indicators to develop a combined index and all the districts of the Northeast region of India were ranked according to the vulnerability index. Study results indicate that most of these districts were subject to climate-induced vulnerability to varying degrees. Similarly, O'Brien et al. (2004) developed an index-based example at national-scale to assess vulnerability of agriculture to stressors of climate change and economic globalization in India. The study used a composite index composed from secondary data sources and developed indices for overall vulnerability and its components. The study also carried out a series of local level case studies. The findings of the study indicated that the areas with high to very high climate sensitivity for agriculture are located in the semi-arid regions of the country, including major parts of the Indian provinces of Rajasthan and Gujarat. Also, findings of the case studies indicate that policies originating at national and provincial level play a critical role in shaping vulnerability at district, village and farm levels.

One common thread found in all these global studies is the link of vulnerability with climate change, i.e. '*vulnerability to what'*, however, these studies vary regarding focus, i.e., '*vulnerability of what',* and variations in methods, i.e. '*how vulnerability can be assessed*.' Understanding vulnerability requires looking at the intersection of who is vulnerable i.e. *vulnerability of what* and to what risks i.e. *vulnerability to what* (Malone and Engle, 2011). The intersection discloses deeper insights about why certain groups are more at risk. For instance, small island nations (*vulnerability of what*) are extremely vulnerable to rising sea levels (*vulnerability to what*) because of their geography and reliance on coastal ecosystems (Martyr-Koller et al., 2021). Likewise, low-income communities are more vulnerable to climate change due to limited resources for adaptation (Deria et al., 2020). The complexity of vulnerability arises because it is context-specific, socially constructed and varies across different settings (Otto et al., 2017). A community might be vulnerable to droughts and floods, but how they experience and respond to these hazards will depend on their economic resources, social networks, and governance structures (Cutter and Finch, 2008; Kuran et al., 2020). *Vulnerability of what* and *vulnerability to what* aspects require understanding that vulnerability is multidimensional and shaped by complex interactions between social, economic, political, and environmental factors (Painter et al., 2024). By recognizing these dynamics, more targeted and just interventions can be developed to reduce vulnerability and enhance resilience.

2.3.7 Use of Mapping

Assessing vulnerability to climate change is widely acknowledged as an essential for effectively communicating research findings to various stakeholders, such as scholars and policymakers (Eakin & Luers, 2006; Preston et al., 2011; Mudashiru et al., 2021). Utilizing mapping techniques serves as a valuable tool to visually represent vulnerability, whether it is in terms of exposure, sensitivity, adaptive capacity, or resulting impacts (Eakin & Luers, 2006). Vulnerability mapping offers flexibility in approaches, including spatial mapping and participatory methods, to depict the geographic distribution of vulnerability and engage diverse perspectives in the assessment process.

Table 2.1 indicates some earlier published examples of vulnerability mapping from global vulnerability assessments to climate change. Examples include vulnerability assessments leading to the development of maps for presenting the spatial distribution of vulnerability within different geographical locations. For example, Chakraborty and Joshi (2016) used an index-based approach for assessing the vulnerability of districts in India to climate-induced disasters using secondary data sources and developed spatial maps for identifying most and least vulnerable districts within provinces. O'Brien et al. (2004) provides another example of developing spatial vulnerability maps to identify districts vulnerable to climate change and economic globalization in India. Likewise, Nelson et al. (2010) provides an example of spatial mapping to highlight the regions of Australian broad-acre farm households which are likely to be vulnerable to external influences. Furthermore, Wickramasinghe et al. (2021) assessed and mapped agricultural vulnerability to climate change in Sri Lanka at divisional secretariat scale (an administrative level in Sri Lanka). Developing spatial maps for comparing places is a common aspect of these vulnerability assessments.

Mapping can also be done through participatory approaches. Goswami et al. (2012) provides an example of a participatory mapping exercise conducted at the village level in West Bengal, India. In this study, rain-fed rice cultivators of the village classified their agricultural fields into distinct micro-farming situations. Farmers mapped distinct farming situations of their rice fields and listed the criteria by which the classification was done. However, the study indicates that more empirical evidence is needed to establish the validity of this participatory mapping tool. In another example, Pearson et al. (2017) examine the use of participatory mapping of resources, at two-time points (2009 and 2015), in a Tanzanian community. The findings of the study indicate the differences in the two participatory exercises may reflect actual changes in resources and livelihoods over time. This suggests that repeated participatory maps, conducted in a trusting environment, are useful for long-term place-based planning.

2.3.8 Vulnerability assessments in Pakistan

Focusing on Pakistan, there is a limited focus on vulnerability assessment and mapping to climate change. Table 2.2 indicates a few studies on climate change vulnerability assessments in Pakistan including four that were local, five provincial and four national scale studies.

Table 2.2: Pakistan vulnerability assessments to climate change literature

Study location	Scale	Focus	Method	Reference
	local	coastal areas	Un-weighted composite index method	(Salik et al., 2015)
	local	Drought	Structured questionnaire	(Ghazal et al., 2013)

Pakistan	local	Flood	Multi-criteria approach, Analytical hierarchy process (AHP)	(Hussain et al., 2021)
	local	Flood	Hydrodynamic models and GIS data	(Tariq et al., 2021)
	provincial	Gender	Statistical logit regression model	(Iqbal et al., 2015)
	provincial	Health	Un-weighted composite index method	(Malik et al., 2012)
	provincial	Social	Un-weighted composite index method	(Rahman & Salman, 2013)
	provincial	Drought	Man-Kendall test and Semi-structured questionnaire	(Ashraf & Routray, 2015)
	provincial	groundwater resources	groundwater potential recharge index (PRI) and groundwater vulnerability index (GVI)	(Arshad et al., 2020)
	national	flood	Index approach and statistical logistic regression method with spatial mapping	(Khan & Salman, 2012)
	national	natural disasters	Delphi method for weights to hazards and damage potential indicators for risk scores	(Rafiq & Blaschke, 2012)
	national	Drought	Three interpolation methods, e.g., spline method is used for comparison	(Mazhar & Nawaz, 2014)
	national	heat waves	Plotted the frequency of heat wave events with linear and moved average methods	(Zahid & Rasul, 2012)

The four local-scale vulnerability assessment studies in Pakistan focused on coastal communities (Salik et al., 2015), drought vulnerability (Ghazal et al., 2013) and flood vulnerability (Hussain et al., 2021; Tariq et al., 2021). These local studies used a questionnaire-based methodology combined with secondary data sources. For example, Salik et al. (2015) assessed the climate-induced vulnerability of mangrove forest-dependent coastal communities in the coastal town of Keti Bandar located in Sindh province of Pakistan. The study used a composite index constructed through a questionnaire-based survey at the household level. The assessment showed that these coastal communities are not only exposed but are also highly sensitive to climate change driven threats. Moreover, lack of access to necessary facilities, inadequate income diversification, and low education levels negatively affected the adaptive capacity of the entire local population. However, the nature of dwellings, strong family networks of the communities and their ability to migrate contributed positively to their adaptive capacity.

The five provincial vulnerability assessment studies in Pakistan focus on different themes including gender, health, social issues, groundwater resources and drought. Some commonalities are found among these provincial studies in terms of methodological considerations. Two of these studies used statistical methods while the other two used an unweighted, index-based approach for assessing vulnerability. For instance, a provincial statistical study by Iqbal et al. (2015) used a logit regression model to examine gender-differentiated impacts on household vulnerability based on survey data. The findings of the study indicate that households with greater empowerment of females were less vulnerable. Malik et al. (2012) provides another example of a provincial, index-based vulnerability study to construct a human health vulnerability index to climate change, and to identify potential health repercussions in the context of Pakistan. The findings of this study indicate that southern Punjab and Baluchistan are ranked as the most vulnerable zones for health-focused vulnerability to climate change.

The four national vulnerability assessment studies focus on themes including flood, heat waves, drought, and a combination of natural disasters. For example, Khan and Salman (2012) developed an index as a summary measure of human vulnerability in five key basic dimensions of human development i.e. population density, lack of knowledge, lack of decent housing, lack of decent standard of living and households with livestock that can help to cope with floods. The study focused on the major 2010 flood event in Pakistan. The data used to construct the human vulnerability index were derived from the Population and Housing 1998 Census (Khan & Salman, 2012). The study also used logistic regression analysis on primary data collected from flood recovery households. The findings indicated that the adult literacy rate, ownership of livestock, and access to electricity were the three key variables that played a critical positive role in recovery after the 2010 flood.

In Pakistan, only a few studies so far have attempted to map vulnerability with a focus mainly on hazards (Table 2.2). Three out of five vulnerability mapping efforts were at national scale while one study was at provincial scale. For example, Khan and Salman's (2012) national study of the 2010 flood event (described above) performed spatial mapping of a human vulnerability index and classified areas as severely, moderately, and least affected by flood. Rafiq and Blaschke (2012) in another national spatial study of hazards and natural disasters, developed a total hazard and risk map. Their study selected hazards and natural disasters by their frequency and severity. Mazhar and Nawaz (2014) mapped drought at national scale in Pakistan. Their study used three precipitation data interpolation methods for meteorological drought intensity patterns in Pakistan during 1980-2010 and developed three maps using three different interpolation methods. Two provincial-scale studies (Ashraf & Routray, 2015; Arshad et al., 2020) also attempted to map vulnerability. Ashraf and Routray's (2015) study mapped vulnerability as the spatial and temporal variability in drought in Balochistan province through analysis of 36 years (1975–2010) of monthly precipitation data.

The literature on vulnerability assessments and mapping to climate change in Pakistan indicates a lack of studies focusing on agriculture, particularly focusing on the major crops sub-sector of the Punjab province. Given the agricultural significance of Punjab province, the critical importance of major crops to agriculture and sensitivity of agriculture to climate change in Punjab, this review of literature points towards the need for a climate change vulnerability assessment to identify vulnerable areas within the Punjab province. Subsequent sections detail the integration of qualitative engagement with quantitative vulnerability assessment and mapping, focusing on these identified vulnerable areas.

2.3.9 Integrated approach to vulnerability assessment and adaptation planning

The significance of an integrated assessment that combines quantitative mapping and qualitative engagement techniques lies in its ability to leverage the strengths of both quantitative and qualitative methodologies, thereby addressing the multidimensional nature of vulnerability and adaptation. Quantitative mapping techniques, such as spatial analysis, allow for the identification of spatial patterns and trends in vulnerability, enabling policymakers to prioritise adaptation interventions in areas most susceptible to climate change impacts. However, quantitative data alone may lack the contextualization necessary to better understand vulnerability dynamics within the local socio-cultural context (e.g. O'Brien et al., 2004).

A mixed methods approach resonates with the need for an integrated understanding of vulnerability, a perspective also evident in the integrated environmental assessments literature (Parson, 1995; Rotmans & Dowlatabadi, 1995; Hisschemöller et al., 2001; Toth, 2004; Mourhir et al., 2016; Dawadi et al., 2021). For instance, Rotmans and Dowlatabadi (1995) propose that integrated environmental assessments serve as research geared towards policy outcomes, transcending disciplinary confines to offer decision-makers nuanced insights for policy formulation. Parson (1995) and Hisschemöller et al. (2001) elaborate on this, highlighting the inclusion of diverse methods and knowledge domains beyond those typically confined to singular disciplines. Dawadi et al., (2021) further emphasise the role of interdisciplinary methods within this integrated framework in enhancing understanding of complex issues.

Mixed methods research combines quantitative and qualitative approaches, aiming to provide a thorough understanding of a research problem (Creswell and Clark, 2017; Dawadi et al., 2021). It is beneficial for exploring complex research questions, as it allows for both numerical generalisations and rich, contextual understanding (Morgan, 2014; Maxwell, 2016; Shorten and Smith, 2017). However, mixed methods research brings significant challenges, especially in terms of design complexity, resource demands, and integrating two types of data (Dawadi et al., 2021). Designing a mixed methods study is often more complex than using a single approach. Researchers need to determine the sequence in which to collect qualitative and quantitative data, such as in different research phases or concurrently (Taherdoost, 2022). Developing such a design requires more advanced planning, and collecting and analysing both types of data takes more time and resources compared to a single method study (Fauser, 2018; Linnander et al., 2018). Qualitative research provides depth and insight, while quantitative research offers breadth and generalisability (Taherdoost, 2022). Balancing these two can be difficult because of the competing demands for detailed versus generalisable data (Dawadi et al., 2021). Despite these limitations, mixed methods research can produce nuanced and impactful insights.

The mixed-methods approach (e.g. Bryman, 2016) offers a comprehensive, context-specific framework for conducting vulnerability assessment and adaptation planning. By engaging in integrated assessments with key stakeholders such as farmers, researchers can capture socio-economic factors, perceptions, adaptive capacities, and local knowledge systems. Contextualizing quantitative findings within the local socio-cultural context ensures the relevance and applicability of adaptation strategies, enhancing their effectiveness in identifying the priorities of local communities.

2.3.10 Smallholder farmers vulnerability

Smallholder farmers in developing countries make a significant contribution to global food security (Azadi et al., 2023) and are among those who will suffer the most from climate change impacts (Lasco et al., 2011). Their livelihoods heavily rely on agriculture, a sector highly susceptible to the adverse impacts of climate change. The vast majority (about 86%) of farmers in Pakistan possess small landholdings (Ahmad et al., 2023). Pakistan's smallholder farmers already suffer from socio-economic vulnerability stemming primarily from widespread poverty in rural Pakistan, affecting approximately 132 million individuals (61%), with 36% (48 million) living below the poverty line, and an additional 22% classified as transitory poor (Arif & Farooq 2014; Mansuri et al., 2018). A significant portion of the poor comprising small-scale farmers and landless agricultural labourers, constitutes around 75% of the overall rural population (Bhutto & Bazmi 2007). The livelihoods of most of this rural population heavily rely on single sector agriculture that is highly susceptible to the adverse impacts of climate change, including rising temperatures, erratic rainfall, floods, and droughts. Past occurrences of climate-related disasters have already caused significant damage. Looking ahead, the projected escalation of extreme climate events under 1.5ºC and 2ºC warming scenarios poses an even graver risk to the already vulnerable small-scale farmers in the Punjab. The importance to agricultural production of smallholder farms and their high levels of existing vulnerability merits a deeper understanding of their responses to climate change.

2.3.11 Importance of understanding farmer perceptions

Personal experience strongly shapes how individuals understand climate phenomenon. Individuals tend to recognise gradual, long-term changes only when they directly encounter them in ways that affect their livelihoods (Brügger, 2020). However, climate change impacts can be misperceived, and this often stems from a variety of factors including cultural and experiential biases. Also, psychological distance plays a role in misperception (Manning et al., 2018). If climate change is perceived as happening in distant places or at some point in the future, people may underestimate its local relevance and significance, downplaying its immediacy (Pahl et al., 2014; van der Linden et al., 2015; Brügger, 2020). The mismatch between scientific data on climate change and lived experience can lead to a divergence between perceptions and actual climate impacts. In addition, local communities may have generations of experience with particular climates, but when the patterns shift beyond familiar bounds, traditional knowledge systems may struggle to explain these changes. Also, if the changes do not fit local explanatory models, they may be attributed to causes other than climate change. Therefore, when local knowledge systems are overwhelmed by unprecedented changes, communities may be more vulnerable, lacking the means to anticipate and respond to climate impacts.

In many cases, local perceptions are often considered subordinate to scientific knowledge in dominant policy and development discourse, particularly in the Global South (Chakraborty and Sherpa, 2021). This reflects a broader hierarchy in which scientific knowledge is privileged as objective and authoritative, while local knowledge is often seen as subjective (Dare Kolawole, 2022). When local knowledge is perceived as subservient to scientific knowledge, it can create tensions in how climate adaptation strategies are designed and implemented (Naess, 2013). This hierarchy can marginalise local communities and restrain their capacity to contribute meaningfully to climate adaptation strategies. Such dynamics can undermine trust and cooperation between local communities and external actors. However, there is a growing recognition of the value of integrating local knowledge into climate responses (Chakraborty and Sherpa, 2021). Local knowledge can offer fine-grained, context-specific insights that are often missing from broader scientific models.

Understanding farmer perceptions and adaptation strategies is paramount for effective climate change adaptation planning (Tripathi & Mishra, 2017). Farmers, as key actors in agriculture, possess invaluable insights into the localised impacts of climate change and the adaptive measures undertaken to mitigate its effects (Keshavarz et al., 2014). Farmers are at the frontline of action, and their practices directly impact climate adaptation (Aniah et al., 2019). Their perceptions not only reflect lived experiences but also inform adaptive decision-making processes that are deeply rooted in socio-cultural contexts (Shaffril et al., 2018). Farmer perceptions offer crucial insights into the specific challenges and vulnerabilities faced at the local level. By understanding how farmers perceive climate change risks and adapt to them, policymakers and practitioners can develop adaptation strategies that are tailored to the unique socio-economic and environmental context. Furthermore, understanding the drivers and barriers to adaptation at the farmers level is essential for promoting adaptive behaviour (Li et al., 2017). Farmer perceptions shed light on factors such as attitudes towards risk, access to resources, and social networks, which significantly influence adaptation decision-making (Aniah et al., 2019). By leveraging these insights, policymakers can design targeted interventions such as extension programs, financial incentives, and capacity-building initiatives aimed at fostering climate-resilient farming practices. Having explored the importance of understanding farmer perceptions, crucially significant is the pivotal role of government in supporting adaptation strategies (Rahman & Alam, 2016; Tripathi & Mishra, 2017)

2.3.12 Role of government in supporting adaptation

Government involvement in supporting climate change adaptation efforts is paramount for fostering resilience and sustainable agricultural development is essential for several reasons. Governments serve as key drivers in formulating and implementing climate change adaptation policies and strategies (Agrawal, 2008). By establishing clear policy frameworks and guidelines, governments provide a roadmap for adaptation action, ensuring coherence and coordination across various levels of governance. Also, governments play a crucial role in allocating financial resources and building institutional capacities to support adaptation initiatives (Hansen et al., 2019). Adequate funding and capacity-building efforts are essential for implementing adaptation measures effectively and strengthening the adaptive capacity of vulnerable communities. Governments can mobilise resources from national budgets, international development assistance, and public-private partnerships to support adaptation efforts, ensuring that adaptation interventions reach those most in need. In addition, governments can play a crucial role in mainstreaming climate change adaptation considerations into sectoral policies and development planning processes (Fankhauser, 2017). By integrating adaptation into sectoral policies such as agriculture, water resources and disaster risk reduction, governments can ensure that adaptation is embedded in decision-making processes and investment planning. Furthermore, governments can facilitate collaboration among actors involved in adaptation planning and implementation (Ishtiaque et al., 2021). In particular, the role of local government in supporting climate change adaptation is multifaceted and indispensable (Bhatta et al., 2017; Agrawal, 2008). Through policy implementation, resource allocation, coordination, mainstreaming, and support for vulnerable communities, local governments can enhance the resilience of the vulnerable regions to climate change impacts (Lesnikowski et al., 2021; Dannevig et al., 2012). Chapter 7 section 7.1 further elaborates on the critical significance of local governments in supporting adaptation strategies, emphasizing their pivotal role in addressing the nuanced needs of communities.

Governments are expected to lead efforts in climate adaptation by developing and enforcing policies to help communities become more resilient to climate impacts (Osberghaus et al., 2010; Fila et al., 2024). However, the reality of government action can vary significantly depending on the context and available resources (Fila et al., 2024). While governments are central to coordinated, large-scale adaptation efforts, their actions are often constrained by priorities and inefficiencies (Pasquini et al., 2015; Musah-Surugu et al., 2019). In many countries, especially developing nations, economic development remains a higher priority

(Magdalena and Suhatman, 2020). In some contexts, government priorities may reflect unequal distribution of resources, with wealthier areas or politically connected regions receiving more adaptation support than marginalised communities (Traber et al., 2022). In situations where governments are ineffective or absent, the consequences are profound, particularly for vulnerable communities, who may be left with little support (Gannon et al., 2021). In the absence of government action, non-governmental actors and local communities may attempt to fill the gap through informal adaptation strategies (Schweizer et al., 2021). While grassroots efforts can be effective, they are often fragmented, poorly coordinated, and underfunded (Yeleliere et al., 2022). Private sector involvement may also prioritise profit over equity (Crick et al., 2018). This can lead to uneven outcomes, with some areas adapting better than others, and a lack of comprehensive, systemic resilience.

In summary, the integration of qualitative insights with quantitative data enriches vulnerability assessments, providing a more holistic understanding of vulnerability to climate change (O'Brien et al., 2004; Cochrane et al., 2019). This review underscores the significance of adopting an integrated approach to vulnerability assessment and adaptation planning, particularly in the vulnerable areas of the Punjab province where agricultural livelihoods face substantial risks. By synthesizing quantitative vulnerability assessment and mapping techniques with qualitative engagement, such as understanding the perceptions of farmers and local government officials, insights into vulnerability and adaptation dynamics can be obtained. Therefore, this points towards adopting a mixed methods approach (Hennink et al., 2010; Bryman, 2016; Dawadi et al., 2021) as the suitable strategy for assessing the vulnerability of farmers cultivating major crops in the Punjab province. By adopting a mixed-methods research design approach, this study explores different aspects of vulnerability, which could lead to an integrated vulnerability assessment. This research adopts an integrated perspective by consciously combining quantitative and qualitative methods to capture both the measurable, objective aspects of vulnerability and the nuanced, subjective experiences of key stakeholders (Åkerblad et al., 2021; Taherdoost, 2022). The integration occurs through the thoughtful design of the study, where the findings from the quantitative vulnerability assessments and mapping inform and complement the qualitative analysis. This interaction allows for a richer and deeper understanding of vulnerability wherein quantitative data reveal broad trends and areas of high vulnerability, while qualitative insights help explain why these patterns exist and how they are experienced on the ground. The approach is not just a combination of methods but an integrative process where each method contributes to a deeper, multidimensional understanding of the research problem, by addressing both macro-level patterns and micro-level experiences (Sesana et al., 2020; Dawadi et al., 2021). This approach not only acknowledges the complex interplay of factors affecting vulnerability but also provides a useful framework for identifying factors that enable and constrain adaptation measures.

Chapter Three: Theoretical Framework

In this chapter, I explore the fundamental concepts that form the foundation of this research. I discuss these in three distinct yet interconnected sections, critical in shaping the framework and direction of the study.

In Section 3.1, the exploration of the Rural Livelihood Framework unveils the intricate dynamics of rural livelihoods, revealing the essence of livelihood capitals. Within the context of climate change adaptation, understanding these livelihood dynamics becomes essential for identifying vulnerable areas and devising appropriate strategies. Exploring the concept of livelihood capitals is crucial for examining the socioeconomic factors that shape agricultural communities, offering a comprehensive lens to examine the interplay between livelihood resources and community resilience within the scope of this research. The development of an index of adaptive capacity (Chapter 5) drew on the theory and practice of the rural livelihoods analysis (detailed in Section 3.1).

Section 3.2 describes the concept of Climate-Smart Agriculture (CSA) and introduces its evolution towards Vulnerable-Smart Agriculture (VSA) thinking from the foundational principles of CSA. Climate-smart agricultural practices inherently embed adaptation strategies aimed at mitigating the impacts of climate change on agricultural productivity and rural livelihoods. Understanding this transition becomes pivotal as it underscores the imperative for adaptive strategies tailored to address vulnerabilities, a central theme within the purview of this study.

Finally, section 3.3 pivots toward the explanation of the building blocks comprising the Vulnerable Smart Agriculture (VSA) model, drawing insights from the literature. This transition underscores the imperative to integrate climate change adaptation measures into agricultural practices, thus ensuring the resilience of rural livelihoods amidst changing environmental conditions. It serves as a scaffold upon which the subsequent empirical analysis (Chapter 6, Chapter 7), and discussions (Chapter 8) are anchored.

These sections serve as the bedrock of this thesis, not only providing theoretical scaffolding but also delineating the rationale behind their inclusion within this research. By emphasizing the interconnectedness between rural livelihoods, climate change adaptation, and agricultural practices, this theoretical framework seeks to provide understanding of the challenges and opportunities inherent in fostering sustainable development in rural areas. By scrutinizing the intricate intersections between livelihood dynamics, adaptive agricultural strategies, and evolving paradigms, this chapter seeks to lay a foundation for the empirical investigations that follow.

3.1 Rural livelihoods framework

The livelihoods approach centres on the foundational concept of livelihoods, which encompasses the capabilities, assets, and activities necessary for sustaining a means of living (Chambers & Conway, 1992; Bebbington, 1999). A livelihood is considered sustainable when it can withstand and recover from various pressures without depleting the natural resource base (Scoones, 1998). Building upon sustainable livelihoods research, Ellis (2000) devised the rural livelihoods analysis framework, illustrated in Figure 3.1. This framework outlines key components, including livelihoods strategies, assets, livelihoods security, and structures. Within this framework, livelihoods strategies are pivotal for survival, especially in managing the impacts of shocks and trends such as climate change on livelihood security and environmental sustainability. These strategies denote the amalgamation of activities and decisions individuals undertake to attain their livelihoods objectives, exemplified by the agricultural practices adopted by impoverished rural communities for their sustenance (Ellis, 2000; Scoones, 2009). Shocks and trends denote external factors that significantly impact the lives and livelihoods of people, factors beyond their control or influence (Hammill et al., 2005). These external forces form an essential aspect of the context within which individuals operate and make crucial livelihood choices.

Various shocks, including floods and droughts, as well as ongoing trends like economic shifts and population changes, significantly impact livelihoods (Nelson et al., 2005; Ahmad et al., 2022). Ensuring the security of livelihoods involves maintaining specific income levels and stability, which enhance the resilience and fortitude of individuals against adverse shocks and ongoing trends (Ellis, 2000; Antwi-Agyei et al., 2013; Peng et al., 2022). The livelihoods framework, depicted in Figure 3.1, encompasses other elements such as organisational structures, rules, and policies. Entities like governmental agencies, international organisations, and local administrative bodies establish and execute policies and legislations that directly or indirectly influence the resilience and choices concerning the livelihoods of individuals (Ellis, 2000; Hammill et al., 2005; Berman et al., 2012).

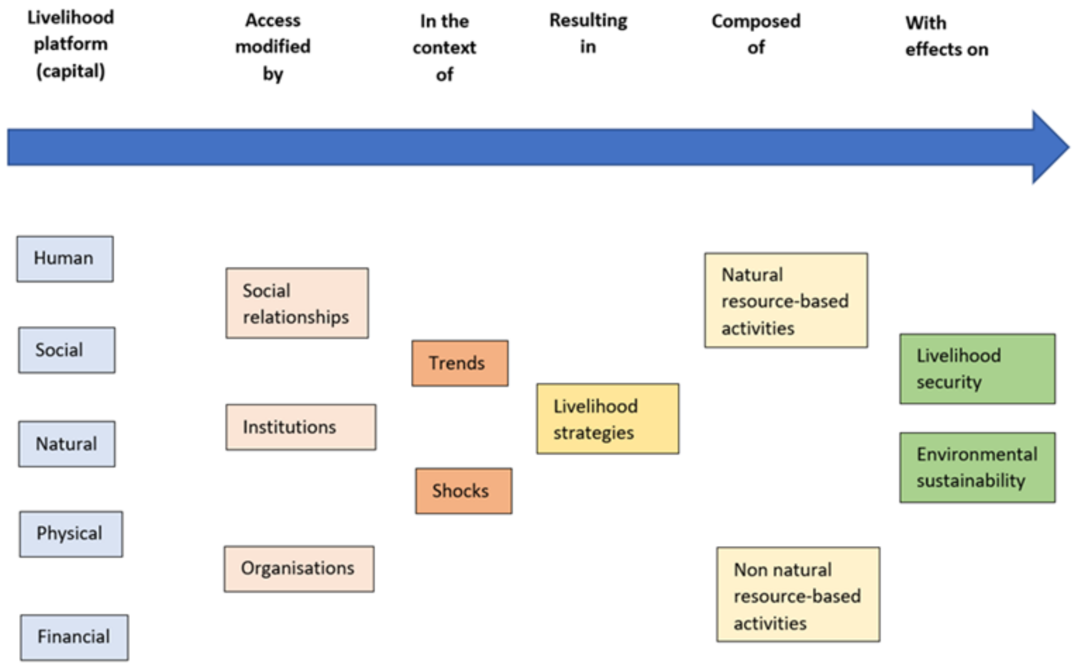


Figure 3.1: Summarised rural livelihoods analysis framework. Adapted from Nelson et al. (2005)

Earlier work by Sen on entitlements (Sen, 1981) has served as a pivotal inspiration for researchers exploring livelihoods (De Haan & Zoomers, 2005). Aligned with the entitlements approach (Sen, 1981), the livelihoods approach has introduced valuable concepts, drawing on engagement from various international organizations e.g. DFID, FAO, and UNDP (Hammill et al., 2005). Nevertheless, the livelihoods approach, encompassing its diverse components, has faced criticism for its perceived breadth (Carney et al., 1999; Iwasaki et al., 2009), time-intensive nature (DFID 2001), lack of temporal dimensions of climatic events (Laube et al., 2012; Natarajan et al., 2022), and its demand for substantial information and budgets in its entirety (Ellis, 2000; Scoones, 2009). Furthermore, a major challenge within the livelihoods approach lies in analyzing the dynamic nature of livelihood strategies (Turner et al., 2003; Antwi-Agyei et al., 2013; Jiao et al., 2017; Gumel 2022).

In both livelihoods perspectives and the rural livelihoods analysis framework, a common emphasis lies in assessing the asset status of individuals, which is crucial for understanding their available options, the strategies they adopt for survival, and their vulnerability to adverse events such as floods and droughts (Scoones, 1998; Ellis, 2000; ADB 2023).

The rural livelihoods framework outlines adaptive capacity through its focus on assets, strategies, structures, and the vulnerability context (Scoones, 1998; Ellis, 2000; Natarajan et al. 2022). Adaptive capacity is embedded in the interaction between these components and the ability of households to respond to challenges. The livelihood framework can be used to assess the adaptive capacity of communities to endure both climatic and non-climatic stressors (Antwi-Agyei et al., 2013; Choden et al., 2020). The rural livelihoods framework offers a way to understand how rural households survive and adapt to challenges by considering the complex interaction of resources, strategies, and institutional contexts (Natarajan et al., 2022). The framework implicitly highlights that households with more assets and the ability to utilise those assets are likely to have greater adaptive capacity, as they can draw on these assets in times of stress and shocks (Nelson et al., 2010; Choden et al., 2020). The vulnerability context directly affects how households respond and adapt. The livelihood framework is valuable for understanding climate change vulnerability as it offers a framework to examine both the essential elements of livelihoods and the contextual factors that affect them (Choden et al., 2020). It emphasises the need for rural livelihoods to be flexible and resilient in the face of changing circumstances (Keshavarz and Moqadas, 2021). The choice of livelihood strategies demonstrates the adaptive responses of the households to their contexts and may diversify their practices to cope with challenges. This flexibility is a core part of adaptive capacity (Barnes et al., 2020). Moreover, sustainable livelihood outcomes such as improved well-being, reduced vulnerability, and environmental sustainability reflect the long-term success of adaptive capacity. If livelihoods are resilient and sustainable over time, it indicates that adaptive capacity has been effectively built into the livelihood system. The figure 3.1 typically shows assets, structures, processes, and outcomes as interconnected. Adaptive capacity is the dynamic ability of households to mobilise assets, responding to the vulnerability context, leveraging institutional support, and adjusting livelihood strategies (Matthews and Sydneysmith, 2010; Angeler et al., 2019). These, then, are the dimensions of adaptive capacity and contribute to the ability of a household to adapt.

The rural livelihoods framework identifies stocks of various forms of capitals: natural capital, human capital, physical capital, financial capital, and social capital, as detailed in Table 3.1. In the context of resource dynamics crucial to livelihoods, different forms of capital play pivotal roles, each contributing distinctly to the ability to thrive and pursue sustainable livelihood strategies. These diverse forms of capital collectively weave an intricate web of resources, interconnecting to shape and fortify the capacity for sustainable livelihoods.

Table 3.1: Capitals description

Capital type	Description
Natural capital	It comprises the land, water and biological resources that are utilised by people to generate means of survival.
Human capital	It refers to education, skills and health of the persons for the effective pursuit of livelihood strategies.
Physical capital	It comprises the capital parts (such as structures, roads, power, canals, tools) that are created by economic production processes.
Financial capital	It refers to the capital base (cash, savings, access to credit) which are essential for the pursuit of any livelihood strategy.
Social capital	The social resources (networks, social relations, affiliations, associations) upon which people draw when pursuing different livelihood strategies requiring coordinated actions.

Source: Scoones, 1998; Ellis, (2000)

These capitals hold significant potential in shaping adaptive capacity and livelihood outcomes due to their flexible substitution, fungibility and interconversion during stressful events (Ellis 2000; Reed et al. 2013; Ahmad et al., 2022). Also, adaptive capacity can result in broader livelihood strategies, such as seeking off-farm and non-farm employment, particularly when there are changes in farm management (Jacobs & Brown 2012; Antwi-Agyei et al., 2017). The concepts of diversification and substitution of assets remain central in crafting livelihood strategies (Ellis, 2000; Nelson et al., 2005; Olsson et al., 2014). Additionally, a well-balanced diversity of assets and actions is likely to enhance adaptive capacity by offering greater flexibility to adopt alternative livelihood strategies (Nelson et al., 2010). Adaptive capacity in the context of climate change is defined as the ability of a system to adjust to climate change including climate variability and extremes to moderate potential damage, to take advantage of opportunities or to cope with the consequences (McCarthy et al., 2001). Adaptive capacity holds a central position in understanding vulnerability and serves as a crucial component in its assessment, representing both the available resources for adaptation and the proficiency in effectively utilizing these resources for adaptive purposes (Brooks & Adger, 2005; Pelling, 2010).

Rural livelihoods analysis has been used for assessing adaptive capacity in both developed and developing countries (Ellis & Freeman, 2005; Nelson et al., 2010; Natarajan et al., 2022), and it can be applied by using indicators and indices (Jacobs et al., 2010). The rural livelihoods analysis can be carried out on a range of scales and is particularly useful as a guide to policies in rural areas (Ellis, 2000; Natarajan et al., 2022). A focus on a livelihoods approach in rural societies can be considered effective in understanding adaptation of communities and related policy-making strategies (Iwasaki et al., 2009). Also, livelihoods analysis is a useful policy tool for prioritising further detailed investigation to develop practical strategies for building adaptive capacity (Jacobs et al., 2010). These applications are aligned with the circumstances in Punjab province where the majority of the population live in rural areas and are engaged heavily in climate-sensitive agriculture. With the view of applications in developing countries, scale, flexibility and alignment with the methodology adopted for this research (see Chapter 4 Methodology), this study adopts a livelihoods approach suitable for assessing adaptive capacity as part of vulnerability assessment in Punjab province.

After detailing the foundational elements of rural livelihoods within the framework outlined in Section 3.1, the subsequent segment explores an intersecting domain crucial for sustainable agricultural practices: Climate-Smart Agriculture (CSA) in Section 3.2.

3.2 Climate-smart agriculture (CSA)

Climate-Smart Agriculture (CSA) represents an approach aimed at transforming and reorienting agricultural systems to effectively support food security in the face of changing climatic conditions (Lipper et al., 2014). It encompasses a threefold objective that collectively seeks to enhance agricultural practices and mitigate the impacts of climate change. These three core components of the CSA approach include increasing agricultural production, enhancing resilience to climate variability and change, and mitigating agriculture-related greenhouse gas emissions (Campbell et al., 2014). The first component emphasises sustainable productivity, focusing on the need to sustainably increase agricultural productivity to meet the escalating global demand for food (Harvey et al., 2014; Raza et al., 2019). It underscores the necessity of adopting methods that enhance productivity without compromising the environment. The second component, adaptation, centres on bolstering the resilience of agricultural systems against the adverse effects of climate change. It involves implementing adaptive measures that aid agricultural systems in withstanding and adapting to fluctuating climatic conditions (van Wijk et al., 2020). The third component, mitigation, targets reducing the environmental impact of agriculture by curbing greenhouse gas emissions and promoting environmentally friendly practices (Lipper et al., 2014; van Wijk et al., 2020).

A comprehensive overview of various climate-smart options essential for sustainable agricultural practices in changing climate scenarios is outlined in Table 3.2 including water-smart, energy-smart, nutrient-smart, carbon-smart, knowledge-smart, and climate-resilient services (Long et al., 2016; Khatri-Chhetri et al., 2017).

Table 3.2: Climate-smart agriculture options

CSA Options	Examples	Objective
Water-Smart	rainwater harvesting, drip irrigation, laser land leveling, drainage management	improve water use efficiency
Energy-Smart	minimum soil disturbance, conservation agriculture	improve energy use efficiency
Nutrient-Smart	intercropping, integrated nutrient management	improve nutrient use efficiency
Carbon-Smart	agro-forestry, fodder management, integrated pest management	reduce GHG emissions
Knowledge-Smart	improved crop varieties, crop planning	assist in applying advanced agricultural methods
Climate-Resilient Services	crop insurance, climate information-based agro-advisories	assist in managing climate-related risks

Source (Khatri-Chhetri et al., 2017)

These climate-smart options encompass a range of strategies aimed at enhancing agricultural productivity while mitigating environmental impact. Within this table, a spectrum of innovative techniques is elucidated, starting with water-smart technologies. For instance, water-smart advancements, encompassing methodologies like rainwater harvesting and drip irrigation, aim to optimise water utilization within agricultural settings. By embracing these techniques, farmers can enhance water use efficiency and resilience against fluctuating water availability, vital in the face of changing climate patterns.

Given the escalating challenges posed by climate change to agricultural systems, the emergence of climate-smart agriculture (CSA) has drawn significant interest. This approach holds promise in effectively addressing the crucial issues of food security while concurrently tackling climate change through adaptation and mitigation strategies. However, the concept of CSA has encountered criticism due to the vagueness surrounding its conceptual boundaries and the practical mechanisms for implementation (Zougmore et al., 2016; Long et al., 2016). The swift uptake of CSA upon its introduction and the widespread adoption of CSA terminology without a formalised conceptual and methodological framework led to diverse interpretations of the term, sparking debates (Azadi et al., 2022). For CSA to fulfil its objectives of ensuring equitable income growth, food security, and sustainable development, there is a fundamental need to augment agricultural productivity in a sustainable manner. At its core, CSA strives to stimulate agricultural innovation that not only adapts to climate change but also enhances resilience within farming practices (Jellason et al., 2020). Although CSA presents potential benefits, its widespread acceptance among farmers faces multifaceted challenges (Fathi et al., 2023). Despite its commendable objectives, CSA has faced several criticisms including that it is a technology-centric approach (Bhattacharyya et al., 2020) and that its limited inclusivity risks exacerbating inequalities (Das et al., 2023). Critics argue that CSA has often been overly focused on technological solutions, neglecting the socioeconomic aspects of agriculture (Zerssa et al., 2021). Overreliance on technology may not always be feasible or appropriate in all contexts, especially for resource-poor farmers. The implementation of CSA practices often overlooks the involvement and perspectives of small-scale farmers and local communities (Das et al., 2023). Failure to engage these stakeholders can result in the neglect of traditional knowledge and practices that are crucial for adaptation. There are concerns that the adoption of certain CSA practices may benefit larger commercial farms more than smallholder farmers, potentially exacerbating existing socioeconomic inequalities (Harvey et al., 2014; Abera et al., 2020; Zeng et al., 2018). Other critiques have highlighted a predominant emphasis on the commercial production of high-value, water-intensive crops, overshadowing the importance of fostering localised, small-scale food production systems. Notably, the literature on CSA has often overlooked the circumstances of vulnerable farmers (Schaafsma et al., 2019; Khamkhunmuang et al., 2022), necessitating a re-evaluation of CSA approaches to encompass a broader understanding of their needs (Zougmore et al., 2016; Azadi et al., 2021; Ogunyiola et al., 2022).

3.3 Transition to vulnerable-smart agriculture (VSA)

Recognizing the limitations of CSA, a new approach, VSA thinking, has emerged that aims to empower vulnerable communities, particularly small-scale farmers, by integrating their knowledge and needs into the design and implementation of agricultural interventions (Azadi et al., 2021; Jones et al., 2022; Negera et al., 2023). In this context, VSA emerges as a pragmatic development within the CSA approach. It systematically examines adaptive and mitigative measures at the grassroots level while devising strategies to confront challenges posed by climate change and food security. VSA acknowledges the significance of climate resilience but uniquely emphasises social and economic dimensions. Its primary objective is to fortify the resilience of marginal and small-scale farmers against climate-induced vulnerabilities by enhancing the adaptive capacities of agricultural systems through participatory design of intervention programs to assist farmers (Frimpong et al., 2023). As an extension to CSA, VSA advocates a demand-driven approach that integrates vulnerability considerations into CSA paradigms (Azadi et al. 2021). This suggests that areas facing higher vulnerability due to climate change necessitate more immediate interventions aimed at bolstering their adaptive capacities. Accordingly, the planning and implementation of VSA practices should include a holistic assessment encompassing social, economic, and biophysical dimensions to ascertain their suitability and effectiveness in targeted regions (Longo et al., 2023).

3.3.1 Components of VSA model

The VSA model illustrated in Figure 3.2, as conceptualised by Azadi et al. (2021), operates on the premise that understanding and addressing obstacles are pivotal to uplifting small-scale farmers (Frimpong et al., 2023). The VSA model integrates both grassroots-level involvement (involving small-scale farmers) and top-down governmental strategies to address vulnerabilities in agriculture. It emphasises understanding the resources available to farmers (by applying the rural livelihoods analysis capital framework), their coping strategies, and a structured approach involving prediction, assessment, and adaptation, while also considering government-led interventions focusing on vulnerability indicators, exploration, and capacity-building. This approach aims to create a framework that combines local insights and governmental initiatives to address vulnerabilities and enhance agricultural sustainability.

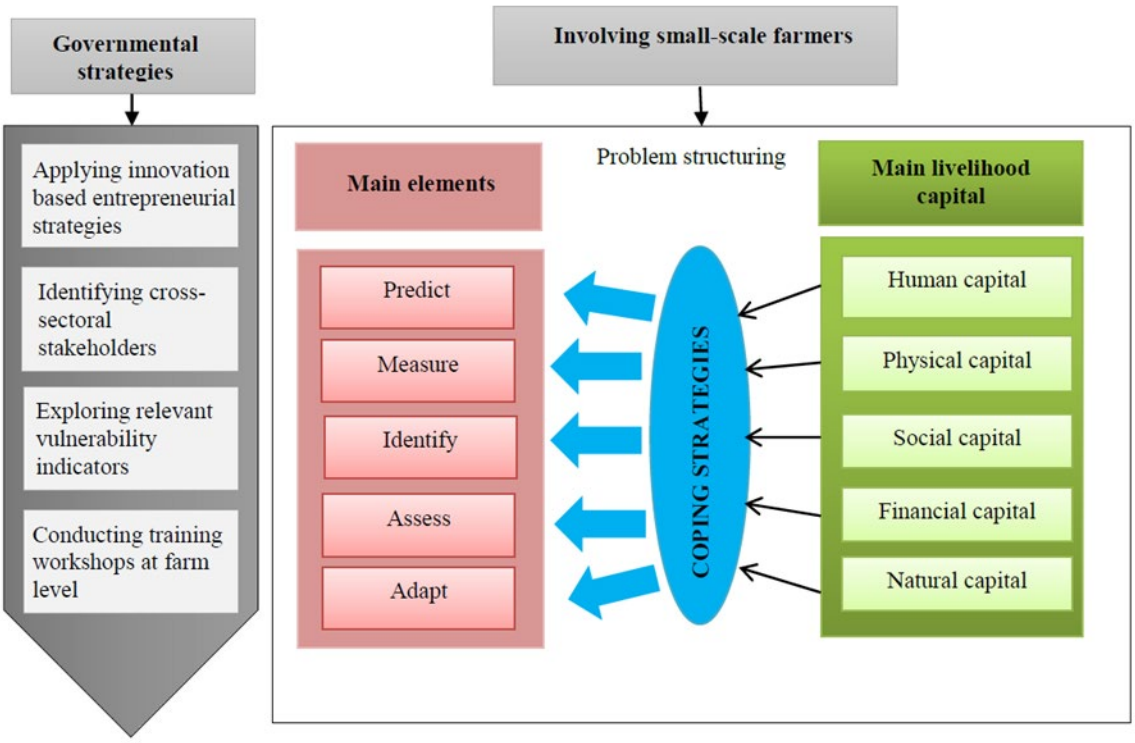


Figure 3.2: Vulnerable-smart agriculture model conceptualised by Azadi et al. (2021)

The implementation of VSA relies on a structured approach encompassing five pivotal elements (Azadi et al., 2021). This model seeks to understand and address vulnerabilities in the context of small-scale farming by systematically predicting, measuring, identifying, assessing, and adapting to challenges. Element *predict* examines comprehending the predictive mechanisms employed by small-scale farmers regarding climate change incidents. This involves understanding their perceptions, predictive tools, and indicators. By leveraging modern technologies like early-warning systems, farmers can proactively anticipate climate change events, thereby enabling effective coping strategies. Element *measure* focuses on assessing how small-scale farmers measure the impacts of these incidents. Understanding the multifaceted consequences, including social, economic, and environmental dimensions, is crucial. Accurate measurement aids in mitigating the adverse effects on livelihoods of farmers, contributing to sustainable resilience. Element *identify* involves identifying the diverse coping strategies adopted by small-scale farmers to navigate vulnerable situations. Selecting appropriate strategies aligned with the magnitude of the incidents and available resources is key. This approach empowers farmers to develop coping mechanisms to alleviate the impacts of climate change on their livelihoods. Element *assess* addresses the evaluation of small-scale farmers' livelihood capital when confronted with incidents. Considering sustainable livelihood capitals, this aspect emphasises meeting the livelihood requirements during crises. Enhancing the utilization of farmers strategies alongside advisory services reinforces resilience against climate-induced challenges. Element *adapt* explores the adaptation of farmers to climate change through the establishment of resilient farming systems. Emphasizing the utilization of natural assets such as land and water resources, this element advocates for the adoption of farming practices resilient to climate variations. Implementing suitable interventions within a resilient farming system becomes a strategic coping mechanism. In summary, the VSA approach revolves around understanding predictive mechanisms, measuring impacts, identifying coping strategies, evaluating livelihood capital, and fostering resilient farming systems.

The VSA model encompasses sections that specifically focus on the involvement of small-scale farmers. It involves problem structuring aimed at organizing and understanding challenges within the agricultural practices and livelihoods of small-scale farmers (Negera et al., 2023), and emphasises assessing the various key resources or capitals (Table 3.1) that contribute to their livelihoods. Additionally, the model highlights the coping strategies used by small-scale farmers to deal with challenges or vulnerabilities. The VSA model of Azadi et al. (2021) operates on a dual-pronged approach by combining grassroots involvement with governmental strategies to tackle vulnerabilities in agriculture comprehensively. Government initiatives within this model are multifaceted, emphasizing innovation-driven entrepreneurial methods in addressing vulnerabilities, cross-sectoral stakeholder identification and engagement, exploration of relevant vulnerability indicators, and the implementation of farm-level training workshops aimed at enhancing the capacities of farmers (Azadi et al., 2021; Longo et al., 2023). It emphasises the importance of employing government strategies to address agricultural vulnerabilities effectively. While the VSA model contributes significantly to managing risks in agriculture, it could be strengthened by paying attention to the erosion of capital assets and the cumulative effects of multiple exposures, especially as they lead to long-term vulnerability (Kim et al. 2018). These aspects are important for ensuring sustainable agricultural systems and community resilience in the face of complex, interacting risks. Multiple exposures and their compounding effects erode assets (McDowell and Hess 2012; Walsh-Dilley 2020). Over time, even resilient practices might be inadequate in the face of cumulative asset erosion (Sultana et al. 2021). In essence, VSA thinking aims to empower small-scale farmers in mitigating the adverse effects of climate change on their agricultural practices and livelihoods.

In wrapping up this chapter, I have delved into essential theoretical frameworks surrounding rural livelihoods, Climate-Smart Agriculture, and the evolution towards Vulnerable-Smart Agriculture conceptualisation. These frameworks lay the groundwork for understanding the complexities of rural communities amidst climate change.

Transitioning to Chapter 4, I will detail my methodology, outlining the research design and the key phases of methodology. The methodological approaches serve as the bridge between theory and practice, allowing me to investigate the practical implications of VSA in vulnerable rural settings.

Chapter Four: Methodology

4.1 Research design introduction

4.1.1 Research objectives

This research aims to assess the vulnerability of the agriculture sector to climate change at the district level in Punjab, Pakistan. The study is designed to achieve three distinct objectives. Firstly, it seeks to develop an index for assessing climate change vulnerability, including its components, specifically tailored to the major crops subsector within agriculture at the district scale. Secondly, the research aims to visualise this vulnerability through mapping techniques, intending to provide spatial insights that will be instrumental in engaging with and assisting vulnerable farming communities. Thirdly, the study aims to gather bottom-up information related to climate adaptation strategies from key stakeholders, emphasizing the perspectives of farmers and government decision-makers in the vulnerable districts of the Punjab region. This information will contribute to a deeper understanding of the responses to climate change in the local context. The research endeavors to assist in identifying adaptation priorities and catalysing the development of well-informed policies to support effective climate adaptation strategies within the agriculture sector. Through these objectives, the study aims to provide a comprehensive foundation for addressing climate change vulnerability in the agricultural landscape of the Punjab province.

4.1.2 Research approach overview

This research employs a mixed-methods methodology (Johnson et al., 2007; Hennink et al., 2010; Bryman, 2016; Dawadi et al., 2021), combining top-down and bottom-up approaches across three distinct phases: vulnerability assessment, vulnerability mapping, and qualitative engagement. In the initial phase, I apply an indicator-based approach for vulnerability assessment. Guided by the rural livelihoods analysis perspective, I utilise a capital framework to assess adaptive capacity, an integral part of the Vulnerable-Smart Agriculture concept (detailed in Chapter 3), which serves as the overarching framework for this research. The second phase involves geospatial mapping using indicators recognised in the first phase to identify vulnerable areas. In the third phase, a case study approach is adopted, incorporating in-depth interviews with key stakeholders (farmers and district government officials) from the vulnerable areas in Punjab identified through the vulnerability assessment and mapping process. The methodology in research design refers to the strategic plan guiding the selection and implementation of specific methods (Crotty, 1998; Mishra & Alok, 2022). It outlines the process or structure of the research, detailing how the intended research outcomes will be achieved. The chosen methodology for this research design is a hybrid approach, combining elements of both quantitative and qualitative research (Cresswell et al., 2003; Mishra & Alok, 2022). The emphasis in this research methodology transitions from a 'quantitative-oriented process' to a 'qualitative engagement-driven process,' facilitated by the incorporation of spatial mapping as a bridging element. The research methodology is structured into three distinct but interrelated phases, outlined in the subsequent sections of this chapter.

4.1.3 Philosophical orientations

As I lay the groundwork for my research, it is essential to describe briefly the philosophical underpinnings that guide my scholarly pursuits, exploring my epistemological and ontological orientations. Epistemology guides how knowledge is acquired and manifested through comprehending phenomenon (Mason, 2002; Creswell, 2007; Kelly 2021). It explores the intricate relationship between the researcher and the subject matter under investigation (Creswell, 2007). Embracing a pluralist epistemology, my research acknowledges the multifaceted nature of knowledge acquisition (Beaumont & Coning, 2022). This perspective not only recognises the existence of diverse ways of learning and knowing but also underscores the importance of accommodating this plurality to foster a more integrative study approach (Miller et al., 2008). A pluralist epistemological stance ensures that various perspectives and choices are valued and considered within the research process (Miller et al., 2008; Beaumont & Coning, 2022). It emphasises inclusivity and openness to diverse perspectives. By adopting a pluralist epistemological stance, the research aims to transcend disciplinary boundaries and methodological constraints, allowing for a more integrated approach. In framing my research, I align with ontological perspectivism, drawing from Creswell (2007) to acknowledge the multiplicity of ontological realities or perspectives into the nature of reality and existence. It emphasises that reality can be understood from various perspectives and that no single perspective can fully capture the complexity of existence (Tebes, 2012). Ontological perspectivism acknowledges the fluidity of ontological boundaries, and encourages collaboration across diverse perspectives, fostering a more inclusive approach to knowledge production (Bergman, 2020). Epistemological and ontological orientations have significance as they shape the philosophical groundings of the research approach.

By adopting a pluralist perspective, this research study values diverse sources of knowledge (Johnson 2017), which justifies the combination of quantitative vulnerability assessment and mapping with qualitative analysis of perspectives from farmers and government officials. The quantitative approach offers objective measurements of vulnerability, providing a broad, data-driven understanding of the issue (Tai et al. 2020). In contrast, the qualitative analysis captures the subjective experiences and insights from key stakeholders, which reflects the complexity and context-specific nature of vulnerability (Mezmir 2020). This approach is also aligned with ontological perspectivism (Berghofer 2020), which acknowledges that multiple realities exist such as the scientific reality captured in the quantitative data and the lived experiences represented in qualitative insights. The use of both methods ensures that the research is not restricted to a single perspective but instead incorporates a broader view of the issue, grounded in both objective measurements and subjective experiences. Thus, the epistemological and ontological orientations fundamentally shape the mixed-methods approach, ensuring that this research is open to diverse forms of evidence and reality.

4.1.4 Study area

The study was conducted within Punjab province of Pakistan (Figure 4.1), notable for being the largest province by population and the second largest in terms of area, spanning 205,344 square kilometres (PBS 2023). Punjab accommodates over 50% of Pakistan's population and contributes to over 60% of the nation's agricultural production (Abbas et al., 2014; PBS 2023). Administratively, Punjab province is divided into 36 districts, comprising both rain-fed areas and irrigated areas. Irrigated areas are serviced by a canal-based irrigation system, while rain-fed areas rely on rainfall. The average annual rainfall for Punjab ranges between 83-1583 millimeters (FAO 2019).

Figure 4.1: Location of the Punjab province within Pakistan

4.2 Phase 1 methodology: vulnerability assessment

4.2.1 Approaches to vulnerability assessment

Vulnerability can be assessed in number of ways. Chapter 2 demonstrated that there is a diversity of approaches and methods for assessing vulnerability and these are used interchangeably in the literature. Exact categorization of these approaches and methods appears to be quite fluid and overlapping. Schipper and Burton (2009) propose that it would be irrational to suggest any particular vulnerability approach as superior or inferior. Despite variations in approaches, it should be recognised that all are important in understanding the link between climate change and related responses (Kelly & Adger, 2000; Adger, 2006; Gumel, 2022). While an exhaustive examination of all vulnerability assessment methods is beyond the scope here, the literature highlights some prominent approaches, such as the risk-hazard approach, entitlements approach, indicator-based approach, and ecological resilience approach (Eakin & Luers, 2006; Malone & Engle, 2011; Patt & Klein, 2012; Biswas et al., 2023). Each of these will be briefly outlined, along with a discussion of their limitations.

4.2.1.1 Risk-hazard approach

The risk-hazard approach, often applied to biophysical systems, treats vulnerability as an *end point analysis*, focusing on the residual impact of environmental changes (O'Brien et al., 2007; Biswas et al., 2023). This method assesses potential losses from climate stressors, utilizing biophysical productivity and bio-economic models to gauge impacts on the agriculture sector (Nelson et al., 2007; Byjesh et al., 2010; Guo et al., 2021).

4.2.1.2 Entitlements approach

The entitlements approach centres on the ability of people to access essential commodities like food. Emphasizing the concept of entitlements, it utilises a *starting point analysis* by assessing vulnerability based on socio-economic differences within communities (Sen, 1981; Ellis, 2000; Gumel, 2022).

4.2.1.3 Indicator-based approach

The indicator-based approach employs sets of indicators to express the relative degree of vulnerability (Birkmann, 2006). Particularly useful for comparing geographical regions, it integrates environmental and socio-economic data, utilizing statistical methods to assign importance to each indicator (Biswas et al., 2023).

4.2.1.4 Ecological resilience approach

Integrating the concept of ecological resilience, this approach focuses on the capacity of a system to withstand disturbances while maintaining crucial relationships (Holling, 1973; Walker & Salt, 2012; Biswas et al., 2023). Key attributes include *thresholds of change* and *re-organization capacity* (Eakin & Luers, 2006; Delettre, 2021).

4.2.1.5 Limitations of vulnerability assessment approaches

Despite their significance, several widely used approaches have limitations. The risk-hazard approach, concentrating on biophysical aspects, often neglects socio-economic considerations, providing a narrow focus on exposure and sensitivity elements (Eriksen & Kelly, 2007; Bedeke, 2023). It also tends to recommend policy options that may be beyond the control of decision-makers (Nelson et al., 2007; Nelson et al., 2010). The entitlements approach faces criticism for underemphasizing ecological aspects (Adger, 2006), primarily focusing on socio-political factors and overlooking environmental influences (Narayan & Sahu, 2006; Gumel, 2022). Similar socio-economic groups might exhibit different vulnerability levels due to varied exposure to environmental factors (Nazari et al., 2015). Indicator-based approaches encounter challenges related to data availability (Chakraborty & Joshi, 2016), and the absence of a standard method for combining biophysical and socio-economic dimensions (Nazari et al., 2015; Birkmann et al., 2022). The use of indirect measures, such as proxy indicators, limits the ability to measure tangible vulnerability elements (Vincent, 2004). The ecological resilience approach is critiqued for its failure to appropriately capture social dynamics, including issues of agency and power relations (Davidson, 2010; Béné et al., 2014; Biswas et al., 2023). The emphasis on system recovery rather than individual choices within the system obscures the agency of people (Coulthard, 2012; Béné et al., 2014). Moreover, the complexity and difficulty in operationalizing resilience, especially in resource-poor settings, pose additional challenges (Carpenter et al., 2001; Nelson et al., 2010; Béné et al., 2014; Delettre, 2021).

4.2.2 Adopted approach: indicator-based vulnerability assessment

In this study, I opt for an indicator-based vulnerability assessment due to several advantages that align with the research objectives. The indicator-based approach is widely applicable, has the potential to capture the essence of the vulnerability problem and is also a powerful tool for communicating research findings to a wider audience (O'Brien et al., 2007, Patt & Klein 2012; Gumel, 2022). This approach involves reducing complex vulnerability concepts into a set of indicators, facilitating vulnerability estimation (Birkmann, 2006). The indicator-based method allows policymakers to recognise vulnerability as a pre-existing state in diverse social settings and regional contexts (O'Brien et al., 2007; Biswas et al., 2023). Focusing on the major crops sub-sector in Punjab province, the research aims to assess vulnerability by considering physical impact (exposure and sensitivity) and ability to adapt to change (adaptive capacity) (IPCC 2007; Bedeke, 2023). The constructed index can identify relative differences in vulnerability at a range of scales subject to data availability, in this case among districts in Punjab.

The examination of prevailing methodologies indicates that the risk-hazard approach predominantly focuses on the exposure and sensitivity aspects of vulnerability, while the entitlements approach leans towards the adaptive capacity element (Nelson et al., 2010; Bedeke, 2023). This observation highlights the need for a vulnerability approach capable of encompassing both biophysical and socio-economic factors within a single analysis. Nelson et al. (2010) advocate for an expanded application of risk-hazard modelling, emphasizing the supplementation with more comprehensive measures of adaptive capacity. The literature review conducted for this thesis underscores the potential of indicator-based approaches to integrate biophysical and socio-economic dimensions into a unified platform (O'Brien et al., 2004; Nelson et al., 2005; Nelson et al., 2010; Murthy et al., 2015; Shukla et al., 2016; Gupta et al., 2020; Wickramasinghe et al., 2021). Consequently, this research adopts an integrated vulnerability perspective, drawing from the IPCC model to assess vulnerability comprehensively by incorporating biophysical and socio-economic factors through indicator-based approaches (O'Brien et al., 2004, Nelson et al., 2010; Patt & Klein, 2012; Bedeke, 2023).

Although data availability is a common limitation (Malone & Engle, 2011; Birkmann et al., 2022), this research benefits from accessible secondary data from various governmental sources (see Chapter 5). The indicator-based approach is particularly suitable for macro-level comparisons among districts in Punjab, aiding in the identification of key vulnerable areas for further investigation (Malone & Engle, 2011; Biswas et al., 2023). However, to enhance the quantitative analysis, the top-down indicator-based approach is complemented with bottom-up, qualitative information gathered through primary data collection (Cash et al., 2003; Patt & Klein, 2012; McNeeley et al., 2017; Bedeke, 2023). This hybrid approach integrates local knowledge and perspectives, ensuring a more comprehensive and legitimate assessment (McNeeley et al., 2017; Bedeke, 2023).

The methodological framework, encompassing quantitative data sources, analysis scale, indicator selection, functional relationship to vulnerability, and justification of indicators, along with detailed Phase 1 Methodology Steps for constructing the composite index, are described in more detail in Chapter 5.

4.3 Phase 2 methodology: spatial vulnerability mapping

In phase 2 of this research, the indices developed in the previous phase translate into Geographical Information Systems (GIS) mapping. GIS serves as a powerful tool for addressing spatially-oriented questions, leveraging its capabilities in spatial analysis (Heywood, 2010; McHaffie at al., 2023). Widely utilised in various domains, including utilities, governmental planning and management, and environmental management, GIS has proven essential in understanding the vulnerabilities of regions impacted by climate change (Preston et al., 2011; Sherbinin et al., 2017; Tsatsaris et al., 2021). GIS mapping can be accomplished using software packages such as ArcGIS (licensed) and QGIS (open source). Geospatial mapping in this research is executed using GIS-based software ArcGIS. The preference for ArcGIS is attributed to its extensive use across diverse applications and its availability at UTS for academic purposes. The ArcMap application within the ArcGIS software is employed to generate maps depicting the relative vulnerability of districts in Punjab.

4.3.1 Vulnerability mapping approach

The indicator-based approach used for vulnerability assessment aligns well with the development of spatial maps. Literature indicates that indicator-based vulnerability studies often integrate geospatial mapping efforts (e.g. O'Brien et al., 2004; Murthy et al., 2015; Biswas et al., 2023). In contrast, other prominent vulnerability assessment methods, such as biophysical productivity models, bio-economic models, and econometric models, are less commonly associated with geospatial mapping (e.g. Attri & Rathore, 2003; Kokic et al., 2007; Narayanan & Sahu, 2016). The growing demand for vulnerability maps from development agencies and governments, especially in policy contexts, is evident (Preston et al., 2011; Sherbinin et al., 2017; Membele et al., 2022). Vulnerability maps have proven valuable in stakeholder discussions and adaptation planning, providing an evidence base for discussions, particularly in developing countries where geographic information may not be readily available to all stakeholders (Sherbinin et al., 2017; Membele et al., 2022).

GIS typically represents real-world features through either raster or vector models (Bolstad, 2012; McHaffie at al., 2023). The raster model, suitable for continuous geographic phenomena like elevation and slope, is particularly advantageous when utilizing remotely sensed images organised into grid cells (McHaffie at al., 2023). On the other hand, the vector model is deemed more suitable for mapping discrete geographic entities such as administrative boundaries, roads, and rivers (Heywood, 2010; McHaffie at al., 2023). The choice between these models will depend on the nature of the data and the specific characteristics being depicted in the vulnerability mapping process. This study depicted vulnerability within the Punjab using district administrative boundaries as discrete geographic entities. The choice of the vector model is appropriate for this mapping task, considering the nature of the data.

Spatial maps using GIS are widely employed for vulnerability mapping, it is a well-established approach supported by numerous studies. Sherbinin et al. (2017) and Membele et al., (2022) highlight the effectiveness of vulnerability mapping through spatial representation, emphasizing its utility in targeting adaptation assistance due to spatial variations in climate impacts, sensitivity, and adaptive capacities. Preston et al. (2011) suggest that vulnerability mapping aids in conveying the local context by interpreting geographically diverse elements within vulnerability assessments. Additionally, vulnerability maps serve as valuable knowledge management tools, offering a comprehensive overview of available data for high-level decision-makers (Sherbinin et al. 2017; Membele et al., 2022). The potential of maps to communicate the 'vulnerability of place' is emphasised by Cutter (1996) and Cutter et al. (2000), defining it as the interaction between climate change-induced harm potential and the local situation.

While vulnerability mapping has been praised for its benefits, Preston et al. (2009) caution against potential misinterpretations, noting that without clear guidance, different audiences may derive varying conclusions, leading to spurious assumptions about vulnerability and its determinants. The limitations of vulnerability mapping approaches are discussed in detail in Chapter 8. Despite critiques, there is broad support for vulnerability maps. Preston et al. (2011) outline multiple benefits, including aiding spatial planning, assisting in risk and disaster management, and identifying priority vulnerable areas. The cross-dependency of services on co-located infrastructure, as seen in power and water utilities, is also effectively addressed through spatial mapping (e.g. Inanloo et al., 2016). Visualization facilitated by vulnerability mapping contributes to its interpretation, offering a powerful tool for decision-making in flood risk management (Sheppard, 2005; Sheppard et al., 2010; Tsatsaris et al., 2021; Membele et al., 2022).

4.3.2 Methodological steps for phase 2

Spatial data, fundamental to GIS, is represented in ArcGIS as shape files. Base shape files for Punjab province, including district administrative boundaries, were sourced from government and UNDP online resources. Spatial or geographical data may be represented as GIS layers, with features like rivers, roads, and administrative boundaries depicted as points, lines, and polygons (Heywood, 2010; McHaffie at al., 2023). For this research, the focus was on administrative boundaries as essential shape files. Spatial data entities can be associated with attribute data (Bolstad, 2012; McHaffie at al., 2023), which includes non-spatial information. ArcMap allows the addition of non-spatial attribute data linked with spatial entities using unique geospatial references. District attribute data, such as population density, district name, and area, may thus be linked with spatial data entities. Using ArcMap, separate maps for each vulnerability component (exposure, sensitivity, and adaptive capacity) were developed. These maps visualise attributes associated with each vulnerability component, allowing the selection of features through functions like 'selection by location' and 'selection by attributes' in ArcMap. ArcMap provides various functions for map editing, including symbolization, labelling, legends, scale bars, directional arrows, and transparency settings. The rearrangement of feature layers ensures that they do not obstruct each other in the map. The overall vulnerability map for Punjab province was created by combining attributes related to exposure, sensitivity, and adaptive capacity. This map highlights the geospatial distribution of vulnerability based on aggregated indicators. Component maps offer flexibility in viewing districts that are more or less sensitive, exposed, or have higher or lower adaptive capacity. This phase addresses the geospatial mapping aspects, acting as a foundation for selecting areas in Phase 3 for more detailed, qualitative, primary data collection to understand district-level adaptation strategies, barriers, enablers and variations with changes in vulnerability aspects.

4.4 Phase 3 methodology: qualitative case study

4.4.1 Integrating bottom-up perspectives

Recognizing the limitations of macro-level analyses, the integration of bottom-up approaches becomes crucial (O'Brien et al., 2004; Zhang et al., 2022). Bottom-up data collection assists in identifying factors influencing adaptive capacity at the local level, adding depth to the assessment (O’Brien et al., 2004; Eicken et al., 2021). Incorporating local knowledge enhances the legitimacy of findings, providing a nuanced understanding of place-based vulnerability determinants (Cash et al., 2003; Patt & Klein, 2012; McNeeley et al., 2017). This integrated perspective combines top-down processes with local-level case studies, capturing interacting factors at different scales (O'Brien et al., 2004; Fischer et al., 2013). The importance of this integration is underscored by the dynamic nature of vulnerability, requiring examination from both top-down and bottom-up perspectives (O'Brien et al., 2004; Fischer et al., 2013; Eicken et al., 2021). Therefore, the research adopts a holistic and integrative approach, combining quantitative and qualitative methods to comprehensively assess vulnerability, ensuring a nuanced understanding of the complexities involved.

An integrated approach to vulnerability assessment encompasses multiple dimensions of the problem, including, but not limited to, methodological diversity (Åkerblad et al., 2021). An integrated approach applies systems thinking, which looks at how different components of a system such as environmental, social, economic, and policy dimensions interact and influence vulnerability (Sesana et al., 2020; Gero et al., 2024). Rather than analysing individual factors in isolation, systems thinking focuses on how these factors interact, potentially amplifying or mitigating vulnerabilities. An integrated approach recognises these interconnections, something that goes beyond what quantitative and qualitative methods can achieve alone. Another critical component of an integrated approach is the involvement of key stakeholders i.e. farmers and government officials in this research. This participatory element is not necessarily a feature of mixed methods. In an integrated approach, vulnerability assessment is not merely academic but often linked to policy planning and interventions (McEntire at al., 2010). Also, an integrated approach explores findings that are directly linked to actions that address vulnerability by integrating the assessment with practical outcomes or informing adaptive measures. A focus of integrated approaches is on creating the conditions for experimenting with multiple kinds of knowledge and ways of knowing to foster sustainability-oriented learning (Caniglia et al., 2021). Qualitative research plays a crucial role in understanding the specific nuances of opinions, behaviours, perceptions, and social contexts within populations and individuals (Hennink et al., 2010; Barbour, 2013; Mishra & Alok, 2022). It provides valuable insights into the human dimension of an issue, complementing quantitative methods by aiding in the interpretation of data and offering a deeper understanding of complex realities (Mack et al., 2005; Eicken et al., 2021). Consequently, this study incorporates qualitative techniques to capture information related to climate adaptation issues in Punjab.

4.4.2 Qualitative research methods

Three commonly used qualitative methods for case study data collection are participant observation, in-depth interviews, and focus groups (Creswell, 2007; Berg & Lune, 2012; Barbour, 2013; Zarestky, 2023), each suitable for obtaining specific types of data. Participant observation involves the researcher immersing themselves in community settings to understand the insider's perspective, though it has limitations such as reliance on memory, time consumption, and subjectivity (Mack et al., 2005). In-depth interviews aim to capture a vivid picture of participants' perspectives, allowing detailed insights into individual experiences, feelings, opinions, and contextual information (Cordell, 2010; Taherdoost, 2022). Despite its effectiveness, in-depth interviews require rapport-building skills, active listening, and significant time commitment for transcription and thematic analysis (Hennink et al., 2010; Zarestky, 2023). Focus group discussions, while efficient for gathering information on social norms and group opinions, have limitations like potential dominance of certain personalities and obtaining only group responses (Berg & Lune, 2012; Akyıldız & Ahmed, 2021).

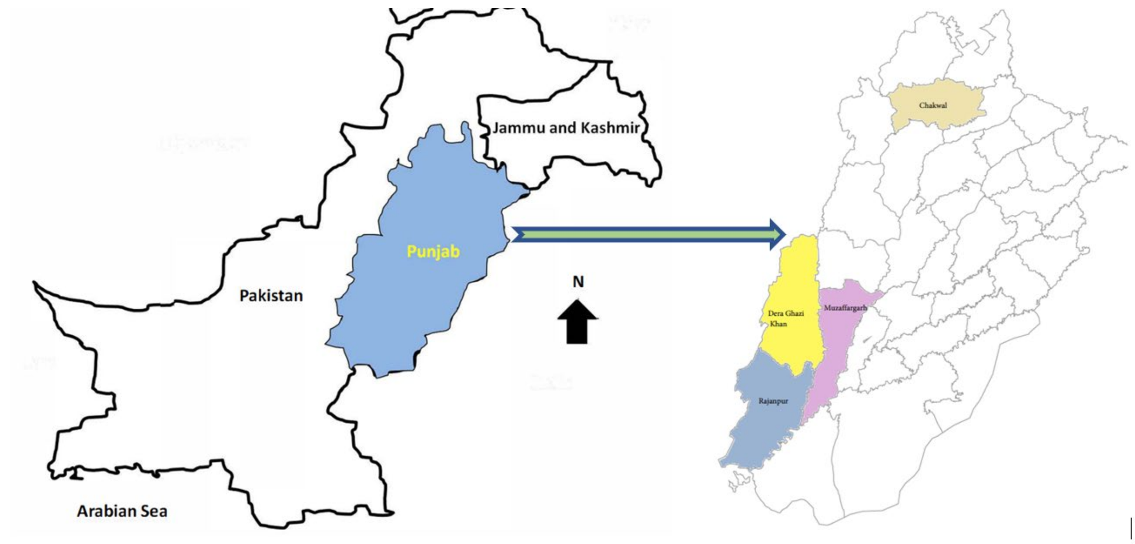
4.4.3 Adopted qualitative approach and method

In Phase 3 of the research methodology, a case study approach is adopted as a suitable qualitative strategy to explore the most vulnerable areas identified through geospatial mapping in Phase 2. Case studies, defined as qualitative inquiries examining phenomena across various units of analysis, including individuals, groups, social settings, businesses, and events (Berg & Lune, 2012; Taherdoost, 2022), allow for in-depth exploration within specific contexts, providing rich, detailed descriptions of the studied phenomena within real-life settings (Yin, 2009; Denzin & Lincoln, 2011; Zarestky, 2023).

For Phase 3 of this research, in-depth semi-structured interviews were chosen as the method of inquiry due to their suitability and specific benefits. Semi-structured interviews allow for obtaining individual perceptions and knowledge, aligning with the research questions focused on farmers and provincial-scale government officials' perspectives on climate change phenomena. Considering resource constraints, time frames, and the remoteness of field study locations, semi-structured interviews were deemed the most appropriate method, offering efficiency and relying less on memory for documentation compared to other qualitative methods.

4.4.4 Case selection

Four districts of Punjab province (Chakwal, Dera Ghazi khan, Muzaffargarh, Rajanpur), were chosen in Chapter 5 for this study (Figure 4.2), due to their agricultural significance and identification as vulnerable to climatic changes through the construction and mapping of the index of vulnerability and its components (McCarthy et al., 2001). In selecting districts for in-depth analysis within the Punjab province, a meticulous approach was adopted to identify those areas exhibiting heightened vulnerability to environmental challenges, socio-economic fragility, and reliance on climate-sensitive agricultural practices. The significance of these districts lies in their susceptibility to extreme weather events and their pivotal role in the region's agricultural landscape. This multi-faceted approach allowed for the identification of districts most susceptible to environmental stressors and least equipped to cope with them. By focusing on districts with such characteristics, this study aims to shed light on the interplay between vulnerability and agricultural practices, thereby informing targeted interventions and policy decisions. The chosen districts play a crucial role in the agricultural productivity of the Punjab province.



Punjab province on Pakistan map

Study districts of Punjab

Figure 4.2: Study districts of Punjab province

The selected districts (Rajanpur, Dera Ghazi Khan, Chakwal, Muzaffargarh) hold significant importance in the production of major crops, encompassing both cash crops (such as cotton and sugarcane) and food crops (like wheat, rice, and maize) (PBS 2023). In the Punjab province, cotton production predominantly occurs in Rajanpur, Dera Ghazi Khan and Muzaffargarh districts (Abbas, 2020). Similarly, district Chakwal holds prominence in wheat production within the rain-fed farming areas of the Rawalpindi division in the Punjab province (PBS 2023). The critical significance of major crops to Pakistan is highlighted in Section 2.2.2.

The environmental and socio-economic characteristics of the chosen districts are featured in governmental and international organization publications, (such as ID GoP 2012; FAO 2019; PBS 2023), with each district's details described individually below.

Chakwal District:

District Chakwal covers 6524 square kilometers with a climate characterised by hot summers and cold winters, receiving an average annual rainfall of 543-1107 millimeters. Chakwal district has an irrigated area of 12 thousand hectares. Its terrain varies from plains to hills, with a population density of 123 persons per square kilometer. Chakwal district has mineral resources such as limestone, coal, rock salt, and iron ore and has 2730 kilometers of metalled roads. The main agricultural crops are wheat, maize while minor crops include mustard seed, moong and sunflower. Livestock farming of goats, sheep, cattle, and buffaloes is significant. Forests cover 72163 hectares of land in District Chakwal, representing 11% of its total area.

Dera Ghazi Khan District:

District Dera Ghazi Khan lies between the River Indus and the Koh-Suleman mountain range, acting as a natural boundary separating it from the neighbouring Baluchistan Province. With an annual precipitation ranging between 83-218 millimeters, the district spans 11,922 square kilometers with a population density of 190 persons per square kilometer. The irrigated land in the district covers 474 thousand hectares. Agriculturally, the district cultivates staple crops such as sugarcane, cotton, wheat, and rice, while also growing maize, sunflower, jawar, and bajra in smaller proportions. Forest coverage extends to 23726 hectares, constituting approximately 2% of the district's total area and the livestock population encompasses goats, sheep, cattle, and buffaloes. Local crafts include mat weaving, basketry, baan and hand fans from date leaves. The district has 1699 kilometers of paved roads.

Rajanpur District:

Rajanpur, situated between the River Indus and the rugged terrain of Balochistan Province, encompasses an area spanning 12,318 square kilometers. Its climatic extremities range from scorching summers to chilling winters, owing to its proximity to the *Koh Suleman* mountain range. Rainfall patterns fluctuate within the 83-218 mm range annually. In the Rajanpur district, the irrigated area amounts to 464 thousand hectares. The district has a population density of 123 persons per square kilometer. The main crops grown are cotton, wheat, and sugarcane, along with smaller quantities of groundnut, gram, rice, maize, and sunflower. Mangoes and citrus fruits are significant in fruit cultivation. The district has approximately 3527 hectares of forest cover, accounting for about 0.3 % of its total area. Livestock include goats, sheep, cattle, and buffaloes.

Muzaffargarh District:

District Muzaffargrah is situated between the rivers Chenab and Indus, covering approximately 8249 square kilometers. The district experiences extreme climate variations, with a population density of 443 persons per square kilometer. The district's irrigated area spans 616 thousand hectares. Agricultural activities primarily focus on crops such as sugarcane, wheat, and cotton, along with fruits like mangoes, citrus, and pomegranates. Forest coverage is limited to 3743 hectares, comprising 0.45 % of the total land area. Livestock rearing is significant, with goats, sheep, cattle, and buffaloes being of primary importance. Rainfall patterns ranges from 83-218 millimeters annually, influencing crop yields and water management.

4.4.5 Data collection and analysis

In conducting qualitative research, I utilised a snowball sampling method (Bryman, 2012; Adeoye, 2023) for selecting interview participants. A total of 16 semi-structured, face-to-face interviews were carried out with government officials at their respective offices. While 13 participants were from specific study districts, an additional three officials were included from the provincial headquarters in Lahore, Faisalabad, and Rawalpindi districts, based on recommendations from the initial participants. Formal permissions were obtained from provincial government departments of Directorate General Agriculture, Extension and Adaptive Research (AED), Government of Punjab (GoP), and Environment Protection Agency (EPA), Government of Punjab (GoP), directly concerned with implementing policy to enable climate change adaptation in agriculture (see Appendix E). Access to district government officials was obtained through authorization from the respective provincial headquarters. Subsequently, these officials assisted in connecting with their field staff. Table 7.1 in Chapter 7 provides information regarding government informants, including their district, gender, designation, and departmental affiliation. Likewise, district agriculture extension workers introduced me to farmers involved in the major crops sub-sector of agriculture. A total of 18 interviews took place with farmers either at their farms or during field days organised near their farms by AED, GoP. Table 6.1 in Chapter 6 provides an overview of the key characteristics of each study district, including soil texture, agro-ecological zone, major crops and number of interviewed farmers. Interviews were conducted in the local language, Urdu, to ensure clear understanding, and were audio recorded. Transcripts were then translated into English, and participant identities were anonymised before analysis. Data analysis involved coding and identification of emerging themes using NVivo analysis software (Wong, 2008; Alam, 2020). I adopted an inductive approach to qualitative coding (Azungah, 2018) to allow recurring narratives to emerge through two coding cycles (Saldana, 2013; Lester et al., 2020).

4.4.6 Ethical considerations

The research obtained approval from the Human Research Ethics Committee (UTS HREC ETH18-2545), with full adherence to its conditions. I translated essential documents like the participant information sheet, consent form into the local language Urdu. Participants provided consent by signing a consent form (see Appendix A). Prior to the interviews, all participants gave informed consent, adhering to ethical guidelines. For participants from farming communities with lower literacy levels, the consent form was translated into the local language and read aloud, with verbal consent obtained thereafter. Literate participants provided written consent. During interviews, I introduced myself, clarified my research objectives, explained the data collection process, and how responses would be handled and analysed. To ensure clarity, I addressed participant queries before seeking their consent. I took care to minimise disruption to participants' daily routines, scheduling interviews outside critical events and primarily during midday or evening hours.

The confidentiality of participants was safeguarded throughout the research process through several measures. Interview data were securely stored in a locked cupboard at the designated location at UTS. Prior to qualitative data analysis, all names were anonymised to protect participant identities. Soft copies of the data were stored on UTS-approved cloud storage platforms, with password protection implemented for added security. All communication pertaining to the research adhered to the approved ethical guidelines.

Chapter Five: Mapping Agricultural vulnerability to impacts of climate events of Punjab

Chapter 5 is a peer-reviewed journal paper published in Springer *Regional Environmental Change*. This paper assesses agricultural vulnerability to climate change for Punjab province by developing indices and maps of the individual components of vulnerability, i.e. exposure, sensitivity and adaptive capacity (McCarthy et al., 2001; Patt & Klein, 2012). The paper addresses RQ 1: *Using available data, can an index of vulnerability be constructed and mapped that identifies the most climate change vulnerable districts for the major crop subsector of Punjab province?* I employed an indicator-based approach for vulnerability assessment and utilised the Rural Livelihoods Framework (RLF), focusing on livelihood capitals, to assess adaptive capacity. Furthermore, correlation analysis was conducted to examine the association between indicators of adaptive capacity and the developed adaptive capacity index. The chapter presented the findings as a series of geospatial maps together with associated statistical analyses in the results section of the paper followed by a discussion on the policy implications and conclusions.

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ORIGINAL ARTICLE

Mapping agricultural vulnerability to impacts of climate events of Punjab, Pakistan

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Abstract

Pakistan has an agriculture-dependent economy vulnerable to climate impacts. Within Pakistan, Punjab province is a leading regional producer of food and cash crops, and an exporter of agricultural commodities of significance in South Asia. Punjab agriculture provides livelihoods for agriculture-dependent communities living in one of the most populous countries of the world and these will be disrupted under incremental climate changes (e.g. rising temperatures) and the impacts of extreme climate events (such as droughts and floods). Climate impact assessments and mapping are widely accepted initial approaches to address climate change as they have the potential to facilitate bottom-up adaptation. However, to date, policy responses in Pakistan have tended to be top-down, driven by national adaptation planning processes. This paper assesses agricultural vulnerability to impacts of climate events at the district scale for Punjab province by developing maps of the individual components of vulnerability, i.e. exposure, sensitivity and adaptive capacity. An indicator-based approach using a composite index method was adopted for the assessment. The mapping separated and categorised districts in Punjab based on their vulnerability to climate change and revealed spatial patterns and factors influencing district-level vulnerability. These geospatial variations in vulnerability illustrate the need for a nuanced policy on adaptation that recognises the importance of local biophysical and socio-economic context to build adaptive capacity for vulnerable regions rather than the current concentration on broad-scale top-down action embedded in National Adaptation Plans.

Keywords Vulnerability assessment · Mapping · Impacts of climate events · Agriculture · Punjab

Introduction

Climate change is a global problem with potentially wide-ranging effects (IPCC 2007, 2014) that are not uniformly distributed globally and vary spatially. Agriculture is recognised to be highly climate sensitive (Howden et al. 2007) and this sensitivity is projected to rise with future climatic changes (FAO 2009; Li et al. 2015). In particular, the effects of climate change on agriculture are concerning for developing countries where livelihoods of vast populations depend heavily on outcomes from farming, both subsistence and commercial (Patt and Klein 2012; Maharjan and Joshi 2013). Global and local studies indicate that Pakistan, an agriculture-dependent developing country, is among the most vulnerable nations to the impacts of climate events owing to its limited coping capacity (Kelly et al. 2005; TFCC 2010; Barr et al. 2010). Pakistan's agriculture contributes 24% of GDP and 60% in foreign exchange earnings to the national economy (PBS 2020). Furthermore, nearly three-quarters of Pakistan's population has direct or indirect dependence on agriculture, which employs around 46% of the total labour force (Rehman 2016).

Within Pakistan, Punjab province dominates the nation's output of major staple crops including food crops (wheat, rice and maize) and cash crops (cotton and sugarcane). It has a leading role in national food production by contributing 74% to the total cereal production of the country (PBS 2020) and is not only a national food bowl but is also an important exporter of agricultural produce

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(Noorka and Shahid 2013). For instance, Punjab is a major contributor to global rice exports and is one of the few cotton-producing regions of the world (Rehman et al. 2015; Yuansheng et al. 2016).

The effects of climate change threaten agriculture in Punjab. Analyses of long-term temperature trends indicate the region is experiencing a warming pattern (Abbas 2013; Penas et al. 2016). Future projections show that the increase in average annual temperature in Punjab is likely to be above the global average by 2100 (GCISC 2005; Salik et al. 2015). Crop production in Pakistan is vulnerable to the impacts of climate events (TFCC 2010). For instance, wheat crop yield in Pakistan would likely decrease by about 4–5% for each 1 °C rise in temperature (GCISC 2005). Also, already stressed surface water availability is expected to be further reduced with climatic changes which have potential implications for crop irrigation in Pakistan (Qureshi 2011). In addition, increased incidence of crop pests is likely in the warm climate and a growing problem in all cotton-growing areas of Pakistan (Bakhsh et al. 2005). Moreover, Punjab province has experienced an increase in floods in recent decades with damage to the economy. For example, direct losses from floods for the 2010–2017 period were estimated to exceed US$18 billion (Federal Floods Commission 2018). Therefore, climate change not only acts as an amplifier of agricultural vulnerability in Punjab province (e.g. Scheffran 2015) but also poses direct serious challenges to the livelihoods of poor, agrarian communities.

Adaptation to the impacts of climatic events has the potential to reduce vulnerabilities of communities through adjustments in processes, structures and practices (Smit and Pilifosova 2003), and is significant because ongoing change is ‘locked in’ to the climate system from past greenhouse gas emission (Patt and Klein 2012). As a policy response to climate change, the national government of Pakistan has formulated a range of strategies including the National Climate Change Policy 2012 (NCCP 2012). These broad policy documents tend to be mitigation—rather than adaptation—centred, which is common to the policy responses of many developing countries (Holler et al. 2020). However, the current policies emphasise the need for climate vulnerability assessments and mapping of impacts, widely accepted as early approaches to address climate change due to their potential to facilitate bottom-up adaptation by tailoring local adaptation plans and measures in accordance with local requirements (Patt and Klein 2012; Malone and Engle 2011). Vulnerability mapping is considered beneficial for targeting adaptation assistance (e.g. Sherbinin et al. 2017) because climate variability and extremes, the sensitivity of populations to climate-induced stressors and capacities to adapt vary spatially. The role of multivariate geographic visualisation in vulnerability mapping (Opach and Rød 2013; Wiréhn et al. 2017) has the potential to serve as a knowledge management tool for decision-makers to guide adaptation action (Sherbinin et al. 2017; Opach et al. 2020).

Despite differences in scope, methodology and geographical aspects, other vulnerability assessments in Pakistan also differ from the current study in research focus. To date, assessments of vulnerability in Pakistan have focused on themes including human health (Malik et al. 2012), social impacts (Rahman and Salman 2013), coastal geographies (Salik et al. 2015), gender (Iqbal et al. 2015), water resource (Shabbir and Ahmad 2016) and natural hazards (Rafiq and Blaschke 2012; Khan and Salman 2012; Zahid and Rasul 2012; Ghazal et al. 2013; Mazhar and Nawaz 2014; Ashraf and Routray 2015; Zuhra et al. 2019; Qaiser et al. 2021). Few vulnerability assessments have reflected the importance of agriculture-related themes per se. For instance, a gender-focused study included the objective of exploring gender- and age-differentiated factors on household vulnerability and food security (Iqbal et al. 2015). Another drought-focused study on Karachi city of Sindh province aimed to explore changes in agricultural patterns in response to the food demands of the inhabitants (Ghazal et al. 2013). However, vulnerability assessments and mapping have rarely focused comprehensively on the agriculture and major crops sector, particularly at the provincial scale. Our purpose in conducting the vulnerability assessment reported here, which is based on a top-down approach employing secondary sources of data, was to identify the districts most vulnerable to the impacts of climate events to guide further place-based studies, rather than seeking to develop definitive policy responses for the national government. This study focused specifically on the assessment of adaptive capacity, a component of vulnerability, because we sought also to inform local action on climate impacts (Jacobs et al. 2015). Although biophysical factors (i.e. temperature, rainfall variability and climate extremes such as floods and droughts) play an important role in shaping exposure to climate variability and change in Punjab, district and provincial policy actors are unable to directly influence them, as they are driven by global changes in atmospheric levels of greenhouse gases. In contrast, and while recognising limitations (e.g. Thomas et al. 2021), these local actors can influence capacity-building interventions for reducing vulnerability. Thus, in keeping with the current policy setting and to address the gap in the literature, this paper aims to assess agricultural vulnerability to impacts of climate events by mapping exposure, sensitivity and adaptive capacity (i.e. the components of vulnerability, McCarthy et al. 2001; Patt and Klein 2012) for the Punjab province to inform future action on adaptation.

Fig. 1 Location of the Punjab province (blue shading) within Pakistan and other nearby countries

Method

Study area

The study was conducted on the Punjab province of Pakistan (Fig. 1). Punjab is the largest province by the population of 110 million and the second largest province in terms of area, covering 205,345 sq. km (PBS 2020). Punjab accommodates over 50% of Pakistan's population and produces over 60% of total national agricultural commodities (Abbas et al. 2014; PBS 2020).

Administratively, Punjab province is divided into 36 districts. In general, Punjab province has long hot summers and cold winters. Rainfall in Punjab is mostly related to the *monsoon* winds. According to the Pakistan Meteorological Department climate classification of Pakistan, Punjab province includes the climate classifications of extremely arid, arid, dry semi-arid, wet semi-arid, wet sub-humid and dry sub-humid (PMD 2021). The combination of seasonal temperatures and rainfall divides the agricultural calendar into two major cropping seasons, *Kharif* (summer) and *Rabi* (winter). Rice, cotton, maize and sugarcane are major *Kharif* crops while wheat is a major *Rabi* crop (Hussain and Mudasser 2007; Naheed and Rasul 2010).

Data sources

The data collection for the study relied on secondary data sources available through the Government of Pakistan, including the Bureau of Statistics (BOS) Punjab, Pakistan Meteorological Department (PMD) and National Disaster Management Authority (NDMA). The meteorological data on temperature and rainfall (2005–2015) were obtained from PMD for all meteorological stations of Punjab province. Obtaining metrological data from government sources was given priority since it was 'cleaned' data after removal of any errors and comes through sources considered official and reliable. Most of the districts of Punjab have only a single meteorological station, while a few districts do not have their own meteorological station. Where a district lacked a meteorological station, the closest station data was taken for calculating temperature and rainfall indicators. Flood exposure data was estimated from NDMA. Secondary data for all sensitivity and adaptive capacity indicators for years (2010–2015) were obtained from BOS official publication reports of annual Punjab Development Statistics from 2012 to 2016 (Pakistan Economic Survey 2010–2011, 2011–2012, 2012–2013, 2013–2014, 2014–2015).

Methodological framework

The methodological framework for the study involved several key steps (Fig. 2):

Step 1: Approach

To assess agricultural vulnerability to impacts of climate events of Punjab province, an indicator-based approach was adopted because it offers several related advantages over alternative approaches, such as risk hazard, entitlements and ecological resilience approaches, and is well aligned with the objectives of this research. Indicator-based approaches are widely used in vulnerability studies (Eriksen and Kelly 2007; Li et al. 2015) because they have the potential to accommodate a range of units of analysis together and enable comparative analysis of vulnerability (Malone and Engle 2011). When mapped, they are a useful tool to communicate research findings to a wider audience including policy decision-makers and can be used as a basis for deeper analysis (O'Brien et al. 2007; Malone and Engle 2011; Patt and Klein 2012; Opach and Rød 2013; Wiréhn et al. 2017). Indicator-based approaches have been extensively applied to a range of situations including disaster vulnerability in India (Chakraborty and Joshi 2016), farming sector vulnerability to climate change and variability in South Africa (Gbetibouo and Ringler 2009), agriculture sector vulnerability in Australia (Nelson et al. 2010) and coastal communities' vulnerability to floods in Ghana (Yankson et al. 2017).

Step 2: Selection of indicators

The selection of all indicators was informed by a review of their use in the literature and, pragmatically, based on the availability and quality of secondary data. Indicators, defined as variables, are an operational representation of an

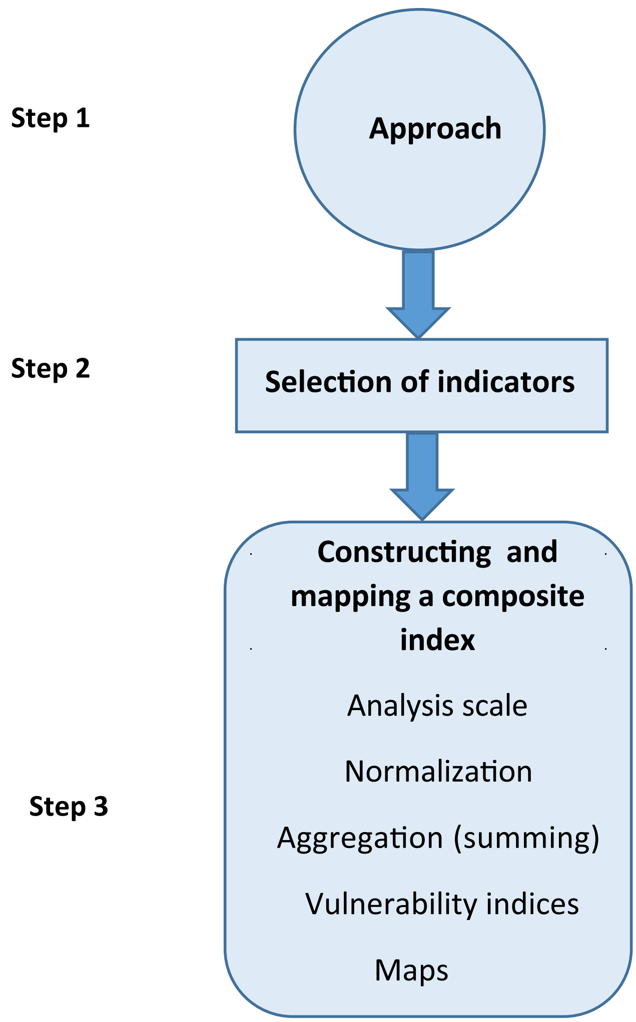


Fig. 2 Methodological framework

attribute (Birkmann 2006; Gallopín 2006). The initial step in their selection was to identify indicators relevant to the current study and categorise these for their representativeness of the dimensions of vulnerability. The term vulnerability has been used in the literature in a variety of ways (Cordell and Neset 2014; Füssel and Klein 2006) and is generally defined as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes' (McCarthy et al. 2001 pg. 995). Vulnerability is commonly conceptualised as three components, i.e. exposure, sensitivity and adaptive capacity (IPCC 1996; McCarthy et al. 2001), and this conceptualisation was adopted in this study. Exposure is considered as an entry point to the concept of vulnerability (Smit and Wandel 2006). Exposure is defined as 'the nature and degree to which a system is exposed to significant climatic variations' (McCarthy et al. 2001 pg. 987). Like exposure, sensitivity is also directly associated with vulnerability. Sensitivity is defined as 'the propensity for exposure to result in harm' (Jacobs et al. 2014). Selected exposure and sensitivity indicators for this study with the justification for their use are shown in Table 1.

Contrary to exposure and sensitivity, adaptive capacity is inversely associated with vulnerability. Adaptive capacity in the context of climate change is defined as 'the ability of a system to adjust to climate change including climate variability and extremes to moderate potential damage, to take advantage of opportunities or to cope with the consequences' (McCarthy et al. 2001 pg. 982). The development of an index of adaptive capacity drew on the theory and practice of the rural livelihoods analysis (Bebbington 1999). The rural livelihoods framework as conceived by Ellis (2000) conceptualises adaptive capacity as comprising different forms of natural, social, financial, physical and human capitals (e.g. Nelson et al. 2005). These capitals have potential significance in shaping respective adaptive capacity and livelihood outcomes due to the flexibility of substitution and inter-conversion between them at times of stress, including extreme weather events such as floods and droughts (Ellis 2000). Rural livelihoods analysis has been used for assessing adaptive capacity in both developed and developing countries (Ellis and Freeman 2005; Nelson et al. 2010) and it can be applied by using indicators and indices (Jacobs et al. 2015). The rural livelihoods analysis can be carried out at a range of scales and is particularly useful as a guide to policies in rural areas (Ellis 2000). With the view of applications in developing countries, and scale, flexibility and alignment with the indicator approach adopted for this research, a livelihoods approach was considered suitable for assessing adaptive capacity as part of vulnerability assessment in Punjab province. The selected adaptive capacity indicators with justification for their use are shown in Table 1.

Step 3: Constructing and mapping a composite index

Identification of *analysis scale* is considered one of the early steps of index construction (Tate 2012). Sub-national level (i.e. district administrative boundaries of Punjab province) was taken as the *analysis scale* for index construction. This scale was chosen because of the availability of more reliable secondary data and to allow a comparison of the relative vulnerability of districts.

The *functional relationship* of each potential indicator with vulnerability was established from the literature since vulnerability can be increased or decreased with a change in an indicator (Table 1). Indices for each of the dimensions of

Table 1 Exposure, sensitivity, adaptive capacity indicators

Dimensions	Variables	Indicators* (units)	Functional relationship to vulnerability	Data sources	Justification (references)
Exposure	Annual temperature	Coefficient of variation COV-temperature (mean, range, standard deviation) (degree Celsius)	Direct	Pakistan Meteorological Department (PMD) Government of Pakistan	Temperature and rainfall variability each has a direct functional association with agricultural vulnerability (Gbetibouo & Ringler 2009; Ravindranath et al. 2011)
	Annual rainfall	Coefficient of variation COV-rainfall (mean, range, standard deviation) (millimetre)	Direct		
	Floods	Houses damaged by flood 2010 megaflood (number)	Direct	National Disaster Management Authority (NDMA), Government of Pakistan	The floods adversely affected vast areas of the country including the fertile agricultural lands of Punjab province with direct and indirect economic losses (Federal Floods Commission 2018), selected as a proxy for the area's agricultural exposure to floods
Sensitivity	Irrigated land	Irrigated to the non-irrigated area (percent)	Inverse	Punjab Development Statistics, Bureau of Statistics (BOS) Punjab, Government of Punjab	Irrigated land has a positive association with enhanced agriculture production, and in turn, higher agricultural productivity has positive effects on the livelihoods of agricultural communities (O'Brien et al. 2004; Ravindranath et al. 2011)
	Population in administrative jurisdiction	Population density per district (persons per square kilometres)	Direct		Higher population density require greater humanitarian assistance due to more people facing extreme climatic events (Gbetibouo & Ringler 2009)
	Cultivated land	Sown area share in total area (percent)	Direct		Greater area under cultivation is the likelihood to be more sensitive to climatic variations (Chakraborty & Joshi 2016; Ravindranath et al. 2011)
	Farm size	Share of small farm holdings in total holdings (percent)	Inverse		Small farms are less likely to adopt agriculture technologies due to larger associated costs (Daberkow & McBride 2003; Tey & Brindal 2012)
	Crop diversification	Area sown more than once annually (hectares)	Inverse		Higher crop diversification is likely to improve the resilience of agriculture systems in several ways, e.g. create greater ability to suppress pest occurrences, reduce pathogen transmission (Lin 2011; Gbetibouo & Ringler 2009)
Sensitivity	Agroforestry potential	Total forest area (hectares)	Inverse	Punjab Development Statistics, Bureau of Statistics (BOS) Punjab, Government of Punjab	Agroforestry potential improves farm productivity by reducing soil erosion and improving soil fertility (Thorlakson & Neufeldt 2012; Verchot et al. 2007)
Adaptive capacity (human capital)	Literacy level	Adult literacy rate (percent)	Inverse		Educated farmers can better understand and participate in technological and administrative processes than farmers with little or no formal education (Adejuwon 2008; Deressa et al. 2009)
	Health attainment	Hospitals, rural health centres, basic health units and dispensaries (number)	Inverse		Increases in health care expenditure are associated with large improvements in health outcomes including decreased infant mortality rates (Nixon & Ulmann 2006; Berry et al. 2011)
Adaptive capacity (financial capital)	Livelihoods diversification	Registered factories (number)	Inverse		Non-farm income increases the likelihood of adaptation options (Deressa et al. 2009)
	Access to credit	Financial institutions (number)	Inverse		Adoption of agricultural technologies requires sufficient financial well-being (Knowler & Bradshaw 2007; Deressa et al. 2009)
	Livestock ownership	Work animals (number)	Inverse		Livestock ownership is positively correlated with the number of adaptation options (Yirga & Hassan 2010; Deressa et al. 2009)
Adaptive capacity (social capital)	Access to cooperative societies	Membership of cooperative societies (number)	Inverse		Cooperative social networks promote information exchange and cooperation that help communities adapt to climatic changes (Gbetibouo & Ringler 2009; Cinner et al. 2018)
	Means of social support	Share capital (rupees in million)	Inverse		Sharing capital as social collaboration initiatives are dimensions of social capital (Bijman et al. 2011)
	Local committees access	Local zakat committees (number)	Inverse		Committees as social networks have the potential to facilitate bridging social capital and also act as conduits for financial transfers that may ease the farmer's credit constraints (Woolcock & Narayan 2000; Cinner et al. 2018; Gbetibouo & Ringler 2009)

Table 1 (continued)

Dimensions	Variables	Indicators* (units)	Functional relationship to vulnerability	Data sources	Justification (references)
Adaptive capacity (natural capital)	Groundwater availability for agriculture	Tube wells (number)	Inverse	Punjab Development Statistics, Bureau of Statistics (BOS) Punjab, Government of Punjab	Areas with more groundwater available for agriculture are likely to be more adaptable to adverse climatic conditions (O'Brien et al. 2004; Ravindranath et al. 2011)
	Land productivity	Fertiliser consumption (tons)	Inverse		Farmers are more likely to adopt any technologies, such as the use of fertilisers, that will help them maintain or improve their productivity (Gbetibouo & Ringler 2009; Ravindranath et al. 2011)
Adaptive capacity (physical capital)	Access to the power supply	Power generation stations (number)	Inverse		Access to electricity supply enables the usage of water pumps required for irrigation and reduces manual labour (Kirubi et al. 2009; Shukla et al. 2016)
	Agricultural machinery ownership	Tractors and threshers used for agriculture (number)	Inverse		There has been strong advocacy for agricultural machinery for farmers to enhance land productivity and resource base (Kienzle et al. 2013; Mottaleb et al. 2016)
	Access to transport networks	length of metalled road (kilometres)	inverse		Accessibility to roads and markets is critical for remunerative agriculture development, access to agriculture inputs and increases the opportunities for non-farm livelihood activities (Sietz et al. 2011; Shukla et al. 2016)

*Indicators per district

vulnerability (i.e. exposure, sensitivity and adaptive capacity) were constructed separately for the districts of Punjab province using the Composite Index Method (Vincent 2004). Composite Index Method has been used to calculate social vulnerability (Vincent 2004) and applied to assessments of agricultural vulnerability, e.g. South African Farming Sector Vulnerability (Gbetibouo and Ringler 2009) and agricultural drought vulnerability in the Andhra Pradesh state of India (Murthy et al. 2015). Separate indices of exposure and sensitivity were firstly calculated and combined to represent potential impact (PI). Then, the overall vulnerability index was constructed as the difference between potential impact (PI) and adaptive capacity (AC) and is represented mathematically as:

$$Vulnerability(V) = f(PI - AC)$$

where, *Potential Impact (PI) = exposure + sensitivity*.

Since indicators were measured in a variety of units, *normalisation* of exposure, sensitivity and adaptive capacity variables was performed to obtain standardisation to a relative, dimensionless measurement scale (Tate 2012; UNDP 2013) using min–max linear scaling methodology commonly employed in deductive structural designs (Tate 2012).

Weighting may be assigned to selected indicators to reflect their relative importance (Murthy et al. 2015). The literature includes published studies of composite index construction where weightings have been assigned (e.g. Ravindranath et al. 2011) and others wherein indicating variables were of equal importance, and weightings were not assigned (e.g. O'Brien et al. 2004). In general, the most common approach is the use of equal weights (Tate 2012) and this method was applied here.

Following normalisation and equal weighting, indicators were aggregated for the development of respective component indices. Additive aggregation (summing) of normalised indicators is nearly universally used (Tate 2012) and was applied here. All normalised indicators of exposure, sensitivity and adaptive capacity were aggregated to form the overall index of vulnerability. Finally, separate maps of exposure, sensitivity, adaptive capacity and overall vulnerability were developed for Punjab province.

Results

The exposure, sensitivity, adaptive capacity and vulnerability indices were classified into five categories of vulnerability, i.e. very high (0.80–1.00), high (0.60–0.79), moderate (0.40–0.59), low (0.20–0.39) and very low (0.00–0.19) categories and mapped by districts within Punjab province. The normalisation of aggregate scores brought values within a common range (of 0–1). Accordingly, the districts of Punjab province were ranked into respective vulnerability classifications.

Exposure index

Index values were visualised as a map of exposure for the Punjab province (Fig. 3).

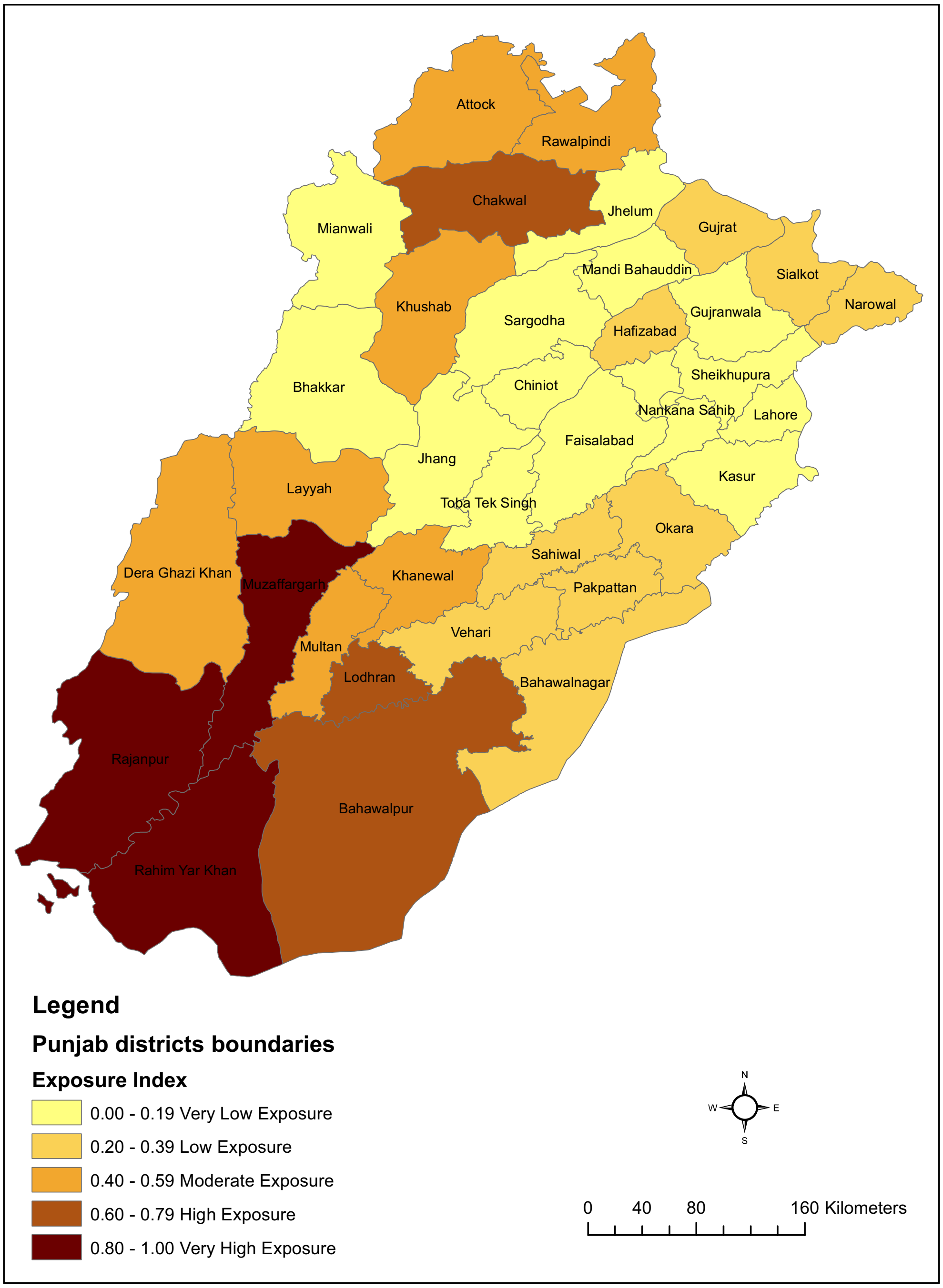


Fig. 3 Map of exposure to impacts of climate events for districts of Punjab province

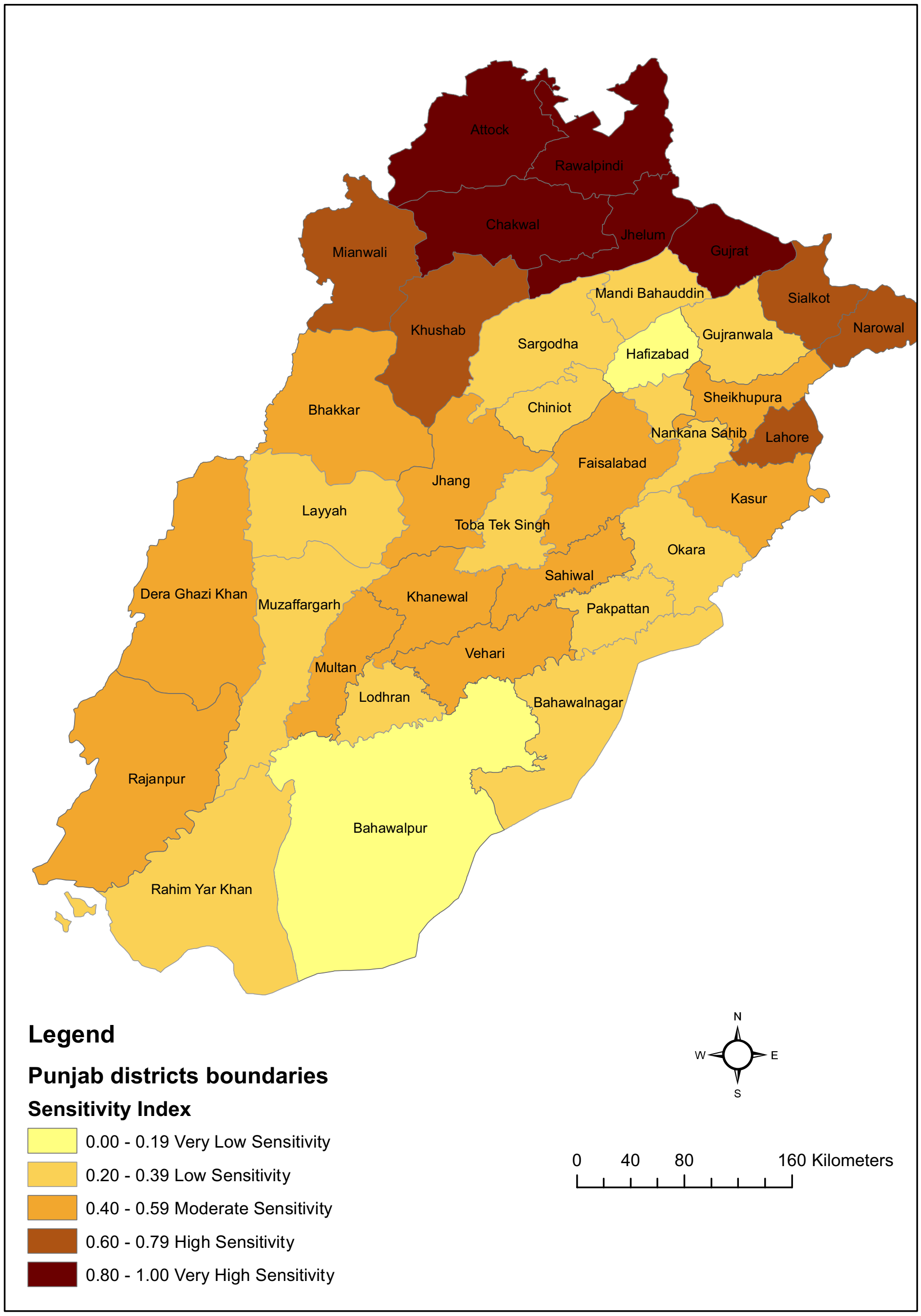
The exposure mapping separated districts of Punjab into very high to least exposed categories. The exposure map indicates that only three southern Punjab districts, which also share their district administrative boundaries (Rajanpur, Rahim Yar Khan and Muzaffargarh) were classified into the very high exposure category. In contrast, generally most of the central and eastern Punjab districts were categorised into low and least exposure categories.

Sensitivity index

Figure 4 shows the spatial pattern of the sensitivity index in Punjab province.

In contrast to exposure, a group of most sensitive districts (Chakwal, Attock, Jhelum, Rawalpindi, Gujrat) emerged in the north of Punjab. Three low-exposure eastern districts also showed high sensitivity. The central

Fig. 4 Map of sensitivity to impacts of climate events for districts of Punjab province



Punjab districts categorised as least exposed showed moderate to low sensitivity. In general, 11 districts were classified as moderately sensitive.

Adaptive capacity index

The map of the adaptive capacity index is illustrated in Fig. 5.

Two high exposure category districts, one in the south (Rajanpur) and one in the north (Chakwal), were classified into the very low adaptive capacity category. Likewise, the three most sensitive category districts in the north (Jhelum, Attock, Chakwal) were also classified under the very low adaptive capacity category, and this is likely to contribute significantly to their vulnerability. However, two very low exposure category districts in the east (Lahore, Faisalabad) were also classified into the very high adaptive capacity category, which will tend to mediate their overall vulnerability. Seven districts (Bahawalpur, Bahawalnagar, Okara, Jhang, Sargodha, Sialkot, Rawalpindi) showed moderate adaptive

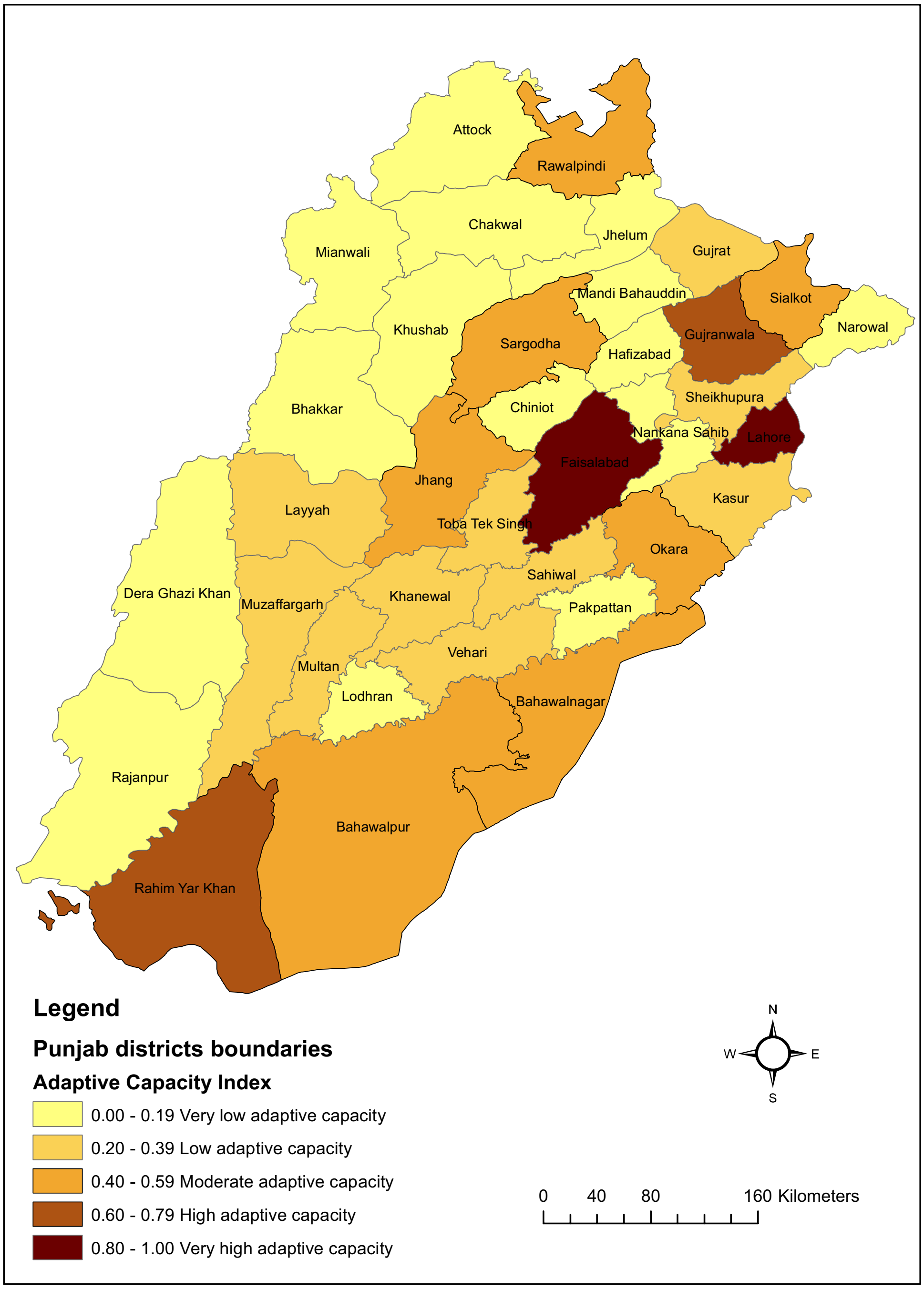


Fig. 5 Adaptive capacity map for the districts of Punjab province

capacity. In general, 10 districts were classified into a low adaptive capacity category and 15 were classified as having very low adaptive capacity.

Correlations among adaptive capacity indicators

To test the association between indicators of adaptive capacity and the developed adaptive capacity index, correlation analysis was performed. The correlations between each of the component indicators and the adaptive capacity index are shown in Table 2.

The analysis indicated that all correlations were significant at ($p < 0.05$). However, some correlations were stronger than others. For example, health attainment (human capital) and local committees (social capital) were most closely correlated with the adaptive capacity index. Other strong correlations included credit access, livelihoods diversification and power access. Literacy level

Table 2 Correlations between indicators of adaptive capacity and the aggregate index

Capital	Indicator	Correlation coefficient	Significance level (*P*)
Financial	Credit access	.745**	.000
	Livestock ownership	.370*	.026
	Livelihood diversification	.797**	.000
Human	Health attainment	.924**	.000
	Literacy level	.299*	.038
Physical	Power access	.772**	.000
	Agricultural machinery	.549**	.001
	Transport access	.590**	.000
Natural	Land productivity	.448**	.006
	Ground water	.384*	.021
Social	Local committees	.910**	.000
	Means of social support	.600**	.000
	Access to cooperative societies	.806**	.000

**Statistical significance at a 0.01 level

*Statistical significance at a 0.05 level

showed the weakest correlation with the index, although it was statistically significant ($p = 0.038$).

To test for the possibility of multicollinearity issues among the variables, collinearity tests were performed in SPSS to indicate variance inflation factor (VIF) and tolerance values.[1] VIF values of variables were found to be between 1 and 10 while tolerance values were greater than 0.1. These statistics suggest no potential issues with multicollinearity in the correlation analysis results.

Vulnerability index

Figure 6 shows the spatial pattern of vulnerability classes in the study region of Punjab.

The vulnerability map indicates that only five districts (Rajanpur, Muzaffargarh, Chakwal, Attock, Khushab) were classified under the very high vulnerability category. Among these most vulnerable districts, two districts (Rajanpur, Muzaffargarh) are situated in the south and share district boundaries. In contrast, three other most vulnerable districts (Chakwal, Attock, Khushab) are located on the north side of the province and share their district administrative boundaries. Six high vulnerability category districts include four northern districts (Rawalpindi, Gujrat, Mianwali, Jhelum) and two southern districts (Dear Ghazi Khan, Lodhran). In general, of the 14 low to very low vulnerability category districts, 10 were low vulnerability districts (eight are in central-east Punjab and two are in southern Punjab), with the remaining four very low vulnerability category districts (Lahore, Faisalabad, Sargodha, Gujranwala) located in east Punjab.

Discussion

Given the agricultural significance of Punjab province, the critical importance of the major crops sector to agriculture and the sensitivity of agriculture to climate, this study assessed Punjab province's agricultural vulnerability to climate change. The key findings arising from this study are:

1. Mapping presented the variation in the pattern of vulnerability and its components, i.e. exposure, sensitivity and adaptive capacity across districts of Punjab.
2. Among the components of adaptive capacity, some aspects of human, social and financial capital were more closely correlated with the capacity for adaptation (e.g. health, local committees and credit) than others (e.g. groundwater access and livestock ownership).
3. Finally, differences in vulnerability illustrate the need for a nuanced policy on adaptation that recognises the importance of local biophysical and socio-economic context. This finding also supports calls for improved linkage between top-down national policy initiatives (such as the National Adaptation Policy) and bottom-up community engagement to support agriculture in Punjab (e.g. Holler et al. 2020).

Variation in Punjab vulnerability

The work of index development differentiated regions in Punjab according to their respective vulnerability to climate change (Fig. 6). Most of the southern and northern Punjab districts were in higher exposure and or sensitivity categories and low adaptive capacity categories. In contrast, most of the eastern and central Punjab districts combined low exposure and or sensitivity with higher levels of adaptive capacity. The study results are relative to the data included in this vulnerability assessment and vulnerability classifications could differ considerably if compared to other regions of Pakistan. Several other studies have developed maps presenting the spatial variations in climate vulnerability focused on other geographical locations, e.g. Australia (Nelson et al. 2010); India (Chakraborty and Joshi 2016; O'Brien et al. 2004) and South Africa (Gbetibouo and Ringler 2009). Considering the breadth of vulnerability research, examples from global vulnerability assessments to climate change in the literature support the aim of this

[1] Although there is no single agreed cutoff value for VIF and tolerance to suggest multicollinearity, however, multicollinearity could be suspected with VIF value > 10 and tolerance value < 0.1 (Pallant 2013).

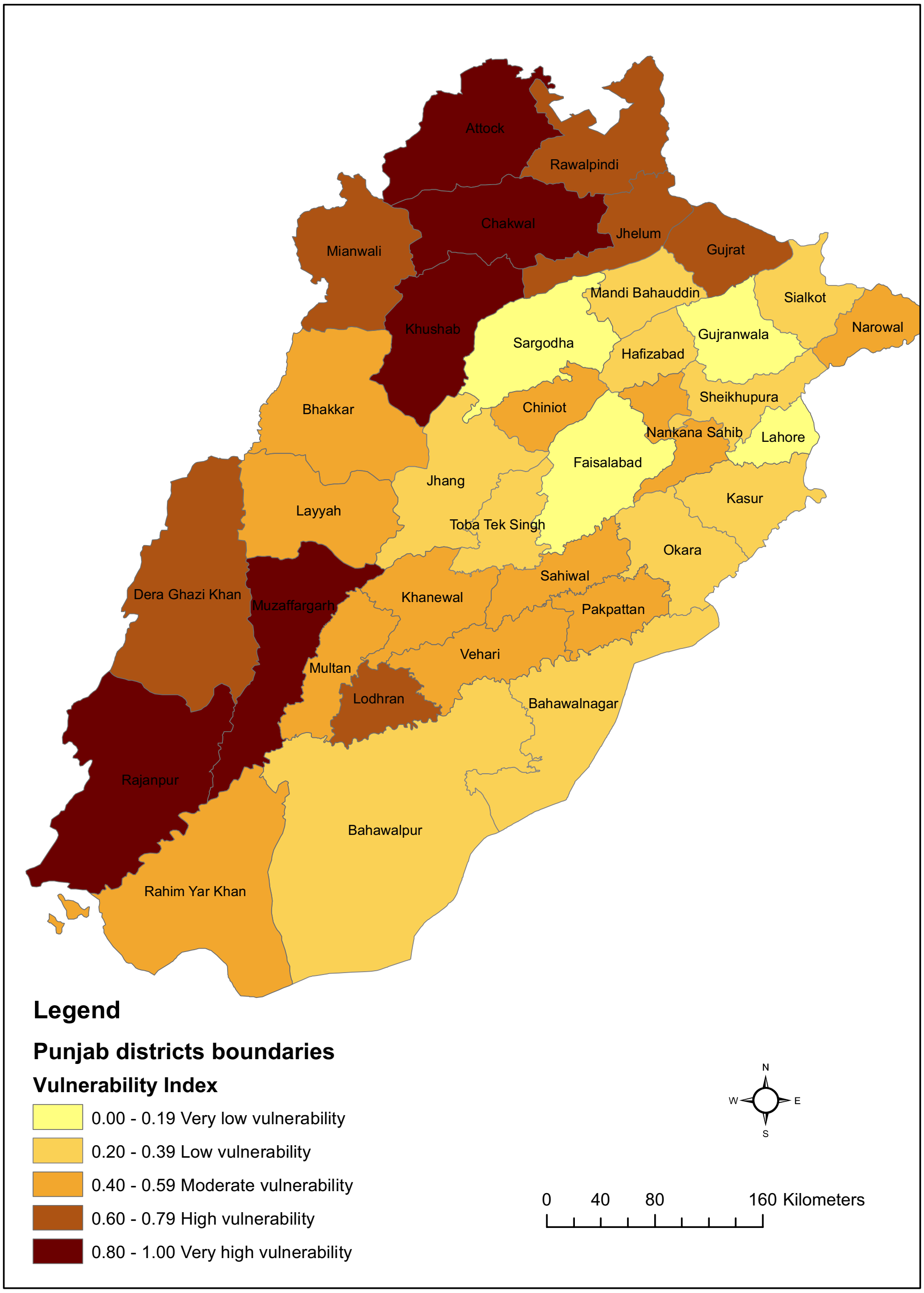


Fig. 6 Map of vulnerability for the districts in Punjab province

study to guide local action on adaptation. For instance, Gbetibouo and Ringler (2009) noted that large differences in the extent of vulnerability between areas suggest the need to develop region-specific policies. Likewise, Nelson et al. (2010) suggested that to better support adaptation, impact modelling needs to be broadened through the inclusion of options for building adaptive capacity in rural communities. In addition, Chakraborty and Joshi (2016) suggested that vulnerability assessments can assist in identifying and enhancing the actions required for adaptation strategies for the most vulnerable communities in resource-constrained countries. Such techniques can act as a useful starting point in understanding the dimensions of vulnerability (Malone and Engle 2011) to identify, for example geographical areas where potential adaptation options can be further examined (Malone and Engle 2011; Sherbinin et al. 2017). O'Brien et al. (2004) and Gbetibouo and Ringler (2009) further suggest that it can serve as a basis for targeting policy intervention.

The key features that contributed to the high vulnerability of southern Punjab districts differed substantially from those in northern Punjab. There are several explanations for the spatial variation in vulnerability. Highly vulnerable districts of southern Punjab share many aspects in common among exposure factors, i.e. frequent large floods, observations of elevated average temperatures and frequent drought conditions. Coupled with high levels of exposure, the southern Punjab districts have a very low potential for adaptive capacity due to very low levels of aspects of human, social, physical and financial capitals.

On the other hand, the vulnerable districts of northern Punjab are not prone to flooding, instead, these are *barani* areas where rainfall is the main source of water for agriculture. For these districts, rainfall variability, experienced in its extreme form as prolonged drought, acts as the key climate risk (Qaiser et al. 2021). In addition, northern Punjab districts have a very high proportion of small farms and less crop diversification, making these districts relatively more sensitive to climate change. Furthermore, the high exposure and high sensitivity of these northern Punjab districts are associated with very low adaptive capacity due to several factors related to low levels of human and social capitals and limited opportunities for livelihoods diversification (e.g. Antwi-Agyei et al. 2014).

In contrast, vulnerability maps for eastern and central Punjab districts indicate relatively very low vulnerability to climate change. Most of these districts are not flood prone and also show low sensitivity to climate change due to the extensive availability of irrigation (e.g. Zaveri and Lobell 2019). These factors are moderated to some extent because of the presence of a few large urban centres (the major cities of Lahore, Faisalabad and Rawalpindi) which skew the index towards moderate to high sensitivity, due to very high population density. In addition to low exposure and low sensitivity, most of these eastern and central Punjab districts show moderate to high adaptive capacity, which leads to their relatively low vulnerability to climate change, most likely also due to the presence of large urban centres (Juhola et al. 2012).

The strength of statistical associations between adaptive capacity and its component indicators varied as shown by correlation analysis (Table 2). Three factors were most strongly correlated with adaptive capacity, i.e. health (human capital), local committees (social capital) and access to credit (financial capital). These statistically significant correlations are consistent with a few studies from other locations. For instance, Berry et al. (2011) found health as an essential component and contributor to adaptive capacity to climate change and suggested that pre-existing health problems are an important factor to consider when designing adaptation programs and policies. A positive association between access to credit and climate change adaptation strategies has been found in many other previous studies. For instance, Deressa et al. (2009) and Fosu-Mensah et al. (2012) found that access to credit has a positive and significant impact on a farmer's likelihood of using many adaptation strategies in the Nile Basin of Africa and Ghana. Likewise, Gbetibouo (2009) noted that lack of access to credit was cited by farming respondents as the main factor inhibiting adaptation to climate change in South Africa.

Aspects of social capital, particularly bridging social capital (Woolcock and Narayan 2000), were strongly associated with adaptive capacity. Bridging social capital brings together people from diverse social backgrounds through networks and connections to attain common goals (Bhandari and Yasunobu 2009). Local zakat committees, used as a proxy for the existence of social networks, were closely correlated with adaptive capacity for Punjab province. The *zakat funds* (transfer payments managed by the government through local zakat committees) are an instrument to bring social welfare to local communities in Pakistan. Through this scheme, needy and marginalised segments of society are provided with *zakat funds* directly via local committees. Many studies found a positive impact of *zakat funds* through local zakat committees in Pakistan. Azam et al. (2014) found that zakat has a positive impact on the economic development of Pakistan and enhances the welfare of households particularly at the micro-level. In addition, Akram and Afzal (2014) found that there is an inverse relationship between poverty and zakat disbursement as a *social safety net* in Pakistan. It is not surprising then, that this indicator appeared to have particular significance, as it is linked not only to social capital but also to the financial capital of communities.

Perhaps surprisingly, literacy level showed the weakest correlation with adaptive capacity (although still statistically significant). In previous studies, the level of education has been shown to play an important role in reducing vulnerability to climate change by increasing an individual's access to information (Donohue and Biggs 2015). However, a possible explanation for the finding in the case of Punjab province is that most of the farmers are generally either illiterate or have no formal school education. Therefore, the low level of education is not as useful to assess relative differences in a district's capacity to adapt as other indicators of human capital. This finding is supported by Fosu-Mensah et al. (2012) who found similar results for a study in Ghana wherein most farmers also had no formal education.

Although there is extensive interest and the demand to quantitatively model vulnerability, there is far less consensus about the ideal set of methods used for the construction of indices (Tate 2012). For example, Reckien (2018) found differences in indices of social vulnerability to climate change depending on the selection methods of index construction (variable addition versus variable reduction) and on the metrics as input data (area based versus population based).

Reckien (2018) further noted that the reductionist approach appears to lack application potential due to difficulty of interpretation and relation to real-world decision-making, while the additive approach does not distort influences of single factors in the overall index, and seems easier to communicate to stakeholders which increases the application potential. In addition, the weighting and aggregation can be determined in several ways including statistical methods (Wiréhn et al. 2017). This paper attempts to include justification for the methodological steps adopted for the study. Comprehensive comparative analysis of different methods for the indicator-based vulnerability assessments is beyond the scope of this paper. However, recent literature indicates that interactive tools such as geovisualisation environment can be useful in vulnerability assessments enabling the underlying indicators and factors determining vulnerability through personalised assessments (Wiréhn et al. 2017). Geovisualisation tools for vulnerability, e.g. ViewExposed (Opach and Rod 2013) and EXTRA interactive tool (Opach et al. 2020) particularly agricultural vulnerability focused tools, is uncommon, e.g. AgroExplore (Wiréhn et al. 2017). Geovisualisation tools facilitate knowledge acquisition and knowledge construction and can be used for communication to facilitate learning about the complexity of vulnerability (Opach and Rød 2013; Wiréhn et al. 2017). Although, even with a comprehensive understanding of the processes and conditions involved, these are limited in their ability to represent dynamic processes such as vulnerability (Vincent 2004). We recognise that the index constructed in this study, based on an additive model with non-weighted variables, will likely have influenced the assessment of vulnerability (Reckien 2018). However, within the limitations imposed by data availability and quality in a developing world context, and when complemented with district scale qualitative assessments, the complex reality of vulnerability can be conveyed to policymakers.

Variations in the vulnerability of Punjab province indicate the key importance of adaptive capacity in shaping vulnerability to climate change. Support for the significance of adaptive capacity for vulnerability mitigation through adaptation is highlighted in several studies. For instance, Pelling (2010) reports that an increase in adaptive capacity has the relative potential to reduce vulnerability, which has placed the enhancement of adaptive capacity at the centre of adaptation research. Adaptive capacity is conceived as the preconditions to enable adaptation and therefore a precursor of it (Nelson et al. 2007). Adaptive capacity can be assessed through top-down national data and through bottom-up locally acquired data (Brown et al. 2010). However, both approaches have benefits and shortcomings. For instance, assessing adaptive capacity using secondary data sources can be time-consuming and may be useful for broad-scale national comparisons but may overlook regional differences and local drivers of adaptive capacity (Brown et al. 2010; Smit and Wandel 2006). In contrast, bottom-up approaches can be easy to operationalise and provide much insight into relevant communities but may lack policy application as specific case studies cannot be readily generalised to other locations (Brown et al. 2010). The findings of this study are useful beginning steps and facilitate comparative analysis across regions, but they are simply pointers to the need for deeper community-level engagement to better understand the factors that constrain or enable local adaptation and support place-based action.

Implications for adaptation policy

The demand for vulnerability maps among development agencies and governments in policy contexts is growing (Preston et al. 2011; Sherbinin et al. 2017). Climate change policy documents in Pakistan also indicated the need to focus on building capacity to develop maps to identify vulnerable and sensitive areas. However, Preston et al. (2011) noted that mapping in isolation of other dimensions of knowledge (e.g. local tacit knowledge of climate impacts) may lead to over-confidence in a decision-making process under the view that once maps are available, ample information is on hand for effective decision-making. In general, and within a developing country context, there is usually a tendency in government departments to see the maps as the end of knowledge gathering. However, by reframing mapping as the start of knowledge gathering, vulnerability maps can be used for a variety of benefits. For example, maps support adaptation planning (Sherbinin et al. 2017), help spatial planning and can potentially assist with risk or disaster management (Preston et al. 2011). Furthermore, they can act as an instrument of knowledge management (Sherbinin et al. 2017), help identify cross-dependency of services to co-located infrastructure (Inanloo et al. 2016) and aid in the identification of vulnerable areas for prioritisation of action (Preston et al. 2011). Therefore, policy actors can utilise vulnerability maps as a starting point for focusing more detailed sector-based local assessments and that encompass bottom-up information to inform adaptation policy development that accounts for the needs of local communities, ensuring that policy incorporates representational, procedural and distributive justice (Thomas and Twyman 2005; Paavola and Adger 2006; Popke et al. 2016). For this research, vulnerability maps were utilised for the identification of potentially vulnerable areas in Punjab with the aim of using these to target key districts for bottom-up qualitative engagement to better understand how vulnerability assessment can support local adaptation to climate change.

The policy on adaptation in Pakistan reflects the current concentration on broad-scale top-down action embedded in National Adaptation Plans. For instance, The National

Climate Change Policy (NCCP 2012) was developed to direct Pakistan towards resilient climate development. The document provides broad policy measures for both climate change mitigation and adaptation for key sectors including agriculture, health, energy and industries. This national-scale policy document within the adaptation domain indicates general policy measures for the agriculture and livestock sector under sub-areas of technology, research and risk management. Likewise, 'Vision 2030' prepared by the Planning Commission of Pakistan is also a broad national planning document for the country that emphasises the imperative to prepare to adapt to the coming climate changes and mitigate their negative impacts (PC 2007). On a provincial scale, The Government of Punjab developed a draft Punjab Climate Change Policy (PCCP) which also briefly indicates general mitigation and adaptation policy measures for sectors of Punjab similar to the NCCP (PEPD 2021). However, these high-level policy documents do not provide specific climate change adaptation plans for sensitive or exposed areas of Punjab. As vulnerability, its components and contributing factors vary spatially, one single policy for the whole Punjab is unlikely to address the needs of all regions. This emphasises the vital importance of local biophysical and socio-economic context to formulate adaptation policy. There is often a tendency among national policymakers to emphasise exposure and sensitivity over adaptive capacity in assessing vulnerability and select adaptation strategies based on cost-effectiveness and synergies with existing development and environmental policies (Holler et al. 2020). However, bearing in mind the metaphor of the wounded soldier (O'Brien et al. 2007; Schipper and Burton 2009) (i.e. prior damage limits the capacity to respond to stress) underlying aspects of social vulnerability must be addressed (Ford et al. 2010; Mikulewicz 2018; Williamson et al. 2012).

The issues discussed above point to the need to mainstream adaptation into other policy silos as emphasised by several researchers. Huq and Reid (2004) suggest that successful adaptation to climate change requires the incorporation of potential climate impacts into ongoing strategies and plans. Likewise, Pouliotte et al. (2009) note that climate change adaptation should be integrated into current development priorities. Also, Wise et al. (2014) and Burnham and Ma (2016) suggest that meeting the objectives of human development and climate change adaptation can be accomplished only if they are undertaken in an integrated way. This evidence supports the need for mainstreaming adaptation into other policy processes involving the Punjab province. Therefore, while shaping the Punjab provincial development policies, priority needs to be given to building the adaptive capacity of the least developed and potentially vulnerable areas to climate change such as Southern and Northern Punjab vulnerable districts.

There is scope for local policy actors to have a greater influence on building adaptive capacities particularly in relation to social and human capital in Punjab's vulnerable regions. For instance, social capital can be enhanced through deliberate and relatively low-cost policy interventions (Shrestha et al. 2015) such as support for strengthening local social networks. These types of interventions can allow for knowledge exchange about local needs and facilitate cooperation on adaptation (Bhandari and Yasunobu 2009; Shrestha et al. 2015). Furthermore, social capital facilitates mobilising of community resources for collective action (Bhandari and Yasunobu 2009). Local policy interventions for vulnerable regions of Punjab could begin by targeting capacity-building activities to the key indicators of human and social capital identified in this analysis (Table 2).

Conclusion

This study presents the spatial variations of agricultural vulnerability to climate change at the district level for Punjab province. The relative differences indicate the significance of adaptive capacity in mediating respective vulnerabilities of Punjab districts. Findings suggest the need for policy to focus on building adaptive capacity for vulnerable regions of Punjab province and that a single adaptation policy that fails to account for variations in the causes of vulnerability at local to district scale is unlikely to be effective for the whole Punjab province. The use of a livelihoods approach and statistical associations that recognised the importance of human, financial and social capital as part of the enabling environment for adaptation revealed the factors that contour adaptive capacity and that may be influenced by effective government policies. A policy focus on socio-economic aspects that accounts for place-based biophysical features also points to the need to integrate climate change policies with other general economic and social development policies in Punjab with emphasis on local scale information to inform top-down policy initiatives.

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References

Abbas F (2013) Analysis of a historical (1981–2010) temperature record of the Punjab province of Pakistan. Earth Interact 17:1–23. https://doi.org/10.1175/2013EI000528.1

Abbas F, Ahmad A, Safeeq M, Ali S, Saleem F, Hammad HM, Farhad W (2014) Changes in precipitation extremes over arid to semiarid and subhumid Punjab, Pakistan. Theoret Appl Climatol 116:671–680. https://doi.org/10.1007/s00704-013-0988-8

Adejuwon JD (2013) Vulnerability in Nigeria: a national-level assessment. In: Climate Change and Vulnerability and Adaptation. Routledge, pp 214–233

Antwi-Agyei P, Stringer LC, Dougill AJ (2014) Livelihood adaptations to climate variability: insights from farming households in Ghana. Reg Environ Change 14:1615–1626. https://doi.org/10.1007/s10113-014-0597-9

Ashraf M, Routray JK (2015) Spatio-temporal characteristics of precipitation and drought in Balochistan Province, Pakistan. Nat Hazards 77:229–254. https://doi.org/10.1007/s11069-015-1593-1

Azam M, Iqbal N, Tayyab M (2014) Zakat and economic development: micro and macro level evidence from Pakistan. Bulletin of Business and Economics 3:85–95

Bakhsh K, Hassan I, Maqbool A (2005) Factors affecting cotton yield: a case study of Sargodha (Pakistan). J Agric Soc Sci 1:332–334

Barr R, Fankhauser .S, Hamilton K (2010) Adaptation investments: a resource allocation framework. Mitigation and Adaptation Strategies for Global Change 15:843-858. https://doi.org/10.1007/s11027-010-9242-1

Bebbington A (1999) Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Dev 27:2021–2044. https://doi.org/10.1016/S0305-750X(99)00104-7

Berry HL, Hogan A, Ng SP, Parkinson A (2011) Farmer health and adaptive capacity in the face of climate change and variability. Part 1: Health as a contributor to adaptive capacity and as an outcome from pressures coping with climate related adversities. Int J Environ Res Public Health 8:4039–4054. https://doi.org/10.3390/ijerph8104039

Bhandari H, Yasunobu K (2009) What is social capital? A comprehensive review of the concept. Asian J Soc Sci 37:480–510. https://doi.org/10.1163/156853109X436847

Bijman J, Muradian R, Cechin A (2012) Agricultural cooperatives and value chain coordination: Jos Bijman, Roldan Muradian and Andrei Cechin. In: Value Chains, Social Inclusion and Economic Development. Routledge, 98–117

Birkmann J (2006) Indicators and criteria for measuring vulnerability: theoretical bases and requirements Measuring vulnerability to natural hazards: towards disaster resilient societies:55–77

Brown PR, Nelson R, Jacobs B, Kokic P, Tracey J, Ahmed M, DeVoil P (2010) Enabling natural resource managers to self-assess their adaptive capacity. Agric Syst 103:562–568. https://doi.org/10.1016/j.agsy.2010.06.004

Burnham M, Ma Z (2016) Linking smallholder farmer climate change adaptation decisions to development. Climate Dev 8:289–311. https://doi.org/10.1080/17565529.2015.1067180

Chakraborty A, Joshi P (2016) Mapping disaster vulnerability in India using analytical hierarchy process. Geomat Nat Haz Risk 7:308–325. https://doi.org/10.1080/19475705.2014.897656

Cinner JE, Adger WN, Allison EH, Barnes ML, Brown K et al (2018) Building adaptive capacity to climate change in tropical coastal communities. Nat Clim Chang 8:117–123. https://doi.org/10.1038/s41558-017-0065-x

Cordell D, Neset T-S (2014) Phosphorus vulnerability: a qualitative framework for assessing the vulnerability of national and regional food systems to the multi-dimensional stressors of phosphorus scarcity. Glob Environ Chang 24:108–122. https://doi.org/10.1016/j.gloenvcha.2013.11.005

Daberkow SG, McBride WD (2003) Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. Precision Agric 4:163–177. https://doi.org/10.1023/A:1024557205871

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob Environ Chang 19:248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Donohue C, Biggs E (2015) Monitoring socio-environmental change for sustainable development: developing a multidimensional livelihoods index (MLI). Appl Geogr 62:391–403. https://doi.org/10.1016/j.apgeog.2015.05.006

Ellis F (2000) Rural livelihoods and diversity in developing countries. Oxford University Press

Ellis F, Freeman HA (2005) Comparative evidence from four African countries. In: Rural livelihoods and poverty reduction policies. Routledge, 31–47

Eriksen SH, Kelly PM (2007) Developing credible vulnerability indicators for climate adaptation policy assessment. Mitig Adapt Strat Glob Change 12:495–524. https://doi.org/10.1007/s11027-006-3460-6

FAO (2009) How to Feed the World in 2050: High-Level Expert Forum, Rome

Federal Floods Commission (2018) Annual Flood Report,Federal Floods Comission of Pakistan. http://www.ffc.gov.pk. Accessed 12 December 2019

Ford JD, Berrang-Ford L, King M, Furgal C (2010) Vulnerability of Aboriginal health systems in Canada to climate change. Glob Environ Chang 20:668–680. https://doi.org/10.1016/j.gloenvcha.2010.05.003

Fosu-Mensah BY, Vlek PL, MacCarthy DS (2012) Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. Environ Dev Sustain 14:495–505. https://doi.org/10.1007/s10668-012-9339-7

Füssel H-M, Klein RJ (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Clim Change 75:301–329. https://doi.org/10.1007/s10584-006-0329-3

Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Chang 16:293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Gbetibouo G, Ringler C (2009) How can African agriculture adapt to climate change: mapping the South African farming sector vulnerability to climate change and variability: a subnational assessment. International Food Policy Research Institute (IFPRI)

Gbetibouo GA (2009) Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa. IFPRI Discussion Paper 00849

GCISC (2005) Enhancement of National Capacities in the Application of Simulation Models for the Assessment of Climate Change and its Impacts on water resources, food and agricultural production. Global Change Impact Studies Center (GCISC),Pakistan

Ghazal L, Kazmi SJH, Afsar S (2013) Spatial appraisal of the impacts of drought on agricultural patterns in Karachi. Journal of Basic & Applied Sciences 9:352

Holler J, Bernier Q, Roberts JT, Robinson S-a (2020) Transformational adaptation in least developed countries: does expanded stakeholder participation make a difference? Sustainability 12:1–24. https://doi.org/10.3390/su12041657

Howden SM, Soussana J-F, Tubiello FN, Chhetri N, Dunlop M, Meinke H (2007) Adapting agriculture to climate change. Proc Natl Acad Sci 104:19691–19696. https://doi.org/10.1073/pnas.0701890104

Huq S, Reid H (2004) Mainstreaming adaptation in development. IDS Bull 35:15–21

Hussain SS, Mudasser M (2007) Prospects for wheat production under changing climate in mountain areas of Pakistan–an econometric analysis. Agric Syst 94:494–501. https://doi.org/10.1016/j.agsy.2006.12.001

Inanloo B, Tansel B, Shams K, Jin X, Gan A (2016) A decision aid GIS-based risk assessment and vulnerability analysis approach for transportation and pipeline networks. Saf Sci 84:57–66. https://doi.org/10.1016/j.ssci.2015.11.018

IPCC (1996): Climate Change 1995: The science of climate change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 572 pp.

IPCC (2007): Summary for policymakers. In: Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7–22.

IPCC (2014) Summary for policymakers. In: Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Iqbal M, Ahmad M, Mustafa G (2015) Climate change, vulnerability, food security and human health in rural Pakistan: a gender perspective. MPRA Paper No 72866

Jacobs B, Lee C, O'Toole D, Vines K (2014) Integrated regional vulnerability assessment of government services to climate change. Int J Clim Change Strateg Manag 6:272–295. https://doi.org/10.1108/IJCCSM-12-2012-0071

Jacobs B, Nelson R, Kuruppu N, Leith P (2015) An adaptive capacity guide book: assessing, building and evaluating the capacity of communities to adapt in a changing climate. Southern Slopes Climate Change Adaptation Research Partnership (SCARP)

Juhola S, Peltonen L, Niemi P (2012) The ability of Nordic countries to adapt to climate change: assessing adaptive capacity at the regional level. Local Environ 17:717–734. https://doi.org/10.1080/13549839.2012.665861

Kelly PM, Brooks N, Adger WN (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob Environ Chang 15:151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Khan FA, Salman A (2012) A simple human vulnerability index to climate change hazards for Pakistan. Int J Disaster Risk Sci 3:163–176. https://doi.org/10.1007/s13753-012-0017-z

Kienzle J, Ashburner JE, Sims B (2013) Mechanization for rural development: a review of patterns and progress from around the world. Integrated Crop Management, Rome

Kirubi C, Jacobson A, Kammen DM, Mills A (2009) Community-based electric micro-grids can contribute to rural development: evidence from Kenya. World Dev 37:1208–1221. https://doi.org/j.worlddev.2008.11.005

Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25–48. https://doi.org/10.1016/j.foodpol.2006.01.003

Li Y, Xiong W, Hu W, Berry P,Ju H et al (2015) Integrated assessment of China's agricultural vulnerability to climate change: a multi-indicator approach. Clim Change 128:355–366. https://doi.org/10.1007/s10584-014-1165-5

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 61:183–193. https://doi.org/10.1525/bio.2011.61.3.4

M Akram M, Afzal M (2014) Dynamic role of zakat in alleviating poverty: a case study of Pakistan. MPRA Paper No 56013

Maharjan KL, Joshi NP (2013) Climate change, agriculture and rural livelihoods in developing countries. Springer, Japan

Malik SM, Awan H, Khan N (2012) Mapping vulnerability to climate change and its repercussions on human health in Pakistan. Glob Health 8:31. https://doi.org/10.1186/1744-8603-8-31

Malone EL, Engle NL (2011) Evaluating regional vulnerability to climate change: purposes and methods. Wiley Interdisciplinary Reviews: Climate Change 2:462–474. https://doi.org/10.1002/wcc.116

Mazhar N, Nawaz M (2014) Precipitation data interpolation for meteorological drought mapping in Pakistan. Pak J Sci 66:356–361

McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (Eds.) (2001) Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 2). Cambridge University Press

Mikulewicz M (2018) Politicizing vulnerability and adaptation: on the need to democratize local responses to climate impacts in developing countries. Climate Dev 10:18–34. https://doi.org/10.1080/17565529.2017.1304887

Mottaleb KA, Krupnik TJ, Erenstein O (2016) Factors associated with small-scale agricultural machinery adoption in Bangladesh: census findings. J Rural Stud 46:155–168. https://doi.org/10.1016/j.jrurstud.2016.06.012

Murthy C, Laxman B, Sai MS (2015) Geospatial analysis of agricultural drought vulnerability using a composite index based on exposure, sensitivity and adaptive capacity. Int J Disaster Risk Reduct 12:163–171. https://doi.org/10.1016/j.ijdrr.2015.01.004

Naheed G, Rasul G (2010) Projections of crop water requirement in Pakistan under global warming. Pak J Meteorol 7:45–51

NCCP (2012) National climate change policy, Pakistan. http://www.mocc.gov.pk. Accessed 10 June 2018

Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: contributions of a resilience framework. Annu Rev Environ Resour 32:395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

Nelson R, Kokic P, Crimp S, Martin P, Meinke H et al (2010) The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. Environ Sci Policy 13:18–27. https://doi.org/10.1016/j.envsci.2009.09.007

Nelson R, Kokic P, Elliston L, King J-A (2005) Structural adjustment: a vulnerability index for Australian broadacre agriculture. Australian Commodities: Forecasts and Issues 12:171. https://doi.org/10.3316/informit.090810822935498

Nixon J, Ulmann P (2006) The relationship between health care expenditure and health outcomes. Eur J Health Econ 7:7–18. https://doi.org/10.1007/s10198-005-0336-8

Noorka IR, Shahid SA (2013) Use of conservation tillage system in semiarid region to ensure wheat food security in Pakistan. In: Developments in Soil Salinity Assessment and Reclamation. Springer, pp 769–782. https://doi.org/10.1007/978-94-007-5684-7_51

O'Brien K, Eriksen S, Nygaard LP, Schjolden A (2007) Why different interpretations of vulnerability matter in climate change discourses. Climate Policy 7:73–88. https://doi.org/10.1080/14693062.2007.9685639

O'Brien K, Leichenko R, Kelkar U, Venema H, Aandahl G et al (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob Environ Chang 14:303–313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

Opach T, Glaas E, Hjerpe M, Navarra C (2020) Vulnerability visualization to support adaptation to heat and floods: towards the EXTRA interactive tool in Norrköping. Sweden Sustainability 12:1179. https://doi.org/10.3390/su12031179
Opach T, Rød JK (2013) Cartographic visualization of vulnerability to natural hazards Cartographica: the International Journal for Geographic Information and Geovisualization 48:113-125. https://doi.org/10.3138/carto.48.2.1840
Paavola J, Adger WN (2006) Fair adaptation to climate change. Ecol Econ 56:594–609. https://doi.org/10.1016/j.ecolecon.2005.03.015
Pallant J (2013) SPSS survival manual, a step by step guide to data analysis using SPSS. McGraw-hill education UK
Patt AG, Klein RJ (2012) Assessing vulnerability to global environmental change: making research useful for adaptation, decision making and policy. Earthscan, London
PBS (2020) Pakistan Bureau of Statistics, Government of Pakistan. http://www.pbs.gov.pk. Accessed 28 September 2020
PC (2007) Vision 2030. Planning Commission, Government of Pakistan
Pelling M (2010) Adaptation to climate change: from resilience to transformation. Routledge, London
Penas A, Iqbal MA, Cano-Ortiz A, Kersebaum K, Herrero L, Del Río S (2016) Analysis of recent changes in maximum and minimum temperatures in Pakistan. Atmos Res 168:234–249. https://doi.org/10.1016/j.atmosres.2015.09.016
PEPD (2021) Punjab Climate Change Policy (draft), Environment Protection Department, Government of Punjab. https://epd.punjab.gov.pk
PMD (2021) Pakistan Meteorological Department, Government of Pakistan. http://www.pmd.gov.pk/ndmc/index_files/Page3406.htm. Accessed 15 August 2021
Popke J, Curtis S, Gamble DW (2016) A social justice framing of climate change discourse and policy: adaptation, resilience and vulnerability in a Jamaican agricultural landscape. Geoforum 73:70–80. https://doi.org/10.1016/j.gloenvcha.2004.10.001
Pouliotte J, Smit B, Westerhoff L (2009) Adaptation and development: livelihoods and climate change in Subarnabad, Bangladesh. Climate Dev 1:31–46. https://doi.org/10.3763/cdev.2009.0001
Preston BL, Yuen EJ, Westaway RM (2011) Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. Sustain Sci 6:177–202. https://doi.org/10.1007/s11625-011-0129-1
Qaiser G, Tariq S, Adnan S, Latif M (2021) Evaluation of a composite drought index to identify seasonal drought and its associated atmospheric dynamics in Northern Punjab. Pakistan Journal of Arid Environments 185:104332. https://doi.org/10.1016/j.jaridenv.2020.104332
Qureshi AS (2011) Water management in the Indus basin in Pakistan: challenges and opportunities. Mt Res Dev 31:252–260. https://doi.org/10.1659/MRD-JOURNAL-D-11-00019.1
Rafiq L, Blaschke T (2012) Disaster risk and vulnerability in Pakistan at a district level. Geomat Nat Haz Risk 3:324–341. https://doi.org/10.1080/19475705.2011.626083
Rahman A, Salman A (2013) A district level climate change vulnerability index of Pakistan. Centre for Environmental Economics and Climate Change (CEECC) Working Paper 5
Ravindranath NH, Rao S, Sharma N, Nair M, Gopalakrishnan R et al (2011) Climate change vulnerability profiles for North East India. Curr Sci 101:384–394
Rehman A (2016) Agricultural and economic development in Pakistan and its comparison with China, India, Japan, Russia and Bangladesh. Andamios Revista De Investigación Social 12:180–188
Reckien D (2018) What is in an index? Construction method, data metric, and weighting scheme determine the outcome of composite social vulnerability indices in New York City Regional environmental change 18:1439-1451 https://doi.org/10.1007/s10113-017-1273-7
Rehman A, Jingdong L, Shahzad B, Chandio AA, Hussain I, Nabi G, Iqbal MS (2015) Economic perspectives of major field crops of Pakistan: an empirical study. Pacific Science Review b: Humanities and Social Sciences 1:145–158. https://doi.org/10.1016/j.psrb.2016.09.002
Salik KM, Jahangir S, ul Hasson S (2015) Climate change vulnerability and adaptation options for the coastal communities of Pakistan. Ocean & Coastal Management 112:61–73. https://doi.org/10.1016/j.ocecoaman.2015.05.006
Scheffran J (2015) Climate change as a risk multiplier in a world of complex crises. Paper presented at the Planetary Security Conference, The Hague, Netherlands, November 2015
Schipper ELF, Burton I (2009) The Earthscan reader on adaptation to climate change. Earthscan, London
Shabbir R, Ahmad SS (2016) Water resource vulnerability assessment in Rawalpindi and Islamabad, Pakistan using analytic hierarchy process (AHP). Journal of King Saud University-Science 28:293–299. https://doi.org/10.1016/j.jksus.2015.09.007
Sherbinin AD, Apotsos A, Chevrier J (2017) Mapping the future: policy applications of climate vulnerability mapping in West Africa. Geogr J 183:414–425. https://doi.org/10.1111/geoj.12226
Shrestha RK, Cameron DC, Coutts J, Cavaye J (2015) Building and maintenance of social capital in rural farming community of the Western Hills of Nepal. International Journal of Asian Business and Information Management (IJABIM) 6:28–41. https://doi.org/10.4018/IJABIM.2015070103
Shukla R, Sachdeva K, Joshi P (2016) Inherent vulnerability of agricultural communities in Himalaya: a village-level hotspot analysis in the Uttarakhand state of India. Appl Geogr 74:182–198. https://doi.org/10.1016/j.apgeog.2016.07.013
Sietz D, Lüdeke MK, Walther C (2011) Categorisation of typical vulnerability patterns in global drylands. Glob Environ Chang 21:431–440. https://doi.org/10.1016/j.gloenvcha.2010.11.005
Smit B, Pilifosova O (2003) Adaptation to climate change in the context of sustainable development and equity. Sustain Dev 8:879–906
Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16:282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008
Tate E (2012) Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Nat Hazards 63:325–347. https://doi.org/10.1007/s11069-012-0152-2
Tey YS, Brindal M (2012) Factors influencing the adoption of precision agricultural technologies: a review for policy implications. Precision Agric 13:713–730. https://doi.org/10.1007/s11119-012-9273-6
TFCC (2010) Task force on climate change-Final Report,Planning Commission, Government of Pakistan. http://www.gcisc.org.pk/TFCC%20Final%20Report.pdf
Thomas A, Theokritoff E, Lesnikowski A, Reckien D, Jagannathan K et al (2021) Global evidence of constraints and limits to human adaptation Regional environmental change 21:1-15 https://doi.org/10.1007/s10113-021-01808-9
Thomas DS, Twyman C (2005) Equity and justice in climate change adaptation amongst natural-resource-dependent societies. Glob Environ Chang 15:115–124. https://doi.org/10.1016/j.gloenvcha.2004.10.001
Thorlakson T, Neufeldt H (2012) Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. Agriculture & Food Security 1:15. https://doi.org/10.1186/2048-7010-1-15
UNDP (2013) Human Development Report, United Nations Development Programme

Verchot LV (2007) Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strat Glob Change 12:901–918. https://doi.org/10.1007/s11027-007-9105-6
Vincent K (2004) Creating an index of social vulnerability to climate change for Africa. Tyndall Center for Climate Change Research. Working Paper 56:41
Williamson T, Hesseln H, Johnston M (2012) Adaptive capacity deficits and adaptive capacity of economic systems in climate change vulnerability assessment. Forest Policy Econ 15:160–166. https://doi.org/10.1016/j.forpol.2010.04.003
Wiréhn L, Opach T, Neset T-S (2017) Assessing agricultural vulnerability to climate change in the Nordic countries–an interactive geovisualization approach. J Environ Planning Manage 60:115–134. https://doi.org/10.1080/09640568.2016.1143351
Wise RM, Fazey I, Smith MS, Park SE, Eakin H, Van Garderen EA, Campbell B (2014) Reconceptualising adaptation to climate change as part of pathways of change and response. Glob Environ Chang 28:325–336. https://doi.org/10.1016/j.gloenvcha.2013.12.002
Woolcock M, Narayan D (2000) Social capital: implications for development theory, research, and policy. The World Bank Research Observer 15:225–249. https://doi.org/10.1093/wbro/15.2.225
Yankson PWK, Owusu AB, Owusu G, Boakye-Danquah J, Tetteh JD (2017) Assessment of coastal communities' vulnerability to floods using indicator-based approach: a case study of Greater Accra Metropolitan Area, Ghana. Nat Hazards 89:661–689. https://doi.org/10.1007/s11069-017-2985-1
Yirga C, Hassan RM (2010) Social costs and incentives for optimal control of soil nutrient depletion in the central highlands of Ethiopia. Agric Syst 103:153–160. https://doi.org/10.1016/j.agsy.2009.12.002
Yuansheng J, Chandio AA, Magsi H (2016) Agricultural sub-sectors performance: an analysis of sector-wise share in agriculture GDP of Pakistan. Int J Econ Financ 8:156. https://doi.org/10.5539/ijef.v8n2p156
Zahid M, Rasul G (2012) Changing trends of thermal extremes in Pakistan. Clim Change 113:883–896. https://doi.org/10.1007/s10584-011-0390-4
Zaveri E, Lobell DB (2019) The role of irrigation in changing wheat yields and heat sensitivity in India. Nat Commun 10:1–7. https://doi.org/10.1038/s41467-019-12183-9
Zuhra SS, Tabinda AB, Yasar A (2019) Appraisal of the heat vulnerability index in Punjab: a case study of spatial pattern for exposure, sensitivity, and adaptive capacity in megacity Lahore. Pakistan Int J Biometeorol 63:1669–1682. https://doi.org/10.1007/s00484-019-01784-0

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Chapter Six: Adapting to climate change in vulnerable areas: Farmers' perceptions in the Punjab

Chapter 6 is a peer-reviewed journal paper published in MDPI *Climate*. The paper presents the empirical findings on qualitative engagement with farmers from vulnerable districts of Punjab identified in Chapter 5 through top–down vulnerability assessment. Chapter 6 addresses RQ2: *For selected districts of Punjab identified through vulnerability mapping, what constrains and enables adaptation to climate change from farmers' perspective?* In this paper, I utilise and broaden the concept of Vulnerable Smart Agriculture (Azadi et al., 2021) to explore the enabling environment of farmers in highly vulnerable areas of Punjab province. Employing qualitative analysis of semi-structured interviews with vulnerable farmers, the chapter explores their perceptions of climate change, their adaptive strategies, the facilitating factors, and the constraints posed by the prevailing enabling environment.

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Article

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].

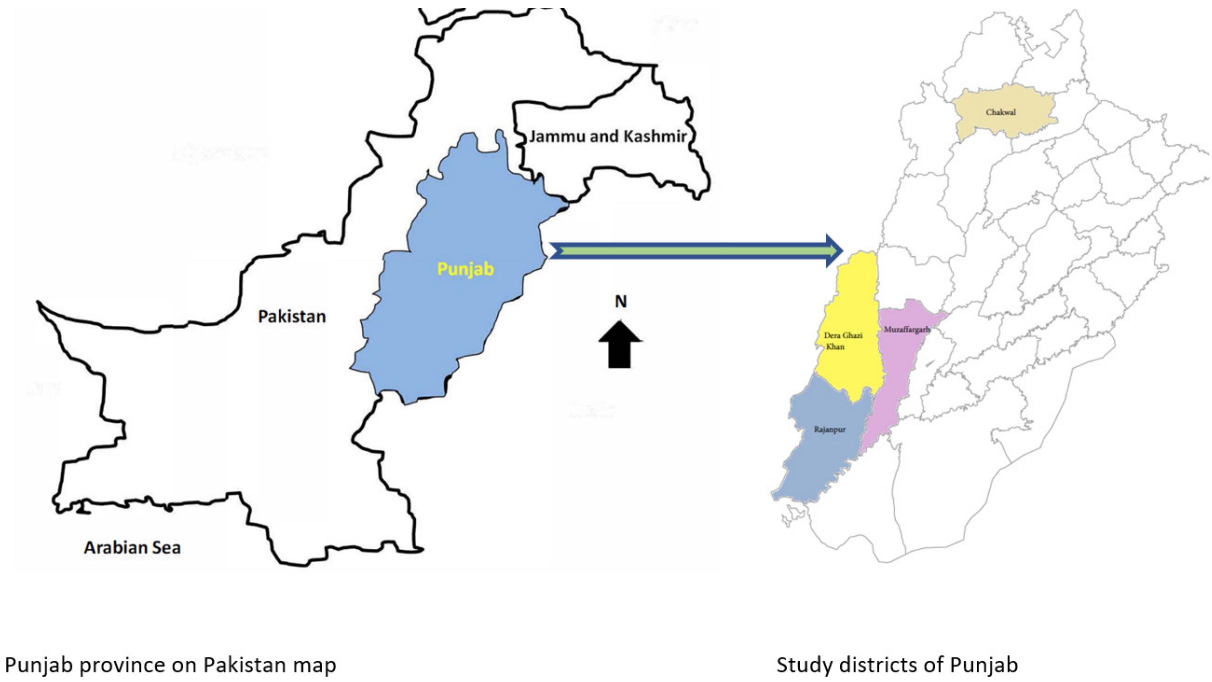

Figure 1. Study districts of Punjab province. Source: author.

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 services 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 varieties 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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References

1. Hoegh-Guldberg, O.; Jacob, D.; Taylor, M.; Bolaños, T.G.; Bindi, M.; Brown, S.; Camilloni, I.A.; Diedhiou, A.; Djalante, R.; Ebi, K.; et al. The human imperative of stabilizing global climate change at 1.5 °C. *Science* **2019**, *365*, eaaw6974. [CrossRef] [PubMed]
2. Lawrence, J.; Blackett, P.; Cradock-Henry, N.A. Cascading climate change impacts and implications. *Clim. Risk Manag.* **2020**, *29*, 100234. [CrossRef]
3. Thornton, P.K.; Ericksen, P.J.; Herrero, M.; Challinor, A.J. Climate variability and vulnerability to climate change: A review. *Glob. Chang. Biol.* **2014**, *20*, 3313–3328. [CrossRef]
4. Eriksen, C.; Simon, G.L.; Roth, F.; Lakhina, S.J.; Wisner, B.; Adler, C.; Thomalla, F.; Scolobig, A.; Brady, K.; Bründl, M.; et al. Rethinking the interplay between affluence and vulnerability to aid climate change adaptive capacity. *Clim. Chang.* **2020**, *162*, 25–39. [CrossRef] [PubMed]
5. Dorkenoo, K.; Scown, M.; Boyd, E. A critical review of disproportionality in loss and damage from climate change. *Wiley Interdiscip. Rev. Clim. Chang.* **2022**, *13*, e770. [CrossRef]
6. Maharjan, K.L.; Joshi, N.P. *Climate Change, Agriculture and Rural Livelihoods in Developing Countries*; Springer: Tokyo, Japan, 2013.

7. Amaru, S.; Chhetri, N.B. Climate adaptation: Institutional response to environmental constraints, and the need for increased flexibility, participation, and integration of approaches. *Appl. Geogr.* **2013**, *39*, 128–139. [CrossRef]
8. IPCC. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Eds.; Cambridge University Press: Cambridge, UK, 2014.
9. Arouri, M.; Nguyen, C.; Youssef, A.B. Natural disasters, household welfare, and resilience: Evidence from rural Vietnam. *World Dev.* **2015**, *70*, 59–77. [CrossRef]
10. Vincent, K.; Dougill, A.J.; Dixon, J.L.; Stringer, L.C.; Cull, T. Identifying climate services needs for national planning: Insights from Malawi. *Clim. Policy* **2017**, *17*, 189–202. [CrossRef]
11. Singh, C.; Daron, J.; Bazaz, A.; Ziervogel, G.; Spear, D.; Krishnaswamy, J.; Zaroug, M.; Kituyi, E. The utility of weather and climate information for adaptation decision-making: Current uses and future prospects in Africa and India. *Clim. Dev.* **2018**, *10*, 389–405. [CrossRef]
12. Azadi, H.; Ghazali, S.; Ghorbani, M.; Tan, R.; Witlox, F. Contribution of small-scale farmers to global food security: A meta-analysis. *J. Sci. Food Agric.* **2023**, *103*, 2715–2726. [CrossRef]
13. Ajayi, O.C.; Catacutan, D. Role of externality in the adoption of smallholder agroforestry: Case studies from Southern Africa and Southeast Asia. In *Externality: Economics, Management and Outcomes*; Sunderasan, S., Ed.; Nova Science Publishers Inc.: Hauppauge, NY, USA, 2012; pp. 167–188.
14. Aniah, P.; Kaunza-Nu-Dem, M.K.; Ayembilla, J.A. Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon* **2019**, *5*, e01492. [CrossRef]
15. Béné, C.; Cornelius, A.; Howland, F. Bridging humanitarian responses and long-term development through transformative changes—Some initial reflections from the World Bank's adaptive social protection program in the Sahel. *Sustainability* **2018**, *10*, 1697. [CrossRef]
16. Béné, C.; Headey, D.; Haddad, L.; von Grebmer, K. Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Secur.* **2016**, *8*, 123–138. [CrossRef]
17. Kates, R.W.; Travis, W.R.; Wilbanks, T.J. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7156–7161. [CrossRef]
18. Shaffril, H.A.M.; Krauss, S.E.; Samsuddin, S.F. A systematic review on Asian's farmers' adaptation practices towards climate change. *Sci. Total Environ.* **2018**, *644*, 683–695. [CrossRef]
19. Tripathi, A.; Mishra, A.K. Knowledge and passive adaptation to climate change: An example from Indian farmers. *Clim. Risk Manag.* **2017**, *16*, 195–207. [CrossRef]
20. Kabir, M.J.; Cramb, R.; Alauddin, M.; Roth, C.; Crimp, S. Farmers' perceptions of and responses to environmental change in southwest coastal Bangladesh. *Asia Pac. Viewp.* **2017**, *58*, 362–378. [CrossRef]
21. Keshavarz, M.; Karami, E.; Zibaei, M. Adaptation of Iranian farmers to climate variability and change. *Reg. Environ. Chang.* **2014**, *14*, 1163–1174. [CrossRef]
22. Ashraf, M.; Routray, J.K.; Saeed, M. Determinants of farmers' choice of coping and adaptation measures to the drought hazard in northwest Balochistan, Pakistan. *Nat. Hazards* **2014**, *73*, 1451–1473. [CrossRef]
23. Rahman, M.; Alam, K. Forest dependent indigenous communities' perception and adaptation to climate change through local knowledge in the protected area—A Bangladesh case study. *Climate* **2016**, *4*, 12. [CrossRef]
24. Bastakoti, R.C.; Gupta, J.; Babel, M.S.; van Dijk, M.P. Climate risks and adaptation strategies in the Lower Mekong River basin. *Reg. Environ. Chang.* **2014**, *14*, 207–219. [CrossRef]
25. Shahid, R.; Shijie, L.; Shahid, S.; Altaf, M.A.; Shahid, H. Determinants of reactive adaptations to climate change in semi-arid region of Pakistan. *J. Arid. Environ.* **2021**, *193*, 104580. [CrossRef]
26. Khan, N.A.; Shah, A.A.; Chowdhury, A.; Tariq MA, U.R.; Khanal, U. Rice farmers' perceptions about temperature and rainfall variations, respective adaptation measures, and determinants: Implications for sustainable farming systems. *Front. Environ. Sci.* **2022**, *10*, 1972. [CrossRef]
27. Shahbaz, P.; Haq, S.U.; Boz, I. Linking climate change adaptation practices with farm technical efficiency and fertilizer use: A study of wheat–maize mix cropping zone of Punjab province, Pakistan. *Environ. Sci. Pollut. Res.* **2022**, *29*, 16925–16938. [CrossRef]
28. Le Dang, H.; Li, E.; Nuberg, I.; Bruwer, J. Farmers' assessments of private adaptive measures to climate change and influential factors: A study in the Mekong Delta, Vietnam. *Nat. Hazards* **2014**, *71*, 385–401. [CrossRef]
29. Eckstein, D.; Künzel, V.; Schäfer, L.; Winges, M. *Global Climate Risk Index 2021*; Germanwatch: Bonn, Germany, 2021; p. 20.
30. PBS. Pakistan Bureau of Statistics, Government of Pakistan. 2022. Available online: http://www.pbs.gov.pk (accessed on 28 September 2022).
31. Howden, S.M.; Soussana, J.F.; Tubiello, F.N.; Chhetri, N.; Dunlop, M.; Meinke, H. Adapting agriculture to climate change. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19691–19696. [CrossRef]
32. Thomas, A.; Rendón, R. *Confronting Climate Displacement: Learning from Pakistan's Floods*; Refugees International: Washington, DC, USA, 2010.
33. Abbas, F. Analysis of a historical (1981–2010) temperature record of the Punjab province of Pakistan. *Earth Interact.* **2013**, *17*, 1–23. [CrossRef]

34. Iqbal, M.A.; Penas, A.; Cano-Ortiz, A.; Kersebaum, K.C.; Herrero, L.; del Río, S. Analysis of recent changes in maximum and minimum temperatures in Pakistan. *Atmos. Res.* **2016**, *168*, 234–249. [CrossRef]
35. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the design of climate change-resilient farming systems. *Agron. Sustain. Dev.* **2015**, *35*, 869–890. [CrossRef]
36. FFC. Federal Floods Commission of Pakistan. 2021. Available online: www.ffc.gov.pk (accessed on 10 December 2021).
37. Government of Pakistan (GoP). *Pakistan Economic Survey, 2022–2023*; Ministry of Finance: Islamabad, Pakistan, 2022.
38. Nadeem, F.; Jacobs, B.; Cordell, D. Mapping agricultural vulnerability to impacts of climate events of Punjab, Pakistan. *Reg. Environ. Chang.* **2022**, *22*, 66. [CrossRef]
39. Grothmann, T.; Patt, A. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Glob. Environ. Chang.* **2005**, *15*, 199–213. [CrossRef]
40. Pisor, A.C.; Basurto, X.; Douglass, K.G.; Mach, K.J.; Ready, E.; Tylianakis, J.M.; Hazel, A.; Kline, M.A.; Kramer, K.L.; Lansing, J.S.; et al. Effective climate change adaptation means supporting community autonomy. *Nat. Clim. Chang.* **2022**, *12*, 213–215. [CrossRef]
41. FAO. Climate-smart agriculture: Policies, practices and financing for food security, adaptation and mitigation. In *Hague Conference on Agriculture, Food Security and Climate Change, Hague, The Netherlands, 1 November 2010*; FAO: Rome, Italy, 2010.
42. Mwongera, C.; Shikuku, K.M.; Twyman, J.; Läderach, P.; Ampaire, E.; Van Asten, P.; Twomlow, S.; Winowiecki, L.A. Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agric. Syst.* **2017**, *151*, 192–203. [CrossRef]
43. Akamani, K. An Ecosystem-Based Approach to Climate-Smart Agriculture with Some Considerations for Social Equity. *Agronomy* **2021**, *11*, 1564. [CrossRef]
44. Zougmoré, R.; Partey, S.; Ouédraogo, M.; Omitoyin, B.; Thomas, T.; Ayantunde, A.; Ericksen, P.; Said, M.; Jalloh, A. Toward climate-smart agriculture in West Africa: A review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agric. Food Secur.* **2016**, *5*, 26. [CrossRef]
45. Campbell, B.M.; Thornton, P.; Zougmoré, R.; Van Asten, P.; Lipper, L. Sustainable intensification: What is its role in climate smart agriculture? *Curr. Opin. Environ. Sustain.* **2014**, *8*, 39–43. [CrossRef]
46. Balasubramanya, S.; Brozović, N.; Fishman, R.; Lele, S.; Wang, J. Managing irrigation under increasing water scarcity. *Agric. Econ.* **2022**, *53*, 976–984. [CrossRef]
47. Azadi, H.; Moghaddam, S.M.; Burkart, S.; Mahmoudi, H.; Van Passel, S.; Kurban, A.; Lopez-Carr, D. Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *J. Clean. Prod.* **2021**, *319*, 128602. [CrossRef]
48. Gardezi, M.; Michael, S.; Stock, R.; Vij, S.; Ogunyiola, A.; Ishtiaque, A. Prioritizing climate-smart agriculture: An organizational and temporal review. *Wiley Interdiscip. Rev. Clim. Chang.* **2022**, *13*, e755. [CrossRef]
49. Das, U.; Ansari, M.A.; Ghosh, S. Effectiveness and upscaling potential of climate smart agriculture interventions: Farmers' participatory prioritization and livelihood indicators as its determinants. *Agric. Syst.* **2022**, *203*, 103515. [CrossRef]
50. Sultan, H.; Zhan, J.; Rashid, W.; Chu, X.; Bohnett, E. Systematic review of multi-dimensional vulnerabilities in the Himalayas. *Int. J. Environ. Res. Public Health* **2022**, *19*, 12177. [CrossRef]
51. Longo, F.; Mirabelli, G.; Solina, V.; Belli, L.; Abdallah, C.B.; Ben-Ammar, O.; Bottani, E.; García-Gallego, J.M.; Germanos, M.; González, F.J.M.; et al. An overview of approaches and methodologies for supporting smallholders: ICT tools, blockchain, business models, sustainability indicators, simulation models. *Procedia Comput. Sci.* **2023**, *217*, 1930–1939. [CrossRef]
52. Negera, M.; Alemu, T.; Hagos, F.; Haileslassie, A. Impacts of climate-smart agricultural practices on farm households' climate resilience and vulnerability in Bale-Eco Region, Ethiopia. *Environ. Dev. Sustain.* **2023**, 1–30. [CrossRef]
53. Bapna, M.; McGray, H.; Mockm, G.; Witheym, L. Enabling adaptation: Priorities for supporting the rural poor in a changing climate. In *Enabling Adaptation: Priorities for Supporting the Rural Poor in a Changing Climate*; WRI: Washington, DC, USA, 2008; p. 12.
54. Bantayan, R.; Cadiz, M.C.; Lasco, R.; Sajise, P. Policy-Enabling Environment for Climate Change Adaptation: Some Experiences in Southeast Asia. *Books Agric. Res. Dev.* **2018**, *2*, 417.
55. Rahman, M.F.; Falzon, D.; Robinson, S.A.; Kuhl, L.; Westoby, R.; Omukuti, J.; Schipper, E.L.F.; McNamara, K.E.; Resurrección, B.P.; Mfitumukiza, D.; et al. Locally led adaptation: Promise, pitfalls, and possibilities. *Ambio* **2023**, *52*, 1543–1557. [CrossRef]
56. Hallegatte, S.; Lecocq, F.; De Perthuis, C. Designing climate change adaptation policies: An economic framework. *World Bank Policy Res. Work. Pap.* **2011**, 5568. [CrossRef]
57. Ampaire, E.L.; Jassogne, L.; Providence, H.; Acosta, M.; Twyman, J.; Winowiecki, L.; Van Asten, P. Institutional challenges to climate change adaptation: A case study on policy action gaps in Uganda. *Environ. Sci. Policy* **2017**, *75*, 81–90. [CrossRef]
58. Holler, J.; Bernier, Q.; Roberts, J.T.; Robinson, S.A. Transformational adaptation in least developed countries: Does expanded stakeholder participation make a difference? *Sustainability* **2020**, *12*, 1657. [CrossRef]
59. Lyon, C.; Jacobs, B.; Martin-Ortega, J.; Rothwell, S.A.; Davies, L.; Stoate, C.; Forber, K.J.; Doody, D.G.; Withers, P.J. Exploring adaptive capacity to phosphorus challenges through two United Kingdom river catchments. *Environ. Sci. Policy* **2022**, *136*, 225–236. [CrossRef]
60. Mortreux, C.; Barnett, J. Adaptive capacity: Exploring the research frontier. *Wiley Interdiscip. Rev. Clim. Chang.* **2017**, *8*, e467. [CrossRef]

61. Elrick-Barr, C.E.; Plummer, R.; Smith, T.F. Third-generation adaptive capacity assessment for climate-resilient development. *Clim. Dev.* **2023**, *15*, 518–521. [CrossRef]
62. Malhado, A.C.; Costa, M.H.; Correia, R.A.; Malhado, A.C.; de la Fuente MF, C.; da Costa, A.M.; Batinga, J.V.; Bragagnolo, C.; Ladle, R.J. Are capacity deficits in local government leaving the Amazon vulnerable to environmental change? *Land Use Policy* **2017**, *69*, 326–330. [CrossRef]
63. Abbas, F.; Ahmad, A.; Safeeq, M.; Ali, S.; Saleem, F.; Hammad, H.M.; Farhad, W. Changes in precipitation extremes over arid to semiarid and subhumid Punjab, Pakistan. *Theor. Appl. Climatol.* **2014**, *116*, 671–680. [CrossRef]
64. Nawaz, Z.; Li, X.; Chen, Y.; Guo, Y.; Wang, X.; Nawaz, N. Temporal and spatial characteristics of precipitation and temperature in Punjab, Pakistan. *Water* **2019**, *11*, 1916. [CrossRef]
65. McCarthy, J.J.; Canziani, O.F.; Leary, N.A.; Dokken, D.J.; White, K.S. (Eds.) *Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2001; Volume 2.
66. Abbas, S. Climate change and cotton production: An empirical investigation of Pakistan. *Environ. Sci. Pollut. Res.* **2020**, *27*, 29580–29588. [CrossRef]
67. Abbas, S.; Waheed, A. Trade competitiveness of Pakistan: Evidence from the revealed comparative advantage approach. *Compet. Rev. Int. Bus. J.* **2017**, *27*, 462–475. [CrossRef]
68. Bakhsh, K.; Kamran, M.A. Adaptation to climate change in rain-fed farming system in Punjab, Pakistan. *Int. J. Commons* **2019**, *13*, 833–847. [CrossRef]
69. ID GoP. *District Pre-Investment Studies*; Directorate of Industries, Government of Punjab: Lahore, Pakistan, 2012.
70. FAO. *Agro-Ecological Zones of Punjab Pakistan*; Food and Agricultural Organization of the United Nations (FAO): Rome, Italy, 2019.
71. Wong, L. Data analysis in qualitative research: A brief guide to using NVivo. *Malays. Fam. Physician Off. J. Acad. Fam. Physicians Malays.* **2008**, *3*, 14–20.
72. Alam, G.M.; Alam, K.; Mushtaq, S.; Sarker MN, I.; Hossain, M. Hazards, food insecurity and human displacement in rural riverine Bangladesh: Policy implications. *Int. J. Disaster Risk Reduct.* **2020**, *43*, 101364. [CrossRef]
73. Azungah, T. Qualitative research: Deductive and inductive approaches to data analysis. *Qual. Res. J.* **2018**, *18*, 383–400. [CrossRef]
74. Saldaña, J. *The Coding Manual for Qualitative Researchers*; Sage: Melbourne, Australia, 2016.
75. Lester, J.N.; Cho, Y.; Lochmiller, C.R. Learning to do qualitative data analysis: A starting point. *Hum. Resour. Dev. Rev.* **2020**, *19*, 94–106. [CrossRef]
76. Lune, H.; Berg, B.L. *Qualitative Research Methods for the Social Sciences*; Pearson: London, UK, 2017.
77. Saunders, B.; Sim, J.; Kingstone, T.; Baker, S.; Waterfield, J.; Bartlam, B.; Burroughs, H.; Jinks, C. Saturation in qualitative research: Exploring its conceptualization and operationalization. *Qual. Quant.* **2018**, *52*, 1893–1907. [CrossRef] [PubMed]
78. Lincoln, Y.S.; Denzin, N.K. (Eds.) *The Handbook of Qualitative Research*; Sage: Melbourne, Australia, 2000.
79. Stenfors, T.; Kajamaa, A.; Bennett, D. How to... assess the quality of qualitative research. *Clin. Teach.* **2020**, *17*, 596–599. [CrossRef] [PubMed]
80. Kafle, K.; Uprety, L.; Shrestha, G.; Pandey, V.; Mukherji, A. Are climate finance subsidies equitably distributed among farmers? Assessing socio-demographics of solar irrigation in Nepal. *Energy Res. Soc. Sci.* **2022**, *91*, 102756. [CrossRef]
81. Jain, M.; Fishman, R.; Mondal, P.; Galford, G.L.; Bhattarai, N.; Naeem, S.; Lall, U.; Balwinder-Singh; DeFries, R.S. Groundwater depletion will reduce cropping intensity in India. *Sci. Adv.* **2021**, *7*, eabd2849. [CrossRef]
82. Adger, W.N.; Agnew, M. *New Indicators of Vulnerability and Adaptive Capacity (Vol. 122)*; Tyndall Centre for Climate Change Research: Norwich, UK, 2004.
83. Azadi, Y.; Yazdanpanah, M.; Mahmoudi, H. Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. *J. Environ. Manag.* **2019**, *250*, 109456. [CrossRef] [PubMed]
84. Li, S.; Juhász-Horváth, L.; Harrison, P.A.; Pintér, L.; Rounsevell, M.D. Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary. *J. Environ. Manag.* **2017**, *185*, 21–30. [CrossRef] [PubMed]
85. Kropf, B.; Mitter, H. Factors Influencing Farmers' Climate Change Mitigation and Adaptation Behavior: A Systematic Literature Review. In *Alpine Landgesellschaften Zwischen Urbanisierung und Globalisierung*; Springer: Wiesbaden, Germany, 2022; pp. 243–259.
86. Ziervogel, G.; Cartwright, A.; Tas, A.; Adejuwon, J.; Zermoglio, F.; Shale, M.; Smith, B. *Climate Change and Adaptation in African Agriculture Stockholm Environment Institute*; SEI: Stockholm, Sweden, 2008; pp. 17–19.
87. Manjula, M.; Rengalakshmi, R. Seasonal climate information for ensuring agricultural sustainability and food security of smallholder Rainfed farmers: Experience from India. In Proceedings of the 15th Annual Global Development Conference, Accra, Ghana, 18–20 June 2014; pp. 10–13.
88. Tall, A.; Hansen, J.; Jay, A.; Campbell, B.M.; Kinyangi, J.; Aggarwal, P.K.; Zougmoré, R.B. *Scaling Up Climate Services for Farmers: Mission Possible. Learning from Good Practice in Africa and South Asia*; CCAFS Report; CCAFS: Frederiksberg, Denmark, 2014.
89. Tall, A.; Coulibaly, J.Y.; Diop, M. Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: Implications for Africa. *Clim. Serv.* **2018**, *11*, 1–12. [CrossRef]
90. Hansen, J.W.; Vaughan, C.; Kagabo, D.M.; Dinku, T.; Carr, E.R.; Körner, J.; Zougmoré, R.B. Climate services can support african farmers' context-specific adaptation needs at scale. *Front. Sustain. Food Syst.* **2019**, *3*, 21. [CrossRef]
91. Pelling, M. *Adaptation to Climate Change: From Resilience to Transformation*; Routledge: Abingdon, UK, 2010.

92. Megersa, B.; Markemann, A.; Angassa, A.; Zárate, A.V. The role of livestock diversification in ensuring household food security under a changing climate in Borana, Ethiopia. *Food Secur.* **2014**, *6*, 15–28. [CrossRef]
93. Mulwa, C.K.; Visser, M. Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Dev.* **2020**, *129*, 104906. [CrossRef]
94. Arshad, M.; Kächele, H.; Krupnik, T.J.; Amjath-Babu, T.S.; Aravindakshan, S.; Abbas, A. Climate variability, farmland value, and farmers' perceptions of climate change: Implications for adaptation in rural Pakistan. *Int. J. Sustain. Dev. World Ecol.* **2017**, *24*, 532–544. [CrossRef]
95. Habib ur Rahman, M.H.; Ahmad, A.; Wang, X.; Wajid, A.; Nasim, W.; Hussain, M.; Ahmad, B.; Ahmad, I.; Ali, Z.; Ishaque, W.; et al. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. *Agric. For. Meteorol.* **2018**, *253*, 94–113. [CrossRef]
96. Abid, M.; Scheffran, J.; Schneider, U.A.; Elahi, E. Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environ. Manag.* **2019**, *63*, 110–123. [CrossRef] [PubMed]
97. Bhatti, M.T.; Ahmad, W.; Shah, M.A.; Khattak, M.S. Climate change evidence and community level autonomous adaptation measures in a canal irrigated agriculture system of Pakistan. *Clim. Dev.* **2019**, *11*, 203–211. [CrossRef]
98. Ahmad, D.; Afzal, M. Climate change adaptation impact on cash crop productivity and income in Punjab province of Pakistan. *Environ. Sci. Pollut. Res.* **2020**, *27*, 30767–30777. [CrossRef] [PubMed]
99. Dodson, J.C.; Dérer, P.; Cafaro, P.; Götmark, F. Population growth and climate change: Addressing the overlooked threat multiplier. *Sci. Total Environ.* **2020**, *748*, 141346. [CrossRef] [PubMed]
100. Farooq, M.S.; Uzair, M.; Raza, A.; Habib, M.; Xu, Y.; Yousuf, M.; Yang, S.H.; Ramzan Khan, M. Uncovering the research gaps to alleviate the negative impacts of climate change on food security: A review. *Front. Plant Sci.* **2022**, *13*, 927535. [CrossRef] [PubMed]
101. Fatima, Z.; Ahmed, M.; Hussain, M.; Abbas, G.; Ul-Allah, S.; Ahmad, S.; Ahmed, N.; Ali, M.A.; Sarwar, G.; Haque, E.U.; et al. The fingerprints of climate warming on cereal crops phenology and adaptation options. *Sci. Rep.* **2020**, *10*, 18013. [CrossRef]
102. Hu, L.X.; Zhang, X.H.; Zhou, Y.H. Farm size and fertilizer sustainable use: An empirical study in Jiangsu, China. *J. Integr. Agric.* **2019**, *18*, 2898–2909. [CrossRef]
103. Borsato, E.; Rosa, L.; Marinello, F.; Tarolli, P.; D'Odorico, P. Weak and strong sustainability of irrigation: A framework for irrigation practices under limited water availability. *Front. Sustain. Food Syst.* **2020**, *4*, 17. [CrossRef]
104. Awan, U.K.; Anwar, A.; Ahmad, W.; Hafeez, M. A methodology to estimate equity of canal water and groundwater use at different spatial and temporal scales: A geo-informatics approach. *Environ. Earth Sci.* **2016**, *75*, 409. [CrossRef]
105. Khan, N.A.; Qiao, J.; Abid, M.; Gao, Q. Understanding farm-level cognition of and autonomous adaptation to climate variability and associated factors: Evidence from the rice-growing zone of Pakistan. *Land Use Policy* **2021**, *105*, 105427. [CrossRef]
106. Bernier, Q.; Sultana, P.; Bell, A.R.; Ringler, C. Water management and livelihood choices in southwestern Bangladesh. *J. Rural. Stud.* **2016**, *45*, 134–145. [CrossRef]
107. Bhatt, S. How does participatory irrigation management work? A study of selected water users' associations in Anand district of Gujarat, western India. *Water Policy* **2013**, *15*, 223–242. [CrossRef]
108. Playán, E.; Sagardoy, J.A.; Castillo, R. Irrigation governance in developing countries: Current problems and solutions. *Water* **2018**, *10*, 1118. [CrossRef]
109. Thapa, B.; Scott, C.A. Institutional strategies for adaptation to water stress in farmer-managed irrigation systems of Nepal. *Int. J. Commons* **2019**, *13*, 892–908. [CrossRef]
110. Reid Bell, A.; Ward, P.S.; Ashfaq, M.; Davies, S. Valuation and aspirations for drip irrigation in Punjab, Pakistan. *J. Water Resour. Plan. Manag.* **2020**, *146*, 04020035. [CrossRef]
111. Qureshi, R.; Ashraf, M. *Water Security Issues of Agriculture in Pakistan*; PAS: Islamabad, Pakistan, 2019; Volume 1, p. 41.
112. Aziz, M.; Rizvi, S.A.; Iqbal, M.A.; Syed, S.; Ashraf, M.; Anwer, S.; Usman, M.; Tahir, N.; Khan, A.; Asghar, S.; et al. A Sustainable irrigation system for small landholdings of rainfed Punjab, Pakistan. *Sustainability* **2021**, *13*, 11178. [CrossRef]
113. Latif, M.; Ahmad, M.Z. Groundwater and soil salinity variations in a canal command area in Pakistan Irrigation and Drainage. *J. Int. Comm. Irrig. Drain.* **2009**, *58*, 456–468. [CrossRef]
114. Mitra, A.; Balasubramanya, S.; Bouwer, R. Can electricity rebates modify groundwater pumping behaviours? Evidence from a pilot study in Punjab, India. In Proceedings of the 2021 Annual Meeting, Austin, TX, USA, 1–3 August 2021.
115. Devineni, N.; Perveen, S.; Lall, U. Solving groundwater depletion in India while achieving food security. *Nat. Commun.* **2022**, *13*, 3374. [CrossRef] [PubMed]
116. FAO. *The State of Agricultural Commodity Markets 2020. Agricultural Markets and Sustainable Development: Global Value Chains, Smallholder Farmers and Digital Innovations*; FAO: Rome, Italy, 2020. [CrossRef]
117. Aryal, J.P.; Sapkota, T.B.; Rahut, D.B.; Marenya, P.; Stirling, C.M. Climate risks and adaptation strategies of farmers in East Africa and South Asia. *Sci. Rep.* **2021**, *11*, 10489. [CrossRef] [PubMed]
118. Fischer, E.; Qaim, M. Linking smallholders to markets: Determinants and impacts of farmer collective action in Kenya. *World Dev.* **2012**, *40*, 1255–1268. [CrossRef]
119. Minot, N.; Sawyer, B. Contract farming in developing countries: Theory, practice, and policy implications. In *Innovation for Inclusive Value Chain Development: Successes and Challenges*; IFPRI: Washington, DC, USA, 2016; pp. 127–155.

120. Aku, A.; Mshenga, P.; Afari-Sefa, V.; Ochieng, J. Effect of market access provided by farmer organizations on smallholder vegetable farmer's income in Tanzania. *Cogent Food Agric.* **2018**, *4*, 1560596. [CrossRef]
121. Nguyen, T.H.; Sahin, O.; Howes, M. Climate change adaptation influences and barriers impacting the Asian agricultural industry. *Sustainability* **2021**, *13*, 7346. [CrossRef]
122. Mizik, T. Climate-smart agriculture on small-scale farms: A systematic literature review. *Agronomy* **2021**, *11*, 1096. [CrossRef]
123. Manikas, I.; Malindretos, G.; Moschuris, S. A community-based Agro-Food Hub model for sustainable farming. *Sustainability* **2019**, *11*, 1017. [CrossRef]
124. Hung, P.Q.; Khai, H.V. Transaction cost, price risk perspective and marketing channel decision of small-scale chili farmers in Tra Vinh Province, Vietnam. *Asian J. Agric. Rural. Dev.* **2020**, *10*, 68–80. [CrossRef]
125. Piñeiro, V.; Arias, J.; Dürr, J.; Elverdin, P.; Ibáñez, A.M.; Kinengyere, A.; Opazo, C.M.; Owoo, N.; Page, J.R.; Prager, S.D.; et al. A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nat. Sustain.* **2020**, *3*, 809–820. [CrossRef]
126. Aryal, J.P.; Sapkota, T.B.; Khurana, R.; Khatri-Chhetri, A.; Rahut, D.B.; Jat, M.L. Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environ. Dev. Sustain.* **2020**, *22*, 5045–5075. [CrossRef]
127. Ahmed, U.I.; Ying, L.; Bashir, M.K.; Abid, M.; Zulfiqar, F. Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PLoS ONE* **2017**, *12*, e0185466. [CrossRef] [PubMed]
128. Khanal, U.; Wilson, C.; Hoang, V.-N.; Lee, B. Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecol. Econ.* **2018**, *144*, 139–147. [CrossRef]
129. Bjornlund, V.; Bjornlund, H.; Van Rooyen, A.F. Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world–a historical perspective. *Int. J. Water Resour. Dev.* **2020**, *36* (Suppl. S1), S20–S53. [CrossRef]
130. Zulfiqar, F.; Shang, J.; Zada, M.; Alam, Q.; Rauf, T. Identifying the determinants of access to agricultural credit in Southern Punjab of Pakistan. *GeoJournal* **2021**, *86*, 2767–2776.
131. Agrawala, S.; Carraro, M. *Assessing the Role of Microfinance in Fostering Adaptation to Climate Change*; FEEM Working Paper No. 82.2010; CMCC Research Paper No. 91; SSRN: Paris, France, 2010. [CrossRef]
132. Ullah, W.; Nihei, T.; Nafees, M.; Zaman, R.; Ali, M. Understanding climate change vulnerability, adaptation and risk perceptions at household level in Khyber Pakhtunkhwa, Pakistan. *Int. J. Clim. Chang. Strateg. Manag.* **2018**, *10*, 359. [CrossRef]
133. Chaudhary, A.; Timsina, P.; Karki, E.; Sharma, A.; Suri, B.; Sharma, R.; Brown, B. Contextual realities and poverty traps: Why South Asian smallholder farmers negatively evaluate conservation agriculture. *Renew. Agric. Food Syst.* **2023**, *38*, e13. [CrossRef]
134. Favretto, N.; Stringer, L.C.; Dougill, A.J.; Kruger, L. Knowledge exchange enhances engagement in ecological restoration and rehabilitation initiatives. *Restor. Ecol.* **2022**, *30*, e13565. [CrossRef]
135. Aich, A.; Dey, D.; Roy, A. Climate change resilient agricultural practices: A learning experience from indigenous communities over India. *PLoS Sustain. Transform.* **2022**, *1*, e0000022. [CrossRef]
136. Feo, E.; Spanoghe, P.; Berckmoes, E.; Pascal, E.; Mosquera-Losada, R.; Opdebeeck, A.; Burssens, S. The multi-actor approach in thematic networks for agriculture and forestry innovation. *Agric. Food Econ.* **2022**, *10*, 3. [CrossRef]
137. Isaac, M.E. Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. *Agric. Syst.* **2012**, *109*, 9–15. [CrossRef]
138. Taylor, M.; Bhasme, S. Model farmers, extension networks and the politics of agricultural knowledge transfer. *J. Rural. Stud.* **2018**, *64*, 1–10. [CrossRef]
139. Wood, B.A.; Blair, H.T.; Gray, D.I.; Kemp, P.D.; Kenyon, P.R.; Morris, S.T.; Sewell, A.M. Agricultural science in the wild: A social network analysis of farmer knowledge exchange. *PLoS ONE* **2014**, *9*, e105203. [CrossRef] [PubMed]
140. Vasin, S.M.; Gamidullaeva, L.A.; Wise, N.; Korolev, K.Y. Knowledge exchange and the trust institution: A new look at the problem. *J. Knowl. Econ.* **2020**, *11*, 1026–1042. [CrossRef]
141. Franco, L.; Justo, A.; Cotelo, C.; Arias, I.; Garrido, L.; Lloret, L.; Rodríguez-Aubó, N. Multi-actor engagement: An open innovation process of knowledge exchange and co-creation. In Proceedings of the ICERI2019 Proceedings, Seville, Spain, 11–13 November 2019; IATED: Valencia, Spain, 2019; pp. 3808–3813.
142. Gore, C.; Robinson, P. Local government response to climate change: Our last, best hope. In *Changing Climates in North American Politics: Institutions, Policymaking, and Multilevel Governance*; MIT Press: Cambridge, MA, USA, 2009; pp. 137–158.
143. Chu, E.; Anguelovski, I.; Carmin, J. Inclusive approaches to urban climate adaptation planning and implementation in the Global South. *Clim. Policy* **2016**, *16*, 372–392. [CrossRef]
144. Castro, B.; Sen, R. Everyday adaptation: Theorizing climate change adaptation in daily life. *Glob. Environ. Chang.* **2022**, *75*, 102555. [CrossRef]
145. Newton, A.; Elliott, M. A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory processes. *Front. Mar. Sci.* **2016**, *3*, 230. [CrossRef]
146. Haddaway, N.R.; Kohl, C.; da Silva, N.R.; Schiemann, J.; Spök, A.; Stewart, R.; Sweet, J.B.; Wilhelm, R. A framework for stakeholder engagement during systematic reviews and maps in environmental management. *Environ. Evid.* **2017**, *6*, 11. [CrossRef]
147. Thomas, A.; Theokritoff, E.; Lesnikowski, A.; Reckien, D.; Jagannathan, K.; Cremades, R.; Campbell, D.; Joe, E.T.; Sitati, A.; Singh, C.; et al. Global evidence of constraints and limits to human adaptation. *Reg. Environ. Chang.* **2021**, *21*, 85. [CrossRef]
148. Schipper, E.L.F.; Burton, I. *The Earthscan Reader on Adaptation to Climate Change*; Earthscan: London, UK, 2009.

149. Burnham, M.; Ma, Z. Linking smallholder farmer climate change adaptation decisions to development. *Clim. Dev.* **2016**, *8*, 289–311. [CrossRef]
150. Moschitz, H.; Roep, D.; Brunori, G.; Tisenkopfs, T. Learning and innovation networks for sustainable agriculture: Processes of co-evolution, joint reflection and facilitation. *J. Agric. Educ. Ext.* **2015**, *21*, 1–11. [CrossRef]
151. Vorley, B.; Cotula, L.; Chan, M.K. *Tipping the Balance: Policies to Shape Agricultural Investments and Markets in Favour of Small-Scale Farmers*; Oxfam: Melbourne, Australia, 2012.
152. FAO. *An In-Depth Review of the Evolution of Integrated Public Policies to Strengthen Family Farms in Brazil*; Del Grossi, M.E., de Azevedo Marques, V.P.M., Eds.; ESA Working Paper No. 15-01; FAO: Rome, Italy, 2015.
153. da Silva, F.C.; Antonio, L.Ã.; Maia, A.H. Public policy on the family farming sector in Brazil: Towards a model of sustainable agriculture. *Afr. J. Agric. Res.* **2018**, *13*, 1719–1729.
154. Perin, G.; de Almeida, A.F.C.S.; Spinola, P.A.C.; Sambuichi, R.H.R. The benefits and challenges of the food acquisition program (PAA) for family farmers. *Portraits Settl.* **2022**, *25*, 9–40.
155. Nie, Y.; Avraamidou, S.; Xiao, X.; Pistikopoulos, E.N.; Li, J.; Zeng, Y.; Song, F.; Yu, J.; Zhu, M. A Food-Energy-Water Nexus approach for land use optimization. *Sci. Total Environ.* **2019**, *659*, 7–19. [CrossRef] [PubMed]
156. McGray, H.; Hammill, A.; Bradley, R.; Schipper, L.; Parry, J.-E. *Weathering the Storm: Options for Framing Adaptation and Development*; World Resources Institute: Washington, DC, USA, 2007.
157. Masters, L.; Duff, L. *Overcoming Barriers to Climate Change Adaptation Implementation in Southern Africa*; African Books Collective: Oxford, UK, 2011.
158. Thomas, K.; Hardy, R.D.; Lazrus, H.; Mendez, M.; Orlove, B.; Rivera-Collazo, I.; Roberts, J.T.; Rockman, M.; Warner, B.P.; Winthrop, R. Explaining differential vulnerability to climate change: A social science review. *Wiley Interdiscip. Rev. Clim. Chang.* **2019**, *10*, e565. [CrossRef] [PubMed]
159. Antwi-Agyei, P.; Dougill, A.J.; Stringer, L.C. Barriers to climate change adaptation: Evidence from northeast Ghana in the context of a systematic literature review. *Clim. Dev.* **2015**, *7*, 297–309. [CrossRef]
160. Wright, H.; Vermeulen, S.; Laganda, G.; Olupot, M.; Ampaire, E.; Jat, M.L. Farmers, food and climate change: Ensuring community-based adaptation is mainstreamed into agricultural programmes. *Clim. Dev.* **2014**, *6*, 318–328. [CrossRef]
161. Sajesh, V.K.; Suresh, A. Public-sector agricultural extension in India: A note. *Rev. Agrar. Stud.* **2016**, *6*, 116–131.

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Chapter Seven: Government Informants' perceptions of barriers to climate change adaptation in Punjab

Chapter 7 presents the empirical findings on qualitative engagement with government officials from vulnerable districts of Punjab province identified through vulnerability assessment (Chapter 5). Chapter 7 addresses RQ3: *What constraints are faced by district-scale government officials in supporting farmers' adaptation in vulnerable districts of Punjab?* I use the Vulnerable Smart Agriculture framework (Azadi et al., 2021) to explore the enabling environment of government officials from vulnerable areas of Punjab. Utilizing qualitative analysis of semi-structured interviews conducted with government officials, this chapter sheds light on the obstacles district-level government officials encounter while striving to foster a conducive atmosphere for adaptation. It explores their endeavours to aid farmers in vulnerable areas of the Punjab as they strive to adapt to changing conditions. The chapter has been prepared in the form of a manuscript for publication in a peer reviewed journal. The findings of this chapter were presented at the 8th International Conference on Climate Change (ICCC 2024) held on 8th-9th February 2024 in Colombo, Sri Lanka. The presentation was included under conference sub-theme (Impacts, Hazards, Risks, and Effective Adaptation to Climate Change), and has been included in a published book of abstracts from the conference.

7.1 Introduction

Climate change is a threat multiplier that amplifies existing risks and creates new risks for natural and human systems (Misiou & Koutsoumanis, 2022; Dodson et al., 2020). Climate change is currently causing catastrophic impacts across the world, and future projections necessitate rapid and effective actions to adapt to the changing conditions and mitigate greenhouse gas emissions (IPCC 2022). Low-income countries and socio-economically disadvantaged people are considered more vulnerable to climate shocks and bear the brunt of the effects of climatic changes (Islam & Winkel, 2017). Pakistan, for example, a developing country of agricultural significance in South Asia, contributes less than 1% of global GHG emissions (NDC 2021) but is one of the most vulnerable countries to the impacts of climate change (Eckstein et al., 2021). This chapter focuses on adaptation measures defined as adjustments that aim to reduce the negative impacts of climate change and to take advantage of any potential opportunities (IPCC 2022). Adaptation measures are needed to sustain agricultural productivity by reducing vulnerability and enhancing the resilience of agricultural systems to climate change (Aryal et al., 2020).

Adaptation to climate change is a complex process and requires an enabling environment to facilitate action (Bantayan et al., 2018). An enabling environment refers to the economic, social, and institutional conditions that support and encourage adaptation (Lewis & Rudnick, 2019). They can include actions to reduce exposure and sensitivity to climate effects and increase adaptive capacity (Ford et al., 2010). Without an enabling environment, adaptation efforts may face various barriers and challenges that limit their effectiveness and sustainability (Moser & Ekstrom, 2010). Therefore, creating and strengthening an enabling environment is essential for successful adaptation to climate change.

Institutions, such as formal government organizations and non-government organizations (NGOs), perform an important role in establishing an enabling environment to support adaptation (Klein et al., 2017). For instance, government institutions structure climate impacts, vulnerability, and mediate between individual and collective responses to climate impacts which shape adaptation outcomes (Agrawal, 2008). Also, government institutions translate adaptation goals into practice through formal and informal measures including policy, planning, and support tools. For example, governments provide a policy environment that is conducive to effective adaptation by incentivizing the right actions and removing potential distortions (Fankhauser, 2017). Moreover, government institutions govern access and delivery of resources to facilitate adaptation through the provision of climate-resilient services, such as climate information services (Hansen et al., 2019), and can provide assistance for vulnerable groups that cannot adapt sufficiently themselves.

In common with the structure of many governments of the world, Pakistan is a federal republic with three tiers of government: national, provincial, and district governments (Ahmed et al., 2015). National and provincial governments through federal and provincial ministries governed by bureaucracy deal with national and provincial affairs (Tariq et al., 2018). District governments herein referred to as local governments deal with local affairs (Ahmed et al., 2015). District governments consist of government departments on various subjects including agriculture and the environment. Despite the global nature of climate change, the impacts of climate stressors manifest at local scales, creating distinct challenges for local governments and requiring local adaptation interventions as key responses (Birchall et al., 2023). Local governments have particular significance for addressing climate change as this is the government level which is often closest to where the climate impacts are to be felt, where individual behavior can be influenced, and where responses to climate change are implemented (Amundsen et al., 2018; Klein et al., 2017). This is supported by a number of studies on climate change responses which indicate the importance of local governments for identifying the needs of local adaptation and for developing adaptive responses that are applicable locally (e.g. Lesnikowski et al., 2021; Bhatta et al., 2017; Dannevig et al., 2012; Musco & van Staden, 2010; Agrawal, 2008) confirming that local governments are central institutional actors in fostering resilience through effective climate change adaptation.

While local governments are deemed essential to the government hierarchy for the implementation of climate change adaptation measures, their capacity to support adaptation is heavily constrained. An extensive body of literature shows that local governments retain significant potential to support adaptation and bolster resilience but their ability to do so in practice is hindered (e.g. de Oliveira, 2009; Ojwang et al., 2017; Rosendo et al., 2018; Williams et al., 2020; Bonnett & Birchall, 2023). It is also widely accepted that local governments are often responsible for taking the lead in implementing adaptation initiatives (Susskind & Kim, 2022). The situation of local government at the 'coal-face' of adaptation often results in their being held accountable by local communities for enabling adaptation as the most visible and accessible tier of government (Musah-Surugu et al., 2019). However, where responsibility for adaptation is devolved to lower tiers of government, it is important that they have the capacity to implement adaptation initiatives and are able to provide an enabling environment to support community action (Rahman et al., 2023). Ensuring the capacity of local governments to enable adaptation in this context remains a major challenge (Gupta et al., 2010; Williams et al., 2020).

In general, within a developing country context, the degree to which policy planning arrangements meet their objectives has received limited attention (Holler et al., 2020). In particular, climate adaptation studies lack evidence from developing countries of the climate-vulnerable Global South (including Pakistan), where institutional arrangements can be fragmented or fragile, and depend on the economic and political context (Ishtiaque et al., 2021; Smucker & Nijbroek, 2020; Di Gregorio et al., 2019; Musah-Surugu et al., 2019). Chapter 5 of the thesis showed agricultural vulnerability varied throughout Punjab. Furthermore, Chapter 6 reported that small-scale farmers within vulnerable districts of Punjab appeared heavily constrained in taking adaptation action owing to capacity deficits. These vulnerable farmers of Punjab looked to local government, i.e. district governments, to provide them with an enabling environment for adaptation through the provision of resources and services. However, a misalignment was found between the expectation of vulnerable farmers and the capacity of local governments to meet those expectations, which appears acute in vulnerable districts of Punjab. Assessment of the capacity of the lower tier of the Punjab government is critical to support local adaptation and to identify capacity-building needs for the implementation of climate-smart policy formulation (Shakya et al., 2018). The constraints that local government officials of Punjab province encounter in facilitating adaptation for vulnerable farmers were investigated in this chapter. The aim was to contrast the perspectives of government officials with the expectations of local farmers.

7.2 Methods

7.2.1 Data collection and analysis

Permissions were obtained to draw study participants from provincial government departments of Directorate General Agriculture, Extension and Adaptive Research (AED), Government of Punjab (GoP), and Environmental Protection Agency (EPA) GoP, directly concerned with implementing policy to enable climate change adaptation in agriculture (see Appendix E). The study focused on districts of Punjab province, i.e. Rajanpur, Dera Ghazi Khan, Muzaffargarh, and Chakwal districts (see Study Area and Figure 4.2 from Chapter 4 for more details). In addition to 13 government participants from the study districts, three more participants were added from provincial headquarters in Lahore, Faisalabad, and Rawalpindi districts based on referrals from existing participants. In total, 16, in-person, semi-structured interviews were conducted with government participants at their offices. Table 7.1 presents the details of government informants i.e., district, gender, designation, departmental affiliation. Before commencing the interviews, a consent form (see Appendix A) was obtained from all participants in line with ethics approval guidelines.

Table 7.1: List of government officials interviewed

Sr. No.	Designation	Department	Gender	District
1	Senior Executive	Agriculture, Extension and Adaptive Research (AED), (GoP)	Male	DA
2	Middle/Field Executive	Environmental Protection Agency (EPA), (GoP)	Male	DA
3	Middle/Field Executive	AED, GoP	Female	DA
4	Middle/Field Executive	AED, GoP	Male	DB
5	Middle/Field Executive	EPA, GoP	Male	DB
6	Middle/Field Executive	AED, GoP	Male	DB
7	Senior Executive	AED, GoP	Male	DC
8	Middle/Field Executive	AED, GoP	Male	DC
9	Senior Executive	EPA, GoP	Male	DC
10	Middle/Field Executive	EPA, GoP	Male	DC
11	Middle/Field Executive	AED, GoP	Male	DD
12	Middle/Field Executive	EPA, GoP	Male	DD
13	Middle/Field Executive	AED, GoP	Male	DD
14	Senior Executive	AED, GoP	Male	DE
15	Senior Executive	EPA, GoP	Male	DF
16	Senior Executive	AED, GoP	Male	DG

While all government informants were literate in English, interview questions were translated and answered by informants in Urdu. All interviews were audio recorded with participant consent. Interview transcripts were transcribed into English and anonymised by assigning unique labels to each participant. The transcripts were then coded using NVivo software by adopting an inductive approach (e.g. Azungah, 2018). Inductive coding, commonly used to analyse qualitative data, uses patterns identified in the data to derive the structure of the analysis (Akinyode & Khan, 2018; Alam, 2020, Burnard et al., 2008). The coding process was performed iteratively through two cycles (Saldana, 2013; Lester et al., 2020) and codes were then grouped by organizing, collating, and merging them into emerging themes.

7.3 Results

The perceptions of government officials (GO) of Punjab province are explored in this section with a focus on resource constraints to governance and policy planning. The implications for the establishment of an enabling environment for local adaptation in the agriculture sector will then be discussed.

7.3.1 Perceptions of climate variability and change

There was a broad acceptance among the GO interviewed that climate change was affecting the Punjab region. All the interviewed government officials confirmed that they were aware of climate variability and change in Punjab province. Collectively they represented decades of experience in the region and reported long-term rises in temperature and changes in rainfall patterns. They also reported experiencing seasonal changes: extended duration of summers and shorter winters. In addition, participants reported more frequent flooding events. These changes were impacting Punjab agriculture. For example, the responses of two government officials were typical of the general view:

> "Winters are starting too late now than in past decades. Rainfall patterns have also changed, less rains occur in winters but more rains occur later now, which adversely affects crops. More changes in climate have occurred in South Punjab. Decades-long average temperature has risen here. The impacts of climate change on crops are quite obvious now. The cropping system in southern Punjab has been disturbed a lot. Three [administrative] divisions (DGK, Multan, and Bahawalpur) are feeding most of Pakistan particularly due to cotton and wheat crops. I think these three divisions' districts are more vulnerable to climate change. Cotton crop has been affected a lot here with rises in temperature, changes in rainfall patterns, and floods in 2010 and 2014"
>
> **GO5**

> "There is no doubt that climate change has occurred and is also occurring in Punjab. Long-term temperatures have risen a lot here from the past and rains are occurring with changing patterns. …. From what I have observed, these changes are not only long term rise of temperature over decades and changing rain patterns but also changes due to [seasonal] fluctuations of temperatures……. Based on 10 years [of] temperature data, I can say that such fluctuations are also quite visible. […] I have observed that the month of October remains quite warm now in Punjab. This change is in contrast from the past when winter used to start from October and wheat was sown but this is not the case now"
>
> **GO7**

7.3.2 Perspectives on resource constraints

Governmental officials not only reported exposure to climate change but also perceived key resource constraints that included natural resources (e.g. water) and financial resources (e.g. market access), which limited the capacity of the region's agriculture sector to adapt to climate change.

7.3.2.1 Water resources

Government officials considered water availability for crops as the region's top priority and a critical resource for adaptation in agriculture. However, there was a general consensus among interviewees that the water requirements of farmers for cropping were currently not being met due to a range of issues associated with resource availability, use efficiency, and farmers' capacity constraints. For instance, a respondent stated:

> "I think water availability is the biggest problem farmers are facing today. We are already facing a water crisis as we don't have adequate irrigation water and rainfall is decreasing. I feel all major water sources are under pressure. Farmers here are facing acute water shortages and irrigation water availability has gradually reduced a lot. Groundwater is not available at the level at which it was previously and is not of the same quality […] The gradual decrease in river water flow coming from our neighboring country [India] needs also to be looked at. But I think these actions are related to broad national-level policies. The government is focusing on measures such as the need for high-efficiency irrigation. But in coming years, I think a lot more needs to be done to meet these water crises"
>
> **GO9**

GO reported all key sources of water for agriculture, i.e., surface reservoirs, groundwater, and rainfall are under tremendous stress. Informants described a number of factors as contributing to this water scarcity at national and local scales. At the national scale, they attributed a lack of water storage capacity to inadequate construction of large reservoirs. One participant suggested that 'we have made the technical issue of building large dams, more of a political issue'. Others indicated that only a few large reservoirs have been constructed so far in Pakistan compared to many neighbouring countries. They estimated about 123 GL of the run-off was 'being wasted annually without utilization and goes back to sea'. They also reported a gradual decrease in the storage capacity of existing reservoirs due to sedimentation. Other GO suggested reduced storage was due to reduced in-flows from catchments that spanned international borders. Most GO agreed that climate change was a contributing factor to water scarcity, which would likely aggravate Punjab's water scarcity in the future.

At the local scale, GO reported low water use efficiency owing to 'wasteful' on-farm practices. Flood irrigation was reported as the most common irrigation system, a practice GO considered highly inefficient because it resulted in large water losses through evaporation and leakage from irrigation canals. They suggested an urgent need to move towards more efficient crop-water delivery systems such as drip irrigation. They noted that the crop water requirements of farmers could possibly be met through the adoption of more efficient irrigation technologies. GO reported rapid growth of tube wells to enable the use of groundwater in Punjab but indicated that areas reliant solely on tube wells often suffered from poor water quality, with high levels of salinity making it unsuitable for drinking or irrigation. GO expressed concern over the excessive use of groundwater by farmers resulting in falling water tables and rising salinity problems as underground aquifers became depleted. However, one GO suggested more extensive exploration of groundwater resources to find 'sweet ground water pockets'. These additional aquifers could be exploited to supply ‘thousands of acres of fertile agricultural land’ with currently limited irrigation access. Respondents suggested the need to promote efficient water use mechanisms, availability of seeds of drought-tolerant crops, and cultivation of less water-intensive crop varieties as ways to improve water use efficiency in Punjab cropping. The following quotes summarise the general views of GO:

> “Actually, resources are being used in the country in a wasteful manner. Irrigation water for farmers is just like a farmer wants ten glasses of water, then he utilises one glass [for cropping] and nine glasses are being wasted. The flood irrigation system is quite useless. At the moment, there is excessive use of groundwater through tube wells for crops, I would say groundwater is like gold and should not be used on crops. Farmers’ crop water requirements cannot be fulfilled by means of a flood irrigation system. However, if we adopt judicial use of water for farmers by applying technologies like drip irrigation systems then farmers’ water requirements could be met”
>
> **GO5**

> “Due to temperature and rainfall variations, different seed varieties need to be developed specific to each area. As of now, the seed variety which is being used in upper Punjab, is the same variety in use here [southern Punjab]. There are no drought-tolerant and disease-tolerant crop varieties here that are much needed. We had one genome in the past from overseas and since then we developed a number of varieties [in Pakistan] by using that genome. Internationally, numerous [improved] genomes have been developed since”
>
> **GO6**

7.3.2.2 Financial resources

GO noted multiple financial complications for farmers belonging to the most vulnerable districts of Punjab that included market access, crop pricing, and credit availability. For instance, one GO summarised the issues related to the marketing of grain as follows:

> “By asking this question you have hit a wounded nerve. Road infrastructure has quite improved generally but what happened with the farmers in selling their agricultural produce, no one has thought about that. The marketing system which is currently in place is such that farmers grow crops with all of their hard work, using all their financial and other resources but when the farmer attempts to sell crops then he faces a marketing system [made up] of middlemen. Middlemen set prices [for produce] whatever suits them. These are perishable goods and farmers are bound to sell their produce to them. But these middlemen [also] provide money [loans] to farmers on occasions and never say no to the farmer. If we look at other countries’ models [by comparison], farm inputs are provided to the farmers, and their agricultural produce is purchased by the government at reasonable rates”
>
> **GO4**

GO reported a number of pricing issues and suggested farmers’ terms of trade (the difference between the purchase price of farm inputs and the selling price of their crops) were adversely affected by the influence of market agents (or ‘middlemen’). GO reported high local prices of farm inputs including seeds, fertilisers, pesticides, and agricultural implements (either for purchase or rent). GO generally considered that farmers are unable to secure reasonable selling prices for their harvested crops in comparison to their cost of production. Furthermore, GO suggested that in dealing with 'middlemen' to sell their crops farmers experienced many trade-offs. For example, they suggested middlemen charge high margins as selling agents and use superior knowledge of local markets for grain to secure prices higher than those offered by official government grain buyers while paying farmers significantly lower rates. One GO suggested that middlemen sometimes sell grain in international markets, meaning that neither government nor farmers benefit from these transactions. In addition, middlemen were viewed as controlling farmers by offering them readily-available credit facilities for purchases of farm inputs, or as personal loans for cultural ceremonies such as weddings and funerals.

While GO indicated that although they preferred direct buying of grain by the government, or indeed any marketing system that limited the role of middlemen, this was often problematic in their districts. For example, GO generally recognised that not all farmers have ready access to transport, labor, grain weighing facilities, or the time needed to access government depots. Other GO noted that while the government crop-buying process did offer supported prices to farmers, this market was limited to purchases of wheat only, suggesting that it could be extended to other grains. GO also identified the limited grain storage capacity for wheat by the government, and for all crops locally, which meant farmers were compelled to take whatever prices were on offer following harvest. For example:

> "Government cannot take all steps on its own such as buying crops from the farmers, the private sector has to come forward. Direct markets for farmers can be acquired by the government so that farmers can directly approach these markets and sell their agricultural produce, eliminating a role for middlemen. Government needs to develop such mechanisms and to regulate those [arrangements] with a proper checks and balances system. In government buying centers for wheat, farmers whether small and large could be registered to bring their grain to that [specific local] government purchase center"

GO7

In addition to the wheat crop support price, the national government and the government of Punjab are trying to address pricing issues through alternative finance mechanisms that include loans, compensation, and subsidies on farm inputs. Although GO acknowledged the importance of agri-credit services, they identified many limitations. All interviewees reported high-interest rates on loans offered through commercial banks and highly complex loan application and processing procedures. They felt the process of obtaining low-interest loans through government schemes was quite complicated as it involves many government departments including banks, such that few farmers were able to access finance. Some GO indicated that farmers who were land-owners experience better access to loans than tenant farmers, as owners are able to use their land as collateral assets. Other GO believed that many farmers utilise these loans for domestic needs rather than to support agriculture practices, which makes repayment of the loan difficult. For example,

"What kind of support are banks or financial institutions providing to farmers here? Instead of providing support, they are actually creating problems for farmers. Interest rates are very high and the whole process is not effective […] Many banks and financial institutions are offering loans for agricultural purposes. But the issue is farmers do not utilise the loans for agriculture. Instead, farmers use loans on domestic issues such as weddings, buying a motorcycle etc. They are not able to return the loans due to increasing interest"

GO5

In addition to loans, GO reported compensation and subsidies as other financial instruments to assist farmers. However, they noted that compensation for crop damage and loss offered by the government was relatively rare and often ad hoc rather than a permanent feature of Punjab agri-finance. Some GO believed that crop compensation should be given to farmers only in the case of crop damage or loss from natural disasters rather than due to farmers' negligence or failure to follow guidance from department advisory services. Other participants noted the significance of an organised crop insurance system, which is currently not in place. Subsidies were reportedly being provided to farmers for inputs such as fertilisers, electricity, installation of more efficient irrigation systems, and in the form of wheat support prices. However, some GO noted that even with access to subsidised prices many farms may not be viable. Other GO believed that subsidies should be discouraged. For instance, a respondent stated:

"Farmers here are bit addicted towards subsidies. Subsidies in the whole world are being cursed and are not good things. Particularly in the case of our country, which is already under the burden of loans. Government is providing subsidies on high-efficiency irrigation systems like drip irrigation system, sprinkler system, wherein the government has a major share in it and farmer has lesser share. However, adoption of such technologies, I can say, [are] similar to first drop of rain [very low]"

GO4

7.3.3 Perspectives on governance constraints

The National Government of Pakistan and the Government of Punjab are attempting to address the threat of climate change through the development of policies and plans in a highly resource-constrained context. To assess how effective these policies and plans are in meeting their objectives at the local scale, GO from two provincial government departments i.e. AED and EPA involved in these activities were interviewed. The results focus specifically on the state of governance and policy planning for climate change adaptation in the major crops sector. The governance issues raised by GO included 'siloed' approaches, ambiguous roles, and disconnected top-down communication from bottom-up consultation.

7.3.3.1 Siloed approach

Interviews revealed a lack of horizontal and vertical coordination in government functions as hampering efforts for effective implementation of tailored federal and provincial policies at the district scale. Horizontal coordination refers to coordination among different government departments while vertical coordination refers to coordination within the same department where it has bureaucratic representation at federal, provincial, and district scales. For instance, on lack of horizontal coordination, a GO stated:

> "National level policies definitely have broad vision within which work is done under some umbrella. But regarding inter-departmental coordination at lower tiers, I feel there is lack of coordination among departments and I think the coordination within departments is not as strong as it should be. The environment department has initiated climate change policy and I think the agriculture department may have their own policies. About those policies, both agriculture and environment departments should work in collaboration on policy documents. As of now, each department has its own rules, regulations and policies in a scattered way, not on a single page and in the same direction"
>
> **GO13**

GO noted a lack of coordination among departments particularly at the district scale. They also noted that cross-agency coordination was mostly ad hoc, on a needs basis, and suffered from a lack of regularity. A field official from AED suggested that occasionally taskforce meetings of all departments were held at a district scale but that issues such as climate change adaptation and agriculture were rarely the focus of such meetings. A district-level AED officer noted that if the meteorological department directly or through EPA shared with them climate data for the district then this could assist them with promoting adaptation at district scale. Another middle-level AED officer noted that divisional agricultural advisory meetings are held occasionally but that the interaction among participants is quite formal due to the fixed agenda. Likewise, an EPA middle management official suggested that departments at a district scale need to work under one umbrella; policies need to be integrated and capacities merged through sharing of experiences. A senior-level GO described the state of this segregated approach through an interesting example:

> "I think currently we are not coordinating to such a level as it should be. All departments need to better coordinate collectively. Now it is being suggested that such things could be done through an integrated approach. At the moment I can say it is 'slipshod'. I can give you a good example on that. Years back a delegation came from Asian Development Bank (ADB) and I was with them. We went on a small dam visit and their consultant walked with us through whole command of the canal till the end. Unfortunately, that canal was not [constructed] on the contour, the area was undulating and there were unnecessary dips […] when we reached the head of the canal after completing the visit, farmers and all departments were present there. Their team lead asked a question about when this dam was built. We answered in 1982. We were visiting the dam in 1997. Their team lead found that the developed irrigation area of the dam was only 25% [of the potential area] and the dam would finish its life early due to sedimentation load. They were surprised that this dam had remained underutilised for 15 years and wondered where were the support staff, such as agronomists and water experts, who should have had important

management roles after completion of the dam. This is an example of missing an integrated approach that [despite examples like this] nearly two decades later, an integrated approach among departments was uncommon."

GO2

7.3.3.2 Ambiguous roles

GO expressed a lack of clarity around their roles, which is reflected not only through policy formulation but in the practicalities of policy implementation. They pointed towards a lack of 'ownership' of climate change adaptation in government, particularly in relation to agriculture and the major crops sector. For instance, a middle-management EPA official stated:

"I think departments should have clear information on their roles, responsibilities, rules and relevant policies on climate change and agriculture. In the development phase of institutional policies, these policies should be in line with lower and higher tiers [of government] and in collaboration with all other departments. Policies need to be developed and implemented by keeping in mind all stakeholders. At the moment, we have some things in place but they are poorly shaped, I would say in a haphazard form or directionless way, that's why the results are not coming and the [policy] outcomes are not coming which are desired"

GO16

GO noted that policy development is usually done at federal and provincial scales but that policies are implemented at district scale. However, some GO noted that the 18^{th} Amendment to the constitution of Pakistan, passed by the legislative assembly in 2010, complicates the policy process because it grants autonomy to provinces in policy formulation and implementation. They suggested that despite this decentralization of powers, many aspects of policy continue to be developed in parallel at the federal scale. They perceived that similar issues are governed at different governance scales creating inconsistency. In addition, district scale GO advised that they have to report not only to their own department directives, which usually come from higher-level departmental management based at provincial headquarters but also must remain engaged with local district management under the current bureaucracy. Also, one district-level GO suggested that each government department sets its own policy direction, while another added that 'whenever there is no clear direction [across government] then funds are less likely to be allocated' to implementation. Moreover, some GO observed that certain laws and policies have been in place for many years but are yet to be implemented on the ground due to ambiguity around jurisdictional responsibility among the range of concerned authorities. For instance, a senior-level EPA official and a middle-level AED official viewed the ambiguity around responsibility and roles in policy thus:

"The focal point for climate change is the federal level not us [provincial level]. I have seen national climate change policy since 2012. We have prepared the Punjab climate change policy but it is under review. One issue came on this is, under the 18th Amendment responsibility for the environment has devolved [to provinces] but not for climate change. So naturally we cannot develop policy on that and we act just as implementers. These things are yet to be cleared between the federal government vs. government of Punjab [...] We have advisory and educational roles. By definition we are the regulator on environment but we (EPA) are not much involved in mitigation and adaptation of climate change so far. If multiple policies are to be made then this brings disparity with that. There should be a single policy but with regional specific targets in it, I think that would be more appropriate. If every province made its own policy, then it would be too difficult to carry forward with that. Recommendations could come from anywhere but ultimately it depends how much priority government gives to environment and whether government acknowledges [provincial] recommendations or not"

GO8

"We don't have good seed and crop varieties so we couldn't address this issue. Problem here is that [national] policymakers have said that they made the Seed Act, a whole act around seed issues and available for implementation. Now the situation is, for a long time both federal and provincial governments are contesting powers and ownership around seed issues and farmers are being grilled in between authorities. Seed quality remains the same as usual, the Seed Act they prepared had no significance at all, couldn't be implemented and has been kept in files only"

GO6

7.3.3.3 Top-down communication

In addition to a lack of horizontal coordination among agencies at federal and provincial levels, GO also reported a lack of vertical communication of key policy documents from federal and provincial scales to district scale. For instance, the district scale GO from AED and EPA stated:

"We need to make climate change part of our [district] plans and policies. Such policies might have developed somewhere at higher levels but I have not seen policies particularly focusing on farmers adaptation to climate change […] No such sharing of policies here, policy documents should come to the district level but there is no route from higher levels of government to district level. Mostly we receive agricultural advisories from top levels which we pass on to farmers"

GO11

"Yes, policies are there but mostly not circulated much to down the hierarchy. I think the agriculture department might have some specific plans or policies motivating farmers to adapt at local level but I am not much aware on these policies and plans [at district level]. In my opinion, farmers' behaviour towards adaptation and incentives for farmers to do adaptation are key elements for farmers to adapt at local level"

GO10

District scale participants viewed misalignment of policy formulation and implementation was associated with a lack of top-down communication. They perceived that implementation of these high-level policy documents was intended to take place at district-scale but they were mostly unaware about the key policy documents of their own department or those of other concerned departments. One GO perceived an absence of coordination among research institutions, policymakers, and policy implementers at the district scale constrained effective adaptation policy responses. However, another participant indicated that during the policy development phase, coordination at the federal and provincial levels is promoted by the circulation of draft policy documents among relevant stakeholders. Collation and incorporation of comments from this inter-departmental consultation occurs but usually, this process does not involve stakeholders at the district scale. GO in general perceived a lack of top-down communication on policy documents as impacting the implementation of these policies at the grass root level. For example, a district-scale AED official expressed:

"Key policy documents such as you have mentioned, the climate change policy 2012, have not been shared with us. We, as part of the agriculture department, are the implementers of any aspects related to agriculture, climate change and adaptation at ground level. If we are not aware of these policies or the relevant aspects of the policies, then how could the implementation take place at ground level? On the basis of my analysis I feel that policies which are being formulated at higher levels have only 10% of implementation significance at field level, and the rest are just for the completion of office paper work and end up in office files and folders. To the best of my knowledge, no comprehensive agriculture policy has been tailored so far. I am not aware of any agriculture department policies particularly focusing on these aspects"

GO6

7.3.3.4 Bottom-up engagement

In addition to top-down communication, participants emphasised the critical importance of bottom-up stakeholder engagement in policies and plans. They perceived that feedback from concerned district-scale field staff and district-scale GO was seldom taken into account when framing national and provincial-scale policy documents. In addition, they indicated that policies are usually prepared for the whole Punjab scale without much consideration of district variations in crop patterns, topography, temperature, and other environmental conditions. These variations suggested a need to tailor responses for each Punjab district instead of having generalised policies. Furthermore, they suggested that problems at the field level are usually at variance from the actions conceived in high-level policy documents. For instance:

"I feel this is very much important to obtain opinions from lower level field staff as these policies and plans will ultimately be implemented at district level. I think that these plans could be implemented much better if field staff opinions and suggestions were obtained in preparing these documents. Our views as field staff are rarely obtained in formulating these policies. Usually these policies are formed at higher levels but then we are forced to implement at lower levels"

GO1

"May be these policies that are prepared at higher levels are addressing the needs of farmers to some extent but I think the effects of these policies do not reach to lower levels. Actually, policies and plans need to be made at district level and these policies should then route from district level to higher levels instead of moving from top to lower levels. If policy documents move from here then they would not only be feasible but also beneficial. If policy documents are to be made on the basis of needs assessment, and after discussing with relevant implementing staff, then this would be effective. Instead if policy comes from top without local engagement then they would be hard to implement it at district level"

GO12

In addition to the lack of bottom-up engagement of government staff, respondents revealed that mostly farmers were not consulted to obtain their feedback and inputs. They perceived that it would benefit farmers if their information was included as part of the government policy-making process. In addition, GO believed that stakeholder engagement was better at the federal and provincial levels compared to the district scale. Moreover, respondents perceived that such stakeholder consultation needed to be 'result-oriented' with a sense of purpose, and that the stakeholders involved should know what their obligations might be under the policy. For example, typical GO views on bottom-up engagement included:

"I think stakeholders' consultation could be improved with group discussions. But the problem here is we usually do not include farmers in such stakeholder consultations when they occur. Farmers are mostly kept out of the consultation process. The few representatives of farmers which I heard in some sittings start using political language. Actually, when they come up a bit they start thinking that they have become leaders and forget that they were representing hundreds of farmers of the area behind them. Whatever the proper issues or real problems of the farmers are, they need to address those instead of their political talks"

GO6

"Usually coordination is not done much at district level and mostly coordination is done among different government departments at provincial level. In provincial level meetings, almost all departments' representatives participate. This type of coordination is not seen at district level. Sometimes, these departments coordinate at district level as well in the case of some working groups on certain tasks. In these working groups, we mostly coordinate with only some departments and not with others. I think we need to include farmers in the form of seminars and meetings with them. Communication needs to be stronger, then the things would likely move in a better way"

GO15

7.3.4 Perspectives on policy and planning constraints

In addition to governance aspects, government officials reported a number of policy and planning constraints that included a focus on mitigation, policy implementation hurdles including capacity constraints, and consistency and equity in policies.

7.3.4.1 Mitigation focus

All interviewed GO acknowledged the significance of climate change adaptation for agriculture and emphasised the need to take practical adaptation actions. However, the interviews reflected a dominance of mitigation over adaptation in the policy landscape, and the same is reflected through practices at the departmental level. For instance, AED officials stated:

"I have not seen any significant policy currently in place unfortunately, which links climate variability and change with agriculture by focusing on adaptation. However, there is a current policy initiative to enhance reforestation [mitigation focused], and we have been given targets for tree plantations at district level. I see that if fully implemented, this policy initiative has the potential to create a bit of positive change in the micro-climate at village and farm fields"

GO6

AED officials described their current engagement in mitigation-focused projects, such as the billion tree plantation initiatives (NDC 2021). In addition to AED, officials from EPA also expressed a clear inclination toward mitigation. EPA GO expressed their focus on converting old brick kiln technology with new technology, applying scrubbers on industrial stacks, and reducing pollution load from vehicles, all these moves to reduce emissions as a mitigation measure for climate change. Other respondents indicated that the subject of climate change adaptation was mostly confined to policy documents only and its practical representation is very limited. For example, respondents from EPA stated:

"I have seen national climate change policy 2012 prepared by ministry of climate change at federal level. Climate change policy stated a number of areas related to farmers' adaptation to climate change. Possibly they have made a few projects for farmers' awareness to adapt at federal level. But work is not visible here at Punjab level. Might be the agriculture department has commenced something on that policy but I have not observed it. In EPA I would say there is no significant work so far on that [adaptation] policy"

GO10

"About climate change adaptation and agriculture, we are at a very primitive stage and this thing has not come into our consideration. The climate change subject is mostly at national level, and coordinated decision making has to be done at the federal level. They participate in meetings here but with reference to our urban area pollution, the agriculture and livestock department look into this [air pollution] from their point of view. Any agricultural policy on adaptation at Punjab level did not come to my notice so far"

GO8

7.3.4.2 Policy implementation

Although GO reported the presence of climate change adaptation policy at the national scale, they indicated little representation of adaptation in programs at the local scale. In addition to relatively uncoordinated governance and a focus on mitigation, GO reported other factors contributing to limited adaptation policy implementation including the absence of an enabling environment and a range of capacity constraints. For instance, senior-level officials from AED and EPA reported:

"Look, I would quote "palaces cannot be built just by talking only". Similarly, all work tasks could not be done just by developing policies only. Policies are the basic documents that show the road map but without fulfilling the related requirements, the policy objectives cannot be achieved effectively. International climate change organisations' funding of climate change adaptation projects is very limited. Government of Pakistan is working mostly at its own level. There is one project on irrigation management by World Bank in progress for the last 2-3 years. Although the focus of this project is not on climate change, however, it will impact climate change issues. There is a need to establish policies and practical demonstration projects with a specific focus on climate change adaptation"

GO7

"So far implementation of these has not come to such a lower farmer level, talks are being carried out at higher levels. Adaptation would require financial input as a component and on that any significant work has not been seen so far. At local level now it may not be possible for farmers to adapt in the light of these policy documents only"

GO8

GO reported a number of missing elements needed to establish an enabling environment for government to act on adaptation locally. Some district scale participants indicated that high-level policies attempted to institute authority at the district scale, 'by hook or by crook' without understanding the local context that could enable or constrain effective implementation. Other GO suggested that for the most part implementation of policies was not planned systematically but instead was often rushed. Moreover, some district scale participants perceived that policy guidelines and recommendations are usually developed for implementation by 'higher-ups' without addressing the basic issues of farmers, meaning that projects were often ineffective in achieving their goals. For example:

"Policies here are quite general. Specific to climate change, unlikely that we have made specific action plans in agriculture with the view of climate change only. But usually departmental letters and recommendations are being carried out. This may not be the case that climate change was taken as a subject for which some action plans were made and then action plans implemented. There is nothing specific in this regard. We usually do things on an urgent basis. Like if a flood occurred, we have to raise awareness. If crops were affected, then an advisory comes from the department to take action and we inform farmers the same. We act according to whatever issues come up from time to time [...] these policy documents rarely meet the needs of farmers at local level. Sometimes things [are included] which are not to the benefit of farmers and not aligned with the needs of the area are also expected to be implemented"

GO5

"Policies are prepared at higher levels and completed there in papers. Policies come down in such a way that I would say 10% implementation at field level. We try to forcefully apply policies at lower levels but if we were not fulfilling the related requirements [of farmers] then how such policies can be applied? Last year, I prepared a farmer project and tried my best to get it implemented at district level. The idea was to provide farmers small machinery items on rent from government for their use in their farm fields with the view that we had been forcing farmers to adopt measures but not helping them to change management, saying it's the farmers problem so you have to solve any way you can. But at the end the department couldn't offer anything to farmers, and the project could not be implemented"

GO6

GO reported a range of institutional, financial, and technical capacity constraints hampering the effective implementation of adaptation policies and plans. Participants emphasised a lack of human resources in government departments and that existing staff are already overburdened. Also, some GO suggested that the shortage of human resources to engage farmers could be partially supplemented through the use of online communication mechanisms where appropriate. In addition, most of the participants suggested the need to create a dedicated section on climate change within EPA and AED. One GO suggested that institutional capacity could be improved through a needs assessment to rationalise, and potentially redeploy, existing departmental human resources to address climate change adaptation. Moreover, all the participants emphasised the need to build their technical capacity through training, research, and development to support farmers' adaptation actions. For instance, respondents from AED and EPA stated:

"There is much improvement needed about the quality of crop seeds but there is only one seed department at federal level. Actually, the thing is they don't have staff to deal with seeds issues. At district level, there is one staff member [for seeds] but with no resources, no capacity. The person is responsible for purchase of seeds, testing and the same person is doing registration and issuing farmers' certification, he is overburdened […] Institutional capability is not as it should be. Government departments are not able to deliver as they should be due to lack of resources. Each government staff member is burdened and may not able to reach out to the whole area under their jurisdiction. I think media campaigns may be able to better reach farmers"

GO12

"I think the technical capability of concerned government departments is lower than it should be. If they don't have resources and low technical capability how they can better assist farmers? Training, refresher courses, like training of the teachers, is required at departmental level through planned activities instead of a haphazard manner. There is a need for capacity building of research institutions, they should suggest to us those crop varieties which are better adapted to climatic changes. As temperatures are rising, we should have varieties of cotton which could bear the heat and not be shedding. We suggest farmers to apply less irrigation water to crops but sometimes even no water is available to farmers, there is a need to develop heat tolerant crop varieties through research. Particularly, we should include climate change adaptation in our research program, such aspects need to be considered where policies are approved"

GO14

In addition to institutional and technical capacity, participants pointed to the critical importance of financial capacity to assist farmers' adaptation actions. They were of the view that the diversion of human resources to address climate change and the raising of technical capacity through staff training may not be sufficient unless financial resources are also provided to farmers. For example, a field officer and a senior official stated:

"Whenever we wish to bring some change, as we are field-based staff many projects come to mind and when problems arise then their possible solutions also come to mind. Farmers also suggest solutions to their problems but we don't have funds to execute those. Farmers suggest to us that they are not financially sound to bring changes and require financial assistance from us. But when we come back and talk in the department, the situation here is our salaries are being managed with difficulty, leaving others things aside"

GO6

"With respect to climate change and adaptation, departments and sections are insufficient. There are few effective departments formed yet relating to climate change. Like the case of Ayub Agricultural Research Institute (AARI), although a climate change centre was formed by notification in the research institute, this centre does not have proper separate set up or facilities, machinery, funds and equipment. This centre depends on funds but the situation is this that Pakistan doesn't have funds and international funding is not available. How can this be working effectively without appropriate funds? When this climate centre was just formed in AARI, then I was asked by the government to give some projects for this centre. I developed a project and sent it. Later I received a response that funding for this project should be done from AARI's own sources [not from central government]. Tell me, how AARI can execute this additional project from its own resources? If you want to develop a centre or department and wish it to work then you need to allocate funds for that"

GO7

7.3.4.3 Consistency and equity in policies

GO not only reported constraints in policy implementation but also a number of constraints to consistency and equity in policies that limit the adoption of these policies. GO reported frequent job rotations among government staff causing instability in district management and poor execution of policies at district scale. Also, respondents noticed discontinuity in mutual dependency of projects relying on external [foreign funding] and internal [government of Pakistan] funding sources. Moreover, GO reported inconsistency in district management systems through different types of command systems for government departments at the district scale including centralization and de-centralization. For example, respondents stated:

> "Prior to 2016, the district government system was run by District Coordination Officers (DCO). Within this system, under the umbrella of Executive District Officer (EDO), many different departments held discussions and liaised with each other. Now we are again in transition away from devolution, so all these departments now are again separated from each other. At that time all departments were on same line but now they are not. I feel there is not much coordination among them, there is less now than before"
>
> GO5

> "I feel no stability in public sector jobs due to frequent rotations. A newly appointed officer needs some time to understand the job requirements and responsibilities, but when the person gets to know about the position and be in a position to execute tasks, then the officer is transferred to other locations"
>
> GO2

> "About funding availability for projects, say one department has a World Bank, Asian Development Bank (ADB) project or any other international organisation funded project, and another department has their project being funded by government of Pakistan. When government financial resources are reduced then it stops funding projects and projects are then capped. Government has its own priorities and it decides where to divert money and what the priority is [unlike externally funded projects]. Many of our projects were capped in such a way. I feel these projects were running very well mutually but when projects were capped like this then this effects the whole program"
>
> GO4

In addition to consistency, GO reported a number of factors contributing to inequity in policies such as crop water management, access to loans, access to markets, and in rates. They indicated that influential landowners take additional benefits through policy loopholes. In addition, participants perceived discrimination in policies against small-scale farmers as compared to large-scale, influential farmers. They viewed small-scale farmers as suffering most from the effects of climate change and having fewer means to support their climate adaptation actions, but also suffering most from the inequity in policies. For example, GO stated:

> "Farmers who are situated at canal head receive more water and tail end farmers receive negligible share. There are problems among farmers, a farmer who is more powerful uses more water and water stealing issues arise. Influential land owners have approval for [more] water even for their gardens and fish ponds […] There should be flat [water allocation] for each piece of land from canal head to *moga* [tail] where the piece of land is situated. It should not be like that if landowner has [say] 25 acres of land at canal head and is influential getting more canal water allocation. While the same 25-acre landowner at the tail end and less influence is getting very less water allocation"
>
> GO1

> "Loans usually are given to particular land holders considering that they have to pay them back. But farmers of smaller land holdings are neglected by private banks and they have their grievances. Even government banks do not address small land holding farmers considering that they don't meet their criteria and small landholding farmers are being neglected. Areas where farmers have less land holdings need to be treated separately with different standard operating procedures (SOP's) than farmers who have large land holdings. Owning a small land

holding is not a mistake for which farmers should be mistreated like that. If the consideration is that small land holders produce less than they should be given smaller loans but on lower interest rates"

GO3

"I think exploitation of farmers in rates is greater in sugarcane crops as sugarcane buying is in the hands of few people. In the case of sugarcane sales, exploitation of farmers takes place except for those influential farmers who have connections. Small [scale] farmers should be paid some minimum profit, at least enough to keep him alive. Larger [scale] farmers are coping with climatic changes as they have resources and savings to do that. But small [scale] farmers don't have resources and savings, therefore they are effected more from this and bear extra stress. There is a need for capacity building of these small farmers"

GO12

7.4 Discussion

The local spatial scale and local institutions have been deemed particularly important for adaptation because climate change impacts materialise most tangibly in a given local context, and local institutions are often considered best placed to promote adaptation through context-based measures and strategies (Lee et al., 2020; Lesnikowski et al., 2021). Local institutions play several roles in adaptation including initiating, shaping, and reshaping the actions and abilities of communities to pursue various adaptation practices; the supply and dissemination of climate-related information; planning response and recovery from climate crises; and promotion of resilience (Mubaya et al., 2017; Bekele et al., 2020). Through qualitative engagement with provincial and district GO of Punjab, this study explored the capability of the government to support local adaptation by farmers. Although I found widespread realization among GO of the impacts of climate variability and change on agriculture, at district scale significant barriers were identified that constrained the establishment of an enabling environment to support adaptation, a key role for institutions (Azhoni et al., 2018; Austin et al., 2019). In this study, the constraints on local adaptation linked to the role of government included:

- Limited capacity to establish an enabling environment to support farmers' adaptation actions owing to water, financial and human resource constraints.
- Policy planning processes that exclude the participation of vulnerable farming communities and lower-tier public sector actors essential to local implementation of adaptation actions.
- Presence of high-level national and provincial adaptation policies and programs that have largely failed to influence adaptation action at the district scale.

7.4.1 Enabling environment for adaptation

The capacity of the government to establish at a district scale in vulnerable areas of Punjab an enabling environment for farmers' adaptation was severely constrained by a lack of resources, particularly a deficiency of water resources for irrigation. Managing irrigation under a rising physical and economic scarcity of water while limiting consumptive water use is an urgent global challenge (Balasubramanaya et al., 2022) and a noteworthy pressing issue experienced in Punjab. GO agreed with farmers that their crops' water requirements currently were not being met. However, they indicated that farmers' expectations for irrigation water supply were unlikely to be satisfied owing to issues mostly beyond their immediate control and linked to water management at broader scales (i.e. national and provincial transboundary issues). For example, catchments on which district farmers depend for irrigation water span both national and provincial administrative boundaries influencing the management and storage of hydrological flows. Conflict over water is a long-standing issue of contention between Pakistan and India as headwaters of major rivers such as the *Indus River* flow from the Himalayas through India, which controls the amount flowing into Pakistan (Jayaram & Sethi, 2023). The flow of water from other rivers, such as the *Jhelum River* and *Chenab River* are similarly affected by the allocation of water to Pakistan from dams under Indian control (Qamar et al., 2019). Furthermore, the distribution of *Indus River* water to provinces within Pakistan is subject to historical inter-provincial transboundary water-sharing issues (Khan et al., 2020; Janjua, 2020; Imran, 2021). These transboundary problems are compounded by the influence of climate change, which is altering river flows due to monsoonal variations and drought-like conditions becoming more common and unpredictable in South Asia (Baruah, 2022). In addition, GO reported that the storage capacity of existing water reservoirs has deteriorated over time because of high rates of sedimentation (e.g. Qureshi & Ashraf, 2019; El Aoula et al., 2021) contributing to water scarcity at district scales. Although initially, the irrigation system enabled the cultivation of cash crops such as cotton in these water-constrained areas of Punjab, the recent experience of farmers raises questions about the long-term feasibility of cotton production in such environments. These supply-side water limitations on irrigation combined with more variable rainfall under climatic changes have led also to the installation of tube wells and overexploitation of scarce groundwater resources by farmers (a common coping strategy globally e.g. Aryal et al., 2020), an issue of concern due to potentially endangering aquifer sustainability (e.g. Latif & Ahmad, 2009; Fishman, 2018). Farmers suggested that the solution to water shortages lay in augmenting supply through the construction of additional dam storages, which is beyond the capacity of local GO to influence. GO indicated the feasibility of previous proposals for the construction of large dams (e.g. *Kalabagh dam*) has often been problematical due to provinces' concerns about salinity, water logging, inundation of agricultural land for water storage and displacement of local communities (Bhatti & Farooq, 2014; Imran, 2021). In common with Pakistan, India, a neighboring country in South Asia with a long history of irrigated agriculture and rapidly depleting groundwater resources (Rodell et al., 2009), has switched focus from augmenting water supply to managing demand through incentives-based approaches and water-saving cultivation practices for staple crops (Fishman et al., 2016; Mitra et al., 2021). In terms of water demand, GO attributed farmers' water scarcity to the use of inefficient farm practices (such as flood irrigation). However, while they sympathised with farmers' pleas for assistance, GO identified many shortcomings in their own enabling environment, set by higher levels of government, that constrained the ability to address issues such as the lack of research into the development of drought-tolerant crop varieties and limited technical and financial capability to provide farmers with more efficient drip irrigation technology (e.g. Aziz et al., 2021).

In addition to hydrological constraints, limited financial resources also curtailed district government action to establish an enabling environment for adaptation by Punjab farmers. Despite being motivated to help, GO indicated that the district-scale financial resources available to support farmers' adaptation were poor and heavily relied on finance allocations from the provincial government. Provincial government budgets were similarly squeezed owing to the budgetary limitations of the Pakistan national government, which is under the burden of foreign loan repayments (Kumar et al., 2019; Khan & Tariq, 2020). Lack of financial resources is cited as a common barrier to encouraging integrated adaptation action among local governments (Mertz et al., 2009; Sietz et al., 2011; Rahman, 2017; Yulandari et al., 2023) and local authorities are often financially ill-equipped to manage climate risk and implement local adaptive responses (Ojwang et al., 2017; Marin-Puig et al., 2022). While GO recognised the difficulties faced by farmers through declining terms of trade and the complexities around obtaining loans, which limits farmers' financial resources (e.g. Bhave et al., 2016), they criticised farmers for their heavy dependence on and calls to expand government subsidies where local governments have limited funds for disbursement from national and provincial governments. Moreover, they expressed reservations about the use of agricultural loans by some farmers for non-agricultural (cultural and domestic) needs making their repayment difficult. Despite these reservations, however, GO identified several deficiencies in the local government's capacity to meet farmers' expectations around improvements to crop marketing arrangements, such as a lack of government buying centers and limited government storage capacity for crops, and inefficient government agri-credit services. This widening gap between local government capacity and farmers' service expectations has been exploited by opportunists (e.g., market agents) that results in trade-offs for small-scale farmers in their ability to negotiate fair prices for their crops (Antwi-Agyei et al., 2015).

My findings on market-related barriers and local government financial capacity constraints are consistent with a number of developing country studies in other contexts (e.g. Ojha et al., 2014; Islam & Nursey-Bray, 2017; Singh, 2020; Lamichhane et al., 2022). Institutional capacity is considered a fundamental component of local responses to climate change because it is an enabling condition for climate adaptation planning and implementation (Cid & Learner, 2023). However, I found several capacity constraints among the key challenges to planning and implementation of climate change adaptation measures faced by district governments in Punjab. GO indicated that the ability of district governments and local agency staff to respond to farmers' concerns was heavily constrained by a lack of human resources, ambiguity of roles and poor information flow among agencies and between levels of government, and insufficient finances to improve local physical capital such as availability of adapted crop cultivars, farmers' access to markets, and local infrastructure (especially roads). Previous studies have identified a lack of human resources and inadequate internal organization as key barriers to enabling and progressing adaptation (e.g., Hoppe et al., 2016; Campos et al., 2017). Also, where human, physical, and financial capital is lacking, adaptation planning is likely to be constrained (e.g. Pasquini, 2020).

7.4.2 Participation in policy planning processes

Knowledge co-production, co-design, and participation are all principles that have been associated with sound approaches to adaptation (Nightingale et al., 2020; Wamsler et al., 2020; Williams et al., 2020). Participation of stakeholders can influence adaptation planning processes by enhancing climate vulnerability assessment, specification of adaptation needs, solicitation of knowledge, prioritization of adaptation actions, and funding (Sherman & Ford, 2014; Hafezi et al., 2018). In this research, district-scale GO of Punjab indicated that they were rarely engaged in national and provincial adaptation policy planning processes and, when invited to participate, were unable to because of a lack of resources (human and financial). I found lack of engagement at the district government scale occurred in both vertical (across tiers of government) and horizontal (across organizations) dimensions. Aside from resource constraints, district GO attributed a lack of engagement in adaptation policy and planning to siloed approaches to communication across tiers of government leading to ad-hoc coordination among government departments in adaptation action. Inadequate actor inclusion in policy formulation and insufficient coordination can result in limited awareness of existing policies, leading to a lack of ownership and limited compliance (Ampaire et al., 2017). A failure to incorporate bottom-up feedback into top-down policy processes has been emphasised in a number of studies as contributing to ineffective adaptation responses (e.g. Islam & Nursey-Bray, 2017; Ishtiaque et al., 2021).

Effective national adaptation policy planning arrangements call for the inclusion of vulnerable groups in participatory processes (Holler et al., 2020). Despite this, I found that communities from the vulnerable districts of Punjab were largely unrepresented in current policy formulation and adaptation planning processes. Notably, GO indicated that vulnerable farmers were not provided opportunities to contribute knowledge or to communicate their feedback in existing or upcoming policy planning processes. District GO appeared reluctant to raise expectations of farmers through engagement on adaptation needs where resources to support adaptation actions from higher levels of government were unlikely to be forthcoming. In addition, some GO expressed reservations about the ability of farmer representatives to contribute meaningfully to formal high-level bureaucratic meetings where meeting agendas tend to be dominated by a few major actors (e.g. Ishtiaque et al., 2021). This situation suggests the need for both new participatory forums to accommodate regular engagement with vulnerable farmers (e.g. Thondhlana et al., 2015; Cochrane et al., 2017) and improved resource allocation (e.g. Shackleton et al., 2015) to tailor adaptation policies and plans for the local context.

7.4.3 Implementation of high-level policy goals

Best practice adaptation policy and planning processes consider key elements including stakeholders' engagement, information flow, resources, and support networks as channels of adaptation policy diffusion (Lim et al., 2005; Keskitalo et al., 2019; Schoenefeld et al., 2022). National and provincial government policies and programs in Pakistan aiming to promote climate change adaptation are devolved to the district level for implementation. However, policies tended to be reactive responses from the government to deal with climatic adversities, such as floods and droughts, rather than proactive responses that might reduce the consequences of climate impacts. Additionally, GO noted that national policies and plans were expected to be applied at district scale as a priority seemingly without recognition of the geographical realities of vulnerable Punjab districts, which were unlikely to achieve intended policy objectives. Previous studies show that effective planning for climate change adaptation and resilience is contingent upon comprehensive risk assessments to identify vulnerabilities to current and future climate impacts (e.g., Adzei & Alornu, 2023). The formulation of adaptation policy and plans in the absence of an understanding of local vulnerability renders centralised planning for climate change ineffective and responses to climate impacts largely reactionary (Pilato et al., 2018; Forino et al., 2018; Fila et al., 2024). Rather than simply responding to or managing climate risks, ongoing and deliberate actions that purposefully seek to bring about systemic change are required in which communities are empowered to participate through government support for adaptation initiatives (Pelling, 2014; Few et al., 2017; Davies et al., 2020).

The Pakistan Government seeks to promote national climate action through the implementation of Nationally Determined Contributions which establishes the country's priority programs (NDC 2021). However, this policy is dominated by mitigation actions rather than focusing on local adaptation and is misaligned with the expectations of farmers and the capacity of vulnerable district governments in Punjab. For example, it attaches a high priority to the reduction of future GHG emissions from *energy generation from renewable energy sources* and investment in nature-based solutions through an *afforestation program* for land-use change and forestry, which are encompassed within two priority adaptation programs, i.e. *Recharge Pakistan* and *Protected Areas*. *Recharge Pakistan* envisages the reduction of flood risks while under the *Protected Areas* initiative, total protected areas in the country will be enhanced to preserve rare fauna or flora, provide green job opportunities, and promote eco-tourism. While these initiatives demonstrate the national government's commitment to global climate action, their implementation at local scale requires district governments to participate in 'adaptation' interventions that do not speak to the needs of local farmers identified in this study (Chapter 6) for enhanced irrigation infrastructure, improved water management, financial resource management, and better-adapted crop cultivars. Rather these interventions appear to be answering international calls for emissions reductions (Lo & Cong, 2022).

7.5 Conclusion

Adaptation to climate change is highly context-specific and requires local action. Local institutions can play a key role in facilitating adaptation by tailoring measures to the specific circumstances of local communities. This chapter has explored the capacity of local government in enabling adaptation to climate change by farmers in vulnerable areas of Punjab. I found that the local government's ability to create a supportive environment for farmers' adaptation at the district level was severely hampered by resource shortages and policy barriers. Notably, policies and plans were prioritised for implementation at the district level without regard for the geographical realities of vulnerable farmers, which undermined the effectiveness of the policy goals. Also, policy planning processes were missing the participation of vulnerable farming communities and lower-level public sector actors who were crucial for the local implementation of adaptation actions. Policy development for adaptation could benefit from co-production processes that are tailored to the local context and can strengthen knowledge, foster capital, and facilitate joint actions. However, capacity constraints within the government limit the use of innovative approaches. My findings contribute to the development of local adaptation plans while providing insight into the existing and potential barriers that the national adaptation policies should seek to address.

Chapter Eight: General Discussion

8.1 Introduction

This discussion engages the multifaceted vulnerabilities of the Punjab region through the particulars of adaptation experienced by farmers and local GO. It seeks to strengthen adaptive capabilities at the local scale by weaving the needs of the farming communities with the resource-constrained realities of local governance to explore the challenges encountered by farmers in regions vulnerable to climate change. Additionally, it draws from thesis findings to shed light on the inadequacies of top-down policy development and the constrained capacity of local government entities to implement adaptation initiatives. In so doing it emphasises the essential nature of bottom-up needs assessments in shaping effective government strategies to support adaptation. Finally, this discussion highlights the transformative potential of participatory co-production as a bridge between top-down policies and contextual realities, substantiating its role in shaping effective climate change adaptation.

8.1.1 Alignment of research objectives

The quantitative vulnerability assessment presented in Chapter 5 advanced the understanding of agricultural vulnerability to climate change in the Punjab province of Pakistan as a policy-science need identified in Chapter 1. In Chapter 5, Research Question 1 *(RQ 1: Using available data, can an index of vulnerability be constructed and mapped that identifies the most climate change vulnerable districts for the major crop subsector of Punjab province?)* has been addressed through the vulnerability assessment process, providing an understanding of the multifaceted vulnerabilities faced by the agricultural sector in Punjab. Notwithstanding the difficulties of obtaining relevant data at fine scale, I conducted an agricultural vulnerability assessment that generated exposure, sensitivity, and adaptive capacity maps at the district scale within the Punjab province. In Chapter 5, I discussed the findings of the vulnerability assessment and the aspects of adaptive capacity (i.e. human, social, and financial indicators) that were most closely correlated with adaptive capacity, which highlighted the potential for enhancing the policy-science interface across scales, bridging the gap between high-level policy directives and actionable, localised adaptation strategies. This study, then, has filled a critical void in the existing literature, shedding light on the specific areas susceptible to climate change impacts that were subjected to deep, qualitative analysis in subsequent thesis chapters.

In addition, the alignment of the vulnerability assessment with the VSA concept has substantiated the theoretical underpinning of this research. The concept of VSA as detailed in Chapter 3, emphasises and focuses on vulnerability, particularly in the context of agriculture and climate change (refer to literature review Chapter 2 on these key knowledge areas of this research). The concept's emphasis on the identification of areas vulnerable to climate change resonates well with the objective of this vulnerability assessment, providing a theoretical foundation for the study's findings. The findings of this assessment not only contribute to the academic discourse but also hold practical implications for policymakers and practitioners seeking to enhance climate change adaptation efforts in the Punjab region.

By engaging in qualitative research with farmers and GO stakeholders (Chapters 6 and 7), I addressed the Research Questions 2 (*RQ 2: For selected districts of Punjab identified through vulnerability mapping, what constrains and enables adaptation to climate change from farmers' perspective?) and 3 (RQ 3: What constraints are faced by district-scale government officials in supporting farmers' adaptation in vulnerable districts of Punjab?).* My qualitative study illuminated the nuanced factors regarding adaptation constraints and enablers that shape stakeholders' adaptive actions. Furthermore, it explored the effectiveness at the local scale of formal, top-down policy interventions aimed at climate change adaptation. In Chapters 6 and 7 of the thesis, I explored the nexus between the VSA concept and the critical dynamics observed within the context of vulnerable regions of Punjab province identified in Chapter 5. Findings revealed the complex relationships between my empirical results and the underpinning VSA model, emphasising the relevance of 'down scaling' in shedding light on the challenges and opportunities faced by farmers and GO under climate change (Castro & Sen, 2022).

In this thesis I used a mixed methods research approach (Hennink et al., 2010). The merger of quantitative vulnerability assessment and qualitative stakeholder engagement has provided a broader understanding of the challenges faced by farmers and local government officials. This insight has paved the way for the identification of co-production interventions that align with the VSA concept, thereby facilitating the creation of an enabling environment more conducive to adaptive actions (discussed below).

8.2 Contextualising vulnerability assessments

The process of developing vulnerability indices and their subsequent mapping has been instrumental in creating a foundation for addressing the complex challenge of climate change. The vulnerability assessment reported in Chapter 5 segregated and characterised areas of Punjab province based on their vulnerability levels, offering it as an initial yet crucial step towards adapting to climate change (e.g. Iliyyan et al., 2022) because it challenges the notion of a one-size-fits-all approach which often lies at the heart of centralised institutional responses to climate change (Brown, 2011). Assessing vulnerability has the potential to offer many benefits including devising targeted adaptation strategies (e.g. Metcalf et al., 2015), prioritisation of resources and strategic planning (e.g. Sherbinin et al., 2017), informed decision-making and benchmarking processes (e.g. Thiault et al., 2018).

In this study, agricultural vulnerability assessment effectively identified regions of Punjab that are most susceptible to climate change impacts. Such prioritisation allows policymakers and stakeholders to allocate limited resources and efforts where they are most needed, potentially optimising adaptation initiatives. The categorisation facilitated by vulnerability indices allows for strategic planning. By understanding the unique vulnerabilities of regions and communities, adaptation strategies can be tailored to address specific challenges increasing their effectiveness (O'Brien et al., 2004). These indices can provide decision-makers with a data-driven foundation to make informed choices regarding adaptation measures. This approach empowers decision-makers to choose strategies that align with the specific vulnerabilities of each situation, encompassing not only spatial areas but also social factors. An initial assessment of vulnerability sets a baseline against which future progress can be monitored. As adaptation strategies are implemented, changes in vulnerability levels can be tracked, guiding adjustments and enhancements to policies. However, it is imperative to acknowledge that vulnerability encompasses a dynamic intersection of biophysical and socio-economic elements due to various factors such as its multi-dimensional nature, interconnected variables, and contextual specificity (e.g. Nelson et al., 2023). However, vulnerability is not confined to a single dimension but rather emerges from a complex interconnection of biophysical and socio-economic factors that are connected in a complex manner. Communities with limited resources might have higher vulnerability due to their reduced capacity to cope with extreme climatic events. For example, findings of this study indicate that small-scale farmers of Rajanpur district in particular exhibit higher vulnerability due to several biophysical and socio-economic factors, including high exposure to extreme climatic events (floods, drought), limited access to irrigation water, poor groundwater quality, limited market access, the influence of market intermediaries coupled with weak access to formal credit, lack of crop storage infrastructure, and limited access to government-subsidised farm inputs. While mapping in Chapter 5 identified districts that shared high levels of vulnerability, each region's vulnerability profile was unique due to variations in local geography, and socio-economic conditions. Therefore, this diversity underscores the importance of nuanced assessments and tailored adaptation strategies.

The spatial variations in vulnerability observed across the Punjab region underline the key role of adaptive capacity, an intrinsic part of vulnerability, in determining a community's susceptibility to climate change impacts (Jacobs et al., 2015; Woroniecki et al., 2021). In regions where vulnerabilities are more pronounced, the lack of adaptive capacity can exacerbate the impacts of climate change. Communities with higher adaptive capacity are better equipped to mitigate, cope with, and recover from these impacts (e.g. Afkhami et al., 2022). The capacity for adaptation allows communities to effectively utilise available resources to address vulnerabilities, and communities with stronger adaptive capacity can better maintain economic stability in the face of climate change shocks (e.g. Zhong et al., 2022). This stability enables them to invest in long-term resilience-building measures. Higher adaptive capacity also reduces dependency on external aid during climate-related disasters, enabling communities to take charge of their own resilience-building efforts (e.g. Tofu & Wolka, 2023).

While mapping offers valuable insights into spatial dimensions of vulnerability including broad-scale policy formulation and spatial prioritisation, it has its limitations. Critiques of vulnerability mapping provide a compelling rationale for complementing quantitative mapping with qualitative local analysis. One of the primary criticisms of vulnerability mapping is its potential to oversimplify complex socio-environmental dynamics (De Sherbinin et al., 2019). By relying solely on quantitative data and indicators, vulnerability mapping may not capture the complex factors contributing to vulnerability. It tends to reduce multifaceted vulnerabilities to numerical values, potentially missing critical nuances. Vulnerability maps often lack a comprehensive understanding of the local context. This limitation can result in strategies to address vulnerability that are mismatched with the specific needs and challenges of the community in question. In addition, vulnerability mapping mainly relies on external data sources and expert-driven assessments, often neglecting the perspectives of the local population (Preston et al., 2011). This exclusion of local knowledge can lead to a lack of ownership and relevance in adaptation strategies. Moreover, vulnerability maps are typically snapshots of vulnerability at a specific point in time (Leichenko & O'Brien, 2012; De Sherbinin et al., 2017) and may not account for dynamic changes and evolving vulnerabilities, especially in the face of climate change. This static nature can hinder the flexibility of strategies over the long term. In light of these critiques, it becomes evident that vulnerability mapping, while a valuable tool, has limitations that necessitate a more comprehensive approach. The current study sought to address these shortcomings of vulnerability mapping through qualitative local analysis, which explored the contextual aspects of adaptive capacity, providing a more nuanced understanding and facilitating the development of context-specific adaptation strategies.

In this context, a synergistic relationship between top-down national policies and bottom-up community engagement becomes imperative. This is particularly evident in the findings of this study where farmers highlighted critical issues such as inadequate local consultation, inconsistent planning, and limited support for farm-scale actions (Chapter 6, sections 6.3.3.1 to 6.3.3.4). These concerns underscore the importance of including localised needs in the adaptation process. Top-down policies provide a broad basis for adaptation, while bottom-up engagement captures localised knowledge (e.g. Andriesse et al., 2022). Together, they create a more comprehensive perspective on vulnerabilities and feasible strategies. Bottom-up engagement ensures that the voices and needs of local communities are integrated into adaptation policies (e.g. Islam et al., 2020). This inclusivity enhances the relevance and effectiveness of national strategies. The findings of this research also highlighted governance challenges, such as siloed approaches, ambiguous roles and disconnected communication in adaptation planning, as outlined in Chapter 7 (sections 7.3.3.1 to 7.3.3.4). Addressing these gaps requires fostering a collaborative framework that aligns top-down directives with bottom-up initiatives. The synergistic relationship fosters a feedback loop, where local insights inform policy adjustments, and policy agendas support community-driven initiatives. This iterative process refines adaptation strategies over time. The combination of top-down and bottom-up approaches allows for tailored interventions that consider the regional context and enhance the impact of adaptation measures (e.g. Cash et al., 2002, Cash et al., 2006; Bremer et al., 2022). Underlying the multifaceted nature of climate vulnerabilities and by integrating diverse perspectives, the adaptation strategy becomes more granular and capable of addressing the complex interplay of factors (e.g. Maikhuri et al., 2019). This integration empowers communities to co-create contextually relevant adaptation pathways, effectively bridging the gap between macro-level policies and localised needs. This aspect is further explored in the subsequent section on co-production.

8.3 Challenges to climate change adaptation

Deficits of livelihood capitals, including natural, social, human, physical, and financial capital, impose capacity constraints on farmers' ability to adapt to climate change in Punjab. Fundamental to the construction of livelihoods in agriculture is the transformation by farmers of natural capital into other forms (Jacobs & Brown, 2011). Deficits of natural capital, in the form of natural resources or unfavourable seasonal conditions, set limits to agricultural productivity. In this study, unreliable rainfall coupled with the limited availability and uncertainty of irrigation water (natural capital) significantly impeded farmers' capacity to sustain agricultural productivity. Reduced water availability during critical crop growth stages results in yield losses (Borsato et al., 2020). However, farmers’ capacity to adapt to deficits of natural capital were impeded by shortfalls of other forms. Notably, the lack of engagement among stakeholders (social capital) hampered the establishment of support systems that might be responsive to farmers' evolving needs in Punjab. Strengthening both vertical (farmer-government) and horizontal (farmer-to-farmer) social capital is essential for overcoming these limitations and fostering effective engagement among farmers and between farmers and government institutions (Cofre-Bravo et al., 2019). Poor knowledge exchange (human capital) among stakeholders in Punjab hindered the effective knowledge sharing and dissemination of crucial information for the adoption of adaptation strategies and available support programs. Effective engagement and knowledge exchange foster a deeper understanding of local agricultural systems, practices, and shared learning essential to enabling the identification of adaptation measures that align with farmers' needs and realities (Haddaway et al., 2017; Aich et al., 2022; Feo et al., 2022). Farmers in Punjab faced challenges in accessing formal credit with imperfect markets (financial capital), characterised by poor market access, price volatility, and limited market information. Additionally, the lack of access to farm inputs (physical capital) further reduced farmers' productivity. Addressing these capital constraints is crucial for enhancing farmers' adaptive capacity and ensuring food security in the face of climate change challenges.

Adaptive capacity, therefore, is seldom influenced by single forms of capital. More often, there is an intersection among various capital types in relation to particular elements of the enabling environment for adaptation. The interaction with farmers and government informants in this thesis highlights how a combination of different assets and a conducive environment can foster adaptation. Because of the intersection among capitals, action to address deficits in one capital alone in the absence of improvement of interacting constraints in other capitals is likely to produce sub-optimal outcomes for adaptation because a balanced portfolio of assets is critical to adaptive capacity (Jacobs et al., 2015). For instance, this situation was evident in the interaction between natural and financial capitals in the context of Punjab, where the aspirations of farmers to implement advanced adaptation practices (such as the adoption of water-efficient drip irrigation) were hindered by the lack of sufficient financial resources to support investment in equipment. This indicates that farmers needed access to and used a variety of forms of capital to support their livelihoods and well-being in the face of climate hazards. Nevertheless capital stocks alone were not sufficient for adaptation, as farmers in Punjab also faced challenges in the enabling institutional and policy environment that constrained their adaptation outcomes. For instance, farmers in this study encountered barriers to the enabling environment such as a lack of supportive policies, insufficient stakeholder coordination, and weak governance. Therefore, farmers not only required crucial capitals but also needed an enabling environment that incorporated facilitating policies and effective governance to provide them with incentives, resources, and support for adaptation.

Adaptation to climate change encompasses a spectrum of responses including coping (maintaining the status quo), incremental changes (modifying within limits), and system transformation (fundamentally altering in pursuit of a new state) (Pelling, 2010; Bene et al., 2018). The findings of this study indicate that adaptation by smallholder farmers in Punjab consisted predominantly of coping mechanisms and incremental strategies to maintain their livelihood systems in response to the changing climate conditions. Coping strategies, such as adjusting planting dates, modifying fertiliser application, and altering crop water management, were readily embraced as immediate, reactive measures when faced with climate-related shocks, like heatwaves. Also, incremental changes, such as diversifying crop cultivation, were adopted by farmers as moderate and proactive adjustments to enhance their existing livelihoods. Several other studies with a focus on Pakistan have recognised the widespread adoption of these coping and incremental adaptation strategies in response to climatic changes (e.g. Arshad et al., 2017; Habib ur Rahman et al., 2018; Abid et al., 2019). This recognition stems from their ease of implementation and cost-effectiveness. Nevertheless, it is crucial to acknowledge that the enabling environment plays a role in restricting adaptation to more limited responses. Government and related institutions play a pivotal role in addressing these constraints, which encompass aspects like effective information and knowledge exchange platforms, the development and dissemination of improved crop cultivars, the strengthening of forms of social capital, improved financial accessibility, and enhanced water governance. The distinction lies in understanding where farmers can independently implement adaptation measures and where they require assistance from institutional actors. By reinforcing supportive measures and facilitating availability of necessary resources, governments can empower farmers to enhance their adaptive capacity, promote deeper change, and ensure long-term livelihood security.

Formal institutions such as government entities, play a pivotal role in supporting vulnerability reduction and climate change adaptation (Klein et al., 2017). At the national level, governments serve as the primary architects of policy frameworks and funding mechanisms aimed at addressing climate-related challenges (Fankhauser, 2017). Their role extends beyond policy formulation to the allocation of resources and coordination of various stakeholders (Hansen et al., 2019). In particular, local governments are essential actors in climate change adaptation (Birchall et al., 2023). Local governments serve as a crucial link between national policies and local action in climate change adaptation. Several factors underscore the importance of local governments. For instance, local governments are in close proximity to affected communities (Amundsen et al., 2018). This proximity allows them to gain firsthand insights into the specific vulnerabilities and adaptation requirements of their constituents. In addition, local governments can develop and implement tailored adaptation strategies that are context-specific and responsive to the immediate challenges faced by their communities (Lesnikowski et al., 2021). This customisation is crucial for effective adaptation. Moreover, local governments are instrumental in translating national climate policies into actionable local initiatives (Bhatta et al., 2017). They are often held responsible for ensuring that climate adaptation plans are put into practice (Dunford, 2018). Therefore, as frontline institutions, local governments can have an indispensable role in building resilience and reducing vulnerability to the impacts of climate change.

The adaptation response of developing countries is emerging through various formal and informal measures to address the devastating effects of climate change. A common response among countries in the developing world is to seek to address adaptation by creating National Adaptation Plans (NAPs), whereas others concentrate on individual projects and initiatives funded by donors, each targeting distinct challenges (UNFCCC 2022; Ishtiaque et al., 2021). Pakistan, a lower middle-income country of agricultural significance, has yet to initiate a National Adaptation Plan under the UNFCCC guidelines for its medium to long-term adaptation responses (NDC 2021). Despite the presence of top-down policies and plans (Chapter 1) at the national and provincial scales, e.g., the National Climate Change Policy (NCCP 2012), these high-level documents were reported by stakeholders in this study to be ineffective in influencing adaptation action at the district scale. Top-down approaches to formulating climate adaptation policies, i.e., global to national and sub-national levels, that fail to establish an enabling environment at appropriate scales frequently obscure policy implementation in local administrative and institutional settings (Adzei & Alornu, 2023; Fuhr et al., 2017; di Gregorio et al., 2017; Hickmann, 2017). Policy planning processes in the absence of an enabling environment that reflects local needs are less likely to achieve their implementation objectives and to bring about intended change (e.g. Ampaire et al., 2017). In this study, a top-down response by the Pakistan government seems to confound adaptation with mitigation contributing to its failure at the district scale in Punjab. The actions promoted in the plans attach a high priority to the reduction of future GHG emissions from (energy generation and transportation, from renewable energy sources, coal gasification, and investment in nature-based solutions through afforestation programs for land-use change and forestry), thereby neglecting the needs of farmers. Action on mitigation of climate change is considered a global priority, and mitigation policies have historically emerged largely from more centralised decision-making processes (Lesnikowski, 2021). In contrast, adaptation to climate change is contextual and local, and requires a bottom-up response to take place (Pelling, 2014). Also, adaptation plans tend to devolve responsibility for implementation to local governments whose budgets are least able to absorb the cost of interventions (e.g. Burton, 2011). Furthermore, the division of roles and responsibilities for adaptation is frequently complex and undefined (Nalau et al., 2015) and fails to recognise that adaptation is often constrained by limited control exercised by local government over the processes involved (Measham et al., 2011; Austin et al., 2019). This aligns with our findings which show that the enabling environment for the lower levels of government in Punjab is established by the upper levels of government as they control scarce resources which might be suitable for mitigation but appear less suited to adaptation. In addition, our findings reflect those of the Asian Development Bank (ADB) which found that action on climate change adaptation in Pakistan is nascent despite the development of policy guidance documents to support action (ADB 2017). The ADB report further noted that Pakistan had not yet planned a transition from the current phase of increased climate change awareness and outreach to the development and implementation of adaptation plans, strategies, and projects at the national, subnational, and local levels (ADB 2017). It appears from the current study that little has changed, at least in vulnerable districts within Punjab. Cochrane et al., (2016) suggested that this situation is unlikely to change unless policy development processes and adaptation strategies are realigned to ensure more inclusiveness, and are informed by the needs and constraints of policy implementers (e.g. lower tiers of government) and rural communities (e.g. farmers) in top-down government adaptation action.

Top-down policies that fail to consider the specific needs and contexts of vulnerable farmers lead to a flawed enabling environment for effective adaptation. One of the main drawbacks of top-down policies is that they tend to be rigid and inflexible, which reduces the ability of vulnerable farmers to respond to the dynamic and uncertain nature of climate change. Such policies generally constrain the adaptive options of smallholder farmers by imposing uniform and standardised solutions that do not match the diverse and changing contexts of different regions. Lamichhane et al. (2022) argued notable variations in adoption, and barriers across agroecosystems were observed in a developing country context, but that top-down adaptation policies did not align with the diverse nature of these agroecosystems. Also, top-down policies usually fail to provide adequate support for innovation and experimentation, which are essential for learning and adapting to new conditions (Gatzweiler & Braun, 2016; Ajwang et al., 2019). Further limitations of top-down policies can occur through lack of stakeholder participation and consultation often ignoring the existing coping strategies and adaptive capacities of vulnerable farmers that are based on their local knowledge and practices (e.g. Ajwang et al., 2019), and which reduces the empowerment of farmers and their ownership of the adaptation process. For example, the Nepalese government recognised a gap between national planning and local settings following the adoption of Nepal's National Adaptation Programme of Action (NAPA) and found ways to ensure that local voices are heard and influence decision-making (Reid, 2015). In addition, in line with the findings of this study, these top-down policies often imposed external agendas and priorities that did not reflect the needs and aspirations of farming communities and lacked contextual relevance and legitimacy, as they were designed by distant and centralised authorities who may not have a sufficient understanding of the local conditions, needs, and preferences of the affected communities (e.g. Ishtiaque et al., 2021). Moreover, top-down policies may also face implementation challenges and resistance, as they may not align with the existing roles and responsibilities of local institutions, and norms of the local stakeholders, or may undermine their autonomy and agency.

Local governments often find their enabling environment heavily constrained due to the actions and policies set forth by higher levels of government (Williams et al., 2020; Bonnett & Birchall, 2023). One prominent reason for this constraint is the centralised governance structure prevalent in many South Asian countries, as found in Punjab and Pakistan. Central governments often hold significant decision-making power and allocate resources disproportionately, leaving local governments with limited autonomy. For instance, a lack of financial autonomy and limited control over revenue sources hamper the ability of local governments to address community needs effectively (Musah-Surugu et al., 2019; Rahman et al., 2023). Also, policy and regulatory mechanisms established by higher-level governments can hinder local governance efforts. These may be ill-suited to the diverse and dynamic contexts of local communities. This is evident in a study by Ishtiaque et al. (2021), which highlights the challenges faced by local governments in Bangladesh due to top-down policies that fail to account for local nuances. Another notable constraint is the inadequate allocation of financial resources to local governments (e.g. Rahman et al., 2023). Insufficient fiscal transfers and overreliance on central government grants may restrict the capacity of local governments to implement development projects and deliver essential services. As a result, local governments struggle to respond effectively to the demands of their constituents, exacerbating the challenges faced by communities. Furthermore, the fragile government structures and dynamics within South Asian countries can also aggravate the constraints faced by local governments. The impact of top-tier governments on local decision-making processes and service delivery can undermines the accountability of local governments and impedes their ability to function as effective representatives of their communities (Rahman et al., 2023; Bonnett & Birchall, 2023). Thus, the enabling environment for local governments is heavily constrained by various factors perpetuated by higher levels of government including centralised governance structures and inadequate financial resources that undermine their autonomy and effectiveness. These constraints have far-reaching implications, affecting the ability of local governments to respond to the unique needs of farming communities and hindering sustainable development in the region.

Since a lower-tier government-enabling environment is established by higher tiers, local governments grapple with significant capacity constraints when it comes to effectively addressing climate change adaptation within their jurisdictions. These challenges arise from a multitude of interrelated factors that impede their ability to respond to the impacts of climate change proactively. Key capacity constraints are the limited financial resources, human resources, and technical expertise within local government agencies (Islam & Nursey-Bray, 2017; Singh, 2020; Lamichhane et al., 2022; Yulandari et al., 2023). For instance, local governments often lack trained personnel with specialised knowledge of the climate change adaptation field and adaptation policies or plans who can assess climate risks, develop locally appropriate adaptation strategies, and implement sustainable measures (e.g., Hoppe et al., 2016; Campos et al., 2017). This knowledge gap hampers their capacity to make informed decisions and integrate climate considerations into local planning and development processes (Pasquini, 2020). Moreover, financial constraints pose a formidable challenge to the local government's efforts in climate change adaptation. Previous studies have shown that the financial limitations faced by local governments inhibit their ability to invest in climate-resilient infrastructure and initiatives (e.g. Ojwang et al., 2017; Marin-Puig et al., 2022). The lack of dedicated funding streams for climate adaptation projects often forces local governments to divert resources from other essential services, creating a trade-off that ultimately hinders comprehensive adaptation efforts.

Institutional barriers further exacerbate capacity constraints for climate adaptation. For instance, complex bureaucratic structures and overlapping mandates can result in unclear roles and responsibilities among local government departments. Such overlapping mandates mirror the ambiguous roles identified in the findings, which were exacerbated by disconnected communication between top-down policies and bottom-up consultations (sections 7.3.3.1 to 7.3.3.4). This is also evidenced in another study by Ishtiaque et al. (2021), which highlights the challenges posed by institutional fragmentation in Bangladesh's government system. Such fragmentation can lead to coordination challenges and hinder the implementation of holistic and integrated climate adaptation strategies. Moreover, inadequate timely access to seasonal forecasts and meteorological data based on climate modelling also constrains local governments' capacity for climate change adaptation. Many local governments lack the necessary tools to gather and analyse climate-related information, hindering their ability to assess vulnerabilities, track changes, and monitor the effectiveness of adaptation measures. Limited data availability and technological resources can hinder local governments' efforts to develop evidence-based adaptation plans and respond effectively to changing climate conditions (Cid & Learner, 2023). Therefore, despite a pressing need for local and contextual adaptation responses, local governments face substantial capacity constraints that hinder their ability to effectively engage in climate change adaptation. Addressing these challenges is crucial for building resilience and ensuring sustainable development in the face of a changing climate.

In a highly resource-constrained setting, local government action in Punjab was hampered by other missing elements needed to establish an enabling environment for adaptation. Notably, action by Non-Government Organisations (NGOs) to fill the gap left by the government was largely absent in the findings of this study[1]. This study indicated a limited NGO presence in

[1] See Appendix D for additional quotes on NGOs' activities in Punjab, not included in the published papers.

areas I identified as most vulnerable, and their engagement in, for example, temporary flood relief operations common in other developing countries, was unreported. In my study, GO pointed out that they were struggling to meet farmers' expectations without external assistance. NGOs are considered an important element in the creation of an enabling environment to support the adaptation efforts of lower tiers of government (Deshpande et al., 2019). In many countries and especially in rural areas, due to the limited capacity of local formal institutions, non-governmental organisations are frequently the main initiators and implementers of actions to address climate change adaptation (Fila et al., 2024). Also, in the context of least-developed African countries (e.g. Malawi), NGOs were found to be influential actors and played an important role in risk reduction and management through building the capacity of local communities and the district governments to prepare and manage natural disasters when they occur (Pasquini, 2020). NGOs may also often act as intermediaries between communities and local government bodies (Deshpande et al., 2019) improving stakeholder engagement. There are several possible reasons to explain the limited roles of NGOs in our study locations. These include, that NGOs find worker safety too difficult to ensure in the climate vulnerable districts of Punjab; that climate change adaptation may be of lesser priority to NGO work programs than poverty alleviation; or, they may focus efforts in regions of Pakistan less climate vulnerable or on countries less developed than Pakistan at the behest of donors.

In addition to limited intervention of NGO workers on the ground, GO also identified that funding from international organisations in the form of local adaptation projects was very limited. Possibly, absence of political stability and of continuity of policies and plans may limit the attraction of Pakistan to international funding bodies. GO identified capping of many mutually funded well-running projects (relying on joint Pakistan government and international organisation funding) due to reductions in Pakistan's financial contributions. Studies show that adaptation finance is primarily allocated to multilateral entities and national governments, rather than local governments who face obstacles in accessing it, and that only a small proportion of resources are channelled to the local level for locally designed and locally led resilience initiatives (e.g. Fenton et al., 2015). This also shows systemic power imbalances within levels of government, and between government and vulnerable communities (Colenbrander et al., 2018). Channelling adaptation finance to the local level could have a catalytic effect on the capacities and impacts of local governments, and may increase the share of resources reaching the most vulnerable by contributing to greater levels of both distributive and procedural justice (e.g. Paavola & Adger, 2006; Barrett, 2013) provided the potential for corruption can be circumvented (e.g. Khan et al., 2022). Resourcing and empowering local governments can instrumentally reduce vulnerability by improving their ability to co-produce their services and infrastructure reducing exposure to risk (Watson, 2014).

The situation in Pakistan requires the central government to focus and divert resources to vulnerable districts of Punjab, which are already low in adaptive capacity but have agricultural significance in terms of food and cash crop production, e.g., cotton and sugarcane are valuable crops that are highly vulnerable to the impacts of climate change. However, the priority of investing in adaptation actions in less vulnerable regions of Punjab from the perspective of the central government remains unknown. While such regions may be important to the Pakistan economy, more densely populated regions may exercise greater political heft thereby attracting a larger share of government resource allocation. Nonetheless, what is known from this study is that these highly vulnerable districts of Punjab are currently failing to attract an appropriate share of government support. This situation points to the need for the government to adopt a different approach to adaptation policy to find ways to overcome resource constraints and move towards inclusive policy planning processes to better address local needs.

8.4 Aligning and Enhancing VSA Conceptualisation

My research is intertwined with the core components of the VSA concept (see Chapter 3) and is aligned with the adopted VSA framework, as proposed by Azadi et al. (2021). The VSA framework emphasises the significance of addressing vulnerabilities within agricultural systems while fostering resilience. It recognises that traditional CSA approaches might overlook the complex socioeconomic and contextual factors that dictate vulnerability levels. My empirical findings align with this shift in thinking, going beyond the conventional understanding of CSA and adopting the more holistic VSA perspective. My thesis chapters align with the conceptual model (Figure 3.2 Chapter 3) adapted from the VSA framework (Azadi et al., 2021) that emphasises rethinking resilient agriculture by moving from the CSA approach to the VSA approach, thereby seeking to overcome deficiencies identified in CSA. CSA is aimed at promoting sustainable agricultural practices to address the challenges posed by climate change (Zougmoré et al., 2016). However, over time, several shortcomings have been identified in the CSA concept. One of the main shortcomings is that the traditional CSA practices often offer generic solutions to farmers, irrespective of their specific vulnerabilities and agroecological contexts (e.g. Autio et al., 2021). Also, the focus of CSA on technological solutions can be limiting, and relying solely on technical interventions neglects the importance of economic, social, and institutional aspects of agriculture (e.g. Prestele & Verburg, 2020). Moreover, the narrow focus on short-term benefits and the failure to promote the participation of local communities further limits CSA (Khoza et al., 2021). For instance, while CSA practices can yield immediate gains in terms of increased productivity, they may overlook their long-term ecological and socio-economic consequences leading to maladaptation (Juhola et al., 2016), potentially increasing vulnerability in the long run. The emergence of the VSA approach and allied framework is a response to these shortcomings in the CSA concept.

My research focused on the concept of 'capitals', from traditional asset deficit models of adaptive capacity assessment (Elrick-Barr et al., 2023), which explores how individuals or communities use, substitute and transform their stocks of capital (typically natural, human, financial, social, and physical capital) to construct a livelihood (Bebbington, 1999). Assessment of and integration across these livelihood assets form the basis of vulnerability assessment (Gumel, 2022) and lie at the heart of the VSA framework (Azadi et al., 2021). VSA concept highlights the importance of a comprehensive assessment of livelihood capitals to understand the vulnerabilities and adaptive capacities of farming communities. My research takes this one step further by not only acknowledging the importance of these capitals but also spotlighting their critical role in shaping adaptive strategies and decisions of farmers and local GO in the Punjab region. The synthesis of empirical insights with theoretical underpinnings of the VSA conceptualisation presented in Chapter 3 marks an advancement in understanding the complexities of climate adaptation within the context of the Punjab region. This discourse transcends the conventional boundaries of CSA, advancing into the more nuanced domain of VSA with enhancements, as illustrated by my modified model of VSA concept in Figure 8.1.

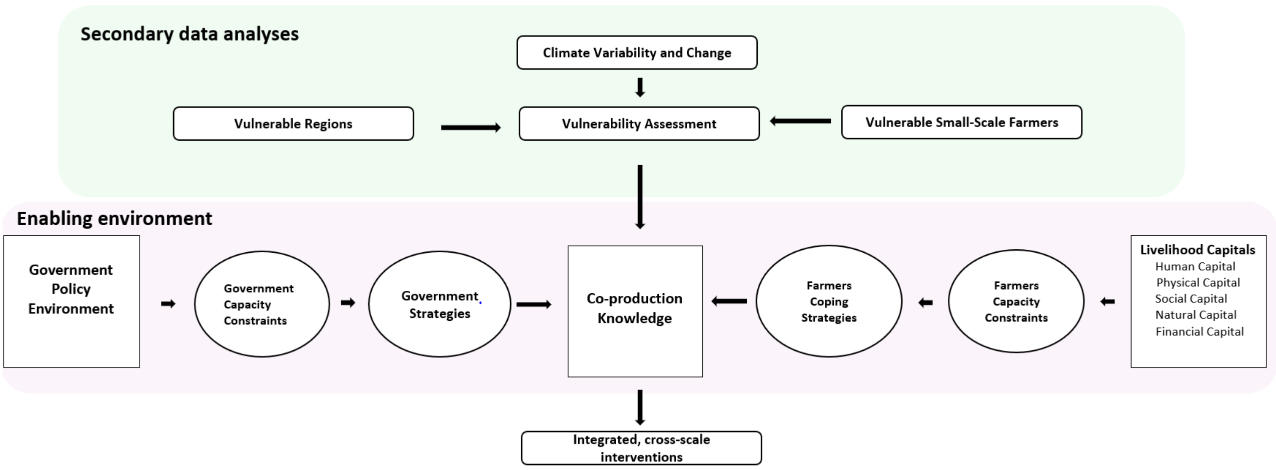

Figure 8.1: Modified VSA model

My identification and incorporation of the 'enabling environment' within the VSA framework (Figure 8.1) is a significant enhancement of the original concept. An enabling environment for adaptation in the context of this research includes supporting institutions and governance arrangements that support sustainable vulnerability reduction (Kuyvenhoven, 2004). While the VSA model of Azadi et al. (2021) primarily focuses on capitals and CSA strategies, my research recognises the essential role of an enabling environment for the deployment by farmers of livelihood capitals in pursuit of adaptation. This mirrors the evolution of the VSA framework itself, a shift from CSA to a more comprehensive, context-sensitive, and vulnerability-aware approach. My engagement with key adaptation actors (farmers and GO) at the district scale, marked a contribution to the adaptation discourse in the Punjab region. Particularly noteworthy was my incorporation of the enabling environment for adaptation involving institutional support (in this case, cross-scale governance), which was missing in the original VSA concept (Figure 3.2 Chapter 3). This inclusion of the enabling environment in the VSA concept in my thesis model (Figure 8.1) in combination with the focus on livelihoods capitals enriched my analysis by explaining the essential role of a conducive environment for both farmers and local governments to effectively harness resources for adaptation. This enhancement also allowed me to explore the depths of farmers' and officials' experiences, discovering valuable insights into their coping strategies and adaptation efforts.

The inclusion of knowledge co-production in the VSA concept in my thesis model (Figure 8.1) emerges as a potentially transformative catalyst. Anchored in the context of participatory co-production, it bridges the gap between top-down policy formulation and grassroots information, and nurtures an environment for climate change adaptation that is better tailored to the unique challenges encountered in the Punjab region. It explores the complex interactions between livelihood capitals, the enabling environment that allows their deployment in pursuit of adaptation, and participatory strategies that can help shape a resilient agricultural landscape. By addressing these missing aspects, my empirical findings extend the boundaries of the VSA concept, making it more adaptable and relevant to the complex realities of the study areas of the Punjab region and the Global South more generally. In essence, my research integrates VSA into the fabric of the Punjab region's agricultural landscape as illustrated in my thesis model (Figure 8.1). My exploration of capitals and the enabling environment resonates with the fundamental principles of vulnerability assessment and the VSA framework, emphasising the significance of vulnerabilities, resilience, and context in shaping adaptive behaviours of farmers. By enhancing the concept with my empirical insights, this thesis offers a nuanced understanding of how VSA practices can be tailored to address the unique challenges and opportunities faced by farmers and local government officials in the Punjab province. This mutually beneficial connection between concept and practice is representative of the transformative potential of my research within the broader framework of VSA.

Finally, in the subsequent section of this discussion, I expand upon the augmented VSA framework in my thesis model (Figure 8.1), illuminating the crucial significance of knowledge co-production to my findings as an essential yet previously missing component. By adopting this participatory approach, top-down policy processes can interconnect with bottom-up information, fostering a balanced interaction that is essential in formulating effective adaptation policies.

8.5 Knowledge co-production to enhance adaptive capacity

The lack of capacity and an unsupportive enabling environment for climate change adaptation at the subnational level have been highlighted as a key barrier to implementing national adaptation policies and plans. Concurrently, the adaptive capacity of local actors is highly context-sensitive, making a "one-size-fits-all" approach unsuitable. Consequently, this necessitates a flexible approach to enhance the enabling environment for adaptation across diverse local contexts (Williams et al., 2020). Knowledge co-production is a collaborative and iterative process involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge (e.g., Nightingale et al., 2020; Norstrom et al., 2020). Engaging stakeholders in co-design of strategies has the potential to prioritise climate-smart options (Andrieu et al., 2019) and co-production encourages mutual learning through knowledge exchange by understanding the actors' needs to influence their decision-making (Kruk et al., 2017). Joshi and Moore (2004) suggest that the institutionalisation of co-production within public sector service delivery has evolved because of a lack of capacity in government. While it is unlikely to be a panacea for all capacity constraints (Jagannathan et al., 2020) the institutionalisation of co-production practice to the enabling environment of vulnerable regions of Punjab would likely help promote climate change adaptation. The subsequent sections of this discussion illustrate knowledge co-production interventions appropriate to my empirical findings pertaining to selected capacity constraints in the vulnerable areas of the Punjab Province. However, the effective adoption of these interventions necessitates adherence to the guiding principles of knowledge co-production as delineated by Norstorm et al. (2020). These principles include a context-based approach, the incorporation of pluralistic perspectives that acknowledge diversity of knowledge and action, an orientation towards achievement of goals, and an interactive engagement fostering active participation among stakeholders. Adhering to these key principles of knowledge co-production increases the likelihood that the resulting knowledge is perceived by end-users as credible (robust outputs), salient (relevant to user needs), and legitimate (information is respectful of all actors) (e.g. Cash et al., 2002; Norstrom et al., 2020), and thus makes the knowledge produced more likely to be incorporated in stakeholders' decision making (Cash et al., 2002; Sherman & Ford, 2014; Norstrom et al., 2020).

The primary contributions that co-production can have in this study context lie in the two most crucial elements: human capital, which encompasses knowledge, and social capital, representing the connections people form when engaging in co-production activities. Farmers in Punjab identified constraints of human capital development, particularly around the lack of effective knowledge exchange. Co-production plays a pivotal role in enhancing human capital, primarily through knowledge sharing and practice adoption. Knowledge exchange facilitates the generation and dissemination of usable information such as through knowledge platforms (e.g. Kaiser et al., 2017), skill development and training (e.g. Tim et al., 2023), and the use of information and communication technology (e.g. Munthali et al., 2021). In addition, human capital development is profoundly influenced by co-production through practice adoption aspects. For instance, field trials of crop varieties, conducted in partnership with local farmers, exemplify this concept (e.g. Mishra et al., 2020). Researchers evaluate different varieties under diverse climatic conditions, while farmers contribute invaluable feedback based on their experiences. This collaborative process identifies crop varieties best suited to local conditions, increasing the likelihood of farmer acceptance and adoption. Co-production also recognises the significance of traditional farming practices and local climate adaptation strategies evolved over generations (e.g., Utter et al., 2021; Nidumolu et al., 2022), thereby enriching the human capital of farming communities and providing valuable insights for practice adoption in the face of climate variability. Another dimension of human capital development facilitated by knowledge co-production is the co-design of planning for climate change, e.g., collaborative design of flood-resilient infrastructure and flood protection measures (Luke et al., 2018).

Aside from human capital aspects of knowledge sharing, enhancement of social capital is the next most significant outcome. Co-production exhibits great potential to enhance the social capital of stakeholders. Farmers in Punjab identified many challenges such as a lack of engagement, trust deficiency, and limited access to support systems. Co-production fosters a participatory and inclusive approach, empowering farmers to build stronger social connections and engage in collective efforts to address common challenges through building trust and inclusivity (e.g. Gerlak et al., 2023). For example, co-production supports the formation and strengthening of farmer networks, cooperatives, and self-help groups (e.g. Maughan & Anderson, 2023). Also, it promotes collaborative decision-making, where farmers are actively involved in identifying problems, setting priorities, and designing solutions (e.g. Steynor et al., 2016). Moreover, co-production strives to empower marginalised groups such as small-scale farmers who often face additional barriers to engagement, by ensuring their active participation and representation in decision-making processes (e.g. Reed et al., 2019). It involves GO including agricultural and environmental experts, and local farming communities coming together in a spirit of mutual trust. Through active engagement and participatory processes, the barriers to cooperation and collective action are gradually overcome. This inclusivity ensures that the voices and perspectives of all stakeholders, including farmers, are heard and valued. It also creates a space for open dialogue where farmers are encouraged to express their concerns, preferences, and aspirations and lays the foundation for stronger social bonds. Therefore, by fostering trust, inclusivity, and collaborative decision-making, co-production empowers farmers to build stronger social connections, engage in collective efforts, and form networks effectively.

Networks act as the cornerstone of social capital upon which other critical aspects rely for their effectiveness (Cunningham et al., 2016). When strong social networks are established, they serve as conduits for the effective utilisation of other capitals in a variety of ways. For instance, once robust networks are in place, they become instrumental in channelling climate-smart practices, fostering cooperation among stakeholders, and ensuring the equitable distribution of resources. Inclusive social capital with trust-building among stakeholders has the potential to address a number of other issues that farmers of Punjab have identified including lack of market information, transport options, and sharing equipment. Networks facilitate the flow of information and knowledge among stakeholders. This interconnectedness allows for the timely exchange of climate-related data (Kaspar et al., 2022), market information systems (e.g. Mozumder et al., 2023), and resource availability through resource pooling and community-based infrastructure (e.g. Singh et al., 2021). Without networks, the dissemination of vital information becomes challenging, hindering informed decision-making in vulnerable agricultural contexts. Through networks and trust-building, resource mobilisation becomes more feasible. Co-production principles can encourage new social interactions among, for example, microfinance institutions and local communities to understand the specific credit needs of farmers and design innovative financial solutions (Abeysekera, 2015). Also, technology transfer and access to critical resources are often facilitated by the relationships and partnerships established within these networks (Singh, 2003). This, in turn, ensures that the necessary tools and inputs are available for sustainable agricultural practices.

In this study, water governance for agriculture was emphasised by farmers and government officials as constraining adaptation. Notably, co-production in water governance stands as a prime example of how collaborative approaches can yield substantial benefits in this context. Water governance serves as an exemplary domain where co-production's transformative potential is evident, particularly in enhancing human and social capital. Through the co-production process, farmers gain technical skills and expertise i.e. human capital, while simultaneously strengthening their connections with experts and fellow farmers i.e. social capital. These intertwined capitals create a mutually reinforcing cycle, amplifying the effectiveness of water governance efforts. This context-specific approach enhances knowledge generation and utilisation by involving stakeholders in the joint identification of knowledge gaps and priorities, such as the development of drought-tolerant crop varieties, climate services, and efficient irrigation technologies. For instance, climate services serve as a prominent example of co-production interventions within water governance in addressing climate-related challenges affecting water resources. Climate services, defined as the provision of climate information in a way that assists decision-making by individuals and organisations (Hewitt et al., 2012), is predicated on interaction between these two groups combined with an effective access mechanism that is responsive to the needs of users (e.g., Lourenco et al., 2016). Typically, government officials and meteorological experts analyse historical climate data and future climate projections, while farmers hold information about their water needs during different stages of crop growth. Action to improve climate services in Pakistan has been identified as a policy priority to address climate change vulnerability (Sipra, 2020). Collaboration among these actors in Punjab could establish improved allocation of water resources, considering climate variations and potential water scarcity. In areas where rainfall patterns are changing, stakeholders may work together to adjust irrigation schedules and cropping patterns to optimise water use based on projected climate conditions. Co-production can foster participatory water governance where farmers have a say in water allocation and management decisions (e.g., Brugnach et al., 2019) because it strives to ensure more equitable access to water resources by addressing the needs of different users particularly small-scale farmers.

While co-production stands as a valuable approach, it is not without its limitations (Lang et al., 2012; Kruijf et al., 2022). Co-production is not a panacea capable of solving all types of problems and challenges identified by farmers in Punjab. The effectiveness of co-production in the context of VSA in Punjab hinges on political will and support from the top-tier government and its adoption necessitates a redirection of the national government's focus. This might be challenging, as governments often have multiple priorities, and re-directing focus to co-production may not be straightforward. Also, aligning government policies with co-production objectives can be complex (Kruijf et al., 2022). Political support is essential for overcoming these hurdles and creating a supporting environment for the practice of co-production (e.g. Cepiku & Filippo, 2014). To realise its full potential of co-production, it is imperative that the effectiveness of co-production is closely tied to the support it receives from higher levels of government in Pakistan (Farooqi, 2016). Without the recognition and endorsement of policymakers, co-production initiatives may struggle to secure the necessary resources, both in terms of funding and expertise. Sustainable co-production efforts require vertical connections and resource flows across tiers of government to ensure that they have the requisite capacity to function effectively. Also, when co-production is viewed as a peripheral activity rather than a central element of governance, its potential may remain untapped. This points to the need for a paradigm shift in government approach, where co-production is not merely an add-on but an integral part of decision-making processes. In addition, the success of co-production hinges on the responsiveness of higher levels of government to the information and recommendations generated through these processes. If the insights and outcomes of co-production efforts are not acted upon, it risks disillusioning participants and eroding trust in the approach. Thus, for co-production to thrive and be a transformative driving factor, it necessitates commitment and action from higher levels of government to ensure that its outcomes translate into tangible benefits for communities. In essence, while co-production offers promise, its limitations and resource dependencies underscore the critical need for thoughtful planning, strategic implementation, and comprehensive support from higher levels of government to maximise its impact. In addition, co-production is not a quick fix; it involves a systematic approach to knowledge co-creation and collaboration. This can be time-consuming (Kruijf et al., 2022), which may deter provincial and district governments that may seek more immediate results or face other pressing issues. Furthermore, co-production initiatives require resources, including funding, expertise, and technology (Sorrentino et al., 2018; Cook et al., 2021). These resources may not always be readily available, and securing them can pose a challenge for local governments, particularly in resource-constrained settings.

Implementing co-production necessitates outside assistance, particularly in the context of Pakistan where resources and expertise are limited. The Government of Pakistan, which is already grappling with numerous complex challenges, cannot independently address them all. Foreign assistance, including funding, technology, and knowledge transfer, can provide critical support. International organisations, NGOs, and academic institutions from abroad can step in to offer their support and enhance the effectiveness of co-production. In particular, the situation calls for the involvement of international development agencies and NGOs specialising in co-production in the developing country context. These external bodies can play a pivotal role in fostering collaboration, knowledge sharing, and capacity-building activities. In resource-constrained environments, where access to information and expertise is limited, NGOs dedicated to co-production can facilitate the co-creation of knowledge by bridging the gap between local stakeholders and global knowledge networks. They can provide essential training, tools, and platforms that empower communities to actively participate in the creation and utilisation of knowledge relevant to their specific needs. Furthermore, to ensure the sustainability of such initiatives, external funding becomes imperative. This funding doesn't necessarily need to originate from Pakistan, it can come from diverse sources. This diversity in funding sources not only ensures financial stability but also promotes international cooperation and shared responsibility in addressing global challenges. Whether it is through governmental aid programs, private foundations, or international development agencies, securing outside funding can be the catalyst that propels co-production initiatives in developing country contexts toward sustainable outcomes. External support of this kind often brings diverse perspectives, resources, and expertise that complement local efforts.

Chapter Nine: Conclusions

In this chapter, I conclude my thesis with some final reflections. It summarises the significance of my study, draws key conclusions, articulates responses to the research questions along with their associated implications, acknowledges the limitations, and offers suggestions for potential avenues of future research. This thesis explored the vulnerability of agriculture, with a focus on small-scale farmers, to climate change in the Punjab province at the district scale inspired by the Rural Livelihoods Analysis (RLA) framework (Bebbington, 1999) and Vulnerable Smart Agriculture (VSA) thinking (Azadi et al., 2021). I strategically employed a comprehensive mixed-methods approach (Hennink et al. 2010), that allowed for the integration of quantitative (mapping, Chapter 5) and qualitative (semi-structured interviews, Chapters 6 and 7) analyses to thoroughly investigate agricultural vulnerability to climate change, presented across three insightful findings chapters.

9.1 Research contributions

The contributions of this research are multifold:

(i) **From a methodological perspective**, the research highlights the value of incorporating vulnerability assessment as a foundational step in the VSA application. This approach facilitates the gathering of critical information necessary to create an enabling environment for small-scale farmers where VSA practices could potentially be implemented.

The primary contribution lies in demonstrating how vulnerability assessment can inform and shape VSA thinking by identifying specific risks and challenges faced by small-scale farmers. This emphasis underscores the methodological importance of integrating vulnerability assessments to support the theoretical and strategic development of VSA. The research explored how engaging with stakeholders' perspectives and understanding vulnerabilities can guide the customisation and contextual adaptation of VSA strategies. In this research, the vulnerability assessment (Chapter 5) provided valuable insights into the spatial distribution of agricultural vulnerability to climate change in Punjab through the identification of vulnerable districts, warranting further qualitative assessment. By anchoring vulnerability assessment within the broader framework of VSA thinking, the study advances an understanding of the enabling conditions required for VSA implementation. It enabled a more nuanced comprehension of the distinct-level obstacles confronting small-scale farmers, serving as a strategic tool to pinpoint and prioritise vulnerabilities within the agricultural context. Moreover, the fusion of vulnerability assessment with VSA provided information about where the enabling environment, primarily government institutions, was failing to support small-scale farmers in their adaptation efforts. A more detailed comprehension of the 'lived expression' of vulnerability may empower policymakers and practitioners to craft more precise interventions tailored to address the specific needs of these farmers. Ultimately, integrating vulnerability assessment into VSA thinking, may serve as a catalyst for fostering a supportive and adaptable environment for adaptation in future assessments, thereby contributing significantly to the development of climate-resilient agriculture for small-scale farming systems in Punjab and beyond.

(ii) **From an empirical perspective,** this study presents empirical evidence on the significance of VSA thinking in the Punjab province and potentially similar contexts.

In this study, concrete empirical evidence (Chapters 6 and 7) was gathered through qualitative research to highlight the significance of VSA thinking in the Punjab region. Key adaptation actors, including farmers and government officials, were engaged through semi-structured interviews conducted at the district scale. This empirical assessment effectively explored the specific challenges and needs of small-scale farmers while assessing the capacity of district government officials to support adaptive actions. This approach provided a 360^{o} view that revealed intricate relationships between livelihood capitals, capacity constraints of actors in building adaptive capacity, the (in)effectiveness of top-down policy actions, and the role of the enabling environment for adaptation. The empirical evidence presented in this thesis emphasises the practical value of adopting VSA strategies to address unique challenges faced by agricultural communities in Punjab. It holds implications beyond this context, offering valuable insights for enhancing agricultural resilience in diverse settings facing similar challenges. By bolstering the case for VSA strategies, this empirical evidence forms a foundation for 'real world' policy recommendations and practical implementation, contributing depth and credibility to the discourse on Vulnerable Smart Agriculture.

(iii) **From a theoretical perspective**, the research critically engages with the concept of knowledge co-production in the context of Punjab, exploring its potential as a strategy to bridge the gap between top-down policies and localised adaptation initiatives.

In Chapter 8, General Discussion, the integration of the knowledge co-production concept into VSA thinking stands out as a compelling and transformative contribution of my thesis (Figure 8.1). This conceptual contribution does not claim to establish a practical implementation of co-production but rather advances the understanding of how its theoretical underpinnings can guide the design of policies and practices. Specifically, the research highlights the potential of co-production principles to serve as a bridge, linking top-down policy processes with the dynamic realities of local adaptation. This integration not only provides a nuanced and participatory pathway to action but also lays the foundation for significantly more effective smart agriculture practices in the unique context of the Punjab region. By incorporating these strategies, my research propels VSA thinking beyond its conventional boundaries, fostering a more nuanced and inclusive approach to climate smart agriculture. Moreover, the incorporation of knowledge co-production serves as a bridge, linking top-down policy processes with the dynamic landscape of localised adaptation initiatives. By strategically weaving knowledge co-production into the fabric of VSA thinking, the research addresses a central challenge identified in this study— the disconnect between top-down policy decisions on climate change and initiatives designed to promote local adaptation. This collaborative knowledge strategy ensures that top-down policies not only acknowledge but actively integrate the diverse perspectives and insights emerging from localised adaptation efforts. In recognising the importance of grassroots insights, the thesis positions them as essential contributors to the formulation of adaptive policies, thereby enhancing the inclusivity and effectiveness of climate smart agriculture practices.

9.2 Key conclusions

The thesis makes eight key conclusions.

First, the research revealed that farmers in vulnerable districts of Punjab reported significant exposure to climate change, encompassing climate variability, temperature shifts, altered seasons, erratic rainfall, and increased vulnerability to climate extremes such as floods and droughts. Therefore, I concluded that immediate attention and action are required to support their adaptability and resilience.

Second, through their experience of both long-term changes in seasonal conditions and extreme events farmers understood the imperative to adapt their agricultural practices to maintain their livelihoods. However, farmers' adaptation actions were primarily limited to coping mechanisms and incremental changes. Consequently, I concluded that there is a pressing need for adaptations that are both broader and deeper to ensure sustained agricultural resilience.

Third, farmers reported that their adaptation responses were limited by their inability to access or deploy key resources in pursuit of adaptation. These included cultivating drought-tolerant crop varieties, market access, and adopting advanced water conservation practices. While recognised by farmers as necessary, these changes surpass their current capacity. Hence, I concluded that it is crucial to enhance the capacity of small-scale farmers to support these adaptations.

Fourth, my research identified that a fundamental reason behind the constraints to farmers' adaptation responses was as an inadequate enabling environment for adaptation. This included limited government support that aligned with farmers' requirements, a failure to provide reliable market arrangements, and inequitable practices that favoured large-scale, influential farmers over small-scale farmers, exacerbating their vulnerability and limiting access to financial support and market opportunities. Therefore, I concluded that the limited adaptation capacity of small-scale farmers was strongly influenced by their access to livelihood capitals and the policy planning constraints set by existing government arrangements.

Fifth, the significance of irrigation water as a key enabler of climate adaptation was unanimously identified by farmers and government officials. Notably, farmers, especially small-scale ones, highlighted substantial issues related to the inequitable amount, access, and distribution of irrigation water under current water governance arrangements, constraining their farm planning. I therefore concluded that effective water resource management is indispensable for fostering climate-resilient farming practices in these districts of Punjab.

Sixth, a notable finding was the lack of knowledge exchange between farmers and formal government actors in Punjab, hindering the effectiveness of top-down climate change policies. Hence, I concluded that improved communication channels and active participation of farmers in policy planning processes are imperative for better adaptation outcomes.

Seventh, my research discovered that district governments face substantial capacity constraints perpetuated by higher levels of government, including limited financial resources, human resources, and technical expertise. Consequently, their autonomy and effectiveness to respond to the demands of vulnerable farmers, especially small-scale ones, were severely compromised. Therefore, I concluded that empowering lower-tier governments is vital to effectively address challenges faced by small-scale farmers.

Finally, my research revealed that the adaptation interventions by higher tiers of government, which followed a top-down response similar to that used for mitigation efforts, neglected the needs of vulnerable farmers at the district scale, resulting in a flawed enabling environment for effective adaptation. Therefore, I concluded that aligning policies with local needs is critical for bringing about positive change and benefiting vulnerable farmers at the district level.

9.3 Addressing research questions

My thesis addressed three primary research questions through three findings chapters. Responses to these questions are provided below.

Research Question RQ1: *Using available data, can an index of vulnerability be constructed and mapped that identifies the most climate change vulnerable districts for the major crop subsector of Punjab province?*

The work on index development in Chapter 5 separated areas of Punjab based on their respective agricultural vulnerability to climate change. A substantial number of the southern and northern Punjab districts were positioned in the higher exposure and/or sensitivity categories, coupled with the lower adaptive capacity categories. In contrast, most of the eastern and central Punjab districts exhibited low exposure and/or sensitivity, along with higher levels of adaptive capacity. The statistical associations between adaptive capacity and its constituent indicators exhibited varying degrees of strength, as evidenced by statistically significant correlations determined through correlation analysis in Chapter 5. Notably, three factors were most strongly correlated with adaptive capacity, namely, local committees (social capital), health attainment (human capital), and access to credit (financial capital). The mapping exercise in Chapter 5 revealed distinct spatial patterns that delineate variations in vulnerability across the districts within the Punjab province. These variations were attributable to the specific combinations of factors associated with the constituent aspects of vulnerability i.e. exposure, sensitivity, and adaptive capacity. The vulnerability map indicated specific districts (e.g. Rajanpur, Muzaffargarh, Chakwal) classified under the most vulnerable category.

RQ2: *For selected districts of Punjab identified through vulnerability mapping, what constrains and enables adaptation to climate change from farmers' perspective?*

The qualitative findings presented in Chapter 6, which centered on the interactions with farmers, revealed that farmers, particularly small-scale farmers, encountered several obstacles due to resource constraints coupled with the lack of an enabling environment for effective adaptation. These obstacles included constrained access to irrigation water, limited market access, which was heavily influenced by market intermediaries, inferior quality groundwater, poor access to formal credit, and weak access to government-subsidised farm inputs. In addition, farmers identified peer-to-peer sharing networks among farmers, irrigation water supply, and the utilization of their experience-based local knowledge as key enablers in facilitating climate change adaptation within agricultural practices. Additionally, farmers revealed policy-related constraints that included a lack of local consultation about needs, inconsistencies in planning policies, limited attention to support for farm-scale action, and limited equity in policies. Farmers expressed reliance on local governments for support, which was met with dissatisfaction as they perceived that government assistance was inadequate and not aligned with their specific local requirements.

RQ3: *What constraints are faced by district-scale government officials in supporting farmers' adaptation in vulnerable districts of Punjab?*

The qualitative findings presented in Chapter 7, centered around the interactions with district-scale government officials, disclosed a distinct perspective, highlighting the substantial limitations faced by local governments in terms of both capacity and enabling environment. Local government officials attributed these limitations to constraints imposed by higher tiers of government adopting a top-down policy approach that neglects to incorporate the crucial element of bottom-up need assessments, thereby hindering the effective integration of local perspectives and requirements. Government informants identified governance of climate change and policy planning constraints as hindering local-scale adaptation in Punjab. The governance issues raised by participants included siloed approaches, ambiguous roles, and disconnected top-down communication from bottom-up consultation. In addition to governance aspects, they reported a number of policy and planning constraints that included a focus on mitigation, and policy implementation hurdles including institutional, financial, and technical capacity constraints.

9.4 Study key implications

Vulnerability maps can initiate knowledge acquisition, rather than being seen as the culmination of knowledge gathering. This perspective recognises vulnerability maps as dynamic tools, continuously adapting to the evolving landscape of climate change impacts. They extend beyond visual representations of vulnerability, laying the foundation for various benefits, particularly in supporting adaptation planning and enhancing knowledge management (e.g. Sherbinin et al., 2017). This reframing of mapping has the potential to transform vulnerability assessments into iterative dynamic processes, and continuous knowledge flow from such processes ensures that adaptation strategies remain adaptive themselves, evolving in response to shifting climate conditions and community requirements. This evolution also enhances the relevance of vulnerability assessments, empowering local communities as active contributors to knowledge creation and adaptation planning.

The underlying causes of climate change vulnerability require particular attention of adaptation policy makers. Climate change exacerbates existing vulnerability and multiplies threats (Dodson et al., 2020). The vulnerability of farmers to climate change extends beyond the commonly considered factors of biophysical exposure and sensitivity. One significant aspect that requires particular attention in adaptation policy is the social vulnerability of farmers. Social vulnerability encompasses a wide range of aspects including social and economic factors that influence a community's ability to cope with and recover from climatic stressors (Otto et al., 2017; Nelson et al., 2023). Resource constraints encountered by farmers are key aspects that can contribute to social vulnerability and significantly impede the farmers' capacity to adapt. By addressing the underlying aspects of social vulnerability, adaptation efforts can be more effective in reducing the impacts of climate change on farmers. This implies not only protecting them from the immediate biophysical threats posed by a changing climate but also improving their long-term resilience by enhancing socio-economic conditions in the region.

Local government capacity limitations to support farmers underscore the intricate relationship between local governments and higher levels of government in shaping the enabling environment for climate change adaptation. It is vital to examine this complex dynamic to support farmers and other local communities in adapting to climate change. This emphasises that the capacity of local governments to assist farmers is heavily influenced by the policies, resource allocations, and the broader enabling environment established by higher levels of government (Williams et al., 2020; Bonnett & Birchall, 2023). Local governments operate within a structure set by national authorities, and their ability to implement effective adaptation initiatives depends on the support and autonomy granted to them.

Policy actors can significantly influence the adaptive capacity of farmers, particularly in relation to building social and human capital. For instance, social capital, in particular bridging social capital (i.e., social capital that exists horizontally between socioeconomic groups of the same level) can be enhanced through thoughtful and cost-effective policy measures (Woolcock & Narayan, 2000; Shrestha et al., 2015). Social capital is a valuable resource that has the potential to influence other forms of capital to enhance adaptive capacity among farmers (e.g. Singh et al., 2021; Kaspar et al., 2022). Policymakers have a crucial role to play in fortifying the social fabric of farming communities, ultimately paving the way for effective climate adaptation. The significance of such policy-driven interventions should not be underestimated. They contribute not only to building adaptive capacity but also to enhancing the overall resilience of farmers in the face of changing climate conditions.

To ensure that adaptation policies are truly effective, it is imperative to establish a connection between top-down policy processes and the bottom-up information generated by local communities. This also highlights the potential of local knowledge in informing and enriching climate change adaptation policies. Local communities possess a deep understanding of their ecological contexts, vulnerabilities, and traditional coping strategies (e.g. Aich et al., 2022). However, this local knowledge often remains disconnected from the top-down policymaking process as found in the context of Punjab. Bridging this crucial gap requires a re-evaluation of policy formulation approaches to create policies that are not only effective but also equitable in addressing climate change challenges.

In the broader perspective of this study, it is evident that promoting participatory approaches (e.g., Nightingale et al., 2020; Norstrom et al., 2020) is essential for ensuring effective climate change adaptation. My findings highlight the multifaceted nature of vulnerability and the interplay of various factors that influence adaptation outcomes. Addressing these challenges requires collaborative efforts that go beyond traditional disciplinary boundaries. However, realizing the full potential of participatory approaches requires overcoming key barriers including resource constraints and deficits in enabling an environment for adaptation (e.g. Cook et al., 2021). These collaborative approaches have the potential to strengthen the adaptive capacity of communities which is crucial in navigating the complex challenges posed by climate change.

9.5 Limitations and future research

It is important to acknowledge the key limitations of this study. The quantitative assessment of agricultural vulnerability to climate change was conducted at the district scale, with limitations in assessing it at the finer-scale Tehsil level, primarily due to data availability constraints. Due to potential heterogeneity, vulnerability may vary within districts, and further fine-scale mapping can highlight such differences. Nonetheless, I supplemented quantitative assessment with qualitative assessment at the district scale to provide a more nuanced understanding of vulnerability and highlighted several factors affecting climate change adaptation. I recommend that future research and assessments focusing on Punjab strive to overcome these data availability limitations and explore new data sources and methodologies to facilitate vulnerability assessments at finer scales, which is consistent with the conceptualisation of adaptation as a 'lived' hyper-local activity (Rahman et al., 2023).

Climate change is an ongoing, dynamic process that continuously influences the vulnerability and adaptation needs of communities (Ford et al., 2013; Kaiser et al., 2022). A snapshot, taken at a specific point in time, may limit a comprehensive understanding of temporal considerations and how these factors evolve in response to changing conditions. For example, Pakistan experienced widespread flooding in 2022 that caused massive agricultural destruction and affected 33 million people (half of whom were children). One year after this extensive flooding in Pakistan, the rate of child undernutrition has increased, with an estimated 44% of children under five showing stunted growth attributed to malnutrition (Riaz et al., 2022; Ali et al., 2023). This highlights the significance of comprehending the enduring impacts of climate-related events on vulnerable populations. It also demonstrates the long-term effects of climate impacts stemming from agricultural vulnerability on community health. 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. By tracking these changes over an extended period, studies can gain a more nuanced understanding of the long-term trends, patterns, and shifting priorities in climate adaptation. Additionally, investigating the effectiveness of adaptive measures over time will offer valuable insights into optimizing strategies to enhance resilience in the face of climate change.

To conclude, I hope that this study serves as a stepping stone for future research that delves further into combined quantitative and qualitative vulnerability assessments, ultimately contributing to more effective and tailored climate change adaptation strategies at various geographic scales.

References

Aartsen, M., Koop, S., Hegger, D., Goswami, B., Oost, J., & Van Leeuwen, K. (2018). Connecting water science and policy in India: lessons from a systematic water governance assessment in the city of Ahmedabad. *Regional Environmental Change*, *18*(8), 2445-2457.

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, 29(28), 42539-42559.

Abbas, S., Kousar, S., Shirazi, S. A., Yaseen, M., & Latif, Y. (2022). Illuminating empirical evidence of climate change: impacts on rice production in the Punjab regions, Pakistan. *Agricultural Research*, 11, 32–47.

Abbas, S. (2020). Climate change and cotton production: an empirical investigation of Pakistan. *Environmental Science and Pollution Research*, *27*, 29580-29588.

Abbas, S., & Waheed, A. (2017). Trade competitiveness of Pakistan: evidence from the revealed comparative advantage approach. *Competitiveness Review: An International Business Journal*, *27*(5), 462-475.

Abbas, F., Ahmad, A., Safeeq, M., Ali, S., Saleem, F., Hammad, H.M. & Farhad, W. (2014). Changes in precipitation extremes over arid to semiarid and subhumid Punjab, Pakistan. *Theoretical and Applied Climatology,* 116:671-680 doi:10.1007/s00704-013-0988-8

Abera, W., Assen, M., & Budds, J. (2020). Determinants of agricultural land management practices among smallholder farmers in the Wanka watershed, northwestern highlands of Ethiopia. *Land Use Policy*, 99, 104841.

Abeysekera, R. (2015). Concepts and Implications of Theory of Co-production. Colombo Business Journal, 6(2).

Abid, M., Scheffran, J., Schneider, U. A., & Elahi, E. (2019). Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environmental Management*, 63(1), 110-123.

ADB (2017). Climate change profile of Pakistan. Asian Development Bank. http://dx.doi.org/10.22617/TCS178761

Adelle, C., Black, G., & Kroll, F. (2022). Digital storytelling for policy impact: perspectives from co-producing knowledge for food system governance in South Africa. *Evidence & Policy*, *18*(2), 336-355.

Adeoye, M. A. (2023). Review of sampling techniques for education. *ASEAN Journal for Science Education*, 2(2), 87-94.

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., o'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. & Takahashi, K. (2007), Assessment of adaptation practices, options, constraints and capacity, *Climate Change*, 717-743.

Adger, W. N. (2006). Vulnerability. *Global environmental change*, 16(3), 268-281.

Adger, W. N., & Agnew, M. (2004). New indicators of vulnerability and adaptive capacity (Vol. 122). Norwich: Tyndall Centre for Climate Change Research.

Adzei, F. A., & Alornu, M. A. (2023). An examination of national climate policy integration at the local level of development in Ghana. *Local Environment*, *28*(3), 322-330.

Afkhami, M., Zahraie, B., & Ghorbani, M. (2022). Quantitative and qualitative analysis of the dimensions of farmers' adaptive capacity in the face of water scarcity. *Journal of Arid Environments*, 199, 104715.

Agrawala, S., & Carraro, M., 2010. Assessing the role of microfinance in fostering adaptation to climate change. FEEM Working Paper No. 82.2010; CMCC Research Paper No. 91, Ssrn, Paris, France. doi:10.2139/ ssrn.1646883.

Agrawal, A. (2008). The role of local institutions in adaptation to climate change. In Paper prepared for the social dimensions of climate change. Washington, DC: Social Development Department, The World Bank.

Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S. A., Ahmad, I., Khaliq, T., Nasir J., Rasul F., Riaz F., Ahmad B., Ahmad S., Baig I.A., Valdivia R.O., & Hoogenboom, G. (2023). Development of Climate Change Adaptation Strategies for Cotton–Wheat Cropping System of Punjab Pakistan. In handbook of climate change and agroecosystems: climate change and farming system planning in africa and south asia: AgMip stakeholder-driven research, Part 2 (pp. 277-327).

Ahmad, M. M., Yaseen, M., & Saqib, S. E. (2022). Climate change impacts of drought on the livelihood of dryland smallholders: Implications of adaptation challenges. *International Journal of Disaster Risk Reduction*, 80, 103210.

Ahmad, A., Ashfaq, M., Rasul, G., Wajid, S. A., Khaliq, T., Rasul, F.,Saeed,U., Rahman, M.H.,Hussain,J.,Baig,I.A., Naqvi S.A.A., Bokhari S.A.A., Ahmad, S., Naseem, W., Hoogenboom, G., & Valdivia, R. O. (2015). Impact of climate change on the rice–wheat cropping system of Pakistan. In *Handbook of climate change and agroecosystems: The agricultural model intercomparison and improvement project integrated crop and economic assessments, Part 2* (pp. 219-258).

Ahmad, D., & Afzal, M. (2020). Climate change adaptation impact on cash crop productivity and income in Punjab province of Pakistan. *Environmental Science and Pollution Research*, 27(24), 30767-30777.

Ahmad, Z., Khalid, I., & Muzaffar, M. (2015). An Analysis of the Relationship Between Local and Provincial Governments in Pakistan (2001-2009). *Journal of Political Studies*, 22(1).

Ahmed, A., Devadason, E.S. & Al-Amin, A.Q., 2016. Implications of climate change damage for agriculture: sectoral evidence from Pakistan. *Environmental Science and Pollution Research*, 23(20), pp.20688-20699.

Ahmed, M. N. & Schmitz, P. M. (2015). Climate change impacts and the value of adaptation-can crop adjustments help farmers in Pakistan? *International Journal of Global Warming* 8(2): 231-257.

Ahmed, M. & Schmitz, M. (2011). Economic assessment of the impact of climate change on the agriculture of Pakistan. *Business and Economic Horizons*, 4(1232-2016-101145): 1-12.

Ahmed, U. I., Ying, L., Bashir, M. K., Abid, M., & Zulfiqar, F. (2017). Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PLOS one*, 12(10), e0185466.

Aich, A., Dey, D., & Roy, A. (2022). Climate change resilient agricultural practices: A learning experience from indigenous communities over India. *PLOS Sustainability and Transformation*, 1(7), e0000022.

Ajwang, F., Atela, J., & Arora, S. (2019). Agricultural policy making in Kenya: why must smallholders' agency be made central? Policy briefing by the ESRC-DFID funded Project reference: ES/N014456/1.

Åkerblad, L., Seppänen-Järvelä, R., & Haapakoski, K. (2021). Integrative strategies in mixed methods research. *Journal of Mixed Methods Research*, 15(2), 152-170.

Akhter, M., & Haider, Z. (2020). Basmati rice production and research in Pakistan. *Sustainable Agriculture Reviews 39*, 119-136.

Aku, A., Mshenga, P., Afari-Sefa, V., & Ochieng, J. (2018). Effect of market access provided by farmer organizations on smallholder vegetable farmer’s income in Tanzania. *Cogent Food & Agriculture*, 4(1), 1560596.

Akyıldız, S. T., & Ahmed, K. H. (2021). An overview of qualitative research and focus group discussion. *International Journal of Academic Research in Education*, 7(1), 1-15.

Alam, G. M., Alam, K., Mushtaq, S., Sarker, M. N. I., & Hossain, M. (2020). Hazards, food insecurity and human displacement in rural riverine Bangladesh: policy implications. *International Journal of Disaster Risk Reduction*, 43, 101364.

Alam, G. M., Alam, K., & Mushtaq, S. (2016). Influence of institutional access and social capital on adaptation decision: Empirical evidence from hazard-prone rural households in Bangladesh. *Ecological Economics*, 130, 243-251.

Allen (2005), Allen Consulting Group, Climate Change Risk and Vulnerability: Promoting an Efficient Adaptation Response in Australia., Australian Government Department of Environment and Heritage, Australian Greenhouse Office.

Ali, A. & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, 16: 183-194.

Ali, S., Liu, Y., Ishaq, M., Shah, T., Ilyas, A., & Din, I.U. (2017). Climate change and its impact on the yield of major food crops: Evidence from Pakistan. Foods 6(6): 39.

Ali, S., Kiani, R. S., Reboita, M. S., Dan, L., Eum, H. I., Cho, J., Dairaku, K., Khan, F., & Shreshta, M. L. (2021). Identifying hotspots cities vulnerable to climate change in Pakistan under CMIP5 climate projections. *International Journal of Climatology*, *41*(1), 559-581.

Ali, M. R., Javed, S. W., Iqbal, Z., & Sartaj, M. (2023). One year on—the persistent plight of the 2022 floods on health in Pakistan. *BMJ*, 2023;382:p1818 http://dx.doi.org/10.1136/bmj.p1818

Alvar-Beltrán, J., Heureux, A., Soldan, R., Manzanas, R., Khan, B., & Dalla Marta, A. (2021). Assessing the impact of climate change on wheat and sugarcane with the AquaCrop model along the Indus River Basin, Pakistan. *Agricultural Water Management*, *253*, 106909.

Ampaire, E. L., Jassogne, L., Providence, H., Acosta, M., Twyman, J., Winowiecki, L., & Van Asten, P. (2017). Institutional challenges to climate change adaptation: A case study on policy action gaps in Uganda. *Environmental Science & Policy*, 75, 81-90.

Amundsen, H., Hovelsrud, G. K., Aall, C., Karlsson, M., & Westskog, H. (2018). Local governments as drivers for societal transformation: Towards the 1.5 C ambition. *Current Opinion in Environmental Sustainability*, 31, 23-29.

Anderson, K., Broderick, J. F., & Stoddard, I. (2020). A factor of two: how the mitigation plans of 'climate progressive'nations fall far short of Paris-compliant pathways. *Climate Policy*, *20*(10), 1290-1304.

Andriesse, E., Saguin, K., Ablo, A. D., Kittitornkool, J., Kongkaew, C., Mang'ena, J., Onyango P., Owusu V., & Yang, J. (2022). Aligning bottom-up initiatives and top-down policies? A comparative analysis of overfishing and coastal governance in Ghana, Tanzania, the Philippines, and Thailand. *Journal of Rural Studies*, 92, 404-414.

Andrieu, N., Howland, F., Acosta-Alba, I., Le Coq, J.-F., Osorio-Garcia, A. M., Martinez-Baron, D., Gamba-Trimiño, C., Loboguerrero, A. M., & Chia, E. (2019). Co-designing climate-smart farming systems with local stakeholders: a methodological framework for achieving large-scale change. *Frontiers in Sustainable Food Systems*, *3*, 37.

Angeler, D. G., Fried-Petersen, H. B., Allen, C. R., Garmestani, A., Twidwell, D., Birge, H. E., Chuang, W., Donovan, V. M., Eason, T., Roberts, C. P., Sundstrom, S. M. & Wonkka, C. L. (2019). Adaptive capacity in ecosystems. In *Advances in ecological research* (Vol. 60, pp. 1-24). Academic Press.

Aniah, P., Kaunza-Nu-Dem, M. K., & Ayembilla, J. A. (2019). Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon*, 5(4).

Antwi-Agyei, P., Quinn, C. H., Adiku, S. G. K., Codjoe, S. N. A., Dougill, A. J., Lamboll, R., & Dovie, D. B. K. (2017). Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: a participatory approach. *Regional Environmental Change*, 17, 213-227.

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, 32, 100304.

Antwi-Agyei, P., Dougill, A. J., & Stringer, L. C. (2015). Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review. *Climate and Development*, *7*(4), 297-309.

Antwi-Agyei, P., Dougill, A. J., Fraser, E. D., & Stringer, L. C. (2013). Characterising the nature of household vulnerability to climate variability: Empirical evidence from two regions of Ghana. *Environment, Development and Sustainability*, *15*, 903-926.

Arif, G. M., & Farooq, S. (2014). Rural poverty dynamics in Pakistan: Evidence from three waves of the panel survey. *The Pakistan Development Review*, *53*(2), 71-98.

Arouri, M., Nguyen, C., & Youssef, A. B. (2015). Natural disasters, household welfare, and resilience: evidence from rural Vietnam. *World Development*, *70*, 59-77.

Arshad, A., Zhang, Z., Zhang, W., & Dilawar, A. (2020). Mapping favorable groundwater potential recharge zones using a GIS-based analytical hierarchical process and probability frequency ratio model: A case study from an agro-urban region of Pakistan. *Geoscience Frontiers*, 11(5), 1805-1819.

Arshad, M., Kächele, H., Krupnik, T. J., Amjath-Babu, T. S., Aravindakshan, S., & Abbas, A., (2017). Climate variability, farmland value, and farmers' perceptions of climate change: implications for adaptation in rural Pakistan. *International Journal of Sustainable Development & World Ecology*, 24(6), 532-544.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Marenya, P., & Stirling, C. M. (2021). Climate risks and adaptation strategies of farmers in East Africa and South Asia. *Scientific Reports*, 11(1), 10489.

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045-5075.

Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon*, 7(4).

Ashraf, M., & Routray, J. K. (2015). Spatio-temporal characteristics of precipitation and drought in Balochistan Province, Pakistan. *Natural Hazards*, *77*, 229-254.

Ashraf, M., Routray, J.K., & Saeed, M. (2014). Determinants of farmers' choice of coping and adaptation measures to the drought hazard in northwest Balochistan, Pakistan. *Natural Hazards* 73:1451-1473

Attri, S. D., & Rathore, L. S. (2003). Simulation of impact of projected climate change on wheat in India. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *23*(6), 693-705.

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., & Ross, N. A. (2019). Enabling local public health adaptation to climate change. *Social Science & Medicine*, *220*, 236-244.

Autio, A., Johansson, T., Motaroki, L., Minoia, P., & Pellikka, P. (2021). Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. *Agricultural Systems*, 194, 103284.

Awan, U.K., Anwar, A., Ahmad, W., & Hafeez, M. (2016). A methodology to estimate equity of canal water and groundwater use at different spatial and temporal scales: a geo-informatics approach. *Environmental Earth Sciences*,75:409.

Awazi, N. P., Tchamba, M. N., Temgoua, L. F., Avana, M. L. T., Shidiki, A. A., Forje, G. W., & Nfornkah, B. N. (2022). Climate-smart and agro-ecological farming systems of smallholder farmers. *Environment and climate-smart food production*, 31-72.

Awazi, N. P., Tchamba, M. N., Temgoua, L. F., & Avana, M. L. T. (2020). Appraisal of smallholder farmers' vulnerability to climatic variations and changes in the Western Highlands of Cameroon. *Scientific African*, 10, e00637.

Azadi, H., Ghazali, S., Ghorbani, M., Tan, R., & Witlox, F. (2023). Contribution of small-scale farmers to global food security: a meta-analysis. *Journal of the Science of Food and Agriculture*, 103(6), 2715-2726.

Azadi, H., Moghaddam, S. M., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *Journal of Cleaner Production*, 319, 128602.

Azadi, Y., Yazdanpanah, M., & Mahmoudi, H. (2019). Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. *Journal of environmental management*, 250, 109456.

Azhoni, A., Jude, S., & Holman, I. (2018). Adapting to climate change by water management organisations: Enablers and barriers. *Journal of hydrology*, *559*, 736-748.

Aziz, M.; Rizvi, S.A.; Iqbal, M.A.; Syed, S.; Ashraf, M.; Anwer, S.; Usman, M.; Tahir, N.; Khan, A.; Asghar, S. (2021) A Sustainable Irrigation System for Small Landholdings of Rainfed Punjab, Pakistan. *Sustainability*, 13, 11178. https://doi.org/10.3390/

Azmat, M., Ilyas, F., Sarwar, A., Huggel, C., Vaghefi, S. A., Hui, T., Qamar, M.U., Bilal, M., & Ahmed, Z. (2021). Impacts of climate change on wheat phenology and yield in Indus Basin, Pakistan. *Science of the Total Environment*, *790*, 148221.

Azungah, T. (2018). Qualitative research: deductive and inductive approaches to data analysis. *Qualitative Research Journal*, 18(4), 383-400.

Balasubramanya, S., Brozović, N., Fishman, R., Lele, S., & Wang, J. (2022). Managing irrigation under increasing water scarcity. *Agricultural Economics*, *53*(6), 976-984.

Bantayan, R., Cadiz, M. C., Lasco, R., & Sajise, P. (2018). Policy-Enabling Environment for Climate Change Adaptation: Some Experiences in Southeast Asia. Books on Agricultural Research and Development, 2.

Bapna, M., McGray, H., Mockm, G., & Witheym, L. (2008). Enabling adaptation: priorities for supporting the rural poor in a changing climate. In Enabling adaptation: Priorities for supporting the rural poor in a changing climate (pp. 12-12).

Barbour, R. 2013, Introducing qualitative research: a student's guide, Sage, ISBN: 9781446254592.

Barnes, M. L., Wang, P., Cinner, J. E., Graham, N. A., Guerrero, A. M., Jasny, L., Lau, J., Sutcliffe, S. R., & Zamborain-Mason, J. (2020). Social determinants of adaptive and transformative responses to climate change. *Nature Climate Change*, 10(9), 823-828.

Barr, R., Fankhauser, S., & Hamilton, K. (2010). Adaptation investments: a resource allocation framework. *Mitigation and adaptation strategies for global change*, *15*, 843-858.

Barrett, S. (2013). Local level climate justice? Adaptation finance and vulnerability reduction. *Global environmental change*, *23*(6), 1819-1829.

Baruah, A. (2022). Water conflicts and resistance: issues and challenges in South Asia: edited by Venkatesh Dutta, Oxon, Routledge, 314 pp., ISBN 9781032203591.

Bastakoti, R.C., Gupta, J., Babel, M.S., van Dijk, M.P. (2014). Climate risks and adaptation strategies in the Lower Mekong River basin. *Regional Environmental Change,* 14:207-219.

Beaumont, P., & Coning, C. D. (2022). Coping with complexity: Toward epistemological pluralism in climate–conflict scholarship. *International Studies Review*, 24(4), viac055.

Bebbington, A. (1999). Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Development, 27:2021-2044. doi:10.1016/S0305-750X(99)00104-7

Bedeke, S. B. (2023). Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: a review on concepts, approaches and methods. *Environment, Development and Sustainability*, *25*(2), 1017-1051.

Bekele, F., Tolossa, D., & Woldeamanuel, T. (2020). Local institutions and climate change adaptation: Appraising dysfunctional and functional roles of local institutions from the bilate basin agropastoral livelihood zone of sidama, southern ethiopia. *Climate*, *8*(12), 149.

Below, T., Artner, A., Siebert, R., & Sieber, S. (2010). Micro-level practices to adapt to climate change for African small-scale farmers. A review of selected literature, IFPRI Discussion Paper 953.

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Resilience, poverty and development. *Journal of International Development*, 26(5), 598-623.

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, 8(1), 123-138.

Béné, C., Cornelius, A., & Howland, F. (2018). Bridging humanitarian responses and long-term development through transformative changes—Some initial reflections from the World Bank's adaptive social protection program in the Sahel. *Sustainability*, 10, 1697.

Berg, B. & Lune, H. (2012), Qualitative research methods for the social sciences, Pearson.

Berghofer, P. (2020). Scientific perspectivism in the phenomenological tradition. *European Journal for Philosophy of Science*, 10(3), 30.

Bergman, M. M. (2020). Mixed Method and Multimethod Research and Design. D. Berg-Schlosser, B. Badie, & L. Morlino, The SAGE Handbook of Political Science, 437-446.

Berman, R., Quinn, C., & Paavola, J. (2012). The role of institutions in the transformation of coping capacity to sustainable adaptive capacity. *Environmental Development*, 2, 86-100.

Bernier, Q., Sultana, P., Bell, A. R., & Ringler, C. (2016). Water management and livelihood choices in southwestern Bangladesh. *Journal of Rural Studies*, 45, 134-145.

Bhattacharyya, P., Pathak, H., & Pal, S. (2020). Climate smart agriculture: concepts, challenges, and opportunities. Berlin/Heidelberg, Germany: Springer.

Bhatt, S. (2013). How does participatory irrigation management work? A study of selected water users' associations in Anand district of Gujarat, western India. *Water Policy*, 15(2), 223-242.

Bhatta, G. D., Ojha, H. R., Aggarwal, P. K., Sulaiman, V. R., Sultana, P., Thapa, D., Mittal, N.,Dahal, K., Thomson, P., & Ghimire, L. (2017). Agricultural innovation and adaptation to climate change: empirical evidence from diverse agro-ecologies in South Asia. *Environment, Development and Sustainability*, 19(2), 497-525.

Bhatti, M. T., Ahmad, W., Shah, M. A., & Khattak, M. S. (2019). Climate change evidence and community level autonomous adaptation measures in a canal irrigated agriculture system of Pakistan. *Climate and Development*, 11(3), 203-211.

Bhatti, M. N., & Farooq, M. (2014). Politics of water in Pakistan. *Pakistan Journal of Social Sciences*, *34*(1), 205-216.

Bhave, A. G., Conway, D., Dessai, S., & Stainforth, D. A. (2016). Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. *Climate Risk Management*, *14*, 1-10.

Bhutto, A. W., & Bazmi, A. A. (2007). Sustainable agriculture and eradication of rural poverty in Pakistan. In *Natural Resources Forum* (Vol. 31, No. 4, pp. 253-262). Oxford, UK: Blackwell Publishing Ltd.

Bilali, H., Bassole, I. H. N., Dambo, L., & Berjan, S. (2020). Climate change and food security. *Agriculture & Forestry/Poljoprivreda i Sumarstvo*, *66*(3).

Birchall, S. J., Bonnett, N., & Kehler, S. (2023). The influence of governance structure on local resilience: Enabling and constraining factors for climate change adaptation in practice. *Urban Climate*, 47, 101348.

Birkmann, J., Jamshed, A., McMillan, J. M., Feldmeyer, D., Totin, E., Solecki, W., Ibrahim, Z. Z., Roberts, D., Kerr, R. B., Poertner, H., Pelling, M., Djalante, R., Garschagen, M., Filho, W. L., Guha-Sapir, D., & Alegría, A. (2022). Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. *Science of The Total Environment*, 803, 150065.

Birkmann, J. (2006). Indicators and criteria for measuring vulnerability: Theoretical bases and requirements. *Measuring vulnerability to natural hazards: Towards disaster resilient societies*, 55-77.

Biswas, S., & Nautiyal, S. (2023). A review of socio-economic vulnerability: The emergence of its theoretical concepts, models and methodologies. *Natural Hazards Research*.

Bjornlund, V., Bjornlund, H., & Van Rooyen, A. F. (2020). Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world–a historical perspective. *International Journal of Water Resources Development*, 36(sup1), S20-S53.

Bolstad, P. (2012). *GIS fundamentals* (Vol. 4). White Bear Lake, MN: Eider Press.

Bonnett, N. L., & Birchall, S. J. (2023). The influence of regional strategic policy on municipal climate adaptation planning. *Regional Studies*, 57(1), 141-152.

Borsato, E., Rosa, L., Marinello, F., Tarolli, P., & D'Odorico, P. (2020). Weak and strong sustainability of irrigation: A framework for irrigation practices under limited water availability. *Frontiers in Sustainable Food Systems*, 4, 17.

Bremer, S., Wardekker, A., Baldissera Pacchetti, M., Bruno Soares, M., & van der Sluijs, J. (2022). High-quality knowledge for climate adaptation: revisiting criteria of credibility, legitimacy, salience, and usability. *Frontiers in Climate*, 4, 905786.

Brooks, N., & Adger, W. N. (2005). Assessing and enhancing adaptive capacity. *Adaptation policy frameworks for climate change: Developing strategies, policies and measures*, 165-181.

Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, *15*(2), 151-163.

Brown, K. (2011). Sustainable adaptation: An oxymoron?. *Climate and Development*, 3(1), 21-31.

Brown, P. R., Nelson, R., Jacobs, B., Kokic, P., Tracey, J., Ahmed, M., & DeVoil, P. (2010). Enabling natural resource managers to self-assess their adaptive capacity. *Agricultural Systems*, *103*(8), 562-568.

Brügger, A. (2020). Understanding the psychological distance of climate change: The limitations of construal level theory and suggestions for alternative theoretical perspectives. *Global environmental change*, 60, 102023.

Brugnach, M., & Özerol, G. (2019). Knowledge co-production and transdisciplinarity: Opening Pandora's box. *Water*, 11(10), 1997.

Bryman, A. (2016). Social research methods, Fifth ed. Oxford university press, ISBN: 980199689453.

Burnard, P., Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Analysing and presenting qualitative data. *British dental journal*, 204(8), 429-432.

Burnham, M., & Ma, Z. (2016). Linking smallholder farmer climate change adaptation decisions to development. *Climate and Development*, *8*(4), 289-311.

Burton, C., Rufat, S., & Tate, E. (2018). Social vulnerability. *Vulnerability and resilience to natural hazards*, 53.

Burton, I. (2011). Adaptation to climate change: context, status, and prospects. Climate change adaptation in developed nations: from theory to practice, 477-483.

Burton, I., Kates, R.W. & White, G.F. (1978). Tle Environment as Hazard, Oxford University Press.

Byjesh, K., Kumar, S. N., & Aggarwal, P. K. (2010). Simulating impacts, potential adaptation and vulnerability of maize to climate change in India. *Mitigation and adaptation strategies for global change*, *15*, 413-431.

Campbell, B. M., Thornton, P., Zougmoré, R., Van Asten, P., & Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture?. *Current Opinion in Environmental Sustainability*, *8*, 39-43.

Campos, I., Guerra, J., Gomes, J. F., Schmidt, L., Alves, F., Vizinho, A., & Lopes, G. P. (2017). Understanding climate change policy and action in Portuguese municipalities: A survey. *Land Use Policy*, 62, 68-78.

Caniglia, G., Lüderitz, C., von Wirth, T., Fazey, I., Martín-López, B., Hondrila, K., König, A., Wehrden, H. V., Schäpke, N. A., Laubichle, M. D., & Lang, D. J. (2021). A pluralistic and integrated approach to action-oriented knowledge for sustainability. *Nature Sustainability*, 4(2), 93-100.

Carney, D., Drinkwater, M., Rusinow, T., Neefjes, K., Wanmali, & S., Singh, N. (1999) Livelihoods approaches compared: a brief comparison of the livelihoods approaches of the UK department for international development (DFID), CARE, Oxfam and the United Nations Development Programme (UNDP). London, Department for International Development.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: resilience of what to what?. *Ecosystems*, 4, 765-781.

Castro, B., & Sen, R. (2022). Everyday Adaptation: Theorizing climate change adaptation in daily life. *Global Environmental Change*, 75, 102555.

Cash, D. W., Adger, W. N., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., & Young, O. (2006). Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World. *Ecology and Society*, 11(2). http://www.jstor.org/stable/26265993

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J. & Mitchell, R.B. 2003. Knowledge systems for sustainable development, *Proceedings of the National Academy of Sciences*, *100*(14), 8086-8091.

Cash, D., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., & Jäger, J. (2002). Salience, credibility, legitimacy and boundaries: linking research, assessment and decision making. *Assessment and Decision Making*.

Cepiku, D., & Giordano, F. (2014). Co-Production in Developing Countries: Insights from the community health workers experience. *Public Management Review*, *16*(3), 317-340.

Chakraborty, R., & Sherpa, P. Y. (2021). From climate adaptation to climate justice: Critical reflections on the IPCC and Himalayan climate knowledges. *Climatic Change*, 167(3), 49.

Chakraborty, A., & Joshi, P. K. (2016). Mapping disaster vulnerability in India using analytical hierarchy process. *Geomatics, Natural Hazards and Risk*, *7*(1), 308-325.

Chaliha, S., Sengupta, A., Sharma, N., & Ravindranath, N. H. (2012). Climate variability and farmer's vulnerability in a flood-prone district of Assam. *International Journal of Climate Change Strategies and Management*, *4*(2), 179-200.

Chambers, R. & Conway, G. 1992, Sustainable rural livelihoods: practical concepts for the 21st century, Institute of Development Studies, UK.

Chandio, A. A., Magsi, H., & Ozturk, I. (2020). Examining the effects of climate change on rice production: case study of Pakistan. Environmental Science and Pollution Research 27(8): 7812-7822.

Chandra, G. (2010). Participatory rural appraisal. Katiha, PK, Vaas, KK, Sharma, AP, Bhaumik, U. & Chandra Ganesh (Eds). Issues and tools for social science research in inland fisheries. Central Inland Fisheries Research Institute, Barrackpore, Kolkata, India. Bulletin, 163, 286-302.

Chaudhary, A., Timsina, P., Karki, E., Sharma, A., Suri, B., Sharma, R., & Brown, B. (2023). Contextual realities and poverty traps: why South Asian smallholder farmers negatively evaluate conservation agriculture. *Renewable Agriculture and Food Systems*, 38, e13.

Choden, K., Keenan, R. J., & Nitschke, C. R. (2020). An approach for assessing adaptive capacity to climate change in resource dependent communities in the Nikachu watershed, Bhutan. *Ecological Indicators*, 114, 106293.

Chu, E., Anguelovski, I., & Carmin, J. (2016). Inclusive approaches to urban climate adaptation planning and implementation in the Global South. *Climate Policy*, 16(3), 372-392.

Cid, A., & Lerner, A. M. (2023). Local governments as key agents in climate change adaptation: challenges and opportunities for institutional capacity-building in Mexico. *Climate Policy*, 1-13.

Cochrane, K.L., Rakotondrazafy, H., Aswani, S., Chaigneau, T., Downey-Breedt, N., Lemahieu, A., Paytan, A., Pecl, G., Plagányi, E., Popova, E., van Putten, E.I., Sauer, WHH., Byfield, V., Gasalla, M.A., van Gennip, S.J., Malherbe, W., Rabary, A., Rabearisoa, A., Ramaroson, N., Randrianarimanana, V., Scott, L.,& Tsimanaoraty, P. M. (2019). Tools to enrich vulnerability assessment and adaptation planning for coastal communities in data-poor regions: application to a case study in Madagascar. *Frontiers in Marine Science*, 5, 505.

Cochrane, L., Cundill, G., Ludi, E., New, M., Nicholls, R. J., Wester, P., Cantin, B., Murali, K. S., Leone, M., & Kituyi, E. (2017). A reflection on collaborative adaptation research in Africa and Asia. *Regional Environmental Change*, 17(5), 1553-1561.

Cofré-Bravo, G., Klerkx, L., & Engler, A. (2019). Combinations of bonding, bridging, and linking social capital for farm innovation: How farmers configure different support networks. *Journal of Rural Studies*, 69, 53-64.

Cook, E. M., Berbés-Blázquez, M., Mannetti, L. M., Grimm, N. B., Iwaniec, D. M., & Muñoz-Erickson, T. A. (2021). Setting the stage for co-production. *Resilient Urban Futures*, 99-111.

Cooper, S. J., & Wheeler, T. (2017). Rural household vulnerability to climate risk in Uganda. *Regional Environmental Change*, *17*, 649-663.

Cordell, D. & Neset, T. S. (2014). Phosphorus vulnerability: a qualitative framework for assessing the vulnerability of national and regional food systems to the multi-dimensional stressors of phosphorus scarcity. *Global Environmental Change*, *24*, 108-122.

Cordell, D. (2010). The story of phosphorus: Sustainability implications of global phosphorus scarcity forfood security : Linko¨ping University Press 220 pp., No. 509. ISBN: 978917393-440-4.

Coulthard, S. (2012). Can we be both resilient and well, and what choices do people have? Incorporating agency into the resilience debate from a fisheries perspective. *Ecology and Society*, 17(1).

Colenbrander, S., Dodman, D., & Mitlin, D. (2018). Using climate finance to advance climate justice: the politics and practice of channelling resources to the local level. *Climate Policy*, *18*(7), 902-915.

Creswell, J. W., & Clark, V. L. P. (2017). Designing and conducting mixed methods research. *Sage publications*.

Creswell, J.W., (2007). Research design: Qualitative, quantitative, and mixed methods approaches, Sage publications, ISBN: 9781412965569.

Cresswell, J. W., Plano-Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), Handbook of Mixed Methods in Social and Behavioral Research (pp. 209–240). https://doi.org/10.1017/CBO9781107415324.004

Crick, F., Gannon, K. E., Diop, M., & Sow, M. (2018). Enabling private sector adaptation to climate change in sub-Saharan Africa. *WIREs Climate Change*, 9(2), e505. https://doi.org/10.1002/wcc.505

Crotty, M. J. (1998). The foundations of social research: Meaning and perspective in the research process. *The foundations of social research*, 1-256.

Cutter, S. L., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the national academy of sciences*, 105(7), 2301-2306.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina. *Annals of the Association of American Geographers*, *90*(4), 713-737.

Cutter, S. L. (1996). Vulnerability to environmental hazards. *Progress in human geography*, *20*(4), 529-539.

Cunningham, R., Cvitanovic, C., Measham, T., Jacobs, B., Dowd, A. M., & Harman, B. (2016). Engaging communities in climate adaptation: the potential of social networks. *Climate Policy*, 16(7), 894-908.

Dannevig, H., Rauken, T., & Hovelsrud, G. (2012). Implementing adaptation to climate change at the local level. *Local Environment*, 17(6-7), 597-611.

Dare Kolawole, O. (2022). Is local knowledge peripheral? The future of Indigenous knowledge in research and development. *AlterNative: An International Journal of Indigenous Peoples*, 18(1), 132-140.

Das, U., Ansari, M. A., & Ghosh, S. (2023). Measures of livelihoods and their effect on vulnerability of farmers to climate change: evidence from coastal and non-coastal regions in India. *Environment, Development and Sustainability*, 1-36.

Das, U., Ansari, M. A., & Ghosh, S. (2022). Effectiveness and upscaling potential of climate smart agriculture interventions: Farmers' participatory prioritization and livelihood indicators as its determinants. *Agricultural Systems*, 203, 103515.

Davidson, D. J. (2010). The applicability of the concept of resilience to social systems: some sources of optimism and nagging doubts. *Society and Natural Resources*, 23(12), 1135-1149.

Davies, J. E., Spear, D., Ziervogel, G., Hegga, S., Ndapewa Angula, M., Kunamwene, I., & Togarepi, C. (2020). Avenues of understanding: mapping the intersecting barriers to adaptation in Namibia. *Climate and Development*, 12(3), 268-280.

Dawadi, S., Shrestha, S., & Giri, R. A. (2021). Mixed-methods research: A discussion on its types, challenges, and criticisms. *Journal of Practical Studies in Education*, 2(2), 25-36.

Dechezleprêtre, A., Glachant, M., Haščič, I., Johnstone, N., & Ménière, Y. (2011). Invention and transfer of climate change–mitigation technologies: a global analysis. *Review of environmental economics and policy*, 5(1), 109-130.

De Haan, L., & Zoomers, A. (2005). Exploring the frontier of livelihoods research. *Development and change*, 36(1), 27-47.

Delettre, O. (2021). Identity of ecological systems and the meaning of resilience. *Journal of Ecology*, 109(9), 3147-3156.

Denzin, N.K. & Lincoln, Y.S. 2011, *The Sage handbook of qualitative research*, Sage publications, ISBN: 9781412974172.

de Oliveira, J. A. P. (2009). The implementation of climate change related policies at the subnational level: An analysis of three countries. *Habitat international*, 33(3), 253-259.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global environmental change*, 19(2), 248-255.

Deria, A., Ghannad, P., & Lee, Y. C. (2020). Evaluating implications of flood vulnerability factors with respect to income levels for building long-term disaster resilience of low-income communities. *International Journal of Disaster Risk Reduction*, 48, 101608.

De Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., Apotsos A., Fish, C., Kienberger, S., Muhonda, P., Wilhelmi, O., Macharia, D., Shubert, W., Sliuzas, R., Brian, T., &

Zhang, S. (2019). Climate vulnerability mapping: A systematic review and future prospects. *Wiley Interdisciplinary Reviews: Climate Change*, 10(5), e600.

Deshpande, T., Michael, K., & Bhaskara, K. (2019). Barriers and enablers of local adaptive measures: A case study of Bengaluru's informal settlement dwellers. *Local environment*, *24*(3), 167-179.

Devineni, N., Perveen, S., & Lall, U. (2022). Solving groundwater depletion in India while achieving food security. *Nature Communications*, 13(1), 1-10.

DFID (2001). Sustainable livelihoods guidance sheets, *SL Approaches in Practice*. *DFID, UK*, 1-24.

Di Gregorio, M., Fatorelli, L., Paavola, J., Locatelli, B., Pramova, E., Nurrochmat, D. R., May, P. H., Brockhaus, M., Sari, I. M., & Kusumadewi, S. D. (2019). Multi-level governance and power in climate change policy networks. *Global Environmental Change*, *54*, 64-77.

Di Gregorio, M., Nurrochmat, D. R., Paavola, J., Sari, I. M., Fatorelli, L., Pramova, E., Locatelli, B., Brockhaus, M., & Kusumadewi, S. D. (2017). Climate policy integration in the land use sector: Mitigation, adaptation and sustainable development linkages. *Environmental Science & Policy*, *67*, 35-43.

Dodson, J. C., Dérer, P., Cafaro, P., & Götmark, F. (2020). Population growth and climate change: Addressing the overlooked threat multiplier. *Science of the Total Environment*, 748, 141346.

Dorkenoo, K., Scown, M., & Boyd, E. (2022). A critical review of disproportionality in loss and damage from climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *13*(4), e770.

Downing, T. E. (1991). Vulnerability to hunger in Africa: A climate change perspective. *Global Environmental Change*, *1*(5), 365-380.

Dumitraşcu, M., Mocanu, I., Mitrică, B., Dragotă, C., Grigorescu, I., & Dumitrică, C. (2018). The assessment of socio-economic vulnerability to drought in Southern Romania (Oltenia Plain). *International journal of disaster risk reduction*, *27*, 142-154.

Dunford, S. (2018). Attributes of good governance for effective adaptation action and regional transitions.(5470). In *Proceedings of the 4th Practical Responses to Climate Change Conference* (p. 63).

Eakin, H., & Luers, A. L. (2006). Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, *31*, 365-394.

Eckstein, D., Künzel, V., Schäfer, L., & Winges, M. (2021). Global climate risk index 2021. Germanwatch.

Eicken, H., Danielsen, F., Sam, J. M., Fidel, M., Johnson, N., Poulsen, M. K., Lee, O. A., Spellman, K. V., Iversen, L., Pulsifer, P., & Enghoff, M. (2021). Connecting top-down and bottom-up approaches in environmental observing. *BioScience*, 71(5), 467-483.

El Aoula, R., Mhammdi, N., Dezileau, L., Mahe, G., & Kolker, A. S. (2021). Fluvial sediment transport degradation after dam construction in North Africa. *Journal of African Earth Sciences*, *182*, 104255.

Elrick-Barr, C. E., Plummer, R., & Smith, T. F. (2023). Third-generation adaptive capacity assessment for climate-resilient development. *Climate and Development*, 15(6), 518-521.

Ellis, F., & Freeman, H. A. (2005). Comparative evidence from four African countries. In *Rural livelihoods and poverty reduction policies* (pp. 31-47). Routledge.

Ellis F (2000). Rural livelihoods and diversity in developing countries. Oxford University Press, ISBN 0198296967.

Eriksen, S. H., & Kelly, P. M. (2007). Developing credible vulnerability indicators for climate adaptation policy assessment. *Mitigation and adaptation strategies for global change*, *12*, 495-524.

Eriksen, C., Simon, G. L., Roth, F., Lakhina, S. J., Wisner, B., Adler, C., Thomalla, F., Scolobig, A., Brady, K., Bründl, M., Neisser, F., Grenfell, M., Maduz, L., & Prior, T. (2020). Rethinking the interplay between affluence and vulnerability to aid climate change adaptive capacity. *Climatic Change*, *162*(1), 25-39.

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, *21*(2), 647-656.

Esham, M. & Garforth, C. (2013). Agricultural adaptation to climate change: Insights from a farming community in Sri Lanka. *Mitigation and Adaptation Strategies for Global Change*, 18(5): 535-549.

Ezra, C. A. (2016). Climate change vulnerability assessment in the agriculture sector: Typhoon Santi experience. *Procedia-Social and Behavioral Sciences*, *216*, 440-451.

Fankhauser, S. (2017). Adaptation to climate change. *Annual Review of Resource Economics*, 9, 209-230.

Fan, S., & Rue, C. (2020). The role of smallholder farms in a changing world. *The role of smallholder farms in food and nutrition security*, 13-28.

FAO 2022, Food and Agriculture Organisation, https://www.fao.org/pakistan

FAO 2020. The State of Agricultural Commodity Markets 2020. Agricultural markets and sustainable development: Global value chains, smallholder farmers and digital innovations. Rome, FAO. https://doi.org/10.4060/cb0665en

FAO (2019) Agro-Ecological Zones of Punjab Pakistan. Food and Agricultural Organization of the United Nations (FAO), Rome.

FAO, I.F.A.D., UNICEF, W.F.P., WHO (2018) The State of Food Security and Nutrition in the World : building climate resilience for food security and nutrition. Rome, FAO.

FAO (2010) Climate-smart agriculture: policies, practices and financing for food security, adaptation and mitigation. In: Hague Conference on Agriculture, Food Security and Climate Change.

Farooq, M. S., Uzair, M., Raza, A., Habib, M., Xu, Y., Yousuf, M., Yang, S.H., & Khan, M.R., (2022). Uncovering the research gaps to alleviate the negative impacts of climate change on food security: a review. *Frontiers in Plant Science*, 13, 927535.

Farooqi, S. A. (2016). Co-production: what makes co-production work? Evidence from Pakistan. *International Journal of Public Sector Management*, 29(4), 381-395.

Fathi, F., Valizadeh, N., Esfandyari Bayat, S., & Bazrafkan, K. (2023). Policy Framework to Introduce Climate-Smart Agriculture. In : Bandh, S.A. (eds) *Strategizing Agricultural Management for Climate Change Mitigation and Adaptation* (pp. 183-205). Cham, Springer Publishing.

Fatima, Z., Ahmed, M., Hussain, M., Abbas, G., Ul-Allah, S., Ahmad, S., Ahmed,N., Ali, M.A., Sarwar, G., Haque, E.U., Iqbal, Pakeeza & Hussain, S. (2020). The fingerprints of climate warming on cereal crops phenology and adaptation options. *Scientific Reports*, 10(1), 18013.

Fauser, M. (2018). Mixed methods and multisited migration research: Innovations from a transnational perspective. *Journal of Mixed Methods Research*, 12(4), 394-412.

Favretto, N., Stringer, L. C., Dougill, A. J., & Kruger, L. (2022). Knowledge exchange enhances engagement in ecological restoration and rehabilitation initiatives. *Restoration Ecology*, 30(2), e13565.

Fellmann, T. 2012, The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. Building Resilience for Adaptation to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop 23-24 April 2012, Food & Agriculture Org, pp. 37-61.

Fenton, A., Reid, H., Wright, H., & Huq, S. (2015). Ten principles to help assess funding for local climate adaptation. International Institute for Environment and Development. http://pubs.iied.org/17323IIED/

Feo, E., Spanoghe, P., Berckmoes, E., Pascal, E., Mosquera-Losada, R., Opdebeeck, A., & Burssens, S. (2022). The multi-actor approach in thematic networks for agriculture and forestry innovation. *Agricultural and Food Economics*, 10(1), 3.

Few, R., Morchain, D., Spear, D., Mensah, A., & Bendapudi, R. (2017). Transformation, adaptation and development: relating concepts to practice. *Palgrave Communications*, *3*(1), 1-9.

FICCP 2013, 'Framework for Implementation of Climate Change Policy (2014-2030), Government of Pakistan.

Fila, D., Fünfgeld, H., & Dahlmann, H. (2024). Climate change adaptation with limited resources: adaptive capacity and action in small-and medium-sized municipalities. *Environment, Development and Sustainability*, 1-21.

Fischer, A. P., Paveglio, T., Carroll, M., Murphy, D., & Brenkert-Smith, H. (2013). Assessing social vulnerability to climate change in human communities near public forests and grasslands: A framework for resource managers and planners. *Journal of Forestry*, *111*(5), 357-365.

Fischer, E., & Qaim, M. (2012). Linking smallholders to markets: determinants and impacts of farmer collective action in Kenya. *World development*, *40*(6), 1255-1268.

Fishman, R. (2018). Groundwater depletion limits the scope for adaptation to increased rainfall variability in India. *Climatic Change*, *147*, 195-209.

Fishman, R., Lall, U., Modi, V., & Parekh, N. (2016). Can electricity pricing save india's groundwater? field evidence from a novel policy mechanism in gujarat. *Journal of the Association of Environmental and Resource Economists*, *3*(4), 819-855.

Ford, J. D., McDowell, G., Shirley, J., Pitre, M., Siewierski, R., Gough, W., Duerden, F., Pearce, T., Adams, P., & Statham, S. (2013). The dynamic multiscale nature of climate change vulnerability: an Inuit harvesting example. *Annals of the Association of American Geographers*, 103(5), 1193-1211.

Ford, J. D., Berrang-Ford, L., King, M., & Furgal, C. (2010). Vulnerability of Aboriginal health systems in Canada to climate change. *Global Environmental Change*, 20(4), 668-680.

Forino, G., Von Meding, J., & Brewer, G. J. (2018). Challenges and opportunities for Australian local governments in governing climate change adaptation and disaster risk reduction integration. *International journal of disaster resilience in the built environment*, *9*(3), 258-272.

Franco, L., Justo, A., Cotelo, C., Arias, I., Garrido, L., Lloret, L., & Rodríguez-Aubó, N. (2019). Multi-actor engagement: an open innovation process of knowledge exchange and co-creation. In ICERI2019 Proceedings (pp. 3808-3813). IATED.

Frimpong, F., Asante, M. D., Peprah, C. O., Amankwaa-Yeboah, P., Danquah, E. O., Ribeiro, P. F., Aidoo, A.K., Agyeman, K., Asante, M.O.O., Keteku, Agbesi & Botey, H. M. (2023). Water-smart farming: review of strategies, technologies, and practices for sustainable agricultural water management in a changing climate in West Africa. *Frontiers in Sustainable Food Systems*, 7, 1110179.

Fuhr, H., Hickmann, T., & Kern, K. (2018). The role of cities in multi-level climate governance: local climate policies and the 1.5 C target. *Current opinion in environmental sustainability*, *30*, 1-6.

Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*, *75*(3), 301-329.

Gabor, T., & Griffith, T. K. (1980). The assessment of community vulnerability to acute hazardous materials incidents. *Journal of Hazardous Materials*, *3*(4), 323-333.

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, *16*(3), 293-303.

Gannon, K. E., Crick, F., Atela, J., & Conway, D. (2021). What role for multi-stakeholder partnerships in adaptation to climate change? Experiences from private sector adaptation in Kenya. *Climate Risk Management*, 32, 100319

Gardezi, M., Michael, S., Stock, R., Vij, S., Ogunyiola, A., & Ishtiaque, A. (2022). Prioritizing climate-smart agriculture: An organizational and temporal review. *Wiley Interdisciplinary Reviews: Climate Change*, *13*(2), e755.

Gatzweiler, F. W., & von Braun, J. (2016). Innovation for marginalized smallholder farmers and development: an overview and implications for policy and research. *Technological and institutional innovations for marginalized smallholders in agricultural development*, 1-22.

Gbetibouo, G.A. & Ringler, C. 2009, Mapping South African farming sector vulnerability to climate change and variability: A subnational assessment. IFPRI Discussion Paper 00885.

Gerlak, A. K., Guido, Z., Owen, G., McGoffin, M. S. R., Louder, E., Davies, J., Smith, K.J., Zimmer, A., Murveit, A.M., Meadow, A., Shrestha, P., & Joshi, N. (2023). Stakeholder engagement in the co-production of knowledge for environmental decision-making. *World Development*, 170, 106336.

Gero, A., Winterford, K., & Davila, F. (2024). A Pacific community resilience framework: Exploring a holistic perspective through a strengths-based approach and systems thinking. *Asia Pacific Viewpoint*.

Ghazal, L., Kazmi, S. J. H., & Afsar, S. (2013). Spatial appraisal of the impacts of drought on agricultural patterns in Karachi. *Journal of Basic and Applied Sciences*, *9*, 352-360.

Gore, C., & Robinson, P. (2009). Local Government Response to Climate Change: Our Last, Best Hope?. *Changing Climates in North American Politics: Institutions, Policymaking, and Multilevel Governance*, 137-158.

Gorst, A., A. Dehlavi & Groom, B. (2018). Crop productivity and adaptation to climate change in Pakistan. *Environment and Development Economics*, 23(6): 679-701.

Goswami, R., Biswas, M.S. & Basu, D. 2012, Validation of participatory farming situation identification: a case of rainfed rice cultivation in selected area of West Bengal, India. *Indian Journal of Traditional Knowledge*, 11 (3) 471–479.

Government of Pakistan (GoP), 2022. Pakistan Economic Survey, 2022- 23, Ministry of Finance.

Gumel, D. Y. (2022). Assessing climate change vulnerability: A conceptual and theoretical review. *Journal of Sustainability and Environmental Management*, 1(1), 22-31.

Guo, H., Wang, R., Garfin, G. M., Zhang, A., & Lin, D. (2021). Rice drought risk assessment under climate change: Based on physical vulnerability a quantitative assessment method. *Science of the Total Environment*, 751, 141481.

Gupta, A. K., Negi, M., Nandy, S., Kumar, M., Singh, V., Valente, D., Petrosillo, I., & Pandey, R. (2020). Mapping socio-environmental vulnerability to climate change in different altitude zones in the Indian Himalayas. *Ecological Indicators*, 109, 105787.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., Van den Brink, M., Jong, P., Nooteboom, S., & Bergsma, E. (2010). The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy*, 13(6), 459-471.

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change*, *15*(3), 199-213.

Habib ur Rahman, M. H., Ahmad, A., Wang, X., Wajid, A., Nasim, W., Hussain, M., Ahmad, B., Ahmad, I., Ali, Z., Ishaque, W., Awais, M., Shelia, V., Ahmad, S., Fahad, S., Alam, M., Ullah, H., & Hoogenboom, G. (2018). Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. *Agricultural and Forest Meteorology*, 253, 94-113.

Haddaway, N. R., Kohl, C., Rebelo da Silva, N., Schiemann, J., Spök, A., Stewart, R., Sweet, J.B., & Wilhelm, R. (2017). A framework for stakeholder engagement during systematic reviews and maps in environmental management. *Environmental Evidence*, 6, 1-14.

Hafezi, M., Sahin, O., Stewart, R. A., & Mackey, B. (2018). Creating a novel multi-layered integrative climate change adaptation planning approach using a systematic literature review. *Sustainability*, *10*(11), 4100.

Hallegatte, S., Lecocq, F., & De Perthuis, C. (2011). Designing climate change adaptation policies: an economic framework. World Bank Policy Research Working Paper 5568.

Hammill, A., Leclerc, L., Myatt-Hirvonen, O. & Salinas, Z. 2005, Using the sustainable livelihoods approach to reduce vulnerability to climate change. *Tropical forests and Adaptation to Climate Change*, 71-96.

Handayani, W., Rudiarto, I., Setyono, J. S., Chigbu, U. E., & Sukmawati, A. M. A. (2017). Vulnerability assessment: A comparison of three different city sizes in the coastal area of Central Java, Indonesia. *Advances in Climate Change Research*, *8*(4), 286-296.

Hansen, J. W., Vaughan, C., Kagabo, D. M., Dinku, T., Carr, E. R., Körner, J., & Zougmoré, R. B. (2019). Climate services can support african farmers' context-specific adaptation needs at scale. *Frontiers in Sustainable Food Systems*, 3, 21.

Harvey, C.A., Chacón, M., Donatti, C.I., Garen, E., Hannah, L., Andrade, A., Bede, L., Brown, D., Calle, A., Chará, J., Clement, C., Gray, E., Hoang, M.H., Minang, P., Rodríguez, A.M., Seeberg-Elverfeldt, C., Semroc, B., Shames, S., Smukler, S., Somarriba, E., Torquebiau, E., van Etten, J. & Wollenberg, E. 2014, Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture. *Conservation Letters*, 7(2), 77-90.

Hasson, S., Saeed, F., Böhner, J., & Schleussner, C. F. (2019). Water availability in Pakistan from Hindukush–Karakoram–Himalayan watersheds at 1.5° C and 2° C Paris Agreement targets. *Advances in Water Resources*, *131*, 103365.

Head, B. W. (2022). *Wicked problems in public policy: Understanding and responding to complex challenges* (p. 176). Springer Nature.

Hennink, M., Hutter, I., & Bailey, A. (2010). *Qualitative research methods*. Sage, ISBN 9781473903906.

Hewitt, C., Mason, S., & Walland, D. (2012). The global framework for climate services. *Nature Climate Change*, 2(12), 831-832.

Heywood, I. (2010), An introduction to geographical information systems, 4th edition,Pearson Education.

Hickmann, T. (2017). The reconfiguration of authority in global climate governance. *International Studies Review*, *19*(3), 430-451.

Hisschemöller, M., Tol, R. S., & Vellinga, P. (2001). The relevance of participatory approaches in integrated environmental assessment. *Integrated Assessment*, *2*(2), 57-72.

Holler, J., Bernier, Q., Roberts, J. T., & Robinson, S. A. (2020). Transformational adaptation in least developed countries: does expanded stakeholder participation make a difference? *Sustainability*, *12*(4), 1657.

Holling, C.S. 1973, Resilience and stability of ecological systems, *Annual review of ecology and systematics*, vol. 4, no. 1, pp. 1-23.

Hoppe, T., Van der Vegt, A., & Stegmaier, P. (2016). Presenting a framework to analyze local climate policy and action in small and medium-sized cities. *Sustainability*, *8*(9), 847.

Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the national academy of sciences*, *104*(50), 19691-19696.

Hu, L. X., Zhang, X. H., & Zhou, Y. H. (2019). Farm size and fertilizer sustainable use: An empirical study in Jiangsu, China. *Journal of Integrative Agriculture*, 18(12), 2898-2909.

Hussain, M., Tayyab, M., Zhang, J., Shah, A. A., Ullah, K., Mehmood, U., & Al-Shaibah, B. (2021). GIS-based multi-criteria approach for flood vulnerability assessment and mapping in district Shangla: Khyber Pakhtunkhwa, Pakistan. *Sustainability*, 13(6), 3126.

Hung, P. Q., & Khai, H. V. (2020). Transaction cost, price risk perspective and marketing channel decision of small-scale chili farmers in Tra Vinh Province, Vietnam. *Asian Journal of Agriculture and Rural Development*, 10(1), 68-80.

Huq, S., & Reid, H. (2004). Mainstreaming adaptation in development. *IDS bulletin*, *35*(3), 15-21.

ID GoP (2012) District Pre-Investment Studies. Directorate of Industries, Government of Punjab, Pakistan.

Iliyyan, D. U., Boer, R., & Hidayati, R. (2022). Assessment of Livelihood Vulnerability to Climate Change Using Three Index Methods. *Agromet*, 36(2).

Imran, K. (2021). Water Sharing Issues in Pakistan: Impacts on Inter-Provincial Relations. *Journal of Development and Social Sciences*, *2*.

Inanloo, B., Tansel, B., Shams, K., Jin, X. & Gan, A. 2016, A decision aid GIS-based risk assessment and vulnerability analysis approach for transportation and pipeline networks, *Safety Science*, 84, 57-66.

IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

IPCC (2014) Summary for policymakers. In: Climate change 2014: mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S.

Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007): Summary for policymakers. In: Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7–22.

Iqbal, M., Ahmad, M., & Mustafa, G. (2015). Climate Change, Vulnerability, Food Security and Human Health in Rural Pakistan: A Gender Perspective. University Library of Munich, Germany.

Iqbal, W., & Zahid, M. (2014). Historical and future trends of summer mean air temperature over South Asia. *Pakistan Journal of Meteorology, 10*(20).

Isaac, M. E. (2012). Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. *Agricultural systems*, *109*, 9-15.

Ishtiaque, A., Eakin, H., Vij, S., Chhetri, N., Rahman, F., & Huq, S. (2021). Multilevel governance in climate change adaptation in Bangladesh: structure, processes, and power dynamics. *Regional Environmental Change*, *21*, 1-15.

Islam, E., Abd Wahab, H., & Benson, O. G. (2020). Structural and operational factors as determinant of meaningful community participation in sustainable disaster recovery programs: The case of Bangladesh. *International Journal of Disaster Risk Reduction*, 50, 101710.

Islam, M. T., & Nursey-Bray, M. (2017). Adaptation to climate change in agriculture in Bangladesh: The role of formal institutions. *Journal of environmental management*, 200, 347-358.

Islam, S., & Winkel, J. (2017). Climate change and social inequality. DESA working paper no. 152. UN Department of Economic and Social Affairs. https://www. un. org/esa/desa/papers/2017/wp152_2017. pdf.

Iwasaki, S., Razafindrabe, B. H. N., & Shaw, R. (2009). Fishery livelihoods and adaptation to climate change: a case study of Chilika lagoon, India. *Mitigation and adaptation strategies for global Change*, *14*, 339-355.

Jacobs, B., Nelson, R., Kuruppu, N., & Leith, P. (2015). An adaptive capacity guide book: Assessing, building and evaluating the capacity of communities to adapt in a changing climate. Hobart, Tasmania: Southern Slopes Climate Change Adaptation Research Partnership (SCARP), University of Technology Sydney and University of Tasmania.

Jacobs, B., Lee, C., O'Toole, D., & Vines, K. (2014). Integrated regional vulnerability assessment of government services to climate change. *International Journal of Climate Change Strategies and Management*, *6*(3), 272-295.

Jacobs, B., & Brown, P.R. (2012). Roles of diverse stakeholders in natural resources management and their relationships with regional bodies in New South Wales, Australia. In: Kaswamila, A. (Ed.), Sustainable Natural Resources Management. InTech, Rijeka, Croatia, pp. 115–137. https://doi.org/10.5772/33019.

Jagannathan, K., Arnott, J. C., Wyborn, C., Klenk, N., Mach, K. J., Moss, R. H., & Sjostrom, K. D. (2020). Great expectations? Reconciling the aspiration, outcome, and possibility of co-production. *Current Opinion in Environmental Sustainability*, 42, 22-29.

Jain, M., Fishman, R., Mondal, P., Galford, G. L., Bhattarai, N., Naeem, S., Lall, U., Singh, B., & DeFries, R. S. (2021). Groundwater depletion will reduce cropping intensity in India. *Science Advances*, 7(9), eabd2849.

Jamir, C., Sharma, N., Sengupta, A. & Ravindranath, N. (2013), Farmers' vulnerability to climate variability in Dimapur district of Nagaland, India, *Regional Environmental Change*, 13, 153-164.

Jamshidi, O., Asadi, A., Kalantari, K., Azadi, H., & Scheffran, J. (2019). Vulnerability to climate change of smallholder farmers in the Hamadan province, Iran. *Climate Risk Management*, 23, 146-159.

Janjua, S., Hassan, I., & Islam, S. (2020). Role and relevance of three enabling conditions to resolve inter-provincial water conflicts in the Indus basin within Pakistan. *Water Policy*, *22*(5), 811-824.

Jayaram, D., & Sethi, G. (2023). Geopolitics of Climate Change and Water Security in South Asia: Conflict and Cooperation. In *Science, Policies and Conflicts of Climate Change: An Indian Perspective* (pp. 77-88). Springer.

Jellason, N. P., Conway, J. S., & Baines, R. N. (2020). Understanding impacts and barriers to adoption of climate-smart agriculture (CSA) practices in North-Western Nigerian drylands. *The Journal of Agricultural Education and Extension*, 27(1), 55–72. doi.org/10.1080/1389224X.2020.1793787

Jiao, X., Pouliot, M., & Walelign, S. Z. (2017). Livelihood strategies and dynamics in rural Cambodia. *World Development*, *97*, 266-278.

Johnson, R. B. (2017). Dialectical pluralism: A metaparadigm whose time has come. *Journal of Mixed Methods Research*, 11(2), 156-173.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, 1(2), 112-133.

Jones, E. C., Ong, C., & Haynes, J. (2022). Disaster-related food security and past general governance strategies in a worldwide sample. *Weather, Climate, and Society*, *14*(1), 3-18.

Joshi, A., & Moore, M. (2004). Institutionalised co-production: unorthodox public service delivery in challenging environments. *Journal of development studies*, 40(4), 31-49.

Juhola, S., Glaas, E., Linnér, B., & Neset, T. S. (2016). Redefining maladaptation. *Environmental Science and Policy*, 55(1), 135-140. https://doi.org/10.1016/j.envsci.2015.09.014

Kabir, M. J., Cramb,R., Alauddin, M., Roth, C., & Crimp, S. (2017). Farmers' perceptions of and responses to environmental change in southwest coastal Bangladesh. *Asia Pacific Viewpoint* 58(3): 362-378.

Kafle, K., Uprety, L., Shrestha, G., Pandey, V., & Mukherji, A. (2022). Are climate finance subsidies equitably distributed among farmers? Assessing socio-demographics of solar irrigation in Nepal. *Energy Research & Social Science*, 91, 102756.

Kaiser, D. B., Gaasch, N., & Weith, T. (2017). Co-production of knowledge: A conceptual approach for integrative knowledge management in planning. *Transactions of the Association of European Schools of Planning*, 18-32.

Kaspar, F., Andersson, A., Ziese, M., & Hollmann, R. (2022). Contributions to the improvement of climate data availability and quality for sub-Saharan Africa. *Frontiers in Climate*, 3, 815043.

Kasperson, J. X., Kasperson, R. E., Turner, B. L., Hsieh, W., & Schiller, A. (2022). Vulnerability to global environmental change. *In Social contours of risk* (pp. 245-285). Routledge.

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences*, 109(19), 7156-7161.

Kelly, M. (2021). Epistemology, epistemic belief, personal epistemology, and epistemics: A review of concepts as they impact information behavior research. *Journal of the Association for Information Science and Technology*, 72(4), 507-519.

Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change*, *47*(4), 325-352.

Keshavarz, M., & Moqadas, R. S. (2021). Assessing rural households' resilience and adaptation strategies to climate variability and change. *Journal of Arid Environments*, 184, 104323.

Keshavarz, M., Karami, E., & Zibaei, M. (2014). Adaptation of Iranian farmers to climate variability and change. *Regional Environmental Change*, 14:1163-1174.

Keskitalo, E. C. H., & Preston, B. L. (2019). Research handbook on climate change adaptation policy. Edward Elgar Publishing 1786432528.

Khamkhunmuang, T., Punchay, K., & Wangpakapattanawong, P. (2022). Cases of Climate-Smart Agriculture in Southeast Asian highlands: Implications for ecosystem conservation and sustainability. *Agriculture and Natural Resources*, *56*(3), 473-486.

Khan, M. A., & Tariq, M. (2020). External Debt and Public Investment: A Case Study of Pakistan. *Journal of Managerial Sciences*, 14.

Khan, A., & Awan, N. (2020). Inter-provincial water conflicts in Pakistan: a critical analysis. *Journal of South Asian and Middle Eastern Studies*, 43(2), 42-53.

Khan, F. A., & Salman, A. (2012). A simple human vulnerability index to climate change hazards for Pakistan. *International Journal of Disaster Risk Science*, *3*(3), 163-176.

Khan, M., Watkins, M., Aminuzzaman, S., Khair, S., & Khan, M. Z. H. (2022). Win-win: designing dual-use in climate projects for effective anti-corruption in Bangladesh. *Climate and Development*, 14(10), 921-934.

Khan, M. A., Tahir, A., Khurshid, N., Husnain, M. I. U., Ahmed, M., & Boughanmi, H. (2020). Economic effects of climate change-induced loss of agricultural production by 2050: A case study of Pakistan. *Sustainability*, 12(3), 1216.

Khan, N. A., Shah, A. A., Chowdhury, A., Tariq, M. A. U. R., & Khanal, U. (2022). Rice farmers' perceptions about temperature and rainfall variations, respective adaptation measures, and determinants: Implications for sustainable farming systems. *Frontiers in Environmental Science*, 10, 1972.

Khan, N. A., Qiao, J., Abid, M., & Gao, Q. (2021). Understanding farm-level cognition of and autonomous adaptation to climate variability and associated factors: Evidence from the rice-growing zone of Pakistan. *Land Use Policy*, 105, 105427.

Khanal, U., Wilson, C., Hoang, V.-N., & Lee, B. (2018). Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecological Economics*, 144, 139–147. https://doi.org/10.1016/j.ecolecon.2017.07.032.

Khatri-Chhetri, A., Aggarwal, P. K., Joshi, P. K., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural systems*, *151*, 184-191.

Khoza, S., van Niekerk, D., & Nemakonde, L. (2021). Rethinking climate-smart agriculture adoption for resilience-building among smallholder farmers: gender-sensitive adoption framework. In *African Handbook of Climate Change Adaptation* (pp. 677-698). Cham: Springer International Publishing.

Kim, H., Marcouiller, D. W., & Woosnam, K. M. (2018). Rescaling social dynamics in climate change: The implications of cumulative exposure, climate justice, and community resilience. *Geoforum*, 96, 129-140.

Klein, J., Juhola, S., & Landauer, M. (2017). Local authorities and the engagement of private actors in climate change adaptation. Environment and Planning C: Politics and Space, 35(6), 1055-1074.

Kokic, P., Nelson, R., Meinke, H., Potgieter, A., & Carter, J. (2007). From rainfall to farm incomes—transforming advice for Australian drought policy. I. Development and testing of a bioeconomic modelling system. *Australian Journal of Agricultural Research*, *58*(10), 993-1003.

Kropf, B., & Mitter, H. (2022). Factors Influencing Farmers' Climate Change Mitigation and Adaptation Behavior: A Systematic Literature Review. *Alpine Landgesellschaften zwischen Urbanisierung und Globalisierung*, 243-259.

Kruijf, J. V. D., Verbrugge, L., Schröter, B., den Haan, R. J., Cortes Arevalo, J., Fliervoet, J., Henze, J., & Albert, C. (2022). Knowledge co-production and researcher roles in transdisciplinary environmental management projects. *Sustainable Development*, 30(2), 393-405.

Kruk, M. C., Parker, B., Marra, J. J., Werner, K., Heim, R., Vose, R., & Malsale, P. (2017). Engaging with users of climate information and the coproduction of knowledge. *Weather, Climate, and Society*, 9(4), 839-849.

Kumar, A., Nagar, S., & Anand, S. (2021). Climate change and existential threats. *Global Climate Change* (pp. 1-31). Elsevier.

Kumar, A., Bhutto, N. A., Mangrio, K. A., & Kalhoro, M. R. (2019). Impact of external debt and exchange rate volatility on domestic consumption. New evidence from Pakistan. *Cogent Economics & Finance*, 7(1), 1568656.

Kuran, C. H. A., Morsut, C., Kruke, B. I., Krüger, M., Segnestam, L., Orru, K., Nævestad, T. O., Airola, M., Keränen, J., Gabel, F., Hansson, S., & Torpan, S. (2020). Vulnerability and vulnerable groups from an intersectionality perspective. *International Journal of Disaster Risk Reduction*, 50, 101826.

Kuyvenhoven, A. (2004). Creating an enabling environment: policy conditions for less-favored areas. *Food Policy*, 29(4), 407-429.

Lamichhane, P., Miller, K. K., Hadjikakou, M., & Bryan, B. A. (2022). What motivates smallholder farmers to adapt to climate change? Insights from smallholder cropping in far-western Nepal. *Anthropocene*, 40, 100355.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, 7, 25-43.

Lasco, R. D., Habito, C. M. D., Delfino, R. J. P., Pulhin, F. B., & Concepcion, R. N. (2011). Climate change adaptation for smallholder farmers in Southeast Asia. World Agroforestry Centre, Philippines. 65p.

Latif M., & Ahmad, M.Z. (2009). Groundwater and soil salinity variations in a canal command area in Pakistan. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage*, 58:456-468

Laube, W., Schraven, B., & Awo, M. (2012). Smallholder adaptation to climate change: dynamics and limits in Northern Ghana. *Climatic Change*, *111*, 753-774.

Lawrence, J., Blackett, P., & Cradock-Henry, N.A. (2020). Cascading climate change impacts and implications. *Climate Risk Management*. 29, 100234

Lee, T., Yang, H., & Blok, A. (2020). Does mitigation shape adaptation? The urban climate mitigation-adaptation nexus. *Climate Policy*, *20*(3), 341-353.

Le Dang, H., Li, E., Nuberg, I., & Bruwer, J. (2014). Farmers' assessments of private adaptive measures to climate change and influential factors: a study in the Mekong Delta, Vietnam. *Natural Hazards*, 71:385-401

Leichenko, R., & O'Brien, K. (2012). Mapping double exposure to climate change and trade liberalization as an awareness-raising tool. In Assessing Vulnerability to Global Environmental Change (pp. 133-146). Routledge.

Lesnikowski, A., Biesbroek, R., Ford, J. D., & Berrang-Ford, L. (2021). Policy implementation styles and local governments: the case of climate change adaptation. *Environmental Politics*, *30*(5), 753-790.

Lester, J. N., Cho, Y., & Lochmiller, C. R. (2020). Learning to do qualitative data analysis: A starting point. *Human Resource Development Review*, 19(1), 94-106.

Lewis, J., & Rudnick, J. (2019). The policy enabling environment for climate smart agriculture: A case study of California. *Frontiers in Sustainable Food Systems*, 3, 31. https://doi.org/10.3389/fsufs.2019.00031

Lewis, P., Monem, M. A., & Impiglia, A. (2018). Impacts of climate change on farming systems and livelihoods in the Near East North Africa. With a special focus on small-scale family farming. Cairo.

Li, S., Juhász-Horváth, L., Harrison, P. A., Pintér, L., & Rounsevell, M. D. (2017). Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary. *Journal of Environmental Management*, 185, 21-30.

Li, Y., Xiong, W., Hu, W., Berry, P., Ju, H., Lin, E., Wang, W., Li, K. & Pan, J. (2015), Integrated assessment of China's agricultural vulnerability to climate change: a multi-indicator approach, *Climatic Change*, *128*(3), 355-366.

Lim, B., Spanger-Siegfried, E., Burton, I., Malone, E., & Huq, S. (Eds.), (2005). Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures. Cambridge University Press, UK, ISBN 0 521 61760 X.

Linnander, E., LaMonaca, K., Brault, M. A., Vyavahare, M., & Curry, L. A. (2018). A Mixed Methods Evaluation of a Multi-Country, Cross-Sectoral Knowledge Transfer Partnership to Improve Health Systems Across Africa. *International Journal of Multiple Research Approaches*, 10(1).

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Sen, P.T., Sessa, R., Shula, R., Tibu, A. & Torquebiau, E.F. (2014), Climate-smart agriculture for food security, *Nature Climate Change*, 4(12), 1068-1072.

Long, T.B., Blok, V. & Coninx, I. (2016), Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: Evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production*, 112, 9-21.

Lo, A. Y., & Cong, R. (2022). Emission reduction targets and outcomes of the Clean Development Mechanism (2005–2020). *PLOS Climate*, 1(8), e0000046.

Longo, F., Mirabelli, G., Solina, V., Belli, L., Abdallah, C. B., Ben-Ammar, O., Bottani, E., García-Gallego, J.M., Germanos, M., Gonzalez, F.J.M., Lacoba, S.R., Sidhom, L., Vignali, G., & Zacharewicz, G. (2023). An overview of approaches and methodologies for supporting smallholders: ICT tools, blockchain, business models, sustainability indicators, simulation models. *Procedia Computer Science*, 217, 1930-1939.

Lourenço, T. C., Swart, R., Goosen, H., & Street, R. (2016). The rise of demand-driven climate services. *Nature Climate Change*, 6(1), 13-14.

Luke, A., Sanders, B. F., Goodrich, K. A., Feldman, D. L., Boudreau, D., Eguiarte, A., Serrano, K., Reyes, A., Schubert, J.E., AghaKouchak, A., Basolo, V., & Matthew, R. A. (2018). Going beyond the flood insurance rate map: insights from flood hazard map co-production. *Natural Hazards and Earth System Sciences*, 18(4), 1097-1120.

Maas, T. Y., Pauwelussen, A., & Turnhout, E. (2022). Co-producing the science–policy interface: towards common but differentiated responsibilities. *Humanities and Social Sciences Communications*, *9*(1), 1-11.

Mack, N., Woodsong, C., MacQueen, K.M., Guest, G. & Namey, E. (2005). Qualitative research methods: a data collectors field guide. Family Health International, ISBN 0939704986.

Magdalena, S., & Suhatman, R. (2020). The effect of government expenditures, domestic invesment, foreign invesment to the economic growth of primary sector in central kalimantan. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, 3(3), 1692-1703.

Mahapatra, M., Ramakrishnan, R., & Rajawat, A. S. (2015). Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. *Natural Hazards*, 76, 139-159.

Maharjan, K.L. & Joshi, N.P. (2013). Climate Change, Agriculture and Rural Livelihoods in Developing Countries, *Advances in Asian Human-Environmental Research*. Springer, ISSN 18797180.

Mahmood, F., Khokhar, M. F., & Mahmood, Z. (2021). Investigating the tipping point of crop productivity induced by changing climatic variables. *Environmental Science and Pollution Research*, *28*, 2923-2933.

Maikhuri, R. K., Rawat, L. S., Maletha, A., Phondani, P. C., Semwal, R. L., Bahuguna, Y. M., & Bisht, T. S. (2019). Community response and adaptation to climate change in Central Himalaya, Uttarakhand, India. *Tropical Ecosystems: Structure, Functions and Challenges in the Face of Global Change*, 213-231.

Malik, S. M., Awan, H., & Khan, N. (2012). Mapping vulnerability to climate change and its repercussions on human health in Pakistan. *Globalization and Health*, *8*, 1-10.

Malone, E. L., & Engle, N. L. (2011). Evaluating regional vulnerability to climate change: purposes and methods. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(3), 462-474.

Manikas, I., Malindretos, G., & Moschuris, S. (2019). A community-based Agro-Food Hub model for sustainable farming. *Sustainability*, 11(4), 1017.

Manjula, M., & Rengalakshmi, R. (2015). Seasonal climate information for ensuring agricultural sustainability and food security of smallholder Rainfed farmers: Experience from India. In *15th Annual Global Development Conference, Casablanca, Morocco* (pp. 10-13).

Manning, C., Mangas, H., Amel, E., Tang, H., Humes, L., Foo, R., Sidlova, V., & Cargos, K. (2018). Psychological distance and response to human versus non-human victims of climate change. *Handbook of sustainability and social science research*, 143-161.

Mansuri, G., Sami, M. F., Ali, M., Doan, H. T. T., Javed, B., Pandey, P., & Asia, S. (2018). When water becomes a hazard: A diagnostic report on the state of water supply, sanitation and poverty in Pakistan and its impact on child stunting. *WASH Poverty Diagnostic Series. Washington, DC: World Bank Group*.

Marin-Puig, A., Ariza, E., & Casellas, A. (2022). Unattended gap in local adaptation plans: The quality of vulnerability knowledge in climate risk management. *Climate Risk Management*, *38*, 100465.

Martyr-Koller, R., Thomas, A., Schleussner, C. F., Nauels, A., & Lissner, T. (2021). Loss and damage implications of sea-level rise on Small Island Developing States. *Current Opinion in Environmental Sustainability*, 50, 245-259.

Mason, J. (2002). Qualitative Researching (2nd ed.). Sage Publications. ISBN 0761974288.

Masters, L., & Duff, L. (2012). Overcoming barriers to climate change adaptation implementation in Southern Africa. Africa Institute of South Africa, ISBN 9780798303095.

Matthews, R., & Sydneysmith, R. (2010). Adaptive capacity as a dynamic institutional process: conceptual perspectives and their application. *Adaptive capacity and environmental governance*, 223-242.

Maughan, C., & Anderson, C. R. (2023). A shared human endeavor: farmer participation and knowledge co-production in agroecological research. *Frontiers in Sustainable Food Systems*, 7, 1162658.

Maxwell, J. A. (2016). Expanding the history and range of mixed methods research. *Journal of mixed methods research*, 10(1), 12-27.

Mazhar, N. & Nawaz, M. (2014). Precipitation data interpolation for meteorological drought mapping in Pakistan. *Pakistan Journal of Science*, *66*(4).

McCarthy, J., Canziani, O., Leary, A., Dokken, D. & White, K. 2001, Climate change 2001: Impacts, adaptation, and vulnerability. *contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

McDowell, J. Z., & Hess, J. J. (2012). Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. *Global Environmental Change*, 22(2), 342-352.

McEntire, D., Gilmore Crocker MPH, C., & Peters, E. (2010). Addressing vulnerability through an integrated approach. *International Journal of Disaster Resilience in the Built Environment*, 1(1), 50-64.

McGray, H., Hammill, A., Bradley, R., Schipper, L., & Parry, J.E. (2007). Weathering the storm: options for framing adaptation and development. *World Resources Institute* Washington, DC.

McHaffie, P., Hwang, S., & Follett, C. (2023). GIS: an introduction to mapping technologies. *CRC Press*.

McNeeley, S. M., Even, T. L., Gioia, J. B., Knapp, C. N., & Beeton, T. A. (2017). Expanding vulnerability assessment for public lands: The social complement to ecological approaches. *Climate Risk Management*, *16*, 106-119.

Measham, T. G., Preston, B. L., Smith, T. F., Brooke, C., Gorddard, R., Withycombe, G., & Morrison, C. (2011). Adapting to climate change through local municipal planning: barriers and challenges. *Mitigation and adaptation strategies for global change*, 16, 889-909.

Megersa, B., Markemann, A., Angassa, A., & Zárate, A.V. (2014). The role of livestock diversification in ensuring household food security under a changing climate in Borana, *Ethiopia Food Security* 6:15-28

Membele, G. M., Naidu, M., & Mutanga, O. (2022). Examining flood vulnerability mapping approaches in developing countries: A scoping review. *International Journal of Disaster Risk Reduction*, 69, 102766.

Mertz, O., Halsnæs, K., Olesen, J. E., & Rasmussen, K. (2009). Adaptation to climate change in developing countries. *Environmental management*, *43*, 743-752.

Metcalf, S. J., van Putten, E. I., Frusher, S., Marshall, N. A., Tull, M., Caputi, N., Haward, M., Hobday, A.J., Holbrook, N.J., Jennings, S. M., Pecel, G.T., & Shaw, J. (2015). Measuring the vulnerability of marine social-ecological systems: a prerequisite for the identification of climate change adaptations. *Ecology and Society*, 20(2).

Mezmir, E. A. (2020). Qualitative data analysis: An overview of data reduction, data display, and interpretation. *Research on humanities and social sciences*, 10(21), 15-27.

Miller, T. R., Baird, T. D., Littlefield, C. M., Kofinas, G., Chapin III, F. S., & Redman, C. L. (2008). Epistemological pluralism: reorganizing interdisciplinary research. *Ecology and Society*, *13*(2).

Minot, N., & Sawyer, B. (2016). Contract farming in developing countries: Theory, practice, and policy implications. *Innovation for inclusive value chain development: Successes and challenges*, 127-155.

Mishra, S. B., & Alok, S. (2022). Handbook of research methodology. Educreation Publishing: Chhattisgarh, India.

Mishra, P., B. Behera, N. S. Bagchi, B. Pariaare, V. R. Reddy, C. Tallapragada, S. Majumdar, and D. B. Rahut. (2023). Development of Capitals and Capabilities of Smallholder Farmers for Promoting Inclusive Intensification in Agriculture: Experiences from Northern West Bengal, India. ADBI Working Paper 1356. Tokyo: Asian Development Bank Institute. doi.org/10.56506/IDLS6570

Mishra, R. R. (2020). Adoption of genetically modified crops can ensure food security in India. *National Academy Science Letters*, 43(2), 213-217.

Misiou, O., & Koutsoumanis, K. (2022). Climate change and its implications for food safety and spoilage. *Trends in Food Science & Technology*, 126, 142-152.

Mitra, A., Balasubramanya, S., & Bouwer, R. (2021). Can electricity rebates modify groundwater pumping behaviours? Evidence from a pilot study in Punjab, India. In Proceedings of the 2021 Annual Meeting, Austin, TX, USA, 1–3 August 2021.

Mizik, T. (2021). Climate-smart agriculture on small-scale farms: A systematic literature review. *Agronomy*, 11(6), 1096.

Morgan, D. L. (2013). Integrating qualitative and quantitative methods: A pragmatic approach. Sage publications.

Moschitz, H., Roep, D., Brunori, G., & Tisenkopfs, T. (2015). Learning and innovation networks for sustainable agriculture: processes of co-evolution, joint reflection and facilitation. *The Journal of Agricultural Education and Extension*, 21(1), 1-11.

Moser S.C., & Ekstrom J.A.(2010). A framework to diagnose barriers to climate change adaptation.*Proceedings of the National Academy of Sciences*107(51), 22026-22031 https://doi.org/10.1073/pnas.1007887107.

Mourhir, A., Rachidi, T., Papageorgiou, E. I., Karim, M., & Alaoui, F. S. (2016). A cognitive map framework to support integrated environmental assessment. *Environmental Modelling & Software*, 77, 81-94.

Mozumder, M. M. H., Schneider, P., Mahmudul Islam, M., Deb, D., Hasan, M., Monzer, M. A., & Nur, A. A. (2023). Climate change adaptation strategies for small-scale Hilsa fishers in the coastal area of Bangladesh: social, economic, and ecological perspectives. *Frontiers in Marine Science*, 10, 1151875.

Mudashiru, R. B., Sabtu, N., Abustan, I., & Balogun, W. (2021). Flood hazard mapping methods: A review. *Journal of hydrology*, 603, 126846.

Murthy, C. S., Laxman, B., & Sai, M. S. (2015). Geospatial analysis of agricultural drought vulnerability using a composite index based on exposure, sensitivity and adaptive capacity. *International Journal of Disaster Risk Reduction*, *12*, 163-171.

Mubaya, C. P., & Mafongoya, P. (2017). The role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe. *Climate Risk Management*, *16*, 93-105.

Mulwa, C.K., & Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development*, 129, 104906.

Munthali, N., Lie, R., Van Lammeren, R., Van Paassen, A., Asare, R., & Leeuwis, C. (2021). Intermediation Capabilities of Information and Communication Technologies (ICTs) in Ghana's Agricultural Extension System. *The African Journal of Information and Communication*, 28, 1-37.

Musah-Surugu, I. J., Ahenkan, A., & Bawole, J. N. (2019). Too weak to lead: motivation, agenda setting and constraints of local government to implement decentralized climate change adaptation policy in Ghana. *Environment, Development and Sustainability*, 21, 587-607.

Musco, F. & van Staden, M. (2010). Local governments and climate change. Sustainable Energy Planning and Implementation in Small and Medium Sized Communities. (Ed.). Springer.

Nadeem, F., Jacobs, B., & Cordell, D. (2022). Mapping agricultural vulnerability to impacts of climate events of Punjab, Pakistan. *Regional Environmental Change*, 22(2), 1-18.

Naess, L. O. (2013). The role of local knowledge in adaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 4(2), 99-106.

Nalau, J., Preston, B. L., & Maloney, M. C. (2015). Is adaptation a local responsibility? *Environmental Science & Policy*, *48*, 89-98.

Narayanan, K., & Sahu, S. K. (2016). Effects of climate change on household economy and adaptive responses among agricultural households in eastern coast of India. *Current Science*, 1240-1250.

Natarajan, N., Newsham, A., Rigg, J., & Suhardiman, D. (2022). A sustainable livelihoods framework for the 21st century. *World Development*, 155, 105898.

Nawaz, Z., Li, X., Chen, Y., Guo, Y., Wang, X., & Nawaz, N. (2019). Temporal and spatial characteristics of precipitation and temperature in Punjab, Pakistan. *Water*, *11*(9), 1916.

Nazari, S., Rad, G. P., Sedighi, H., & Azadi, H. (2015). Vulnerability of wheat farmers: Toward a conceptual framework. *Ecological indicators*, *52*, 517-532.

NCCP (2012). National climate change policy, Pakistan, www.mocc.gov.pk/Policy.

NDC. (2021). Pakistan Updated Nationally Determined Contributions 2021, https://unfccc.int/NDCREG.

NEP (2005). National Environment Policy, Pakistan Environmental Protection Agency, http://environment.gov.pk/NEP/Policy.pdf.

Negera, M., Alemu, T., Hagos, F., & Haileslassie, A. (2023). Impacts of climate-smart agricultural practices on farm households' climate resilience and vulnerability in Bale-Eco Region, Ethiopia. *Environment, Development and Sustainability*, 1-30.

Nelson, R., Kokic, P., Elliston, L., & King, J. A. (2005). Structural adjustment: a vulnerability index for Australian broadacre agriculture. *Australian Commodities: Forecasts and Issues*, 12(1), 171-179.

Nelson, D. R., & Anderies, J. M. (2009). Hidden costs and disparate uncertainties: trade-offs in approaches to climate policy. *Adapting to climate change: Thresholds, values, governance*, *212*.

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S. M., de Voil, P., & Nidumolu, U. (2010). The vulnerability of Australian rural communities to climate variability and change: Part II—Integrating impacts with adaptive capacity. *Environmental Science & Policy*, 13(1), 18-27.

Nelson, R., Kokic, P., & Meinke, H. (2007). From rainfall to farm incomes—transforming advice for Australian drought policy. II. Forecasting farm incomes. *Australian Journal of Agricultural Research*, 58(10), 1004-1012.

Nelson, L. K., Cullen, A. C., Koehn, L. E., Harper, S., Runebaum, J., Bogeberg, M.,Strawn, A., & Levin, P. S. (2023). Understanding perceptions of climate vulnerability to inform more effective adaptation in coastal communities. *PLOS Climate*, 2(2), e0000103.

Newton, A., & Elliott, M. (2016). A typology of stakeholders and guidelines for engagement in transdisciplinary, participatory processes. *Frontiers in Marine Science*, 3, 230.

Nguyen, C. V., Horne, R., Fien, J., & Cheong, F. (2017). Assessment of social vulnerability to climate change at the local scale: development and application of a Social Vulnerability Index. *Climatic change*, *143*, 355-370.

Nguyen, T. H., Sahin, O., & Howes, M. (2021). Climate change adaptation influences and barriers impacting the Asian agricultural industry. *Sustainability*, 13(13), 7346.

Nidumolu, U., Lubbers, M., Kanellopoulos, A., van Ittersum, M. K., Roth, C. H., Mishra, P.,Bagchi, N.S.,Majumdar, S., Carter, L.,Rahman,W.Md.,Das,M., & Gaydon, D. S. (2022). Integrating gender and farmer's preferences in a discussion support tool for crop choice. *Agricultural Systems*, 195, 103300.

Nightingale, A. J., Eriksen, S., Taylor, M., Forsyth, T., Pelling, M., Newsham, A., Boyd, E., Brown, K., Harvey, B., & Jones, L. (2020). Beyond technical fixes: Climate solutions and the great derangement. *Climate and Development*, *12*(4), 343-352.

Niles, M. T., & Salerno, J. D. (2018). A cross-country analysis of climate shocks and smallholder food insecurity. *PloS one*, 13(2), e0192928.

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., & de Bremond, A. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, 3(3), 182-190.

Nunes, A. R. (2021). Exploring the interactions between vulnerability, resilience and adaptation to extreme temperatures. *Natural Hazards*, 109(3), 2261-2293.

O'Brien, K., Eriksen, S., Nygaard, L.P. & Schjolden, A. (2007). Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy*, 7, 73-88.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S. & Nygaard, L. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, 14 (4), 303-13.

Ogunyiola, A., Gardezi, M., & Vij, S. (2022). Smallholder farmers' engagement with climate smart agriculture in Africa: role of local knowledge and upscaling. *Climate Policy*, *22*(4), 411-426.

Ojha, H. R., Sulaiman V, R., Sultana, P., Dahal, K., Thapa, D., Mittal, N., Thompson, P., Bhatta, G. D., Ghimire, L., & Aggarwal, P. (2014). Is South Asian agriculture adapting to climate change? Evidence from the Indo-Gangetic Plains. *Agroecology and Sustainable Food Systems*, *38*(5), 505-531.

Ojwang, L., Rosendo, S., Celliers, L., Obura, D., Muiti, A., Kamula, J., & Mwangi, M. (2017). Assessment of coastal governance for climate change adaptation in Kenya. *Earth's Future*, *5*(11), 1119-1132.

Olsson, L., Opondo, M., Tschakert, P., Agrawal, A., Eriksen, S., Ma, S., Perch, L. and Zakieldeen, S., 2014. Livelihoods and poverty. In *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (pp. 793-832). Cambridge University Press. 10.1017/CBO9781107415379.018

Osberghaus, D., Dannenberg, A., Mennel, T., & Sturm, B. (2010). The role of the government in adaptation to climate change. *Environment and Planning C: Government and Policy*, 28(5), 834-850.

Otto, F. E., Zachariah, M., Saeed, F., Siddiqi, A., Kamil, S., Mushtaq, H., Arulalan, T., AchutaRao, K., Chaithra, S. T., Barnes, C., Philip, S., Kew, S., Vautard, R., Koren, G., Pinto, I., Wolski, P., Vahlberg, M., Singh, R., Arrighi, J., Aaist, M. V., Thalheimer, L., Raju, E., Li, S., Yang, W., Harrington, L. J., & Clarke, B. (2023). Climate change increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan. *Environmental Research: Climate*, 2(2), 025001.

Otto, I. M., Reckien, D., Reyer, C. P., Marcus, R., Le Masson, V., Jones, L., Norton, A., & Serdeczny, O. (2017). Social vulnerability to climate change: a review of concepts and evidence. *Regional Environmental Change*, *17*, 1651-1662.

Paavola, J., & Adger, W. N. (2006). Fair adaptation to climate change. *Ecological Economics*, *56*(4), 594-609.

Pahl, S., Sheppard, S., Boomsma, C., & Groves, C. (2014). Perceptions of time in relation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 5(3), 375-388.

Painter, M. A., Shah, S. H., Damestoit, G. C., Khalid, F., Prudencio, W., Chisty, M. A., Tormos-Aponte, F., & Wilhelmi, O. (2024). A systematic scoping review of the Social Vulnerability Index as applied to natural hazards. *Natural Hazards*, 1-92.

Pandey, R., Jha, S. K., Alatalo, J. M., Archie, K. M., & Gupta, A. K. (2017). Sustainable livelihood framework-based indicators for assessing climate change vulnerability and adaptation for Himalayan communities. *Ecological indicators*, 79, 338-346.

Parson, E.A. (1995). Integrated assessment and environmental policy making: in pursuit of usefulness, *Energy Policy*, 23 (4), 463-475.

Pasquini, L. (2020). The urban governance of climate change adaptation in least-developed African countries and in small cities: the engagement of local decision-makers in Dar es Salaam, Tanzania, and Karonga, Malawi. *Climate and Development*, *12*(5), 408-419.

Pasquini, L., Ziervogel, G., Cowling, R. M., & Shearing, C. (2015). What enables local governments to mainstream climate change adaptation? Lessons learned from two municipal case studies in the Western Cape, South Africa. *Climate and Development*, 7(1), 60-70.

Patt, A. G. & Klein, R. J., (Eds.). (2012). Assessing vulnerability to global environmental change: making research useful for adaptation decision making and policy. Earthscan, ISBN 9781844076970.

PBS (2023). Pakistan Bureau of Statistics, Government of Pakistan, http://www.pbs.gov.pk.

PC (2007). Vision 2030, Planning Commission of Pakistan, http://www.pc.gov.pk/.

PCCA (2017). Pakistan Climate Change Act, http://www.na.gov.pk/uploads/documents/1485513841_966.pdf.

PCCP (2017). Punjab Climate Change Policy, Environment Protection Department, http://epd.punjab.gov.pk/system/files/PCCP%20Draft%20%28internatl%29.pdf.

PEPA (1997). Pakistan Environmental Protection Act, Pakistan Environmental Protection Agency http://environment.gov.pk.

Pearson, A.L., Rzotkiewicz, A., Mwita, E., Lopez, M.C., Zwickle, A. & Richardson, R.B. (2017). Participatory mapping of environmental resources: A comparison of a Tanzanian pastoral community over time. *Land Use Policy*, 69, 259-265.

Pelling, M., O'Brien, K., & Matyas, D. (2014). Adaptation and transformation, *Climatic Change*. Special issue on advancing climate change adaptation and risk management. 133, 113-127. https://doi. org/10.1007/s10584-014-1303-0.

Pelling, M. (2010). Adaptation to climate change: from resilience to transformation. Routledge, ISBN 9780203889046

Peng, Y., Liu, B., & Zhou, M. (2022). Sustainable livelihoods in rural areas under the shock of climate change: Evidence from China labor-force dynamic survey. *Sustainability*, 14(12), 7262.

Pilato, G., Sallu, S. M., & Gaworek-Michalczenia, M. (2018). Assessing the integration of climate change and development strategies at local levels: Insights from Muheza District, Tanzania. *Sustainability*, *10*(1), 174.

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A. M., Kinengyere, A., Opazo, C.M., Owoo, N.,Page, J.R., & Torero, M. (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nature Sustainability*, 3(10), 809-820.

Prestele, R., & Verburg, P. H. (2020). The overlooked spatial dimension of climate-smart agriculture. *Global Change Biology*, 26(3), 1045-1054.

Preston, B., Brooke, C., Measham, T.G., Smith, T. & Gorddard, R. (2009). Igniting change in local government: lessons learned from a bushfire vulnerability assessment, *Mitigation and Adaptation Strategies for Global Change*, 14(3), 251-83.

Preston, B.L., Yuen, E.J. & Westaway, R.M. (2011). Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks, *Sustainability Science*, 6(2), 177-202.

Playán, E., Sagardoy, J. A., & Castillo, R. (2018). Irrigation governance in developing countries: Current problems and solutions. *Water*, 10(9), 1118.

Qamar, M. U., Azmat, M., & Claps, P. (2019). Pitfalls in transboundary Indus Water Treaty: a perspective to prevent unattended threats to the global security. *npj Clean Water*, *2*(1), 22.

Qureshi, R., & Ashraf, M. (2019). Water security issues of agriculture in Pakistan. Pakistan Academy of Sciences (PAS), *1*, 41.

Rafiq, L. & Blaschke, T. (2012). Disaster risk and vulnerability in Pakistan at a district level. *Geomatics, Natural Hazards and Risk*, 3(4), 324-341.

Rahman, A. B. (2017). Mainstreaming climate change adaptation in a developing country context: an Indonesian case study. Curtin University Sustainability Policy Institute.

Rahman, A., & Salman, A. (2013). A district level climate change vulnerability index of Pakistan. Centre for Environmental Economics and Climate Change (CEECC), Pakistan Institute of Development Economics (PIDE).Working Paper, 5.

Rahman, M. H., & Alam, K. (2016). Forest dependent indigenous communities' perception and adaptation to climate change through local knowledge in the protected area—A Bangladesh case study. *Climate*, *4*(1), 12.

Rahman, M. F., Falzon, D., Robinson, S. A., Kuhl, L., Westoby, R., Omukuti, J., Schipper, E.L.F., McNamara, K.E., Resurrreccion, B.P., Mfitumukiza, D., & Nadiruzzaman, M. (2023). Locally led adaptation: Promise, pitfalls, and possibilities. *Ambio*, 1-15.

Raj, S., Roodbar, S., Brinkley, C., & Wolfe, D. W. (2022). Food Security and climate change: Differences in impacts and adaptation strategies for rural communities in the Global South and North. *Frontiers in Sustainable Food Systems*, 5.

Ravindranath, N., Rao, S., Sharma, N., Nair, M., Gopalakrishnan, R., Rao, A.S., Malaviya, S., Tiwari, R., Sagadevan, A. & Munsi, M. (2011). Climate change vulnerability profiles for North East India. *Current Science*, 384-94.

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, 8(2), 34.

Reed, J., Barlow, J., Carmenta, R., van Vianen, J., & Sunderland, T. (2019). Engaging multiple stakeholders to reconcile climate, conservation and development objectives in tropical landscapes. *Biological Conservation*, 238, 108229.

Reed, M. S., Podesta, G., Fazey, I., Geeson, N., Hessel, R., Hubacek, K.,Letson, D., Nainggolan, D., Prell, C., Rickenbach, M.G., Ritsema, C., Schwilch, G., Stringer, L.C., & Thomas, A. D. (2013). Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options. *Ecological Economics*, *94*, 66-77.

Rehman, A., Ma, H., Ahmad, M., Irfan, M., Traore, O., & Chandio, A. A. (2021). Towards environmental Sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan. *Ecological indicators*, 125, 107460.

Rehman, A., Jingdong, L., Shahzad, B., Chandio, A.A., Hussain, I., Nabi, G. & Iqbal, M.S. (2015). Economic perspectives of major field crops of Pakistan: An empirical study. *Pacific Science Review B: Humanities and Social Sciences*. 1(3),145-58.

Reid Bell, A., Ward, P. S., Ashfaq, M., & Davies, S. (2020). Valuation and aspirations for drip irrigation in Punjab, Pakistan. *Journal of Water Resources Planning and Management*, 146(6), 04020035.

Reid, H. (2015). Vulnerable communities: climate adaptation that works for the poor. The International Institute for Environment and Development (IIED) 17329IIED.

Riaz, K., Ahmad, M., Gul, S., Malik, M. H. B. A., & Rehman, M. E. U. (2022). Climate change and its implications on health and the healthcare system: A perspective from Pakistan. *Annals of Medicine and Surgery*, *81*.

Ridder, N. N., Ukkola, A. M., Pitman, A. J., & Perkins-Kirkpatrick, S. E. (2022). Increased occurrence of high impact compound events under climate change. *npj Climate and Atmospheric Science*, *5*(1), 3.

Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*(7258), 999-1002.

Rosendo, S., Celliers, L., & Mechisso, M. (2018). Doing more with the same: A reality-check on the ability of local government to implement Integrated Coastal Management for climate change adaptation. *Marine Policy*, 87, 29-39.

Rotmans & Dowlatabadi (1995), Integrated assessment of climate change: Evaluation of methods and strategies. In Human Choices and Climate Change: *A state of the art report*. Batelle Pacific Northwest Laboratories, Washington, DC.

Rurinda, J., Mapfumo, P., Van Wijk, M. T., Mtambanengwe, F. V., Rufino, M. C., Chikowo, R., & Giller, K. E. (2014). Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis. *Climate Risk Management*, 3, 65-78.

Sajesh, V. K., & Suresh, A. (2016). Public-sector agricultural extension in India: A note. *Review of Agrarian Studies*, *6*(1).

Saldaña, J. (2013). The Coding manual for qualitative researchers (2nd ed.). Sage Publications. https://books.google.com/books/about/The_Coding_Manual_for_Qualitative_Resear.html?id=V3tTG4jvgFkC

Salik, K.M., Jahangir, S. & ul Hasson, S. (2015). Climate change vulnerability and adaptation options for the coastal communities of Pakistan. *Ocean & Coastal Management*, 112, 61-73.

Sardar, A., Kiani, A. K., & Kuslu, Y. (2021). Does adoption of climate-smart agriculture (CSA) practices improve farmers' crop income? Assessing the determinants and its impacts in Punjab province, Pakistan. Environment, Development and Sustainability, 23, 10119-10140.

Schaafsma, M., Ferrini, S., & Turner, R. K. (2019). Assessing smallholder preferences for incentivised climate-smart agriculture using a discrete choice experiment. *Land Use Policy*, *88*, 104153.

Schipper, E.L.F. & Burton, I. (2009), Earthscan reader on adaptation to climate change, Earthscan.

Schoenefeld, J. J., Schulze, K., & Bruch, N. (2022). The diffusion of climate change adaptation policy. *Wiley Interdisciplinary Reviews: Climate Change*, *13*(3), e775.

Schweizer, D., van Kuijk, M., & Ghazoul, J. (2021). Perceptions from non-governmental actors on forest and landscape restoration, challenges and strategies for successful implementation across Asia, Africa and Latin America. *Journal of Environmental Management*, 286, 112251.

Scoones, I. (2009). Livelihoods perspectives and rural development. *The Journal of Peasant Studies*,36(1), 171–196. https://doi.org/10.1080/03066150902820503. http://www.tandfonline.com/doi/full/10.1080/03066150902820503

Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis. Brighton: Institute of Development Studies, 72,1-22.

Sen, A. (1981). Poverty and famines: an essay on entitlement and deprivation, Oxford University Press, Clarendon. ISBN 0198284268.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17, 1585-1600.

Sesana, E., Gagnon, A. S., Bonazza, A., & Hughes, J. J. (2020). An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts. *Journal of cultural heritage*, 41, 211-224.

Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., & Tschakert, P. (2015). Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *Wiley Interdisciplinary Reviews: Climate Change*, *6*(3), 321-344.

Shaffril, H.A.M., Krauss, S.E., & Samsuddin, S.F. (2018). A systematic review on Asian's farmers' adaptation practices towards climate change. *Science of the Total Environment*, 644, 683-695.

Shah, H., Siderius, C., & Hellegers, P. (2020). Cost and effectiveness of in-season strategies for coping with weather variability in Pakistan's agriculture. *Agricultural Systems*, 178, 102746.

Shahbaz, P., Haq, S. U., & Boz, I. (2021). Linking climate change adaptation practices with farm technical efficiency and fertilizer use: A study of wheat–maize mix cropping zone of Punjab province, Pakistan. *Environmental Science and Pollution Research*, 1-14.

Shahid, M., & Rahman, K. U. (2021). Identifying the annual and seasonal trends of hydrological and climatic variables in the Indus Basin Pakistan. *Asia-Pacific Journal of Atmospheric Sciences*, *57*, 191-205.

Shahid, R., Shijie, L., Shahid, S., Altaf, M. A., & Shahid, H. (2021). Determinants of reactive adaptations to climate change in semi-arid region of Pakistan. *Journal of Arid Environments*, 193, 104580.

Shakya, C., Cooke, K., Gupta, N., Bull, Z., & Greene, S. (2018). Building institutional capacity for enhancing resilience to climate change: An operational framework and insights from practice. ACT Learning Paper, Oxford Policy Management.

Sheppard, S.R. (2005). Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science & Policy*, 8(6), 637-654.

Sheppard, S.R., Burch, S., Shaw, A. & Flanders, D. (2010). Planning for climate change in a flood-prone community: municipal barriers to policy action and the use of visualizations as decision-support tools. *Journal of Flood Risk Management*, 3(2), 126-39.

Sherbinin, A. D., Apotsos, A., & Chevrier, J. (2017). Mapping the future: Policy applications of climate vulnerability mapping in West Africa. *The Geographical Journal*, *183*(4), 414-425.

Sherman, M. H., & Ford, J. (2014). Stakeholder engagement in adaptation interventions: an evaluation of projects in developing nations. *Climate Policy*, *14*(3), 417-441.

Shorten, A., & Smith, J. (2017). Mixed methods research: expanding the evidence base. *Evidence-based nursing*, 20(3), 74-75.

Shrestha RK, Cameron DC, Coutts J, Cavaye J (2015) Building and Maintenance of Social Capital in Rural Farming Community of the Western Hills of Nepal. *International Journal of Asian Business and Information Management (IJABIM)* 6:28-41. doi:10.4018/IJABIM.2015070103

Shukla, R., Sachdeva, K. & Joshi, P. (2016). Inherent vulnerability of agricultural communities in Himalaya: A village-level hotspot analysis in the Uttarakhand state of India. *Applied Geography*, 74, 182-98.

Siddiqui, R., Samad, G., Nasir, M., & Jalil, H. H. (2012). The impact of climate change on major agricultural crops: evidence from Punjab, Pakistan. *The Pakistan Development Review*, 261-274.

Sietz, D., Boschütz, M., & Klein, R. J. (2011). Mainstreaming climate adaptation into development assistance: rationale, institutional barriers and opportunities in Mozambique. *Environmental Science & Policy*, *14*(4), 493-502.

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., Zaroung, M., & Kituyi, E. (2018). The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. *Climate and Development*, *10*(5), 389-405.

Singh, R. K., Singh, A., Zander, K. K., Mathew, S., & Kumar, A. (2021). Measuring successful processes of knowledge co-production for managing climate change and associated environmental stressors: Adaptation policies and practices to support Indian farmers. *Journal of Environmental Management*, 282, 111679.

Singh, R. P. (2003). Improving technology transfer through the management of stakeholder networks: theoretical perspectives. *International Journal of Technology Transfer and Commercialisation*, 2(1), 1-17.

Singh, S. (2020). Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India. *Ecological indicators*, 116, 106475.

Sipra, H. (2020). Confronting Pakistan's Climate Reality: Shifting Paradigms. policy brief, Jinnah Institute B0520-53.

Sivakumar, M. (2021). Climate change, agriculture adaptation, and sustainability. *Climate Resilience and Environmental Sustainability Approaches: Global Lessons and Local Challenges*, 87-109.

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, 16(3), 282-92.

Smit, B. & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, 8(9), 9.

Smucker, T. A., & Nijbroek, R. (2020). Foundations for convergence: Sub-national collaboration at the nexus of climate change adaptation, disaster risk reduction, and land restoration under multi-level governance in Kenya. *International journal of disaster risk reduction*, *51*, 101834.

Sultana, P., Thompson, P. M., & Wesselink, A. (2021). Coping and resilience in riverine Bangladesh. In *Environmental Hazards and Resilience* (pp. 111-130). Routledge.

Sultana, H., Ali, N., Iqbal, M. M., & Khan, A. M. (2009). Vulnerability and adaptability of wheat production in different climatic zones of Pakistan under climate change scenarios. *Climatic Change*, *94*, 123-142.

Sorrentino, M., Sicilia, M., & Howlett, M. (2018). Understanding co-production as a new public governance tool. *Policy and Society*, 37(3), 277-293.

Steynor, A., Padgham, J., Jack, C., Hewitson, B., & Lennard, C. (2016). Co-exploratory climate risk workshops: Experiences from urban Africa. *Climate Risk Management*, 13, 95-102.

Sultan, H., Zhan, J., Rashid, W., Chu, X., & Bohnett, E. (2022). Systematic review of multi-dimensional vulnerabilities in the Himalayas. *International Journal of Environmental Research and Public Health*, 19(19), 12177.

Susskind, L., & Kim, A. (2022). Building local capacity to adapt to climate change. *Climate Policy*, 22(5), 593-606.

Taherdoost, H. (2022). What are different research approaches? Comprehensive Review of Qualitative, quantitative, and mixed method research, their applications, types, and limitations. *Journal of Management Science & Engineering Research*, 5(1), 53-63.

Tai, X., Xiao, W., & Tang, Y. (2020). A quantitative assessment of vulnerability using social-economic-natural compound ecosystem framework in coal mining cities. *Journal of Cleaner Production*, 258, 120969.

Tall, A., Coulibaly, J. Y., & Diop, M. (2018). Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: Implications for Africa. *Climate Services*, 11, 1-12.

Tall, A., Hansen, J., Jay, A., Campbell, B. M., Kinyangi, J., Aggarwal, P. K., & Zougmoré, R. B. (2014). Scaling up climate services for farmers: Mission Possible. Learning from good practice in Africa and South Asia. CCAFS Report.

Tariq, A., Tabasam, N., Bakhsh, K., Ashfaq, M., & Hassan, S. (2014). Food security in the context of climate change in Pakistan. *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, *8*(2), 540-550.

Tariq, M. A. U. R., Rajabi, Z., & Muttil, N. (2021). An evaluation of risk-based agricultural land-use adjustments under a flood management strategy in a floodplain. *Hydrology*, 8(1), 53.

Tariq, M., Malik, M. S., & Qumber, G. (2018). Prospects of Federalism in Pakistan. *Global Social Sciences Review*, 3(2), 358-370.

Taylor, M., & Bhasme, S. (2018). Model farmers, extension networks and the politics of agricultural knowledge transfer. *Journal of Rural Studies*, 64, 1-10.

Tebes, J. K. (2012). Philosophical foundations of mixed methods research: Implications for research practice. In L. Jason & D. Glenwick (Eds.), Methodological approaches to community-based research (pp. 13–31). American Psychological Association. https://doi.org/10.1037/13492-002.

TFCC (2010). Task force on climate change-Final Report, Planning Commission, Government of Pakistan. http://www.gcisc.org.pk/TFCC

Thapa, B., & Scott, C. A. (2019). Institutional strategies for adaptation to water stress in farmer-managed irrigation systems of Nepal. *International Journal of the Commons*, 13(2).

Thiault, L., Marshall, P., Gelcich, S., Collin, A., Chlous, F., & Claudet, J. (2018). Mapping social–ecological vulnerability to inform local decision making. *Conservation Biology*, 32(2), 447-456.

Thomas, A., Theokritoff, E., Lesnikowski, A., Reckien, D., Jagannathan, K., Cremades, R., Campbell, D., Joe, T.E., Sitati, A., Singh, C., Segnon, C.A., Pentz, B., Musah-Surugu, I.J., Mullin, A.C., March, J.K., Gichuki, L., Galappaththi, E., Chalastani, I.V., Ajibade, I., Ruiz-Diaz, R., Grady, C., Garschagen, M., Ford, J., & Bowen, K. (2021). Global evidence of constraints and limits to human adaptation. *Regional environmental change*, *21*(3), 1-15.

Thomas, K., Hardy, R. D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J. T., Rockman, M., Warner, B. P., & Winthrop, R. (2019). Explaining differential vulnerability to climate change: A social science review. *Wiley Interdisciplinary Reviews: Climate Change*, 10(2), e565.

Thondhlana, G., Shackleton, S., & Blignaut, J. (2015). Local institutions, actors, and natural resource governance in Kgalagadi Transfrontier Park and surrounds, South Africa. *Land Use Policy*, *47*, 121-129.

Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: a review. *Global Change Biology*, 20(11), 3313-3328.

Tim, S., Providoli, I., Sien, T., Yim, S., Kim, S., & Liniger, H. (2023). Strengthening climate resilience of rural communities by co-producing landscape-specific integrated farming systems in Cambodia. *Journal of Land Use Science*, *18*(1), 152-175.

Tofu, D. A., & Wolka, K. (2023). Evaluating adaptation efforts of food-aid-reliant smallholder farmers in the drought-prone area. *Environmental and Sustainability Indicators*, 19, 100276.

Toth, F.L. (2004). State of the art and future challenges for integrated environmental assessment. *Integrated Assessment*, 4(4), 250-264.

Traber, D., Hänni, M., Giger, N., & Breunig, C. (2022). Social status, political priorities and unequal representation. *European Journal of Political Research*, 61(2), 351-373.

Tripathi, A., & Mishra, A.K. (2017). Knowledge and passive adaptation to climate change: An example from Indian farmers. *Climate Risk Management*, 16:195-207.

Tsatsaris, A., Kalogeropoulos, K., Stathopoulos, N., Louka, P., Tsanakas, K., Tsesmelis, D. E., Krassanakis, V., Petropoulos, G. P., Pappas, V., & Chalkias, C. (2021). Geoinformation technologies in support of environmental hazards monitoring under climate change: An extensive review. ISPRS *International Journal of Geo-Information*, 10(2), 94.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences PNAS*, 100(14), 8074-8079.

Uddin, M. N., Islam, A. S., Bala, S. K., Islam, G. T., Adhikary, S., Saha, D., Haque, S., Fahad, M. G. R., & Akter, R. (2019). Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. *Applied Geography*, 102, 47-57.

Ullah, W., Nihei, T., Nafees, M., Zaman, R., & Ali, M. (2018). Understanding climate change vulnerability, adaptation and risk perceptions at household level in Khyber Pakhtunkhwa, Pakistan. *International Journal of Climate Change Strategies and Management*, *10*(3), 359-378.

UNFCCC (2022). United Nations Framework Convention on Climate Change, National Adaptation Programmes of Action (NAPAs). https://unfccc.int/topics/resilience/workstreams/national-adaptation-programmes-of-action

UNFCCC (2015). Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement

UNFCCC 1992, United Nations Framework Convention on Climate Change. Rio de Janeiro, Brazil. https://unfccc.int

Utter, A., White, A., Méndez, V. E., & Morris, K. (2021). Co-creation of knowledge in agroecology. *Elementa: Science of the Anthropocene*, 9(1), 00026.

Valavanidis, A. (2022). Extreme weather events exacerbated by the global impact of climate change. Available online: Chem-tox-ecotox. org/ScientificReviews.

Van der Linden, S., Maibach, E., & Leiserowitz, A. (2015). Improving public engagement with climate change: Five “best practice” insights from psychological science. *Perspectives on psychological science*, 10(6), 758-763.

van Wijk, M. T., Merbold, L., Hammond, J., & Butterbach-Bahl, K. (2020). Improving assessments of the three pillars of climate smart agriculture: current achievements and ideas for the future. *Frontiers in Sustainable Food Systems*, 4, 558483.

Vasin, S. M., Gamidullaeva, L. A., Wise, N., & Korolev, K. Y. (2020). Knowledge exchange and the trust institution: a new look at the problem. *Journal of the Knowledge Economy*, 11, 1026-1042.

Varadan, R.J. & Kumar, P. (2015), Mapping agricultural vulnerability of Tamil Nadu, India to climate change: A dynamic approach to take forward the vulnerability assessment methodology. *Climatic Change*, 129, 159-181.

Vincent, K. (2004). Creating an index of social vulnerability to climate change for Africa. Tyndall Center for Climate Change Research. Working Paper, 56(41), 1-50.

Wang, M., Li, Y., Ye, W., Bornman, J.F. & Yan, X. (2011). Effects of climate change on maize production, and potential adaptation measures: a case study in Jilin Province, China. *Climate Research*, 46 (3), 223-242.

Wamsler, C., Wickenberg, B., Hanson, H., Olsson, J. A., Stålhammar, S., Björn, H., Falck, H., Gerell, D., Oskarsson, T., & Simonsson, E. (2020). Environmental and climate policy integration: Targeted strategies for overcoming barriers to nature-based solutions and climate change adaptation. *Journal of Cleaner Production*, 247, 119154.

Watson, V. (2014). Co-production and collaboration in planning–The difference. *Planning Theory & Practice*, *15*(1), 62-76.

WFP (2022). World Food Programme, https://www.wfp.org/countries/pakistan

Wickramasinghe, M. R. C. P., De Silva, R. P., & Dayawansa, N. D. K. (2021). Climate change vulnerability in agriculture sector: an assessment and mapping at divisional secretariat level in Sri Lanka. *Earth Systems and Environment*, 5, 725-738.

Walker, B., & Salt, D. (2012). *Resilience thinking: sustaining ecosystems and people in a changing world*. Island press.

Williams, D. S., Celliers, L., Unverzagt, K., Videira, N., Máñez Costa, M., & Giordano, R. (2020). A method for enhancing capacity of local governance for climate change adaptation. *Earth's Future*, *8*(7), e2020EF001506.

Walsh-Dilley, M. (2020). Resilience compromised: Producing vulnerability to climate and market among quinoa producers in Southwestern Bolivia. *Global Environmental Change*, 65, 102165.

Wong, L. P. (2008). Data analysis in qualitative research: A brief guide to using NVivo. *Malaysian Family Physician*, 3(1), 14.

Wood, B. A., Blair, H. T., Gray, D. I., Kemp, P. D., Kenyon, P. R., Morris, S. T., & Sewell, A. M. (2014). Agricultural science in the wild: A social network analysis of farmer knowledge exchange. *PloS one*, 9(8), e105203.

Woolcock, M. & Narayan, D. (2000). Social capital: implications for development theory, research, and policy. *The World Bank Research Observer*, *15*(2), 225-249.

World Bank (WB), Asian Development Bank (ADB), Government of Pakistan (GoP), (2010).Pakistan Floods 2010: Preliminary Damage and Needs Assessment. Islamabad.

Woroniecki, S., Spiegelenberg, F. A., Chausson, A., Turner, B., Key, I., Md. Irfanullah, H., & Seddon, N. (2023). Contributions of nature-based solutions to reducing people's vulnerabilities to climate change across the rural Global South. *Climate and Development*, *15*(7), 590-607.

Yankson, P.W.K., Owusu, A.B., Owusu, G., Boakye-Danquah, J. & Tetteh, J.D. (2017), Assessment of coastal communities' vulnerability to floods using indicator-based approach: a case study of Greater Accra Metropolitan Area, Ghana. *Natural Hazards*, 89(2), 661-689.

Yeleliere, E., Nyamekye, A. B., Antwi-Agyei, P., & Boamah, E. F. (2022). Strengthening climate adaptation in the northern region of Ghana: insights from a stakeholder analysis. *Climate Policy*, 22(9–10), 1169–1185. https://doi.org/10.1080/14693062.2022.2134085

Yin, R. (2009). Case Study Research Design and Methods, Fourth Edition Sage Publications, California.

Yulandari, E. D., Murayama, T., & Nishikizawa, S. (2023). Climate change adaptation through policy integration by local governments in Indonesia. *Mitigation and adaptation strategies for global change*, *28*(1), 3.

Zahid, M. & Rasul, G. (2012). Changing trends of thermal extremes in Pakistan. *Climatic Change*, 113 (3), 883-896.

Zarestky, J. (2023). Navigating multiple approaches to qualitative research in HRD. *Human Resource Development Review*, 22(1), 126-138.

Zerssa, G., Feyssa, D., Kim, D. G., & Eichler-Löbermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture*, *11*(3), 192.

Zeng, D., Alwang, J., Norton, G., Jaleta, M., Shiferaw, B., & Yirga, C. (2018). Land ownership and technology adoption revisited: Improved maize varieties in Ethiopia. *Land Use Policy*, *72*, 270-279.

Zhang, K., Shalehy, M. H., Ezaz, G. T., Chakraborty, A., Mohib, K. M., & Liu, L. (2022). An integrated flood risk assessment approach based on coupled hydrological-hydraulic modeling and bottom-up hazard vulnerability analysis. *Environmental Modelling & Software*, 148, 105279.

Zhong, F., Ying, C., & Fan, D. (2022). Public Service Delivery and the Livelihood Adaptive Capacity of Farmers and Herders: The Mediating Effect of Livelihood Capital. *Land*, 11(9), 1467.

Zhou, T., Yang, D., Meng, H., Wan, M., Zhang, S., & Guo, R. (2023). A bibliometric review of climate change cascading effects: past focus and future prospects. *Environment, Development and Sustainability*, 1-26.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M., & Smith, B. (2008). Climate change and adaptation in African agriculture. Stockholm Environment Institute.

Zougmoré, R., Partey, S., Ouédraogo, M., Omitoyin, B., Thomas, T., Ayantunde, A., & Jalloh, A. (2016). Toward climate-smart agriculture in West Africa: a review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agriculture & Food Security*, 5(1), 1-16.

Zulfiqar, F., Shang, J., Zada, M., Alam, Q., & Rauf, T. (2021). Identifying the determinants of access to agricultural credit in Southern Punjab of Pakistan. *GeoJournal*, *86*, 2767-2776.

Zulfiqar, F., Datta, A., & Thapa, G. B. (2017). Determinants and resource use efficiency of better cotton: An innovative cleaner production alternative. *Journal of cleaner production*, *166*, 1372-1380.

Zulfiqar, F., Ullah, R., Abid, M., & Hussain, A. (2016). Cotton production under risk: a simultaneous adoption of risk coping tools. *Natural Hazards,* 84(2): 959-974.

Appendices

Appendix A: Consent form

Exploring agriculture sector vulnerability to climate change at district level in Pakistan
(UTS HREC ETH18-2545)

I ____________________ *[participant's name]* agree to participate in the research project exploring agricultural vulnerability assessment to climate change at district level in Pakistan *[UTS HREC approval reference number ETH18-2545]* being conducted by Faisal Nadeem UTS Building 10, 235 Jones street, Ultimo NSW 2007 phone number: +[redacted]. I understand that funding for this research has been provided by University of Technology Sydney.

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research as described in the Participant Information Sheet.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time without affecting my relationship with the researchers or the University of Technology Sydney.

I understand that I will be given a signed copy of this document to keep.

I agree to be:
☐ Audio recorded

I agree that the research data gathered from this project may be published in a form that:
☐ Does not identify me in any way
☐ May be used for future research purposes

I am aware that I can contact Faisal Nadeem if I have any concerns about the research.

____ ____/____/____
Name and Signature [participant] Date

____ ____/____/____
Name and Signature [researcher or delegate] Date

____ ____/____/____
Name and Signature [witness*] Date

*** Witness to the consent process**
If the participant, or if their legally acceptable representative, is not able to read this document, this form must be witnessed by an independent person over the age of 18. In the event that an interpreter is used, the interpreter may not act as a witness to the consent process. By signing the consent form, the witness attests that the information in the consent form and any other written information was accurately explained to, and apparently understood by, the participant (or representative) and that informed consent was freely given by the participant (or representative) *(delete this section and the 'Signature of witness' section above if this form does not need to be signed by a witness to the consent process).*

Appendix B: Interview guide for farmers

Section 1 – About the agricultural farm and the farmer

Tell me about your farm – how much land do you have? What do you produce? How long have you been farming? What are your main crops/livestock? Where are the markets for these crops/livestock?

Why you do farming? How many of your family work on this farm? Who are they?
How much of your household income comes from the farm? Any other sources of income (off farm income)?

Section 2 – Farmer's perceptions & knowledge of climate change, agricultural vulnerability and climate adaptation

Have you noticed any changes in the climate in your life time or in your parent's time? If so, how have these changes affected your farm?

In your opinion why climate is changing?

Where do you get your information about weather?

Do you trust that the information is accurate? If not why is this so?

How and how much does the information you get about weather influence or effect your farm practices? If not much why is this so?

Do you think climate change is effecting/will effect Punjab agriculture in general (beyond your personal farm)?

Do you think changes in climate are affecting major crops (wheat, rice, cotton, maize and sugarcane) How, if you think so?

When you plan out your agricultural year, are there things that you are changing or considering to change because of the changing climate? Describe these changes?

Do these changes represent a major change in your farm management decisions? If so describe these major farm management decisions

Section 3 – Barriers, enablers and opportunities for local scale adaptation actions

How do farmers in your area learn about new agricultural techniques and ideas? How do you find agriculture extension services in your area?

What kind of support do you receive from the district and provincial government departments related to your farm business?

How and what kind of support you would like to receive from the district and provincial government departments related to your farm business? How would this assistance help you cope with weather extremes?

Do you think you have good access to the markets for your harvested crops? If no why is this so?

How you do you satisfy your crop's water requirement? Do you think your crops water requirements are being sufficiently met? If no why?

Have crops failed due to insufficient water?

How do you cooperate or collaborate with other farmers or farming communities? If not much why?

Do you have you access to farm credit services? Do you think you have suitable setting to use these farm credit services? If not much why is so?

In your opinion how can the current practices be improved, especially to help you cope with variations in weather or climate change?

Appendix C: Interview guide for government officials

Section 1 – About government organisations and officials

What role does your organisation play in climate change?

Have you, personally, interacted with issues of climate change in any capacity so far in your government service? If so describe your role?

Section 2 – Government official's perceptions and knowledge of climate change, agricultural vulnerability and climate adaptation

Do you think climate change has occurred, is occurring or likely to occur in Punjab? Why do you think that?

Have you noticed any changes in the climate in Punjab? If so, describe these changes? In your opinion what are the causes of these changes in climate?

Where do you get your information about climate change? (prompt: personal observation, meteorological department, electronic media, print media, social media, other experts etc.)

From which source and what kind of information has the biggest impact on you? Do you consider this information reliable? If not why is so?

How and how much does the information you get about climate change influence your work assignments and practices? If not much why is this so?

Do you consider agriculture in Punjab (in general) is vulnerable to climate change, with the consideration of agriculture as climate-sensitive? If you think so how vulnerable is agriculture to climate change in Punjab?

Do you think (in particular) major crops of agriculture in Punjab is vulnerable to climate change? If you think so how vulnerable is major crops subsector of agriculture to climate change in Punjab?

Do you think climate change adaptation has the potential to deal with vulnerability of climate change of major crops of agriculture in Punjab? How if you think so? What is the role of adaptation in dealing with vulnerability?

In your opinion, do farmers adapt to changes in climate? How if you think so? How do changes in climate represent or require a change in farmer's major farm management decisions? (e.g. new investments in infrastructure, new equipment needed, changes in timing of decisions – sowing, harvesting etc.)

Section 3 – Barriers, enablers and opportunities for local scale adaptation actions
Describe some of the key aspects from policies, programs and plans of your organisation which you consider at the nexus of climate change adaptation, agriculture and/or major crops in Punjab?

How do these key documents address the needs of the farmers to adapt at local level? In your opinion, where and what are the potential areas to focus on?

How do the range of government departments coordinate their roles at federal, provincial and district level focusing climate change adaptation and agriculture?

Where and what are the potential areas to focus on? How could the coordination among different stakeholders can be improved?

What is your view on how farmers in Punjab learn about new agricultural techniques and ideas? How do agricultural extension services help farmers to learn about these innovations? Where and what are the potential areas to focus on to improve information exchange?

In your opinion, how do farmers get support from the concerned district and provincial government departments related to their farm business?

How do you see the technical capability of concerned government departments supporting farmer's climate adaptation actions? Describe the technical capacity building areas to focus on?

How do you see the financial capability of concerned government departments supporting farmer's climate adaptation actions? Describe the financial capacity building areas to focus on?

How do you see the institutional capability of concerned government departments supporting farmer's climate adaptation actions? Describe the institutional capacity building areas to focus on?

Do you think farmers have good access to the markets for their harvested crops? If not why is this so? What actions lead to betterment?

Do you think crop water requirements of farmers are being met sufficiently? If not why is this so? What actions need to be focused?

What is your view on how farmers collaborate with other farmers or farming communities? (prompt: sharing farm related inputs, outputs, information etc.) How could farmers networks and collaboration be improved from the government perspective?

Do you think farmers have suitable financial environment and access to farm credit services? If not much why is so? How it can be facilitated?

In your opinion how can the concerned stakeholder's capacity to assist farmers be improved helping them to better adapt to climate changes at local level?

Appendix D: Additional quotes

"I feel policies are not rightly planned, farmers going into loss due to government policies [….] I did not get compensation from government on my crop failures. There is no system of crop insurance here. For crop damages in the 2010 flood, I received fertilizer bags through an NGO (one bag per acre) which was negligible with respect to my losses"

"Getting loan is not easy. They ask lots of documents to bring, loans conditions are very tough and whole process is complicated. Giving loans to poor farmers also may not be good as they cannot be able to return the loans with interest. I know some NGOs worked in the past 3-4 years here but they left now tired as they could not recover their loans. There should be some scheme by government of giving animals to poor farmers for them to grow these and get bit better off from this."

"Government cannot take all steps by its own such as buying crops from the farmers and private sector has to come forward. Direct markets for farmers can be acquired by government where farmers can directly approach markets and sell their agricultural produce by eliminating middle-men. However, government needs to develop such mechanisms and to regulate those with proper check and balance system. In government centres of wheat crop buying, farmers whether small and large farmers if registered have to bring their wheat grains to government purchase centres"

"There are capacity issues not only in public sector but in private sector as well. Capacity is much limited against what it should be. Institutional capacity of government departments is very low to support farmer's adaptation actions. For business as usual scenario, things are going the way they are. But if we want to compete with the standard and really wish to solve issues practically by forming clear policy and priority, then firstly we should have a need assessment. Then based on that need assessment we can see the requirement of creating new sections, merging or closing of sections within institutions to improve institutional capacity."

Appendix E: Government of Punjab approval letters

F.No. 6-4 / ES-1 / EPA / 2007
GOVERNMENT OF THE PUNJAB
ENVIRONMENTAL PROTECTION AGENCY
NATIONAL HOCKEY STADIUM, LAHORE
DATED: 8th October, 2018

To

Dr. Brent Jacobs,
Associate Professor,
University of Technology Sydney (UTS)
15 Braodway, Ultimo, NSW 2007
Sydney.

SUBJECT: **REQUEST FOR SUPPORT FOR MR. FAISAL NADEEM, PhD CANDIDATE UNIVERSITY OF TECHNOLOGY SYDNEY (UTS).**

Apropose of the subject. Your request dated 3rd September was examined and I am directed to state that the Director General, Environmental Protection Agency, Punjab is pleased to permit Mr. Faisal Nadeem a postgraduate student of the University to share/contribute the knowledge of his Research ***" Agricultural Vulnerability to Climate Change at District Level in Pakistan"*** and to interviews the Directors/ Deputy Directors and staff of EPA including field staff of EPA at any time convenient to him during office hour (from 09:00 am to 05:00 pm) at any day.

DA/ As above

Production Note:
Signature removed prior to publication.

NAZIM MAQBOOL
Deputy Director (Admin)
(042) 99232232

Cc to:-

1. All Directors/ Deputy Directors (Field) and Assistant Directors (Field), EPA, Punjab, with the request to extend full cooperation with Mr. Faisal Nadeem.
2. PS to Secretary, EPD, Punjab, Lahore

No. 29913-61 / /Dev. Dated: 01/09/2018.

DIRECTORATE GENERAL AGRICULTURE (EXT. & AR) PUNJAB
21 – DAVIS ROAD, LAHORE.
Phone: (042) 99200752 **Fax:** 99200743 **E-Mail:**

All Divisional Directors of Agriculture
(Extension), in the Punjab.

Subject: **Request for Support for Mr. Faisal Nadeem, Ph.D. Candidate UTS**

This is with reference to the University of Technology Sydney (UTS), Australia letter dated 3rd September, 2018 concerning the Ph.D. research that Mr. Faisal Nadeem of the University of Technology Sydney has proposed to carry out in Punjab Province of Pakistan.

Mr. Faisal has expressed interest in engaging with the Department of Agriculture while researching his topic **'Agricultural Vulnerability Assessment to Climate Change at District Level in Punjab'**.

Punjab Agriculture Extension is in support of the research proposal that Mr. Faisal has put forth that has potential to contribute in knowledge to support Provincial scale efforts for the betterment of Agriculture in Punjab. Mr. Faisal is permitted to engage with the staff of the Punjab Agriculture Extension at all levels including Deputy Directors, Assistant Directors, Agriculture Officers and Field Assistants during his research interviews as required.

We hope that Mr. Faisal will let us know about the findings of his research when available. We wish him best for his research that can be beneficial to the Agriculture in Punjab Province, a region of great significance in Agriculture production.

Production Note:
Signature removed prior to publication.

Director of Agriculture (Ext.) Hqrs.
for DIRECTOR GENERAL AGRICULTURE
(EXTENSION & A.R.), PUNJAB, LAHORE

CC:

- **Deputy Directors of Agriculture (Extension)** Lahore, Gujranwala, Sheikhupura, Okara, Kasur, Faisalabad, Jhang, Chiniot, Khushab, Sargodha, Rawalpindi, Chakwal, Jhelum, Attock, Multan, Muzaffargarh, Dera Ghazi Khan, Rajanpur, Mianwali, and Rahim Yar Khan. They are requested to please inform all concerned Assistant Directors Agriculture (Extension), Agriculture Officers (Extension) and Field Assistant of their District for extending full cooperation to Mr. Faisal Nadeem of University of Technology Sydney (UTS), Australia.
- **All Concerned**