

**Climate change Impacts and Adaptation in the Agricultural
Sector of Pakistan- Socioeconomic and Geographical
Dimensions**

Dissertation

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Eidesstattliche Versicherung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

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I hereby declare, on oath, that I have written the present dissertation by my own and have not used other than the acknowledged resources and aids.

Hamburg, den 09.11.2016

Muhammad Abid

*I dedicate this thesis to
my parents, my beloved wife and daughter
for their unconditional love and support!*

Publication arising from this thesis and in co-authorship with other researchers

This list provides the details about peer reviewed publications derived from PhD work as first author; either published (1-3), submitted (4) or in preparation for submission (5-7) to scientific journals. Further, this list also includes peer reviewed publications (8 to 15), where doctoral candidate appears as a co-author.

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Zusammenfassung

Prognostizierte Klimaveränderungen und ein steigendes klimatisches Risiko im 21. Jahrhundert bringen ernstzunehmende Herausforderungen für die globale wirtschaftliche Entwicklung, Sicherheit von Menschen und Ernährungssicherheit mit sich. Aufgrund von Ressourcenknappheit und ihrer eingeschränkten Anpassungsfähigkeit ist das klimatische Risiko in Entwicklungsländern größer. Derzeit gibt es nur wenig wissenschaftliche Forschung über die Auswirkungen des Klimawandels, die Vulnerabilität und mögliche Anpassung der Agrarsysteme in Entwicklungsländern im Vergleich zu zahlreichen Untersuchungen in entwickelten Ländern. Solche Untersuchungen sind jedoch wichtig für Länder wie z.B. Pakistan, wo die klimasensitive Landwirtschaft Lebensgrundlage und Einkommensquelle für den Großteil der Bevölkerung ist. Die Abschätzung möglicher Auswirkungen des Klimawandels sowie damit assoziierte Anpassungsoptionen für den landwirtschaftlichen Sektor in Pakistan ist daher eine sowohl relevante und zeitgemäße als auch herausfordernde wissenschaftliche Fragestellung.

Daher setzt sich diese wissenschaftliche Arbeit mit den sozialen Dimensionen des Klimawandels auseinander und analysiert die Interaktionen zwischen Menschen und ihrer Umwelt, indem sie die Verbindungen zwischen Klimawandel, Vulnerabilität, Anpassung, lokalen Akteuren und den sozioökonomischen Bedingungen in Pakistan untersucht. Die vorliegende Arbeit umfasst acht Kapitel und vereint interdisziplinäre Forschung sowie die Anwendung von aktuellen statistischen und Optimierungstechniken, um der Komplexität des Themas gerecht zu werden.

Das erste Kapitel beschreibt die Gegenstände der Untersuchung sowie die Methodik, und gibt eine Übersicht über die Datenbeschaffung und das Untersuchungsgebiet des Fallbeispiels. Diese Studie bezieht sich im Wesentlichen auf die Punjab-Provinz Pakistans und nutzt historische Klimadaten und Interviews von 450 Farmhaushalten, die vom Autor in drei agro-ökologischen Zonen in der Punjab Provinz durchgeführt wurden.

Das zweite Kapitel untersucht die Vulnerabilität, Sensitivität und assoziierte Anpassungsfähigkeit an den Klimawandel auf Haushaltsebene. Die Bauern beobachten extreme Temperaturen, eine Ausbreitung von Krankheiten im Nutztierbestand sowie den Befall der Anbaupflanzen als entscheidende klimatische Risiken für ihre Betriebe. Außerdem berichten Bauern von Unsicherheit und einem Abfall in der Produktivität, veränderten Aussaat- und Erntezeiten und Wasserknappheit aufgrund der beobachteten klimatischen Risiken. Die Bauern bauen daher andere Pflanzenarten an, verändern das Aussaatdatum und pflanzen Bäume, um sich an den Klimawandel anzupassen. Die abnehmende Wasserverfügbarkeit, Armut und die ungünstige institutionelle Lage verstärken die Empfindlichkeit der Haushalte gegenüber möglichen negativen Auswirkungen des Klimawandels.

Das dritte Kapitel analysiert mittels der logistischen Regression, wie die Bauern den Klimawandel wahrnehmen und welche Anpassungen sie vornehmen, sowie ihre Bestimmungen und Einschränkungen. Die Ergebnisse zeigen, dass die Bauern den Klimawandel gut wahrnehmen, sich jedoch nur wenig anpassen aufgrund von unterschiedlichen Ressourcen- und Informationsbeschränkungen. Eine Anpassung ist daher auf einfache Maßnahmen begrenzt und beinhaltet normalerweise keine fortschrittlicheren Methoden. Die Wahl der Anpassungsmaßnahme wird von zahlreichen sozio-ökonomischen und institutionellen Faktoren beeinflusst.

Das vierte Kapitel evaluiert die Anpassungen des Weizenanbaus an den Klimawandel und seine Auswirkungen auf die Produktivität und das daraus generierte Einkommen mittels der *propensity score matching* und *nearest neighbor* Methode. Die empirischen Ergebnisse dieser Studie bestätigen die Effektivität der Anpassungsmaßnahmen auf der Ebene von Bauernhöfen. Sie leisten einen Beitrag zur gesamten Ernährungssicherheit.

Das fünfte Kapitel beinhaltet die Entwicklung und Analyse eines Multi-Farm-Modells für Pakistan mithilfe von Optimierungstechniken in GAMS (*General Algebraic Modeling System*). Es bezieht sich dabei im Wesentlichen auf die Entscheidungsfindung der Farmhaushalte in verschiedenen politischen, kooperativen und Anpassungsszenarien.

Im sechsten Kapitel werden die Wahrnehmungen des Klimawandels der Bauern mit historischen Klimaaufzeichnungen verglichen und die Kausalverknüpfung zwischen verschiedenen Stadien der Anpassung mittels des *Multivariate Probit* Modell analysiert.

Trotz einiger Diskrepanzen bei veränderten Niederschlagsmustern stimmen die historischen Trends gut damit überein, wie der Klimawandel von den Bauern wahrgenommen wurde. Diverse interne und externe Faktoren beeinflussen die Genauigkeit der Wahrnehmung und anderer Anpassungsstadien.

Mit Hilfe der Soziale Netzwerkanalyse untersucht Kapitel sieben die Interaktionen zwischen den Bauern und lokalen Akteuren sowie ihren Zugang zu verschiedenen institutionellen Services im Kontext der Anpassung an den Klimawandel. Es wurden mehrere strukturelle Lücken im derzeitigen institutionellen System gefunden, die die Anpassungsfähigkeit von Bauernhöfen und Gemeinschaften im landwirtschaftlichen Sektor beschränken. Ein integrierter Rahmen wird vorgeschlagen, um die Rolle lokaler Institutionen und die Zusammenarbeit im Anpassungsprozess zu stärken.

Das achte Kapitel untersucht interne Migrationsvorhaben unter Haushalt und die Zusammenhänge zu veränderten Umweltbedingungen sowie sozioökonomischen und institutionellen Faktoren. Außerdem untersuchen diese Kapitel das Ausleihen von Land im Untersuchungsgebiet und befassen sich mit möglichen Ursachen für den Anstieg dieses Trends.

Das letzte Kapitel fasst die wichtigsten Erkenntnisse der vorangegangenen Kapitel zusammen und spricht Empfehlungen für weitere Untersuchungen und politische Maßnahmen aus.

Abstract

Projected changes in climate and increasing climatic risk over the 21st century pose serious challenges to global economic development, food and human security. The climatic risk is generally higher in developing countries due to a lower adaptive capacity and higher resource scarcity. The research about climate change impacts, vulnerability and adaptation of the agricultural systems in developing countries is relatively scarce compared to abundant research in developed countries. These assessments are important for countries such as Pakistan where the majority of the population relies on climate-sensitive agriculture for livelihood and income generation. The estimation of possible climate change impacts and associated adaptation capacities for the agricultural sector in Pakistan is thus not only a very relevant and timely but also a very challenging research question given the data constraints and limited literature on climate change adaptation in Pakistan.

Therefore this thesis focuses on the social dimensions of climate change and analyzes the human-environment interactions by exploring linkages between climate change, vulnerability, adaptation, local actors and socio-economic settings in Pakistan. To grasp this complexity, the thesis combines nine chapters, comprising interdisciplinary research and applying both state-of-the-art statistical and optimization techniques.

The first chapter describes the study objectives and research methods and provides an overview of sampling and data collection procedures and case study area. This study mainly focuses on the Punjab province of Pakistan and uses historical climate data and a cross-sectional survey of 450 farm households conducted by the author in three agro-ecological zones of Punjab province, Pakistan.

The second chapter explores the household level vulnerability, sensitivity and associated adaptive capacities to climate change. Farmers observe extreme temperatures, animal diseases and crop pests as key climatic risks to their farming. On the other hand, farmers report uncertainty and decrease in farm productivities; changes in cropping calendars and shortage of water due to observed climatic risks. Farmers change their crop types, varieties, sowing dates and plant trees in order to adapt to climate change. Declining water availability, poverty and poor institutional setting increase the household sensitivity to climatic risks.

The third chapter analyzes farmers' perceptions of and adaptation to climate change and their

determinants and constraints using a logistic regression approach. The results show that farmers perceive changes in climate well but adapt less due to different resource and informational constraints. Therefore, adaptation is limited to simple measures and does generally not include advanced measures. The choice of adaptation measures is influenced by various socio-economic and institutional factors.

The fourth chapter evaluates adaptation of wheat farming to climate change and its impact on food productivity and crop income using propensity score matching and nearest neighbor method. The empirical findings of the study confirm the effectiveness of adaptation at farm level and its contribution to overall food security.

The fifth chapter involves the development of an agricultural sector model for Pakistan in General Algebraic Modeling System (GAMs) using optimization techniques. The chapter mainly analyses the farm households' decision making under different adaptation, policy and cooperation scenarios.

The sixth chapter compares farmers' perceptions of climate change with historical climate records and analyzes the casual link between different adaptation stages using a multivariate probit model. Perceptions of climate change matched well with historical trends despite some discrepancies in case of rainfall changes. Moreover, various internal and external factors influence the accuracy of farmers' perception and other adaptation stages.

Using social network analysis, Chapter seventh explores the interactions of farmers with local actors and their access to different institutional services in the context of adaptation to climate change. Study found various structural gaps in the current institutional setting that limit the adaptation capacities of farming communities. The study suggests an integrated framework to enhance the role of local institutions and collaboration in the adaptation process.

The eighth chapter examines internal migration intention among household heads and its interrelationships with environmental changes, socio-economic and institutional factors. Further, these chapters also investigate land borrowing in the study areas and identification of possible reason for increasing borrowing trend.

Finally, the last chapter summarizes the key findings of the previous chapters and provides recommendations for further researches and policies.

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Abbreviations

IPCC	Intergovernmental Panel on Climate Change
GAMs	General Algebraic Modeling System
GDP	Gross Domestic Product
AEZs	Agro-ecological zones
PARC	Pakistan agricultural research council
GOP	Government of Pakistan
GOPP	Government of Punjab, Pakistan
MVP	Multivariate probit model
PMD	Pakistan Meteorology Department
PSM	Propensity score matching
NNM	Nearest neighbor methods

LUCC	Land use and cover changes
ASMGHG	The Agricultural Sector and Greenhouse Gas. Mitigation Model
PKR	Pakistani Rupee
SML	Simulated maximum likelihood
GHK	Geweke-Hajivassiliour-Keane
OFWM	On-farm water management
PASSCO	Pakistan Agricultural Storage and Services Corporation
PPPs	Public-private partnerships
KNU	Kompetenzzentrum Nachhaltige Universität
CLISEC	Climate Change and Security
SICSS	School of Integrated Climate System Sciences
DAAD	Deutscher Akademischer Austauschdienst
HEC	Higher Education Commission of Pakistan

1 Introduction

Climate change is expected to adversely affect agricultural production, food security and rural livelihoods in South Asia (IPCC, 2014b). Climate models suggest temperature increases between 0.5 and 2°C by 2030 and between 1 and 7°C by 2070 in the Asian Pacific region (Hii *et al.*, 2009; Leal Filho, 2015). Particularly, temperatures are expected to increase more rapidly in arid zones of Pakistan, India and western China (Leal Filho, 2015). Studies suggest significant losses (4-10%) in cereal yields by 2100 in South Asian countries due to an increase in temperatures (Lal, 2011). Similarly, the uncertain and uneven rainfall distribution along with risks of floods and droughts are likely to undermine the agricultural growth in most of the South Asian countries. Pakistan is expected to experience losses in productivity of main staple crops, such as wheat and rice (IPCC, 2014b).

South Asian countries are particularly vulnerable to climate change due to limited lower adaptive capacity and more severe resource scarcity (Schilling *et al.*, 2013). Climate change adds to the development challenges of the countries in the region that are still struggling with food insecurity and poverty issues. These impacts are very important for countries such as Pakistan, where agriculture employs 44% of the total labor force and provides livelihood to more than half of the population (Abid *et al.*, 2016b). The majority of the population in Pakistan lives in rural areas and is characterized by poor and resource constrained small farming households. During the last decade, extreme weather and climatic events such as floods and droughts have increasingly affected the agricultural sector and the rural population in Pakistan. Particularly, the historic floods during 2010-2014 and severe droughts lasting from 1999 to 2003 showed the vulnerability of rural households in Pakistan (Abid *et al.*, 2016b). Alone the floods in 2010 damaged 2 million hectares of unharvested crops and caused an estimated loss of 4 billion US dollars only to the agricultural sector (GOP, 2011).

The sensitivity of any system largely depends on its adaptive capacity and the potential to adapt to changing environment. In the absence of adaptation, climate change can considerably affect food production by altering production capacities of the sector (Trapp, 2014). Therefore, adaptation is important to enhance the resilience of the agricultural sector and to protect the livelihoods and ensure local food security (Bryan *et al.*, 2013). However, type and extent of adaptation strategies vary across regions, socio-economic and agro-ecological settings (Deressa

et al., 2009). Like many other developing countries, the adaptive capacity of agricultural systems in Pakistan is very low due to the lack of necessary infrastructure and effective policy instruments (Schilling *et al.*, 2013). Serious efforts are required to develop and implement efficient adaptation policies with particular focus on the agricultural sector. In this regard, efforts are required at various scales ranging from national to local. At the national level, it requires greater investments in designing new adaptation strategies and integrated disaster risk management plans while at local level the adjustment in existing farming systems and resource use patterns may be required (Bryan *et al.*, 2013). In this regard, the role of stakeholders in the agricultural sector cannot be ignored including farmers, crop scientists, and policy makers, attached public and private institutions. A comprehensive understanding of potential climate risks and coping strategies needs to be developed before implementing any adaptation plan (Howden *et al.*, 2007).

1.1 Objectives and Research Questions

Given the increasing climatic risks and frequency of extreme events in Pakistan, it is highly important to understand the human-environment interactions in a local context by exploring the effects of climate change on rural livelihoods and associated adaptation efforts. However, the knowledge on the social dimensions of climate change in the agricultural sector is still limited especially in developing countries due to limited research on environmental vulnerability, local risk perceptions and adaptive capacity (Schilling *et al.*, 2013). This particularly applies to Pakistan, where most of the climate change literature emphasizes the bio-physical and/or economic relationships between climate change and agriculture in different regions and districts (e.g. Hussain and Mudasser, 2007; Hanif *et al.*, 2010b; Ashfaq *et al.*, 2011; Nomman and Schmitz, 2011). Many existing studies in Pakistan show the need for adaptation and household vulnerability research, but actual field-based studies on farm level effects, vulnerability and adaptation are rare. To the author's knowledge, this is the first time that the social dimension of climate change impacts and adaptation with a particular focus on agriculture and rural livelihoods in Pakistan is analyzed. This study contributes to an overall understanding of farm level impacts, vulnerability aspects and adaptation to climate change and explores the role of local stakeholders in the adaptation process.

For this thesis, the Punjab province is chosen as the research region due to its variety of

characteristics such as a high share in the country's agricultural GDP, projected climatic changes as well as various agro-ecological settings. In Punjab, the study focuses on three agro-ecological zones that are indifferent in terms of climate, cropping pattern, irrigation systems, socio-economic and ecological settings. Thus, the findings of this study are likely to be relevant for other provinces of Pakistan as well as for other developing countries with similar geographical profiles, agro-ecological and socio-economic settings. These results can also assist policy makers in establishing climate change adaptation policies keeping in view the regional differences. The present thesis attempts to answer the following research questions.

1. How vulnerable are farmers to climate change? What types of risks do farmers perceive and what are the options for adaptation to climate change (adaptive capacity)?
2. How do farmers perceive and adapt to climate change and what are the constraints and factors driving their adaptation decision-making at farm level?
3. What is the value of adaptation for farmers? How does it affect food productivity and crop income?
4. How does farmers' decision-making change under different adaptation, policy and cooperation scenarios?
5. How accurate are farmers' perceptions of climate change? What factors influence the three adaptation stages? How do accuracy and adaptation vary across farmers?
6. What role do local actors or institutions play in the adaptation of the agricultural sector to climate change? How can the role of local actors in the adaptation process be enhanced?
7. How do changes in environmental conditions affect household heads' intentions to migrate and to diversify their income options? How do the land borrowing trends in the study region link (directly or indirectly) to climate change?

The listed questions are interlinked and are addressed using different research methods and datasets.

1.2 Sampling and primary farm data collection

The thesis uses a mix of primary and secondary datasets. The secondary dataset consists of station level climate data (1980-2013) collected from the Pakistan Meteorology Department (PMD). For the primary data, the author designed, organized and conducted a very comprehensive agricultural survey among 450 farmers in three representative districts between

March and April 2014. A multi-stage sampling technique is used for the selection of 450 farmers for interviews, about 150 farmers from each district (Figure 1.1). At each stage the following elements are selected:

1. Punjab province as the main study area.
2. Three agro-ecological zones (AEZs), keeping in view the geography, climate and cropping patterns in different zones.
3. Three representative districts among three zones using a random sampling technique.
4. Two sub-districts (*tehsils*) from each district using a simple random sampling technique.
5. 5-6 union councils from each city using the stratified random sampling technique.
6. 2-3 random villages from each union council.
7. About 5-6 farmers randomly selected from each village.

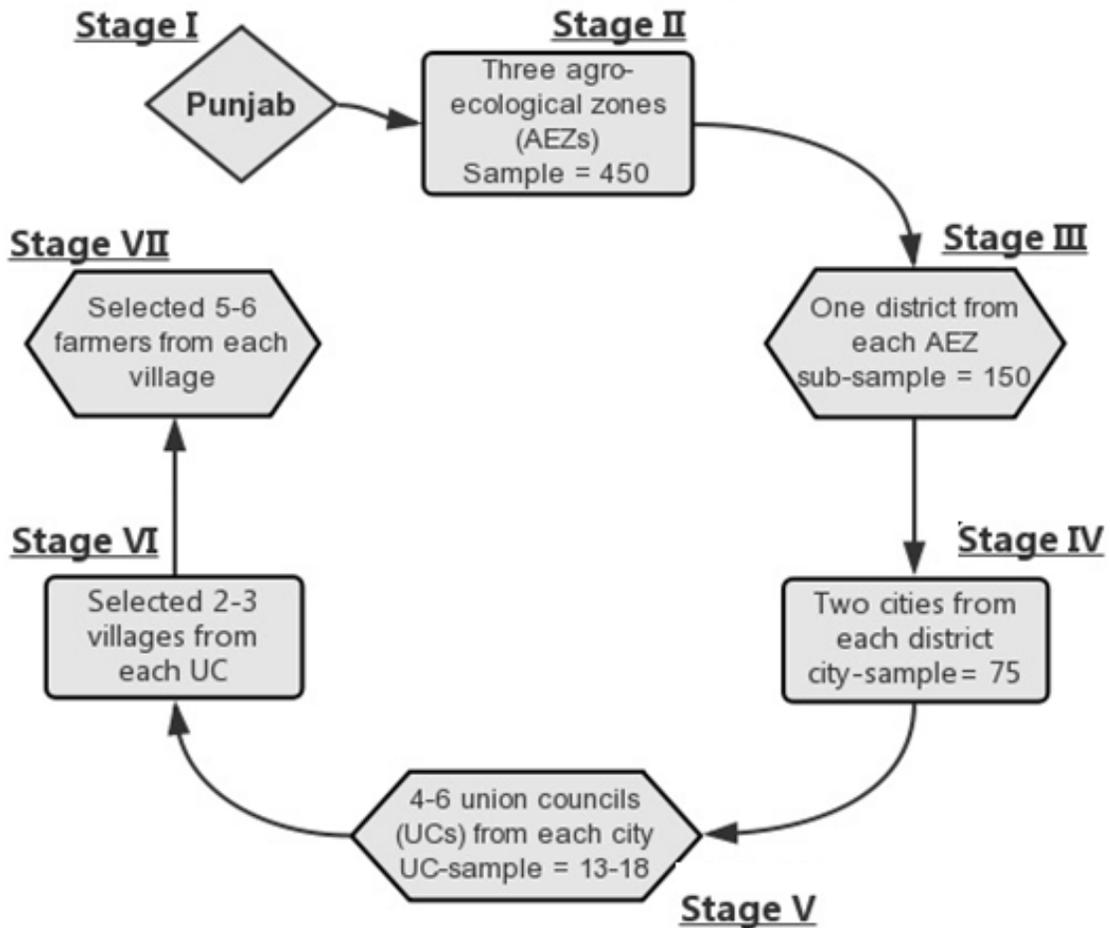


Figure 1.1 Sampling framework of the study

A structured questionnaire is used for the interviews to explore the study objectives. For enumeration, graduate students from the local agricultural university are hired. Before the start of the survey, the enumerators are trained about the study objectives and data collection methods and the questionnaire is pretested in the field to ensure the survey quality and to avoid important information gaps. During the implementation stage, the informal verbal consent of the farmers is taken before starting an interview and farmers who refused to give interviews were replaced with other farmers. Through the questionnaire, farmers are asked to provide information on socio-economic characteristics, farm management, climate change perceptions, adaptation actions and capacities, and actors' interactions

1.3 Study area

This study is conducted in the Punjab province in the southeast of Pakistan, which is located in the semiarid lowlands zone (Abid *et al.*, 2016a). Being the most populous and second largest province and having fertile agricultural lands, Punjab plays a leading role in the overall economy of Pakistan by sharing 53% of the total agricultural gross domestic product (GDP) and 56% of the total cultivated area (Badar *et al.*, 2002). Figure 1.2 shows the map of the Punjab province and the location of our study areas.

Overall the climate of the province is hot in summer and cold in winter (Abid *et al.*, 2016a). The rainfall in the province is mainly linked to the monsoon winds and about two-third of total rainfall happened in the monsoon season which varies from June to August every year. Our study districts are situated in different agro-ecological zones (AEZs) which are categorized by the Pakistan agricultural research council (PARC) based on the climate, geography and cropping patterns (Table 1.1). Our first study district Rahim Yar Khan is located in the alluvium plain between river Indus in the West and the Cholistan in the East and partly falls in the irrigated plains AEZ (cotton sub-zone) and marginal land AEZ (Cholistan sub-zone) (GOPP, 2010b). The major crops grown in the district are cotton, wheat and sugarcane. The second study district, Toba Tek Singh falls in the irrigated plains AEZ (central mixed cropping sub-zone). Wheat, cotton, sugarcane, maize and tobacco are the major crops grown in the district. Our third district, Gujrat partly falls into the *Barani* (rain-fed) AEZ (high rainfall sub-zone) and irrigated plains AEZ (rice sub-zone) and lies between the Jhelum and Chenab rivers (GOPP, 2010a).

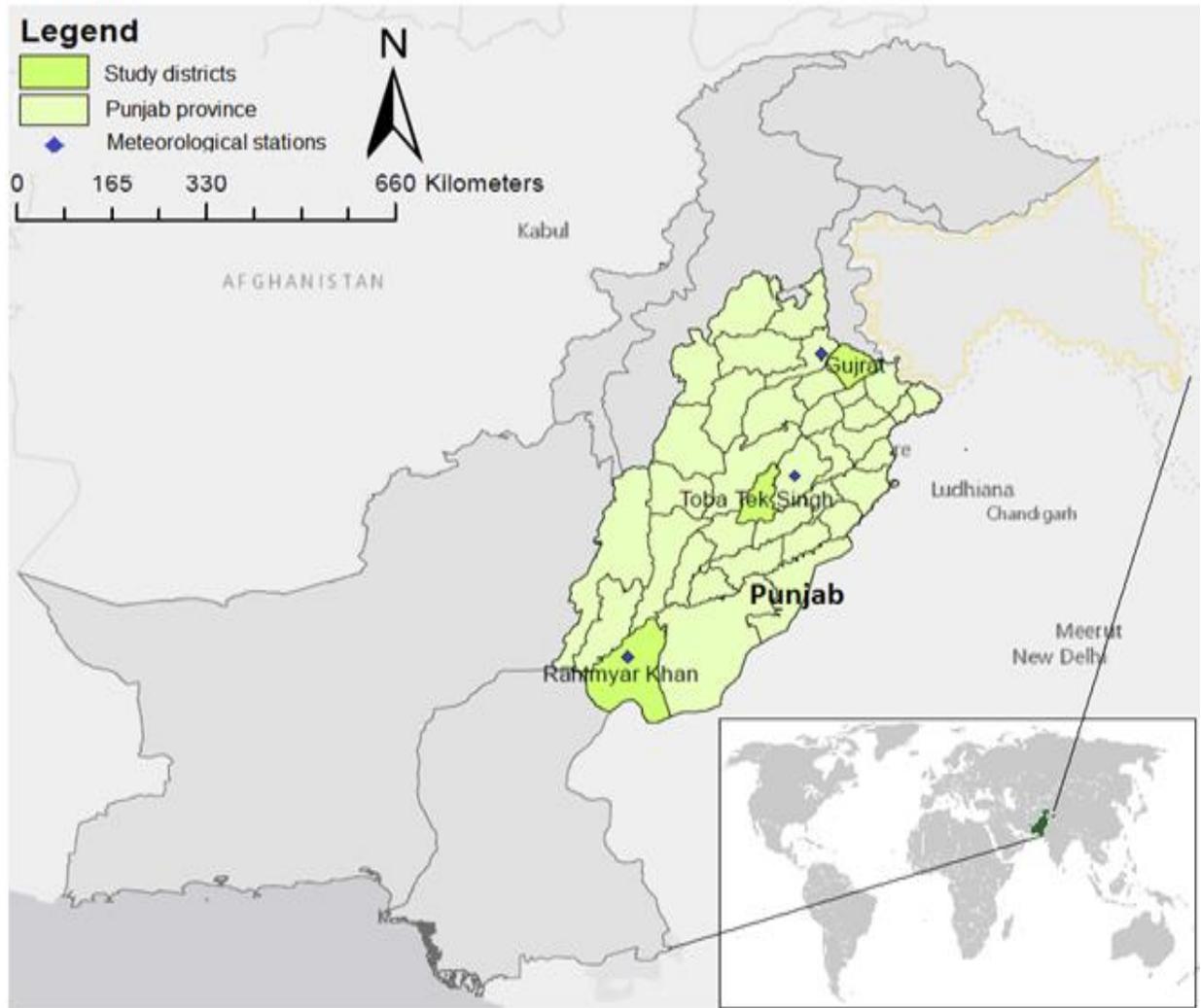


Figure 1.2 Study area map (World map source: ESRI, 2015)

Overall the climate of the province is hot in summer and cold in winter (Abid *et al.*, 2015). The rainfall in the province is mainly linked to the monsoon winds and about two-third of total rainfall happened in the monsoon season which varies from June to August every year (Abid *et al.*, 2015). Our study districts are situated in different agro-ecological zones (AEZs) which are categorized by the Pakistan agricultural research council (PARC) based on the climate, geography and cropping patterns (Table 1.1). Our first study district Rahim Yar Khan is located in the alluvium plain between river Indus in the West and Cholistan in the East and partly falls in the irrigated plains AEZ (cotton sub-zone) and marginal land AEZ (Cholistan sub-zone) (GOPP, 2010b). The major crops grown in the district are cotton, wheat and sugarcane. The district is characterized by high temperature of 17-33°C and low rainfall ranges from 42 mm to 399 mm

over the period of 1980-2013 (Table 1.1).

Table 1.1 Climate characteristics of the study area

Study sites	Agro-ecological zone	Annual rainfall (mm)*	Annual mean Min. Temp. (°C)	Annual mean Max. Temp. (°C)
Rahim Yar Khan	Irrigated plains (cotton) and marginal lands (Cholistan)	133.27 (42-399 mm)	17.40	33.31
Toba Tek Singh	Irrigated plains (mixed cropping zone)	382.77 (291-807 mm)	17.20	31.10
Gujrat	<i>Barani</i> (rain-fed) zone and irrigated plains (rice zone)	863.72 (668-1336 mm)	16.70	30.30
Average of three zones		465.69 (334-871 mm)	17.10	31.57

1.4 Methods

This study requires both qualitative and quantitative data collection and use of the historical time series climate data to facilitate a deeper understanding of the topic. Further, the spectrum of methods used in this thesis includes both state-of-the-art statistical and optimization techniques. Each chapter differs in terms of data and methods. For instance, Chapter 2 involves the use of a bottom-up approach and various indicators to capture the different aspects of farm level vulnerability to climate-related risks, including risk perceptions, their sensitivity and adaptive capacity. In chapter 3, correlation analysis is used to examine household perceptions of long term changes in seasonal climate change. Further, a logistic regression modeling is used to model different adaptation measures and to investigate factors affecting the choice of different adaptation measures. Furthermore, correlation analysis and graphs are also used to interpret adoption of adaptation strategies across various scales and groups of farmers categorized based on socio-economic characteristics. Propensity score matching (PSM) and nearest neighbor methods (NNM) are used in chapter 4 to quantify farm level adaptation benefits in terms of food productivity gains and crop income. In Chapter 5, a multi-farm model for Pakistan is developed in software GAMs (General Algebraic Modeling Systems) using optimization techniques. Further, we develop different adaptation, cooperation and policy access scenarios to assess their impact on farm revenue and land use decision making using the multi-farm model. Chapter 6

employs a multivariate probit model (MVP) to examine the chain relationship between different adaptation stages and their determinants. Further the farmers' perceptions of climate change are compared with historical climatic trends using correlation graphs and regression analysis. Moreover, the same MVP model is also used to test the hypothesis about the role of accuracy of farmers' perceptions in adaptation decision making. In next step, Chapter 7 uses social network analysis (SNA) to investigate farmers' access to different institutions and their services. SNA is also used to investigate the actors' interactions in adaptation and financial support networks and their role in local adaptation to climate change. Structural gaps are also estimated using this technique. Moreover, chapter 8 assesses household heads' migration intentions and its interaction with different socio-economic, environmental and institutional factors using a binary logistic regression technique. Further, correlation analysis is used to test the hypothesis of increasing land borrowing trends in the study area due to changes in environmental conditions and indirect climatic factors.

1.5 Structure

The thesis consists of nine chapters including three published, one submitted and two likely to be submitted journal articles. In all papers, the author of this thesis is the lead author and responsible for the majority of the chapter's content. The thesis comprises interdisciplinary research and involves diverse methods from the fields of geography, economics, sociology, statistics, engineering, and natural sciences. Thematically, the thesis revolves around four major aspects of the social dimensions of climate change:

- Climate change vulnerability, impacts, risk perceptions, adaptive capacities, adaptation determinants and constraints (Chapter 2,3,5 and 6);
- Value and impacts of climate change adaptation, different policy and cooperation scenarios on farmer welfare and food security (chapter 4 and 5);
- Role of social networks and local stakeholders in the climate change adaptation (Chapter 7).
- Internal migration as a coping strategy in changing environmental conditions and associated land borrowing trends (Chapter 8).

The second chapter provides insights into the climate-related risks faced by farmers, sensitivity to climate change, the adaptive responses employed by farm households, constraints that address

the adaptive capacity and the role of local level collaborations in the adaptation process at the farm level.

Chapter 3 examines the farmers' perceptions of and adaptation to climate change and their determinants and constraints using logistic regression analysis and estimating marginal effects and partial elasticities. Further, adaptation is also analyzed across different farmer groups based on education and farming experience. Moreover, this chapter also examines regional differences in the choice of adaptation measures using partial elasticities.

The fourth chapter evaluates the ongoing adaptation efforts at farm level and analyzes their impacts on food productivity and crop income. In the first step, the study employs logistic regression analysis and propensity score matching (PSM) technique to find adaptation conditions for wheat farmers and propensity scores. Then the study uses nearest neighbor method to compare adapters and non-adapters (NNM) based on calculated propensities and estimates the causal impact of adaptation on food productivity and crop income. Moreover, through this Chapter, implications of adaptation to climate change for local food security are also discussed. Based on the findings of the study, different recommendations are provided to improve the effectiveness of adaptation actions in the study area as well in other regions of Pakistan.

Chapter 5 involves the development of a multi-farm model for Pakistan in a software GAMs (General Algebraic Modeling System) using optimization techniques and farm household data collected. Further, this model is used to estimate the impact of different adaptation, cooperation and policy scenarios on welfare and land use decision making of farmers in the study area.

The sixth chapter investigates farmer perceptions of climate change and their agreement with observed climatic trends. Also, this study explores the different stages of adaptation to climate change by looking into the causal links and key drivers using the multivariate probit model. This study also investigates the accuracy of farmer perceptions and adaptation measures across different farmer groups based on land tenure and land holdings.

The seventh chapter uses social network analysis to investigate the stakeholder networks in the agricultural sector of Pakistan and to assess the institutional support surrounding farmers for climate change adaptation and existing structural gaps in the current institutional setup.

The eighth chapter examines the household heads' perceptions about climatic risks and their intentions to migrate and its interactions with climatic as well as socioeconomic and institutional factors using logistic regression technique. Further, migration intentions were also assessed

across different categories of farmers based on level of education, family size, land holding and access to different institutional services. Further, this chapter also explores the land borrowing trends and associated reasons.

The last chapter summarizes the key findings of the previous chapters according to the research objectives and the research questions. Conclusions and implications are drawn to inform further research and to provide policy recommendations.

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2 Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan

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Climate change vulnerability, adaptation and risk perceptions at farm level in Punjab, Pakistan



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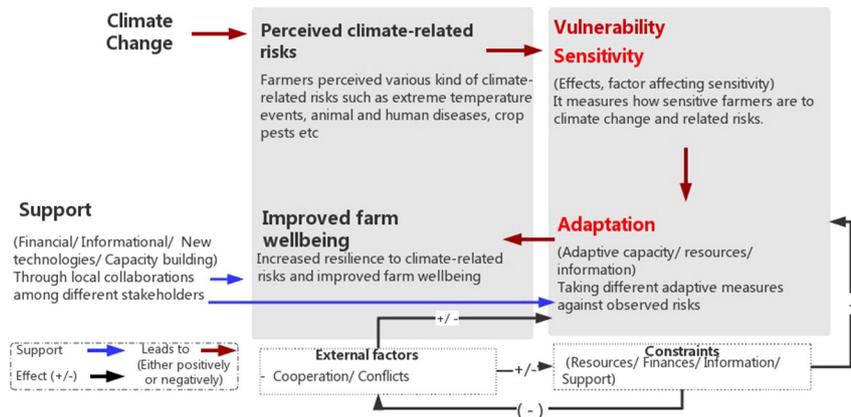
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HIGHLIGHTS

- Farmers perceive various climate-related risks: extreme temperature, animal and human diseases, crop pests and droughts
- Sensitivity of farmers to climate-related risks depends on the availability of resources
- Farmers are adapting to climate risks subject to various constraints which limit adaptive capacity at farm level
- Cooperation and conflict significantly affect the process of adaptation at the farm level
- Outreach of the institutional services, especially the climate-specific advisory services, need to be enhanced

GRAPHICAL ABSTRACT



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ABSTRACT

Pakistan is among the countries highly exposed and vulnerable to climate change. The country has experienced many severe floods, droughts and storms over the last decades. However, little research has focused on the investigation of vulnerability and adaptation to climate-related risks in Pakistan. Against this backdrop, this article investigates the farm level risk perceptions and different aspects of vulnerability to climate change including sensitivity and adaptive capacity at farm level in Pakistan. We interviewed a total of 450 farming households through structured questionnaires in three districts of Punjab province of Pakistan. This study identified a number of climate-related risks perceived by farm households such as extreme temperature events, insect attacks, animal diseases and crop pests. Limited water availability, high levels of poverty and a weak role of local government in providing proper infrastructure were the factors that make farmers more sensitive to climate-related risks. Uncertainty or reduction in crop and livestock yields; changed cropping calendars and water shortage were the major adverse impacts of climate-related risks reported by farmers in the study districts. Better crop production was reported as the only positive effect. Further, this study identified a number of farm level adaptation methods employed by farm households that include changes in crop variety, crop types, planting dates and input mix, depending upon the nature of the climate-related risks. Lack of resources, limited information, lack of finances and institutional support were some

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constraints that limit the adaptive capacity of farm households. This study also reveals a positive role of cooperation and negative role of conflict in the adaptation process. The study suggests to address the constraints to adaptation and to improve farm level cooperation through extended outreach and distribution of institutional services, particularly climate-specific farm advisory services.

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1. Introduction

The effects of climate change have become increasingly apparent over the past decades (Patt and Schröter, 2008). Climate change projections suggest a more variable climate with higher vulnerabilities in lower income countries (Easterling et al., 2000; McCarthy, 2001). With its mainly arid geographical profile and resource scarcity, Pakistan is among the highly vulnerable countries to climate change (Schilling et al., 2013). The country is already experiencing an increase in the frequency and severity of climatic events such as droughts, extreme temperatures, severe water shortage, floods in certain regions and increased incidents of pests and diseases (Smit and Skinner, 2002). According to the Global Climate Change Vulnerability Index (CCVI), Pakistan was ranked as the 29th most vulnerable country over 2009–2010, and the 16th most vulnerable over 2010–11 (Khan and Fee, 2014). The consecutive floods of 2010, 2011, 2012 and 2014 and the severe drought lasting from 1999 to 2003 are some examples of more frequently occurring climate-related events in Pakistan.

Livelihoods in Pakistan are highly sensitive to climatic changes as agriculture is by far the most important sector, providing 45% of employment (Abid et al., 2015). The impact of climate-related events strongly depends on the capacity to adapt to those risks (O'Brien et al., 2006). Pakistan is among one of the countries with least adaptive capacity due to existence of high level of poverty and lack of physical as well as financial resources (Abid et al., 2015; Adger et al., 2005; Wandel and Smit, 2000). Impacts of non-climatic stimuli on adaptation decision are among the main complications in the process of farm level adaptation. The farmers, who are the main decision makers in farming, have to work in a very complex environment characterized by political, economic, institutional and biophysical conditions (Belliveau et al., 2006). These multiple exposures directly or indirectly interact to influence the farmers' management and adaptation decisions to climate change and related risks (Abid et al., 2015; Adger et al., 2005; Wandel and Smit, 2000). There are also certain internal factors such as personal characteristics, farming practices and individual circumstances which further define individual farmer's response and adaptive capacity (Bryan et al., 2013). Further, interaction within the farming community may also influence the adaptive capacity at farm level. A positive cooperation, i.e. exchanging information or resources could also have a positive impact on the adaptive capacity while a negative interaction or conflict at farm level may lead to low adaptive capacity.

The knowledge about the current process of adaptation and vulnerability aspects at farm level is still very limited especially in developing countries due to lack of research on environmental vulnerability, local level risk perceptions and stimuli that lead to adaptation (Bryant et al., 2000; Lemmen and Warren, 2004). This particularly applies to Pakistan, where the current literature on climate change and agriculture mainly focuses on the bio-physical and economic relationship between climate change and agriculture across different regions and districts (e.g. Hanif et al., 2010; Hussain and Mudasser, 2007; Nomman and Schmitz, 2011). Many existing studies in Pakistan reference the need for adaptation, but actual field-based studies on farm level vulnerability and adaptation responses to climate change are rare (e.g. Abid et al., 2015; Ahmad et al., 2013; Gorst et al., 2015). There is increasing recognition of the need for field-based studies in order to truly understand the local level vulnerability and adaptation responses to climate change (Moser and Luers, 2008). Therefore this study will be a valuable contribution to an overall understanding of farm level vulnerability in

developing countries such as Pakistan. The findings of such field-based studies may also assist policy makers in designing effective need- or demand-based policies to better protect farmers from climate change vulnerabilities.

Against this backdrop, the overall goal of this paper is to contribute to the understanding of the farm level vulnerability to climate-related risks in Punjab, Pakistan. The aim is further divided into four objectives. The first objective is to investigate the climate-related risk perceptions at farm level. The second objective of the study is to assess the farm level sensitivity including effects of climate-related risks. The third and fourth objectives relate to the adaptive capacity aspect of vulnerability. Specifically, the third objective of the study is to show how farmers adapt their farming in response to observed climate-related risks. The fourth goal is to understand the adaptive capacity of farm households by exploring the constraints and role of local level cooperation and conflict in the process of adaptation.

In a first step, this paper briefly addresses and synthesizes key issues of farm level vulnerability and adaptation in Pakistan to climate-related risks (1) and provides a general overview of the vulnerability concept (2). This is followed by a material and method section (3) which includes the framework of the study, sample design, sampling and data collection, and description of study areas. In the next step, the findings of the study are divided into different sub-sections based on the objectives of the study (4) followed by the conclusion and recommendations (5).

2. Farm-level vulnerability

The vulnerability concept is rooted in various fields such as climate change, natural hazards, food security and political ecology where it has various meanings and interpretations (Brooks, 2003; Smithers and Smit, 1997). Biophysical vulnerability usually deals with the likelihood of impacts of natural hazards with a focus on its magnitude, frequency and extent (Belliveau et al., 2006; Turner et al., 2003). However, social vulnerability usually takes into consideration the state of human systems which is influenced by political, economic and social factors that may put people at risk and also reduce their capability to adapt to those risks (Belliveau et al., 2006; Cutter et al., 2003). Literature (e.g. Downing et al., 2001; Kelly and Adger, 2000) has identified examples of such factors, i.e. access to various institutional services, resources, poverty and food insecurity.

In the field of climate change, the concept of (environmental) vulnerability combines natural and social factors and may be defined according to IPCC (2014) as "the propensity or predisposition to be adversely affected". Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Until the fourth Assessment report of IPCC (2007), vulnerability was viewed as comprising three elements: exposure, sensitivity, and adaptive capacity. However in IPCC (2014), vulnerability focuses only on the sensitivity and capacity, with exposure more appropriately included into the concept of risk. It implies that a system is vulnerable if it is more sensitive to climate-related risks and has limited adaptive capacity at the same time. On the contrary, a system is less vulnerable only if it is less sensitive or has strong adaptive capacity (Fellmann, 2012). We used a similar approach in our study for the vulnerability analysis consistent with the vulnerability framework explained in the fifth assessment report of the IPCC (2014). Here, we defined climate change as observed or perceived changes in the local environment over the last ten to twenty years or more in terms of

occurrence of extreme environmental events such as droughts, floods, extreme high or low temperatures (Bryan et al., 2013). The degree to which a system (in our case a farm) is vulnerable to an environmental stimulus is related to the system's capacity to be negatively affected and the ability to cope with its adverse impacts (Smith and Pilifosova, 2003). Here a system's capacity is related to the observed risks and sensitivity of a system where sensitivity of a system refers to the "degree to which system is affected or responds to an environmental stimulus and is related to characteristics of the system and to broader non-climatic factors e.g. livelihood, infrastructure and government policy" (Adger, 2006; Turner et al., 2003).

There are various kinds of climate-related risks (e.g. floods, droughts, extreme temperature events) that affect the livelihoods and farming systems (e.g. loss in crop yields, shortage of water). Vulnerability to those risks may be reduced if farmers affectively adapt to the changing conditions (Bryant et al., 2000; Smit and Skinner, 2002; Wheaton and Maciver, 1999). According to IPCC (2007), the ability or potential of a system to respond successfully to climate variability and change is known as adaptive capacity. Adaptive capacity is usually considered as a positive attribute of a system for reducing vulnerability (Engle, 2011). The more adaptive capacity a system has, the greater is the probability that the system is able to cope with and thus is less vulnerable to climate change and variability (Bryan et al., 2013; Bryant et al., 2000; Gorst et al., 2015). Further, how climate uncertainties and risks are understood and perceived by farm households (the main decision makers) is important because it can influence short-term as well as long-term management practices and adaptation decisions at farm level (Lebel et al., 2015). Farmers with accurate perceptions make decisions depending on that understanding about what crops to grow, when and with which inputs. Other factors that may influence the adaptive capacity at farm level include availability of the technological, financial and information resources, institutions, social setups and local interactions (Bryan et al., 2013; Bryant et al., 2000; Gorst et al., 2015). These factors do not only reflect the local characteristics of the system but also the external influences in which systems work (Kelly and Adger, 2000; Wheaton and Maciver, 1999).

3. Material and methods

Based on the case of farmers in Punjab, this paper intends to capture the vulnerability at farm level to climate-related risks, including the extent of farmers' awareness about risk perceptions, their sensitivity, adaptation and adaptive capacity at farm level against various climate-related risks. The nature of this study implies selection of both qualitative and quantitative data collection to facilitate deeper understanding of the topic. The study applies a bottom-up approach and investigates actual farmers' experiences with climate and their responses to climatic conditions that might influence their farm level decisions — including questions regarding what, how, when and where were used in the study (Berg, 2004). In order to identify climate-related risks, farm households were asked to share their experience over the last ten to twenty years about climate change and associated risks. To specify the broad definitions of sensitivity, we focused on the resource dimension of sensitivity as suggested by Barnett and Adger (2007). The resource dimension can be taken as a function of the reliable availability of the affected resources (prior to the climate stimuli) and the significance of the resource for the communities (Schilling et al., 2013). Hence to explore the farm level sensitivity, on the one hand farm households were asked about farm level effects of observed risks, while on the other hand the level of different factors were explored, i.e. water availability, poverty and the role of local government. In the next step, to explore the adaptive capacity aspect of vulnerability, farm households were investigated about the types of adaptation methods employed at farm level against observed climate-related risks. Further different constraints were identified, based on farm level investigation and the review of literature that may affect the adaptive capacity and adaptation

process. Further local level interactions and their role in the adaptation process and farm level adaptive capacity were investigated through qualitative questions.

3.1. Sample design

The farm level household survey was conducted in rural areas of Punjab province. We selected Punjab as a main study area due to its importance for the country's economy especially in terms of its agricultural share of total GDP (cross domestic product), employment and provision of livelihood (Abid et al., 2015). Punjab is the largest province of Pakistan with respect to population. The geographical area of Punjab is 20.63 million hectares, out of which 59% is being cultivated. The province contributes 53% to the total agricultural GDP and 74% to the total cereal production in the country (Abid et al., 2015; Badar et al., 2002).

The Punjab province consists of 36 districts and 27,059 *mouzas* (revenue villages), and may be divided into four main agro-ecological zones according to maps of the Pakistan Agricultural Research Council (PARC) (Abid et al., 2015). The sample universe includes farm households, the residents of selected study areas who are directly and actively involved in farming irrespective of their tenancy or land ownership status. We used village statistics for the selection of union councils (UCs) and revenue villages based on data provided by the PBS (1998). To prepare the sampling frame, we removed all UCs located in urban areas and classified as urban UCs. Further, we acquired lists of farmers in the selected villages from the revenue department for the selection of our sample farmers.

3.2. Sampling and data collection

The primary data collection was done between March and April 2014. Representatives of farm households (in most cases the household head) were interviewed using a structured questionnaire to explore the research objectives of the study. A multi-stage stratified random sampling technique was used to select study sites and 450 sampled farm households (Fig. 1). In the first stage, for the selection of study regions, we used the agro-ecological map of Punjab prepared by the PARC where Punjab is divided into four major agro-ecological zones, i.e. irrigated plains, Barani (rain-fed) region, Thal region and marginal land. In this stage, we selected only three zones and excluded Thal region due to budget constraints. In the second stage, three districts were selected from all three agro-ecological zones (one from each), keeping in view both heterogeneity and homogeneity in some characteristics such as climatic conditions, cropping patterns and irrigation systems. In the third stage, two cities were randomly selected from each district. In the fourth stage, we selected four to six UCs from each city by using stratified sampling keeping in view the distance from UC to UC and from UC to city centre. Here, a UC refers to a sub-section of the city administrative government in Pakistan. One UC may consist of several villages (Abid et al., 2015). In the fifth stage, two to three villages were randomly selected from each UC by using Pakistan's village statistics (PBS, 1998). In the sixth and last stage, about five to six farm households were randomly selected from each village irrespective of their size of land holding, household's size or location of farm. Overall 450 and specifically 150 farm household from each district were interviewed. Prior to the start of the study, the enumerators were given off-field and in-field training about the study objectives, questionnaire and data collection methods. Further, pre-testing of the questionnaire was done in the field not only to serve the purpose of in-field training of interviewers but also to improve the survey quality and to avoid missing any relevant information.

All interviews were conducted based on shared research principles and research ethics (Bogner et al., 2009). Informal agreements were made before the start of any farm household interview by explaining the purpose and objectives of the study. Ten of the farm households,

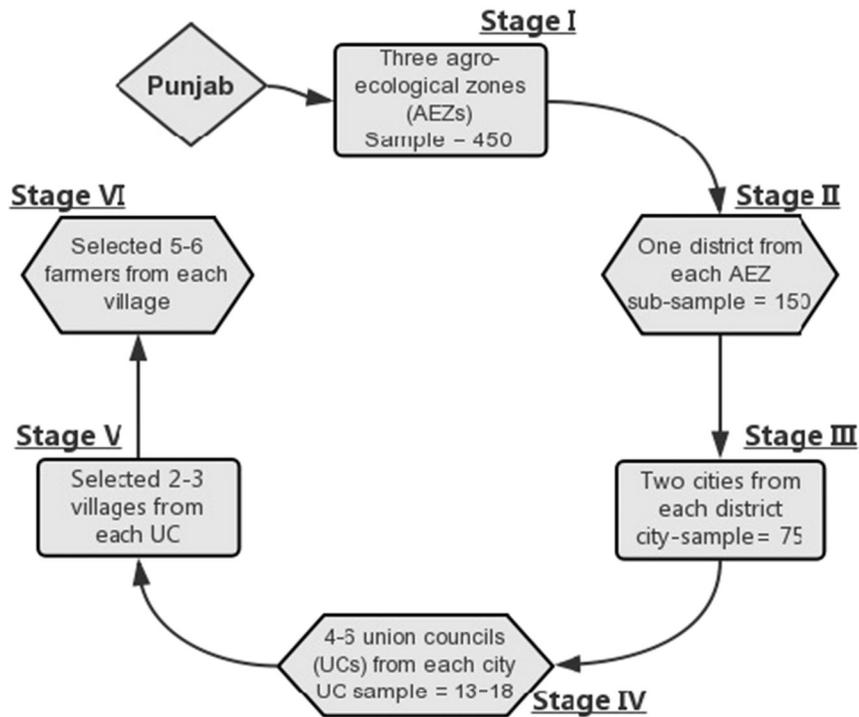


Fig. 1. Stages of sampling to select sample farm households in the study areas.

who refused to give an interview at the informal agreement stage, were replaced with other farm households. The refusal rate was about 2.2% of the total conducted 450 interviews. The farm household survey includes questions on household’s characteristics, farming, climate-related risks, effects, adaptation and constraints to adaptation to climate-related risks.

3.3. Study area characteristics

Punjab, the most populated and second largest province of Pakistan in terms of area, is located in the semi-arid lowlands zone (Abid et al., 2015). In Punjab, the overall mean annual minimum temperature ranges from 16.3 to 18.2 °C while the mean annual maximum temperature ranges

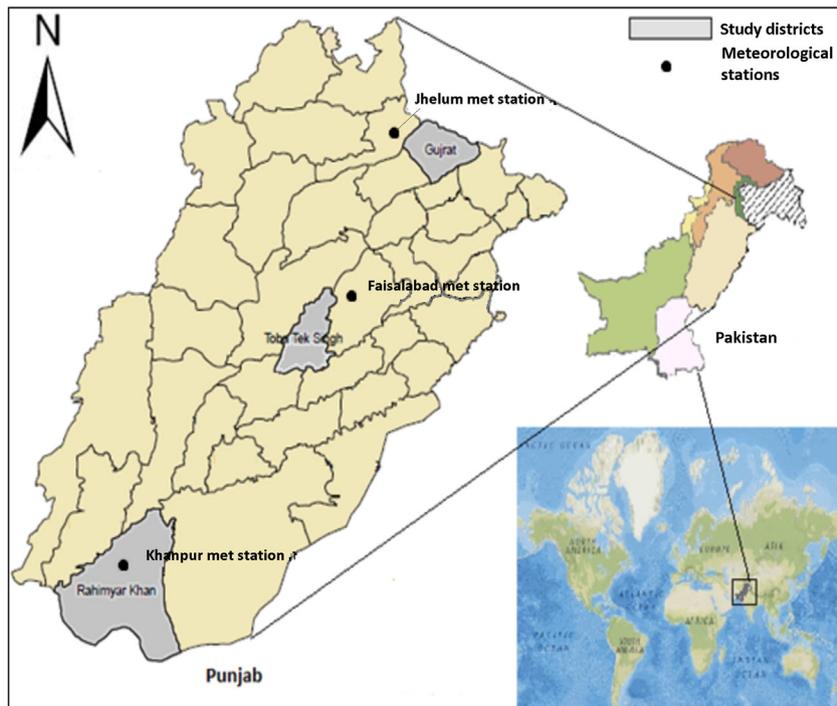


Fig. 2. Sample study districts in Punjab province, Pakistan (World map source: ESRI, 2015).

from 29.3 to 31.9 °C over the period 1970–2001 (Abid et al., 2015). The rainfall in Punjab, which is mainly linked to monsoon winds, is widely spread, and the rain-fed (*Barani*) zone receives the highest rainfall followed by the irrigated plains, Thal region and marginal land (Mohammad, 2005). Within Punjab province, the study focused on the three districts Rahim Yar Khan, Toba Tek Singh and Gujrat (Fig. 2). All three study districts belong to three different agro-ecological zones, have distinct climate, geography, and environment and hence observe different kinds of environmental and socio-economic problems that may sometimes overlap with other zones or regions.

Rahim Yar Khan, the largest district (11,880 km²) in the province, is located in southern Punjab and comes partially under irrigated plains and marginal lands. The principal crops grown in the district are wheat, cotton and sugarcane. The district has a very hot and arid climate in summer with a maximum temperature recorded at 49.7 °C and minimum temperature recorded at 6.8 °C. On average, the district receives an annual rainfall of 165 mm (Abid et al., 2015; DOI, 2012b). The historical data of Khanpur station (located in the same district) show an increasing trend in both summer and winter temperature and rainfall over the period of 1980–2013.

Toba Tek Singh district covers 3252 km² and is located in a mixed cropping zone, as part of the main irrigated plains zone. The district is characterized by both extremes of hot (in summer) and cold climate (in winter). The principal crops grown in the district are sugarcane, wheat, cotton, maize and tobacco (DOI, 2012c). The climate data of the (closest) meteorological station in Faisalabad show an increasing trend for summer and winter temperature and a decreasing trend in winter rainfall over the period of 1980–2013.

The study district Gujrat is partially located in a rice and rain-fed zone (Abid et al., 2015). The climate of the Gujrat district is moderate. Average annual rainfall in Gujrat ranges from 697 mm to 1401 mm. Wheat, rice and sugarcane are the main crops grown in the district (DOI, 2012a). The meteorological data of Jhelum station (the closest station) depicts an increasing trend for summer and winter temperature and a decreasing trend in summer rainfall over the period of 1980–2013.

All three regions also share some common and diverse socio-economic characteristics which play an important role in shaping the adaptive behavior of farm households against climate change vulnerabilities. For instance, the average land holding size varies across three districts, i.e. Rahim Yar Khan (7 ha), Toba Tek Singh (5.7 ha) and Gujrat (6 ha). Little variation was observed in the average family size (9–10 members) and years of education (8–9 years) across the three study districts. On the other hand, all three districts show huge variation in terms of the importance of agriculture for total income. The importance of agriculture was found to be highest in Rahim Yar Khan (85%) followed by Toba Tek Singh (79%) and Gujrat (26%). The low share of agriculture in total income in Gujrat is evident for low agricultural productivity in rain-fed regions due to resource constraints and various environmental problems. These findings are in line with the previous studies conducted in Punjab (e.g. Abid et al., 2011a; BOS, 2013; Nazli et al., 2012; Sial et al., 2012).

The study has some limitations. The survey does not cover the whole province or all agro-ecological zones. Our sample size is relatively small compared to the total rural populations of each district. Hence, the conclusions drawn from this study are area-specific and may not be generalized for the entire province or country. Instead, the case study is designed to identify the vulnerability including farm level risk perceptions of and adaptations to climate-related risks in the specified areas.

4. Results and discussion

The findings of the study start with the analysis of farmers' perceptions of climate-related risks to their farming including both direct and indirect risks (4.1). The analysis then moves on to consider the different aspects of vulnerability (4.2), including farm level sensitivity to

climate-related risks and the effects of observed risks at farm level (4.2.1); farm level adaptation and adaptive capacity including constraints to adaptation and role of local collaboration in enhancing adaptive capacity (4.2.2); and finally the synthesis of results (4.3).

4.1. Climate-related risk perceptions

Farmers' identification of various risks reveals the importance of climate-related conditions for their farm level operations. The distribution of various climate-related risks across study districts are summarized in Fig. 3. In Rahim Yar Khan, the five most important climate-related risks identified by farmers were animal diseases, insect attacks, extreme maximum temperature, human diseases and crop pests. Similarly, in Toba Tek Singh and Gujrat, extreme maximum and minimum temperature, animal diseases, crop pests and insect attacks were the five most reported climate-related risks at farm level. Soil problems, incidents of more weeds, droughts and floods were among the other climate-related risks identified by farm households in all three study districts.

Differences in how risk is perceived by the farm households among regions are common. This perception responds to the environmental conditions in the different regions. For example, in Rahim Yar Khan, where farmers observed more incidents of animal diseases, insect attacks, crop pests, soil problems, human diseases and more weeds, higher variations in the climate indicators were observed over the period of 1980–2013 along with massive rainfall and consecutive floods during 2010 and 2014. In contrast, in Toba Tek Singh and Gujrat, where historical trends show a decrease in the seasonal rainfall and an increase in the seasonal temperature, farmers reported more incidents of drought. On the other hand, increased incidents of floods in Rahim Yar Khan were mainly caused by massive rainfall both in the upper and lower Indus basin and more floods in the eastern rivers.

Farmers were more concerned with extreme maximum temperature in summer and extreme minimum temperature in winter. This makes sense as productivity of wheat and other crop species falls significantly at extreme temperatures. For instance, extreme maximum temperature in summer can cause heat stress in rice during *anthesis* which may lead to a reduction in pollination and grain numbers (Rasul et al., 2011). On the other hand, extreme minimum temperature may affect the nighttime plant respiration rates which can potentially reduce biomass accumulation during the growth stage and hence the crop yield (Hatfield and Prueger, 2015). Concerns over animal diseases, insect attacks, crop pests and human diseases are also important to consider as they directly or indirectly (negatively) affect the productivity of livestock, crop and labor at farm level. Soil problems such as soil erosion, soil infertility and soil salinity were further important concerns raised by farm households in the study areas. Soil erosion and soil infertility may be caused by runoff of the fertile soil layer and intense rainfall. Soil erosion may result in loss of rooting depth, decrease in plant-available water reserves and reduction in organic matter which ultimately adversely affect the crop yields (Lal and Moldenhauer, 1987). Likewise, increasing soil salinity in certain regions is also adversely affecting the crop yields.

These findings extend and nuance results from previous work carried out in different regions of Pakistan particularly in Punjab, which identified an increase in the extent and occurrence of climate-related events. For instance, Sheikh and Manzoor (2005) and Zahid and Rasul (2011) also observed most pronounced changes in the mean temperature over the period of 1951–2000 and the frequency of extreme maximum temperatures over the period of 1965–2009 in central and southern Punjab respectively. Various other studies (e.g. Baylis and Githeko, 2006; Hussain, 2015; Younas et al., 2012) reported an increase in the frequency of animal diseases, crop pests and insect attacks in Pakistan due to excessive rains and floods. Further, studies show that increasing incidents of extreme minimum or maximum temperature in

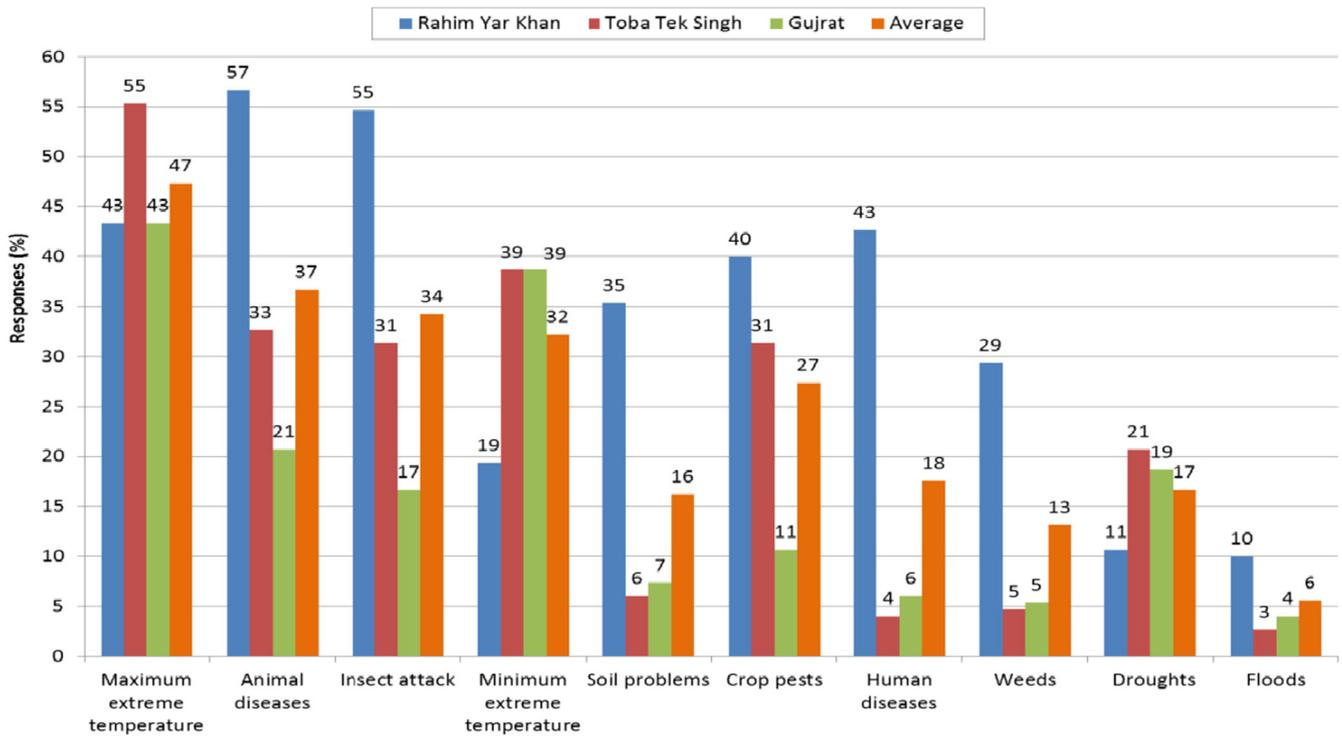


Fig. 3. Perceived climate-related events in the past 10 to 20 years in Punjab, Pakistan.

Punjab have affected the soil fertility by increasing water stress and changing maturity and harvest dates (Ahmad et al., 2013). On the other hand, excessive rainfall in most of the study areas in recent years has led to soil erosion due to higher runoff of fertile soil nutrients especially in Rahim Yar Khan (Abid et al., 2011b).

4.2. Farm level vulnerability in Punjab, Pakistan

4.2.1. Sensitivity

Sensitivity to climate change and related risks describes the degree to which a system is affected by environmental stimuli. In this paper,

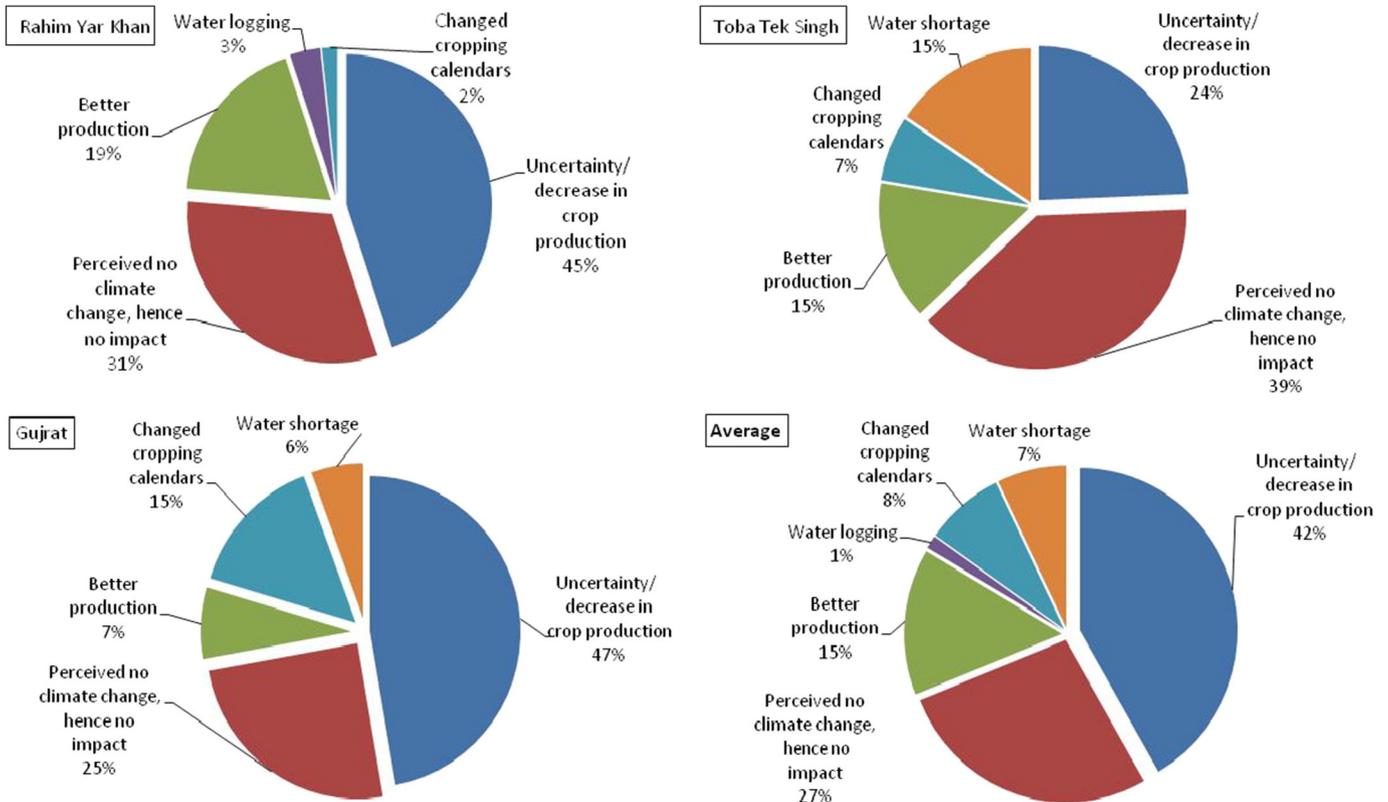


Fig. 4. (a)-(d). Effects of climate-related events as perceived by farmers.

we focus on the resource dimension of sensitivity as suggested by Barnett and Adger (2007) and therefore discuss the status of resources at the local level. Hence, on the one hand we discuss the effect of observed climate-related risks at farm level to show how farm households are being affected by climate change. On the other hand we discuss the number of factors, such as availability of water, status of poverty and the role of local effects in order to describe the farm level sensitivity to climate change.

4.2.1.1. Effect of climate-related risks. Fig. 4 summarizes the adverse as well as positive effects that may result from the changing climate and related risks. Overall, uncertain or reduced crop yields, shortage of water and changing cropping calendars were among the adverse impacts due to climate-related risks while better crop production was reported as the only positive effect of climate change in some areas. However, on average about one-fifth of the farmers perceived neither negative nor positive effects of climate change on their farming, while this percentage was higher in Toba Tek Singh. Here one-third of the farm households did not perceive any changes in the climate and hence no effect. About half of the interviewed farmers in Gujrat, one-third in Toba Tek Singh and more than one-third in Rahim Yar Khan reported uncertainty or reduction in crop or livestock yields. These were associated with various climate-related risks, including extreme temperature events, animal diseases, crop pests, soil salinity and decreased soil fertility.

Changes in cropping calendars were mainly reported by farmers in Gujrat followed by farmers in Toba Tek Singh. The rainfall in Gujrat shows more uncertainty and follows a declining trend over the period of 1980–2013 which ultimately disturbs the current cropping calendars and creates water shortage especially in the regions where farming is fully dependent on rainfall, such as in Gujrat. Water shortage was also reported as an important effect of climate-related risks such as extreme maximum temperature by farm households in Toba Tek Singh. Regarding positive impacts of climate-related risks, a number of farmers in the three regions reported better crop production due to climate-related changes such as changing temperature, massive rainfall or floods. One likely reason for this positive effect may be the massive rainfall during 2010–2014, which was beneficial to sugarcane and rice in the region.

The results of the study are in accordance with the findings of other studies in Pakistan. A number of studies (e.g. Ahmad et al., 2013; Baig and Amjad, 2014; Tingu et al., 2014) have indicated a considerable decline and inconsistency in the yields of major crops such as wheat, maize, rice, sugarcane and cotton in Pakistan as well as in Punjab due to climate-related risks. Further studies (e.g. Asif, 2013; Bukhari and Sayal, 2011) have expressed concerns over the increasing water scarcity in arid (including Gujrat) and semi-arid regions (including Toba Tek Singh) due to ongoing climate change and related risks. Few studies also show a short term positive effect of changes in rainfall and temperature on wheat, rice and sugarcane yields in Punjab (Siddiqui et al., 2012).

4.2.1.2. Factors affecting sensitivity at farm level. One of the most important resources in Pakistan at farm level is water, which is scarce or under stress. Ground water is being extracted at fast pace in order to meet mainly the agricultural and household needs. The reason for heavy exploitation of ground water mainly lies in increased crop water requirements due to increased temperature, less surface water availability at sowing stage and uncertain changing rainfall patterns in different regions. The absence of the ground water extraction policy could be another reason for over exploitation of water reserves. Pakistan ranked fourth among the 15 countries with the largest estimated ground water extraction (64.82 km³/year) in 2010, and with respect to usage, Pakistan is the largest user of ground water for agricultural purposes (94%) (NGWA, 2013). Hence, per capita water availability in Pakistan dropped to 990 cm³ in 2013 as compared to 5650 cm³ in

1947 (Ali, 2013). Pakistan has been categorized as a water-stressed country due to the expected acute water shortage over the next 5 years and is placed in the red zone by the World Bank and the Asian Development Bank (ADB) (Ali, 2013). Continuously decreasing both surface and ground water availability put agriculture and livelihood of rural populations at risk. On the other hand, current storage capacity of dams in Pakistan is very limited compared to dams in other South Asian countries. Another issue, in addition to water availability, is the quality of ground water which is also diminishing due to over exploitation and more indulgence of waste water in the aquifer (Bhutta et al., 2005).

We asked farmers about their experience with trends in ground water quality and water table depth over the last 10–20 years (Fig. 5). According to the study results, more than half of the farmers in Rahim Yar Khan reported improvement in the ground water table which may be attributed to the ground water recharge due to massive rainfalls and floods during 2010–2014. These findings also confirm the farmers' perception about increased incidents of water logging in Rahim Yar Khan due to the rise in water table in some areas. In Gujrat, the majority of the farm households were not aware of the trends in ground water depth. In Toba Tek Singh, about 45% of the farm households observed improvement in the ground water table. On the other hand, the study shows variation in responses over the quality of ground water across different regions. In Rahim Yar Khan and Gujrat, more than half of the farm households perceived a decline in ground water quality. In Toba Tek Singh the study shows mixed results as in some areas farmers reported a decline in ground water quality and in other areas farmers observed improvements in ground water quality. This contrary information may be due to differences in the rate of ground water extraction and pollution by industrial waste.

Poverty in Pakistan is widespread and could be one of the reasons making farmers more sensitive to the climate-related risks. Poverty in Pakistan is a rural phenomenon as more than 80% of the poor in Pakistan belong to rural areas (IFAD, 2014). In this study, we used the definition of a poverty line of \$2 per day to calculate poverty at farm level. According to the findings of the study, the highest level of poverty was found in rain-fed regions, i.e. Gujrat where about 60% of the households earned less than 2\$ per day, while the households living under the poverty line in Rahim Yar Khan and Toba Tek Singh were 40% and 35% respectively.

Many rural livelihoods still depend heavily on agriculture characterized by low yields due to limited access to productive assets such as land, labor, fertilizer, infrastructure and financial services. Due to the high level of rural poverty and associated limited access to farm resources, crop yields in Punjab including study areas are less compared to potential yields. Poor households usually do not have access to improved seeds, advanced technologies and other inputs that can reduce the vulnerability of crops to climate-related risks. Poor and small farmers thus have little capacity to absorb crop or livestock income shocks and to recover. A small income loss may be devastating and set off a ratchet effect that leads to further poverty and future vulnerability, due to lack of limited assets and the absence of economic and social safety-nets.

Local government, the level closest to the people directly affected by climate-related risk events, can play an important role in making local livelihoods less sensitive to climate-related risks by providing better infrastructure, easy access to inputs, markets and information services. To date, however, the role of local governments in providing above mentioned services is very limited. We have asked direct and indirect questions to farmers in order to get their views about the role of local government in providing different services at local level. Findings of the study show that the average distance of farms from local markets were around 12 km with the highest distance found in Gujrat where local markets were located 15 km away from the farm gate. The average distance of the farm to paved roads was found to be about 1 km. On the other hand, the majority of the farmers reported the absence of public or private organization working for farmers' welfare specifically helping

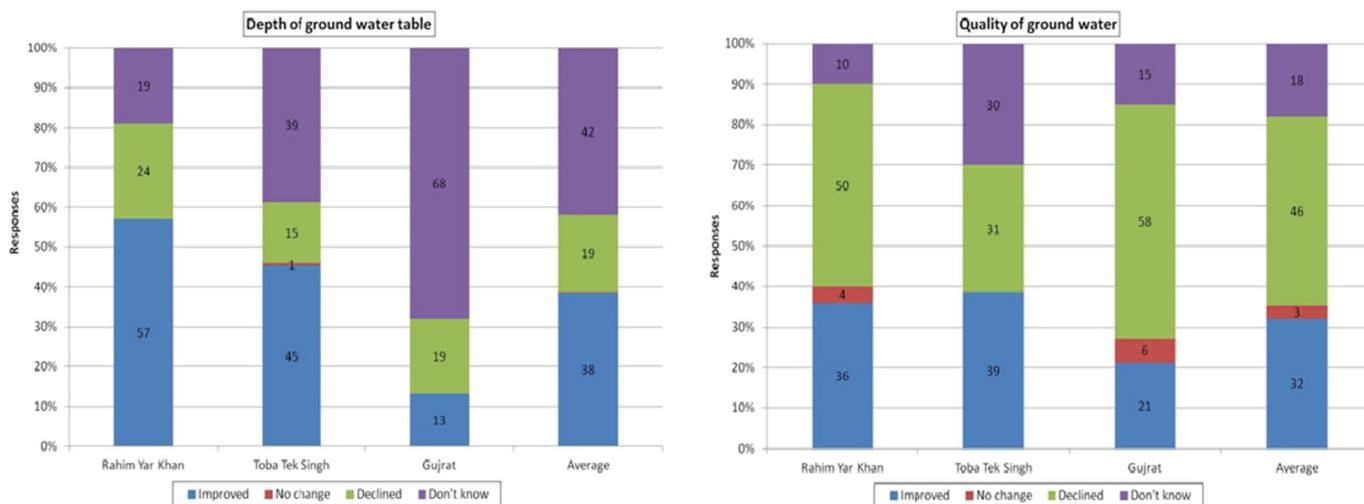


Fig. 5. (a)-(b). Perceptions about quality and depth of ground water table in study areas.

them in adapting to climate-related risks. Farmers in the rain-fed region (Gujrat), where they are found to be more deprived of basic infrastructure as compared to other regions, are likely to be more sensitive to climate change and variability.

4.2.2. Adaptation and adaptive capacity

While the farm households are exposed to a variety of climate-related risks, the degree of their vulnerability depends on their ability to adapt to those risks. Farm households who adapt timely to risks may be less vulnerable or more profitable compared to farm households who adapt late or do not adapt at all. Distinguishing between adaptation to climate-related risks and adaptation to other risks is difficult. However, when farm households were asked about risks, the households were able to distinguish between measures to manage climate-related risks and other risks. Further they reason for selecting certain adaptation measures.

4.2.2.1. Adaptation measures. Table 1 shows the type of adaptation measures taken in response to various observed climate-related risks by farm households. We here divided the adaptation options into four main categories; 1) Changing cropping practices which include the choice of new varieties, changing crop types and planting dates; 2) Changing farm management practices, i.e. changing input mixes such as fertilizers/pesticides, water and changing farming technologies etc.; 3) Advanced land management measures i.e. soil conservation, tree plantation etc.; and 4) Changing livelihood options which include farm diversification, renting out crop land and migration to urban areas.

Changing cropping practices, which were implemented by farm households at farm level, could be short term or long term depending on the nature of the problem or risk. Specifically, a changing crop variety was employed by farmers in response to more crop pest attacks on old varieties or to extreme maximum temperature which were negatively affecting the growth of old varieties. For example, farmers in Rahim Yar Khan reported the change of traditional cotton variety with genetically modified cotton varieties due to heavy pest attack on traditional cotton varieties. Similarly farmers in Gujrat reported a higher use of heat-tolerant wheat varieties in response to an increase in the frequency of extreme maximum temperature events. Changing crop types were adopted by farmers against incidents of heavy pest and insect attacks, soil problems and extreme temperature events. For instance, in Toba Tek Singh, a reasonable number of farmers reported that they had replaced cotton crops with maize crops since 2010 due to its exposure to heavy pest attacks and changing weather conditions. Likewise, in Gujrat, farm households reported to grow low water demanding crops

such as millet instead of maize due to shortage of water caused by less rainfall in the region. The measure of changing planting dates was adopted by farm households in response to variability in daily weather conditions.

Changing farm management practices include changing fertilizers and pesticides, as well as irrigation and changing farming techniques that were implemented at farm level. For instance, in case of drought or extreme maximum temperature, farmers reported to use more irrigation for their crops especially at sowing stage. In case of more crop pests due to heavy rainfall in the monsoon season, farm households reported an increased use of pesticides in order to protect their crops from pests. Similarly farmers who reported soil problems also reported the use of micro nutrients or changed combinations of different fertilizers to maintain soil fertility. For instance in Rahim Yar Khan, farmers observed significant reductions in crop productivity due to loss of fertile layers by heavy rainfall in monsoon seasons since 2010. In response they used more fertilizers and micro-nutrients in order to maintain the nutrient balance in the soil. The increased irrigation adaptation measure was mainly used by farmers in Gujrat who reported a decrease in overall rainfall since the last decade. Farmers in Gujrat, who were relying on rainwater, now reported more use of ground water for their crops at sowing stage due to an increase in the number of hot and dry days. Changing farming techniques were implemented by farmers in order to protect their crops from different weeds and soil issues such as salinity. For instance, farmers in Toba Tek Singh and Rahim Yar Khan reported the use of the furrow method of sowing instead of flat sowing due to the increased salinity at their farms.

Advanced land management measures were also adopted at farm level in order to protect livelihoods against different climate-related risks. Farmers who reported an increase in the frequency of extreme temperature and concerns about soil fertility used soil conservation and tree plantation methods in order to maintain their land fertility and crop productivity. For instance, farmers in Rahim Yar Khan reported a higher use of organic matter (farm yard manure) as a soil conservation technique in order to preserve soil quality which was reduced due to heavy runoff of the fertile layer by heavy rainfall since 2010. Tree plantation was also used as another adaptation measure by farmers in Rahim Yar Khan and Toba Tek Singh in order to protect crops from increased temperature.

Changing livelihood options were mainly adopted at household level against great loss due to climate-related risks. For instance, farm households in Gujrat reported partial migration by one or few members of households as an adaptation strategy in response to loss in agricultural income due to drought-like conditions attributed

Table 1
Types of adaptations employed to manage climate-related risks identified by farm households.

Adaptation categories	Type of adaptation measures	Source of risk
Changing cropping practices (Farm level)	Changing crop variety	Maximum extreme temperature/crop pests
	Changing planting dates	Daily weather variability
	Changing crop type	Insect attack/soil problems/crop pests/extreme temperature
Changing farm management practices (Farm level)	Changing fertilizer/pesticide	Soil problems/crop pests
	Changing irrigation	Minimum or maximum extreme temperatures/drought
Advanced land use management measures (Farm level)	Changing farming technique (sowing, harvesting etc.)	Soil problems/weeds
	Planting shaded trees	Minimum or maximum extreme temperatures/soil problems
	Soil conservation	Droughts
Livelihood options (Household level)	Farm diversification	Soil problems/animal diseases
	Migration to urban areas	Floods/human diseases
	Rent out crop land	

to less rainfall. Similarly, few farm households diversified their farms by increasing the number of animals and having more crops under cultivation. Mostly the farm diversification was implemented by farm households in Gujrat or Rahim Yar Khan. Some farmers also partially rented out their lands in order to protect themselves from potential risks due to climate vulnerabilities. Farm households in Rahim Yar Khan also reported an increasing renting out trend in their area due to increased economic risks related to climate change.

Table 2(a) shows the distribution of adaptation methods employed into different categories and Table 2(b) shows the extent of adaptation at farm level. Results from Table 2(a) depict that the majority of the households in all three districts preferred changing cropping practices as key adaptation options followed by changing farm management practices etc. at their farms keeping in view the nature of the problem and their capacity. A few farm households adopted advanced land use management options such as soil conservation and plantation of trees. Results also demonstrate that a very small number of farmers in the study districts adopted different livelihood options as an adaptation measure to climate variability and related risks. Results show that only the farm households in Rahim Yar Khan adopted all types of adaptation options to some extent compared to the farmers in Toba Tek Singh and Gujrat who mainly focused on the first two adaptation options. This may be due to the reason that farmers in Rahim Yar Khan were more exposed to various kinds of climate-related risks such as extreme temperature, floods, increased pests and diseases compared to the farmers in other two districts.

Table 2(b) shows adaptation in all three districts irrespective of the type of adaptation options. According to the results, overall 42% of the farmers did not adapt to climate variability and related risks. From the remaining 58%, most of the farmers in the study areas were restricted to only one or few adaptation options except farmers in Rahim Yar Khan, of whom the majority implemented five or more adaptation

measures. The highest numbers of farmers who were restricted to only one adaptation measure were found in Gujrat and the lowest in Rahim Yar Khan. The highest numbers of farmers who adopted five or more than five adaptation measures belong to Rahim Yar Khan and the lowest belonged to Toba Tek Singh. All the above findings show that adaptation in the study areas is not implemented to the full extent.

The findings of the study are in accordance with the findings of other studies conducted in Punjab, Pakistan. For instance, [Gorst et al. \(2015\)](#) mentioned similar kinds of adaptation measures (changing planting dates, crop types, changing varieties, changing input mix) being adopted by farmers in Punjab as well as in Sind province of Pakistan. [Ahmad et al. \(2013\)](#) also found that farmers in Punjab as well as in Pakistan are adopting various kinds of adaptation strategies depending on their location and type of climate issue. He further found that in the rain-fed region, farmers mostly changed planting dates according to variation in climate indicators (rainfall, temperature) while in irrigated regions, changing crop types and varieties were other primary strategies implemented by farmers. [Yasin \(2011\)](#) reported the use of different rice varieties by farmers in Punjab as an adaptation measure to changing climate.

4.2.2.2. Constraints to adaptation/adaptive capacity. Based on the qualitative field research and literature review, the study identified the following four major constraints to adaptation and adaptive capacity in the study areas which may exist in other regions of Pakistan with similar social and geographical conditions (1) limited farm resources, (2) financial capacity, (3) lack of knowledge and information, and (4) lack of support from local public or private institutions.

Here, limited resources relate to limited access or use of available or required resources to effectively adapt farming to climate risks. Water was the primary resource constraint in the three study districts. According to local perceptions, current surface water availability coupled with rainfall is not enough to support their crops to achieve maximum

Table 2
Adaptation measures adopted by farm households (%) across three study areas in Punjab, Pakistan.

	District			
	Rahim Yar Khan (N = 150)	Toba Tek Singh (N = 150)	Gujrat (N = 150)	Average (N = 450)
<i>a. Adaptation options implemented by farmers:</i>				
i. Changing cropping practices (e.g. choice of crops, changing crop varieties, planting dates)	38	41	50	43
ii. Changing farm management practices (changing input mixes such as fertilizer, water)	33	27	47	36
iii. Advanced land use management measures (soil conservation, planting trees)	21	05	13	13
iv. Livelihood options (crop diversification, renting out crop land, migration to urban areas etc)	21	03	07	10
<i>b. Extent of adaptation at farm level</i>				
No adaptation	51	45	30	42
Adapted only one measure	27	60	37	42
Adapted any two measures	8	18	29	20
Adapted any three measures	18	16	13	15
Adapted any four measures	10	01	10	07
Adapted any five or above than five measures	37	05	11	17

productivity. District Gujrat is mostly rain-fed and highly dependent on rainfall and ground water resources for crop production (DOI, 2012b). Historical trends show a drastic decrease in rainfall patterns in the rain-fed region as well as in Gujrat, which is likely to affect crop productivities negatively in rain-fed areas in Punjab (Abid et al., 2015). In Rahim Yar Khan and Toba Tek Singh, the areas irrigated by canal water is 46% and 58% respectively (BOS, 2013). The rest of water demand is fulfilled by ground water. Due to water shortages, a vast area left fallow in both Rahim Yar Khan (12%) and Toba Tek Singh (3%) (BOS, 2013). In some areas of district Rahim Yar Khan, canals are non-perennial and only flow during the summer season. So farming in those areas mainly depends on ground water as well as on rainfall. But farmers in those villages are small landholders with limited funds and they are unable to cultivate all of their lands due to the high cost of ground water pumping. Literature shows that the availability and sufficient supply of good quality inputs, i.e. climate smart/heat resistant varieties and quality pesticides and fertilizers are an important factor for effective adaptation to climate risks at farm level (Bryan et al., 2013; Deressa et al., 2005). However, in most of the cases, small farm households do not have access to quality inputs such as seeds and pesticides due to its absence or shortage (Akram et al., 2011; Joshi et al., 2015). It is also found that in Pakistan there are several input sellers in local markets looting farmers by selling low-quality farm inputs in the name of branded agricultural inputs. This trend is increasing due to absence of proper monitoring of input markets at the local level (Joshi et al., 2015). For instance, about 80% of the annual seed requirements are met through uncertified seeds (Rana, 2014). Most of the input dealers are unauthorized and selling generic pesticides and non-registered seeds (Joshi et al., 2015).

Lack of financial means is another important constraint on adaptation in the study areas. Most of the sample farm households reported access to farm credit services, but they were reluctant to use credit facilities due to high interest rates and related conditions and processing. The literature also shows that in most of the cases, farm credit is not used for agricultural purposes. Instead, it was used for non-farm purposes such as festivals, purchase of household items and alike (Jan et al., 2012). Hence, proper monitoring is required along with improved credit facilities to farmers.

The third constraint to adaptation is a lack of support, which implies the absence of proper support from local institutions such as public agricultural departments and local private input providers or non-governmental organizations (NGOs). Farmers in all three study districts reported that they do not have proper access to public institutional services such as information on water deliveries, market prices and farm advisory services, farm implements and weather forecasting information and alike. According to the results presented in Table 3, overall only 55% of the farmers have proper access to different institutional services, of which only 22% and 16% were provided by public and private institutions respectively. For the rest, farmers have to rely on community, relatives and their own sources. These results are in line with the findings of other studies (e.g. Davidson et al., 2001; Luqman et al., 2014; ur Rahman et al., 2014) conducted at different scale in Punjab and Pakistan. Agricultural extension is the primary farm advisory service provided by the agricultural extension department in study districts through its local staff. These have proper infrastructure and staff at UC level, but their outreach

and effectiveness is questionable due to absence of their services to sample farmers in the study area. Farmers also complained that services of local extension staff are biased towards large and influential farmers in most of the cases. The findings of the various studies (e.g. Davidson et al., 2001; Khan, 2003) point to the ineffectiveness of various public extension programs and their biased outreach.

The fourth constraint is also linked to the lack of support from local institutions which are sometimes responsible for the lack of knowledge among farming communities. Lack of knowledge and information implies that farmers in study areas do not have adequate knowledge and information of advanced adaptation measures such as soil and water conservation, crop diversification and alike. As we see in Table 2, most of the adaptation in the study areas are limited to simple measures and do not focus on the advanced adaptation measures such as soil and water conservation, crop diversification etc. The main reason behind this lack of adopting advanced measures is the lack of proper knowledge and information about those measures. In some cases, farmers are also unaware of the exact requirement of resources for certain crops that lead to inefficient use of available resources. Various studies (e.g. Abid et al., 2011a; Ashfaq et al., 2012; DOI, 2012c; Shafiq and Rehman, 2000) showed the existence of allocative and technical inefficiencies in the use of inputs for crop production in Punjab, Pakistan.

4.2.2.3. Role of local collaborations in adaptation. Cooperation within farming communities may enhance the farm households' adaptive capacity to climate change and related risks. Various studies (e.g. Reid and Huq, 2007; Van Aalst et al., 2008) have shown the positive impact of cooperation among farming communities in enhancing adaptation to climate change.

Table 4 shows the different kinds of cooperation and conflicts among farmers at local level in the study area. On average nearly two-third of the respondents do cooperate or collaborate with other farmers and exchange different types of services (e.g. inputs, outputs, information etc.) (Table 4) and the rest reported no cooperation or certain types of conflict with other farmers. The highest collaboration among farmers was found in Gujrat and the least in Toba Tek Singh. Among the farmers who are in conflict with other farmers, half of them reported conflicts on water as the key issue followed by land-related conflicts. The conflicts on irrigation water among farmers in irrigated areas especially in Toba Tek Singh have increased given the decreasing surface water availability in Pakistan, particularly in arid and semi-arid regions (Abbas, 2013). In rain-fed regions i.e. Gujrat, the major conflicts reported by farmers were over land and water. Most of these water conflicts reported in irrigated areas (Rahim Yar Khan and Toba Tek Singh) were on allocation, timing and theft of surface irrigation water from canals. On the other hand, major water conflicts reported in the rain-fed region (Gujrat) were on the use of ground water or rain harvesting. Further, according to the results of the correlation analysis, a positive association ($r = 0.50$) between cooperation and adaptation and a negative but weak correlation ($r = -0.20$) between conflict and adaptation to climate risks was found (Table 5). Hence, it can be concluded that farmers who cooperate with other farmers, are more likely to adapt. Farmers, who are in a conflict with other farmers or do farming in so-called isolation, are less likely to adapt to climate-related risks.

Table 3
Access to and source of different institutional services (%) in study districts.

Study districts	Access	Source of institutional services ^a		
		Public institutions	Private institutions	Community or own sources
Rahim Yar Khan	58	23	15	62
Toba Tek Singh	61	25	19	56
Gujrat	45	18	13	69
Average	55	22	16	62

^a Institutional services include agricultural credit, farm implements, marketing information, weather forecasting, water deliveries and farm advisory services.

Table 4
Level of cooperation and conflict among farm households (%) in the study districts.

		Districts			
		RYK ^a (N = 150)	TTS ^a (N = 150)	Gujrat (N = 150)	Average (N = 450)
Cooperation within farming community	Have no cooperation	30	52	25	36
	Have cooperation	70	48	75	64
Type of cooperation/collaboration with co-farmers	Exchange of inputs (e.g. labor, water, seed, fertilizer)	29	35	33	32
	Exchange of information (weather, varieties, prices, water etc.)	17	26	17	19
	Exchange of both inputs and outputs	21	17	23	21
	All types of collaborations mentioned above	34	22	27	28
Type of conflicts among farmers	Conflicts on water	44	62	26	48
	Land-related conflicts	47	26	66	41
	Other type of conflicts (e.g. outputs, inputs, household issues etc.)	09	13	08	11

^a RYK and TTS stand for Rahim Yar Khan and Toba Tek Singh respectively and N represents the number of observations.

Exchange of information within farming communities is an important tool in shaping decision making of individual farmers and managing their farm practices in order to better adapt to climate change (Drafor and Atta-Agyepong, 2005). In our case, about one-third of the farmers exchanged different kinds of information (e.g. weather, inputs, prices etc.) with their neighboring farmers which implies that communication within the farming communities in study areas is limited (Table 4). Hence, we can conclude that there are not only barriers to the flow of information from local institutions to farming communities but there are also gaps in exchange of information within the farming communities. This may restrict the adaptive capacity of farm households.

4.3. Synthesis of results

The overall objectives of this study were to investigate the farm level vulnerability to climate related risk with the following specific objectives; (a) to investigate climate-related risk perception at farm level, (b) to investigate the sensitivity including effects of climate-related risks at farm level, (c) to discuss the farm level adaptation against observed climate-related risks, and (d) to explore the adaptive capacity at farm level including a role of local level collaborations in adaptation to climate change and related risks. Fig. 6 provides an overview of the main results of the study and their connections. The right column shows the vulnerability and its elements sensitivity and adaptation (Section 4.2.1 and 4.2.2). The upper center column summarizes the different kinds of climate-related risks perceived by farm households (Section 4.1) The lower central column shows the effect of adaptation on the farm wellbeing. On the left, potential support options/measures are shown and their linkages to enhanced adaptive capacity and resilience to climatic risks. At the bottom, dotted boxes show external factors and constraints to adaptation. Red arrows refer to impact (leads to) while black arrows indicate the positive or negative effects of external factors and constraints on the farm level adaptation process. The blue arrows indicate the potential support to enhance adaptive capacity and farm wellbeing.

In Punjab, the major climate-related risks included floods, droughts, extreme temperature events, animal diseases, crop insects, pests and

water logging (Fig. 6). The findings of the qualitative research are supported by the literature analysis described in Sections 4.1 and 4.2.

The study shows that the limited level of adaptation to climate-related risks in agriculture is due to various constraints faced by farmers. The main obstacles found in the study areas include lack of resources, information, financial capacity and lack of support (for details see Section 4.2.2). All these constraints are adversely affecting the adaptation process by limiting farmers' adaptive capacity. On the other hand, external factors such as the level of collaboration or conflict with other farmers can affect the adaptation process either positively or negatively. Further a two-way relationship between constraints and external factors may be seen in the lower boxes in Fig. 6. The constraints discussed above may also adversely affect the external factors that shape farming households' adaptive behavior by limiting the level of cooperation and increasing conflicts with other farmers. This in turn limits adaptation. External factors may either affect constraints positively (by limiting the extent) or negatively (by increasing the extent of the constraints to adaptation). The study also found very little physical support specifically related to adaptation to climate risks for farmers at the local level, either from public or private institutions. As we discussed in Section 4.2.2, collaboration within farming communities is very limited. Fig. 6 further illustrates the role of potential support in enhancing adaptive capacities of farm households, handling constraints and increased resilience of the agriculture sector to climate risks in Pakistan. This support requires collaborations of different stakeholders at the local level. Public institutions, private organizations and farming communities need to cooperate to enhance adaptation of agriculture to climate risks and to increase farm wellbeing. The study suggests various services through these local collaborations. These services may include soil and water conservation methods and technologies, the introduction of new climate-smart varieties, reshaping existing cropping calendars and patterns to avoid farming from adverse impacts of climate risks. Through these collaborations, this study also suggests to provide farm-based trainings to farmers to demonstrate advanced ways of adaptation to climate-related risk which may include the use of water saving technologies, efficient use of farm resources, farm diversification, soil conservation methods and alike. This finding is likely to be relevant for other regions facing environmental risks with similar conditions and geography (Adger et al., 2005; Schilling et al., 2013).

5. Conclusion and recommendations

This study provides insights into the climate-related risks faced by farmers, including their sensitivity to climate change, the adaptive responses employed, constraints that limit the adaptive capacity and the role of local level collaborations in the adaptation process at farm level. Different kinds of climate-risks were identified by farmers that were consistent with other climate studies related to agriculture at various scale in Pakistan as well as in Punjab. Farmers in this study, for example, identified extreme maximum and minimum temperature

Table 5
Spearman correlation results between cooperation, conflict and adaptation to climate-related risks.

	Cooperation	Conflict	Adaptation
Cooperation	1	–	0.50***
Conflict	–	1	–0.20**
Adaptation	0.50***	–0.20**	1
N	288	161	–

*** Shows significance of correlation coefficient (r) at less than 1% significance level (p-value).

** Shows significance of correlation coefficient (r) at less than 5% significance level (p-value).

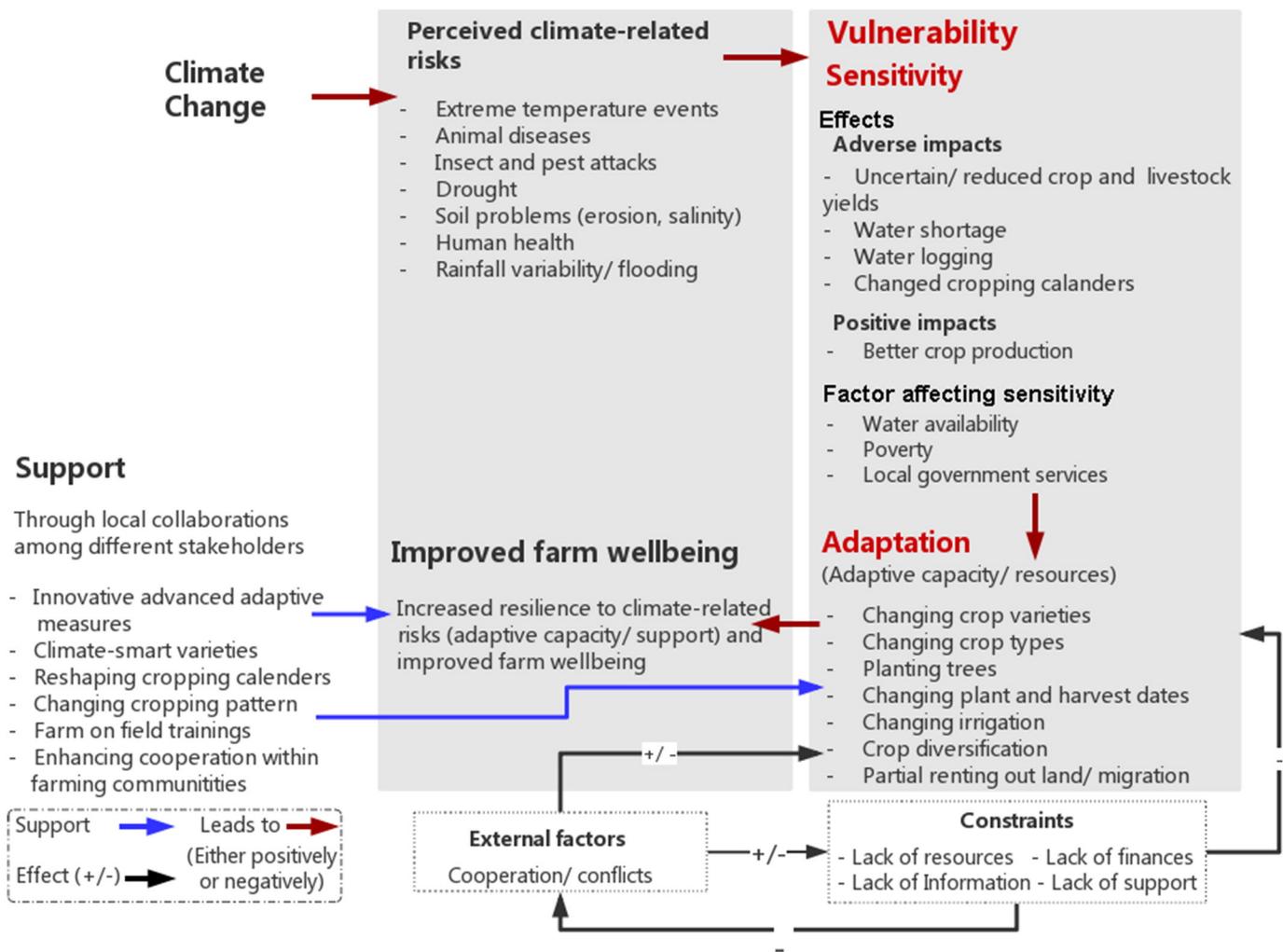


Fig. 6. Schematic overview of vulnerability and adaptation to climate-related risks in Punjab (the authors).

events, animal diseases, crop pests and soil problems as major climate-related risks.

Under the sensitivity aspect of vulnerability, the study investigated the effects of climate-related risks and explored the different factors that affect the farm level sensitivity to climate-related risks. Uncertainty and decrease in crop and livestock yields, changing cropping calendars and water shortage were some major impacts of climate-related risks. The study also found variations across different regions in terms of impact of climate-related risks. For example, in rain-fed regions, farm households reported more uncertainty and reduction in crop and livestock yields and changes in cropping calendars compared to the other two regions. It implies that the areas which are more dependent on rainfall are likely to be more sensitive to climate change. This study also found that challenges of decreasing water availability, poverty and weakness of local institutions in the process of adaptation make farm households more sensitive to climate-related risks. In addition to issues of water availability, farmers also identified a declining quality of irrigation water. Poverty was found to be higher in rain-fed regions such as Gujrat.

Major adaptation methods identified by farm households include changing crop types, changing crop varieties, changing planting dates and planting trees. A number of constraints were identified at farm level that concern the adaptive capacity of the farm households. Lack of resources and financial assets, limited access to various institutional services such as credits, farm inputs, machinery, marketing services, weather forecasting and information were major constraints that limit the adaptive capacity at farm level.

This study also emphasized the role of local collaborations in the adaptation process and found a positive correlation or association between cooperation at farm level and adaptation to climate-related risks. Farmers identified cooperation in terms of exchange of information, farm inputs and outputs (crop produce) while the issues on water allocation and land distribution were the major sources of conflict identified by farm households.

In order to reduce the farm level vulnerability to climate-related risks and to enhance the adaptive capacity at farm level, the outreach and extent of institutional services, especially the advisory services related to climate change adaptation, need to be enhanced. There is a significant gap between the services provided by local institutions and what is needed at farm level. For instance, current farm advisory services being provided by local agricultural departments are outdated and do not include climate-specific information which is currently required at farm level in order to protect farmers from various climate-related risks. Further cooperation among farmers is promising to improve the adaptive capacity at farm level.

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Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan

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Abstract. Climate change is a global environmental threat to all economic sectors, particularly the agricultural sector. Pakistan is one of the countries negatively affected by climate change due to its high exposure to extreme events and low adaptive capacity. In Pakistan, farmers are the primary stakeholders in agriculture and are more at risk due to climate vulnerability. Based on farm household data from 450 households collected from three districts in three agroecological zones in the Punjab province of Pakistan, this study examines how farmers perceive climate change and how they adapt their farming in response to perceived changes in climate. The results demonstrate that awareness of climate change is widespread throughout the area, and farm households make adjustments to adapt their agriculture in response to climatic change. Overall 58 % of the farm households adapted their farming to climate change. Changing crop varieties, changing planting dates, planting of shade trees and changing fertilizers were the main adaptation methods implemented by farm households in the study area. The results from the binary logistic model reveal that education, farm experience, household size, land area, tenancy status, ownership of a tube well, access to market information, information on weather forecasting and agricultural extension services all influence farmers' choices of adaptation measures. The results also indicate that adaptation to climate change is constrained by several factors such as lack of information, lack of money, resource constraints and shortage of irrigation water in the study area. Findings of the study suggest the need for greater investment in farmer education and improved institutional setup for climate change adaptation to improve farmers' wellbeing.

1 Introduction

Climate change is a global environmental threat and development concern. Developing countries are the most adversely affected by the negative effects of climate-induced events because of their low level of adaptation (IFAD, 2010). It is projected that climate change may severely affect global food security by the middle of the 21st century. The largest number of food-insecure people will be located in South Asia

(Hijioka et al., 2014). It is estimated that from 2001 to 2059 in South Asia, per hectare cereal yield will decline up to 30 % along with an up to 37 % loss of gross per capita water (Parry, 2007).

According to various studies and reports (IUCN, 2009; Kreft and Eckstein, 2013; LP, 2010), Pakistan is one of the highly affected countries by climate change. Pakistan has been ranked 12th in the Global Climate Risk Index in terms of exposure to various extreme climate events over the period

of 1993 to 2012 (Kreft and Eckstein, 2013). The World Bank included Pakistan in the list of 12 highly exposed countries to variability in climate (Noman and Schmitz, 2011). Pakistan is an agro-based economy where agriculture contributes about 21.4 % to GDP, employs around 45 % of the total labor force and provides a livelihood for 62 % of the rural population (Abid et al., 2011a; Farooq, 2013). Despite its significant share of the overall economy, this sector faces serious challenges from climate-change-induced impacts, i.e., rising temperatures, floods, droughts and yield losses (Noman and Schmitz, 2011).

Agriculture is the main source of support for the majority of the rural households and attached urban populations in developing countries as well as in Pakistan. Hence, adapting the agricultural sector to the negative effects of climate variability may be necessary to assure food security for the country and to protect the livelihood of rural households. Adaptation to climate change is an effective measure at the farm level, which can reduce climate vulnerability by making rural households and communities better able to prepare themselves and their farming to changes and variability in climate, avoiding projected damages and supporting them in dealing with adverse events (IPCC, 2001).

The current level of support for the agriculture sector in terms of climate change adaptation in Pakistan is very limited due to an ineffective climate policy and the very low technological and financial capacity of the country in adapting to climate change (OECD, 2011). At the national level, an integrated policy for adapting the agriculture sector to changes in climate is required (Farooqi et al., 2005). Research shows that farmers' awareness, investment in new heat-tolerant varieties, crop insurance, social awareness and protection programs may be some important aspects of the adaptation policy to climate change (Schlenker and Lobell, 2010).

Perceiving climate variability is the first step in the process of adapting agriculture to climate change (Deressa et al., 2011). A better understanding of farmers' concerns and the manner in which they perceive climate change is crucial to design effective policies for supporting successful adaptation of the agricultural sector. Further, it is also important to have precise knowledge about the type and extent of adaptation methods being taken up by farmers and need for further advances in existing adaptation setups. Hence, understanding how farmers perceive changes in climate and what factors shape their adaptive behavior is useful for adaptation research (Mertz et al., 2009; Weber, 2010). The choice of adaptation methods by farmers depends on various social, economic and environmental factors (Deressa, 2007; Bryan et al., 2013). This knowledge will ultimately enhance the credibility of policies and their strength to tackle the challenges being imposed by climate change on farmers (Deressa et al., 2009). Adaptation will require the participation of multiple players from sectors such as research and policy, those in the agricultural extension services and private welfare organiza-

tions, as well as local communities and farmers (Bryan et al., 2013).

A great number of studies have been done on farm-level adaptation to climate change across different disciplines in various countries which explored farmers' adaptive behavior and its determinants (Bryan et al., 2009; Deressa et al., 2009; Hassan and Nhemachena, 2008; Thomas et al., 2007). Despite internationally extensive research on adaptation in the agriculture sector to climate change, little work has been done so far in South Asia. Similarly in Pakistan, the scope of research linking climate change to agriculture is very restricted (TFCC, 2010). To date, studies on climate change and agriculture in Pakistan have been entirely limited to impacts of climate change on particular crops or sectors (Noman and Schmitz, 2011; Hussain and Mudasser, 2007; Hanif et al., 2010; Ashfaq et al., 2011). None of the studies considered farmers' perspectives of climate change adaptation. Hence, this study was designed to fill the existing research gap in Pakistan with respect to climate change adaptation in the agriculture sector.

This study mainly seeks to answer two research questions. First, we will look at how farmers perceive long-term changes to the local climate. Second, we will analyze how farmers adapt their farming in response to perceived changes in climate. Further, this study also considers the factors affecting farm-level adaptation methods adopted by farm households in the study area. Most of the factors affecting the farm household's choice of adaptation measures to climate change are already known, but the actual impact of these factors varies across regions. Hence, this study attempts to quantify the actual impacts of various explanatory factors on the probability of adopting different farm-level adaptation measures by farmers. The present study employs a logistic binary model to examine determinants of adaptation measures.

This paper is divided into four sections. Section 2 of the study presents a conceptual framework and empirical specification of explanatory variables. Section 3 describes the materials and method. Section 4 describes the results and discussion of the study, and in Sect. 5 we conclude our results and present some policy implications of the study.

2 Conceptual framework and methodology

2.1 Description of the study area

This study was done in the Punjab province, which is geographically located approximately at 30°00' N, 70°00' E in the semiarid lowlands zone (Ahmed et al., 2012). Punjab is the most populous and second largest province of Pakistan. It is a fertile agricultural region built on an extensive irrigation network and it plays a leading role in the development of the economy (Abid et al., 2011b). The province accounts for 56.2 % of the total cultivated area, 53 % of the total agricultural gross domestic product and 74 % of the total cereal production in the country (PBS, 2011; Badar et al., 2007).

Figure 1 shows the map of study areas located in Punjab province.

The mean annual minimum temperature in Punjab ranges from 16.3 to 18.2°C over the period 1970–2001. Mean annual maximum temperature in Punjab ranges from 29.3 to 31.9°C. The distribution of rainfall in Punjab is wide-ranging, mostly linked with the monsoon winds. Punjab receives 50–75 % of rainfall during the monsoon season. The rain-fed zone receives the highest quantity of rainfall, followed by the rice zone, mixed zone and cotton zone, in decreasing order (Mohammad, 2005).

Based on Pakistan Agricultural Research Council's (PARC) agroecological maps (PARC, 2014), the Punjab province can be divided into 4 major and 11 sub-agroecological zones based on climate, agricultural production and aridity. Study districts come from three of the main agroecological zones. Study sites in the Rahim Yar Khan district are located in cotton and Cholistan sub-zones where average rainfall ranges from 72.8 to 462.5 mm annually. The second study district, Toba Tek Singh, is located in the central mixed zone, which receives average rainfall ranging between 219.5 and 718 mm annually. The third district, Gujrat, is partially located in both rain-fed and rice zones which receive average rainfall between 697 and 1401 mm annually (Mohammad, 2005). The average household's characteristics which play an important role in shaping the decision-making process in climate change adaptation vary to some extent in all three regions. For example, according to our study, the average landholding size varies between the Rahim Yar Khan (18 acres), Toba Tek Singh (14 acres) and Gujrat (16 acres) districts. Little variation is found for average household size (9–10 members) and years of schooling (8–9 years) in all three districts. In terms of agricultural contribution to the share of income, relatively high values are found for the districts of Rahim Yar Khan (85 %) and Toba Tek Singh (79 %), but a substantially lower value for Gujrat (26 %).

2.2 Sampling and data collection

To investigate the farm-level perceptions of climate change and associated choices of adaptation methods in Punjab, the selection of study districts took into account different agroecological zones (AEZs), cropping patterns, irrigation source networks and climate. In particular, the study sites in the Rahim Yar Khan district are located mainly in irrigated plains (zone A) and partially in marginal lands (zone D). The study site in the Toba Tek Singh district is located in irrigated plains (zone A). The study site in the Gujrat district is located in a rain-fed zone (zone B) (PARC, 2014).

A multi-stage sampling technique was used to select the study sites and sample farm households in the study area. In the first stage, the Punjab province of Pakistan was selected as the overall study area. In the second stage, three districts were selected from three agroecological zones based on

the agriculture share of the total national economy, weather and climatic conditions, cropping patterns and irrigation networks in the area. In the third stage, two cities were selected from each district. In the fourth stage, we choose 10–13 union councils from each district depending on the number of union councils located in each district. Here, union council refers to a sub-section of the city government (*tehsil*) in Pakistan. In rural areas, a union council may consist of several villages. We excluded the urban union councils. In the fifth stage, two to three villages were randomly selected from each union council using Pakistan Village Statistics (Government of Pakistan, 1998) and in the sixth and last stage, six farmers were randomly selected from each village. Table 1 depicts the numbers of farmers interviewed from the study areas.

The survey was conducted between March and April in 2014. For the data collection, about 450 farmers were interviewed irrespective of gender, farm size or tenancy status through a farm household survey. Interviews were conducted for the crop year 2012–13 which includes the *rabi* (winter) season 2012–2013 and the *kharif* (summer) season of 2013. A fully structured questionnaire was used to gather information on socioeconomic characteristics, crop and domestic livestock management, land tenure, detail of farm inputs and outputs, access to various institutional services, current and past knowledge of climate change, current adaptation measures undertaken and limitations to adaptation. Prior to the study, a pretesting of the questionnaire was performed to avoid missing any important information. The enumerators received field training about the study objectives and farm household survey.

2.3 Dependent and independent variables

Several agricultural adaptation measures can reduce losses due to increasing temperature and decreasing precipitation (Hassan and Nhemachena, 2008). In this study, a binary logistic model was used to examine the factors influencing the choice of different adaptation measures applied by the farm households in the study area. The decision to adapt requires that farm households recognize local changes in the long-term climate such as temperature and rainfall patterns (Bryan et al., 2013).

Following previous studies by Kato et al. (2011) and Bryan et al. (2013), we assume that farm households will adapt only if they perceive a reduction in the risk to crop production or an increase in expected net farm benefits. Consider a latent variable (Y_{ij}^*) which is equal to expected benefits from the adoption of certain adaptation measures:

$$Y_{ij}^* = \alpha + \sum \beta_k X_k + \varepsilon_{Y_{ij}^*}. \quad (1)$$

In this equation, Y_{ij}^* is a latent binary variable with subscript i depicting the household who adapted to climate variability and j depicting eight different adaptation measures. X_k represents the vector of exogenous explanatory variables that influence the farmers' choice of adopting particular adaptation

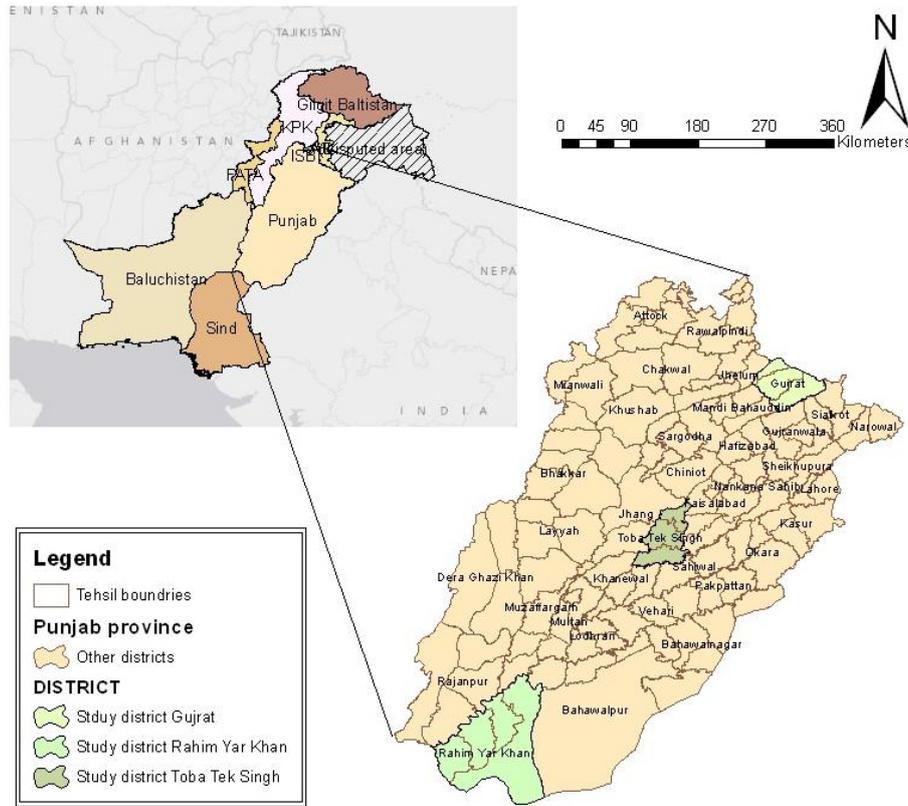


Figure 1. Sample study districts in Punjab province, Pakistan.

Table 1. The study districts.

Districts	City (Tehsil)	Union councils selected	No. of farmers interviewed
Rahim Yar Khan	Khanpur	4	75
	Liaqatpur	6	75
Toba Tek Singh	Toba Tek Singh	6	75
	Gojra	6	75
Gujrat	Gujrat	7	75
	Kharian	6	75
Total		35	450

measures and k in the subscript shows the specific explanatory variable (varies from zero to 14). The symbol α denotes the model intercept, β_k the vector of binary regression coefficients and $\varepsilon_{y_i^*} \cong N(0, \sigma^2)$ is the error term which is normally distributed and homoscedastic (zero mean and constant variance; Schmidheiny, 2013).

We do not observe the latent variable (Y_{ij}^*) directly. All we observe is

$$Y_{ij} = \begin{cases} 1 & \text{if } Y_{ij}^* > 0 \\ 0 & \text{if } Y_{ij}^* \leq 0, \end{cases} \quad (2)$$

where Y_{ij} is an observed variable which indicates that household i will opt for certain measures j (Fig. 4) to adapt to perceived changes in climate ($Y_{ij} = 1$) if their anticipated benefits are greater than zero ($Y_{ij}^* > 0$), and otherwise household i will not choose adaptation measure j if the expected benefits are equal to or less than zero ($Y_{ij} \leq 0$).

Hence, we can interpret Eq. (2) in terms of the observed binary variable (Y_{ij}) as

$$\Pr(Y_{ij} = 1) = Y_{ij} = G(X_k \beta_k), \quad (3)$$

where $G(\cdot)$ takes the specific binomial distribution (Fernihough, 2011).

2.4 Marginal effects and partial elasticities

The estimated parameters (β_k) of the binary logistic model only give the direction of the effect of the independent variables on the binary dependent variable and statistical significance associated with the effect of increasing an independent variable just like ordinary least square (OLS) coefficients (Peng et al., 2002). Thus, a positive coefficient β_k

Table 2. Description of explanatory variables used in the model.

Explanatory variable	Mean	SD	Description	Expected signs
Years of experience in farming	24.37	11.97	Continuous	(+)
Years of education	8.510	4.256	Continuous	(+)
Household size (individuals)	9.664	5.133	Continuous	(+)
Landholding (acres)	16.06	28.53*	Continuous	(+)
Livestock ownership	0.607	0.489	Dummy takes the value 1 if owned and 0 otherwise	(+)
Tube well ownership	0.630	0.482	Dummy takes the value 1 if owned and 0 otherwise	(-)
Distance from local market (kilometers)	9.089	7.610	Continuous	(-)
Access to credit	0.096	0.294	Dummy takes the value 1 if have access and 0 otherwise	(±)
Agricultural extension services provided for crop and livestock production	0.260	0.439	Dummy takes the value 1 if have access and 0 otherwise	(+)
Information on weather forecasting	0.836	0.371	Dummy takes the value 1 if have access and 0 otherwise	(+)
Access to marketing information	0.762	0.426	Dummy takes the value 1 if have access and 0 otherwise	(+)
Access to information on water delivery	0.784	0.412	Dummy takes the value 1 if have access and 0 otherwise	(±)
Irrigated plains cotton zone (base rain-fed zone)	0.330	0.472	Dummy takes value 1 if district Rahim Yar Khan and 0 otherwise	(±)
Irrigated plains mixed crop zone (base rain-fed zone)	0.330	0.472	Dummy takes value 1 if district Toba Tek Singh and 0 otherwise	(±)

* This large standard deviation is due to presence of large land holders in Rahim Yar Khan district.

shows that an independent variable X_k increases the likelihood that $Y_{ij} = 1$ (which is the adoption of a particular adaptation measure in our case). But this coefficient cannot explain how much the probability of household i adopting a particular adaptation measure ($Y_{ij} = 1$) will change when we change X_k , i.e., the coefficient (β_k) does not show the magnitude of the effect of a change in explanatory variable X_k on $\Pr(Y_{ij} = 1)$. Thus, to interpret and quantify the results, we need to calculate either marginal effects or partial elasticity. Marginal effects (y'_{ij}) describe the effect of a unit change in the explanatory variable on the probability of a dependent variable, i.e., $\Pr(Y_{ij} = 1)$. Derivation of marginal effects is discussed in detail in Appendix A. The final equation of the marginal effect (y'_{ij}) after derivation becomes

$$y'_{ij} = \Pr(Y_{ij} = 1) \cdot (1 - \Pr(Y_{ij} = 1)) \beta_k. \quad (4)$$

Another alternative to interpret the results of a logistic regression is to use partial elasticities which measure the percentage change in probability of the dependent variable (adoption of certain adaptation measure to climate variability) due to a 1 % increase in the explanatory variable X_k (see Appendix A for further details). We may interpret the partial elasticity of the logit model calculated at mean as

$$\eta_Y(\bar{X}_k) = \beta_k \bar{X}_k \Pr(Y_{ij} = 1) \cdot (1 - \Pr(Y_{ij} = 1)). \quad (5)$$

2.5 Description of explanatory variables

The choice of explanatory (independent) variables used in this study is based on data availability and review of the literature. The independent variables include household characteristics (e.g., farming experience of household head, household head's education, size of household, tube well ownership, landholding and tenancy status of the farm household), institutional factors (e.g., access to credit, market information, weather forecasting information, information on water delivery, agricultural extension services), and dummies for agroecological zones. Instead of using agroecological factors (e.g., temperature and rainfall) and cultural traits in different

regions directly, we used dummy variables for agroecological and cultural settings given the absence of variability in temperature and rainfall for households in the same district.

Prior to the survey, a multinomial logit (MNL) modeling approach was proposed based on literature where most of the previous studies of farmers' adaptation to climate change employed the MNL approach (Deressa et al., 2009; Hassan and Nhemachena, 2008; Hisali et al., 2011), where respondents are restricted to select only one from a given set of adaptation measure. However, in the course of this study, we frequently found that farm households adopted more than one adaptation measure simultaneously. This behavior made the use of the MNL approach inappropriate. A possible remedy would be to combine similar measures into single categories (Bryan et al., 2013). However, such grouping into self-defined categories may lead to misinterpretation (Bryan et al., 2013). Furthermore, the set of explanatory variables influencing the farmers' decision was also expected to be different for different adaptation measures. Therefore, we employed the logistic regression technique to examine the factors that affect the choice of adaptation measures. Table 2 shows the description and expected signs of explanatory variables used in this study.

2.6 Hypothesis testing for model significance

We tested all of our models for significance and accuracy of predictions. There are different ways to measure goodness of fit for logistic models. In the first step, we used the classification table method to measure the extent to which our models accurately predict the dependent variable (in our case, adoption of the particular adaptation measure by the farm household). The classification table is calculated by comparing the predicted scores of observations, on the basis of independent variables in our model, with their actual responses given in the data (Hosmer Jr. and Lemeshow, 2004). Higher percentages indicate a better fit of the model. The results of the classification table test (Table 3) show that the overall percentage

correctness for all models is above 71 % which confirms the better fit of all of the models used in this study.

In the second step, to test the overall significance of models, we used a global null hypothesis approach. For this analysis, we established a null hypothesis by assuming and setting all the regression coefficients of logistic models equal to zero versus the alternative that at least one of the regression coefficients (β_k) is not zero (Peng et al., 2002):

$$H_0 : \beta_k = 0,$$

$$H_1 : \text{at least one } \beta_k \neq 0.$$

This approach is the same as the F test for model testing in OLS regression. This test checks whether the model with predictors, i.e., Eq. (1), fits significantly better than the model with just an intercept (i.e., an intercept-only model):

$$Y_{ij}^* = \alpha. \quad (6)$$

The test statistic is calculated by taking the difference of the residual deviance for the model with predictors or independent variables from the null deviance of intercept-only model. The test statistic is distributed χ^2 with a degree of freedom that is equal to the differences between the number of variables in the model with predictors and intercept-only model (Stephenson et al., 2008).

From Table 3, it can be examined that χ^2 values for all adaptation models are positive and vary between 28 and 65. The associated p values are less than 0.001 except in the model for crop diversification that is significant at p value 0.01 from which it can be concluded that our models with predictors fit significantly better than the intercept-only model. Hence, on the basis of test statistics, we can reject the null hypothesis (H_0) and accept the other alternative hypothesis (H_1) that at least one of the regression coefficients (β_k) is not zero.

Further, we calculated the pseudo- R^2 measure to determine the goodness of fit of our adaptation models. The values of pseudo- R^2 for all models ranged from 0.15 to 0.28 which indicate a better fit of our models in explaining adaptation to climate variability.

Based on the results from the classification table, global null hypothesis and pseudo- R^2 , it can be assumed that all the models selected for this study are fit and can accurately estimate the factors affecting the adoption of different adaptation methods.

3 Results and discussion

3.1 Farm-level perceptions of climate change

As discussed above, farmers' perceptions of long term or short term changes in climate are a crucial pre-indicator in the adaptation process (Adger et al., 2009). Hence, respondents were asked how they perceive long-term changes in climate indicators in their area.

The study results (Fig. 2a) indicate that the large number of farmers perceived a slight increase in temperature for both summer (56.9 %) and winter seasons (39.3 %). In perceiving the precipitation patterns, the percentage of farmers who reported a slight decrease in precipitation in both summer (44 %) and winter (48.9 %) seasons are more than the farmers who perceived significant or no change in both summer and winter seasons (Fig. 2b). The majority of the surveyed farmers (52.2 %) perceived an increase in growing season length for the *rabi* season, while 57.1 % of the farmers observed no change in growing season length for the *kharif* season (Fig. 2c).

Farm-level perceptions of the majority of farmers about climate indicators in both summer and winter seasons are in accordance with actual trends presented in Fig. 3a and b. According to Fig. 3a, the mean temperature in winter and summer season shows a significant slight increase over the period of 1990–2010, while Fig. 3b depicts a slight decrease in winter and summer precipitation over the same period.

3.2 Farm-level adaptation process

In our study, we also analyzed the whole adaptation process across all three study districts (Fig. 4). The results show that overall and across districts there is a substantial reduction in the number of responses of farmers, from perceptions of changes in climate to the final adaptation to climate change. In the first stage (perception stage), overall 81 % of the respondents indicated climate change, with the highest perception in Gujrat district (86 %) and the lowest in Rahim Yar Khan (73 %). In the second stage (intention stage), overall 75 % of the farmers showed their intentions to adapt to climate change with the highest intentions in Gujrat district (85 %) and the lowest in Rahim Yar Khan (66 %). In the third and last stage (adaptation process), overall only 58 % of the respondents adapted to climate variability with greatest adaptation in Gujrat district (70 %) and the least in Rahim Yar Khan (49 %). In Toba Tek Singh district, about 55 % of the farm households adapted their farming in response to climate variability. As can be observed from the results, from perception stage to intention stage on average a drop from 81 to 75 % was observed in responses while from intention stage to adaptation stage, responses of farm households dropped from 75 to 58 % on average. In the same way, moving from perception stage to adaptation stage, farmers' responses dropped from 81 to 58 %. From the results, it can be determined that the number of farmers who adapted to climate change is substantially less than the farmers who perceived some form of climatic risk or planned to adapt in earlier stages of the adaptation process. This reduction in numbers may be associated with various constraints, and internal or external factors explained in the next section.

Table 3. Hypothesis testing for model significance and predictive power.

Models	χ^2 (Chi-squared)	Degree of freedom (df)	<i>P</i> level ^b	−2log likelihood	AIC ^a	Model correctness ^c (%)	Nagelkerke pseudo- <i>R</i> ²
Changing crop type	65.18	14	0.00	−115.89	261.77	89.90	0.28
Changing crop variety	64.91	14	0.00	−250.38	530.77	71.30	0.19
Changing planting dates	66.99	14	0.00	−235.20	500.40	76.40	0.20
Planting shade trees	68.55	14	0.00	−220.41	470.82	76.40	0.21
Soil conservation	56.71	14	0.00	−188.25	258.07	91.10	0.22
Changing fertilizer	46.52	14	0.00	−114.04	406.51	83.60	0.19
Irrigation	42.51	14	0.00	−122.82	275.65	90.40	0.19
Crop diversification	28.19	14	0.01	−106.40	242.81	92.40	0.15

^a AIC (Akaike information criterion) measures the relative quality of the statistical mode. ^b *P* level shows the statistical significance to reject the null hypothesis (*H*₀). ^c based on the classification table.

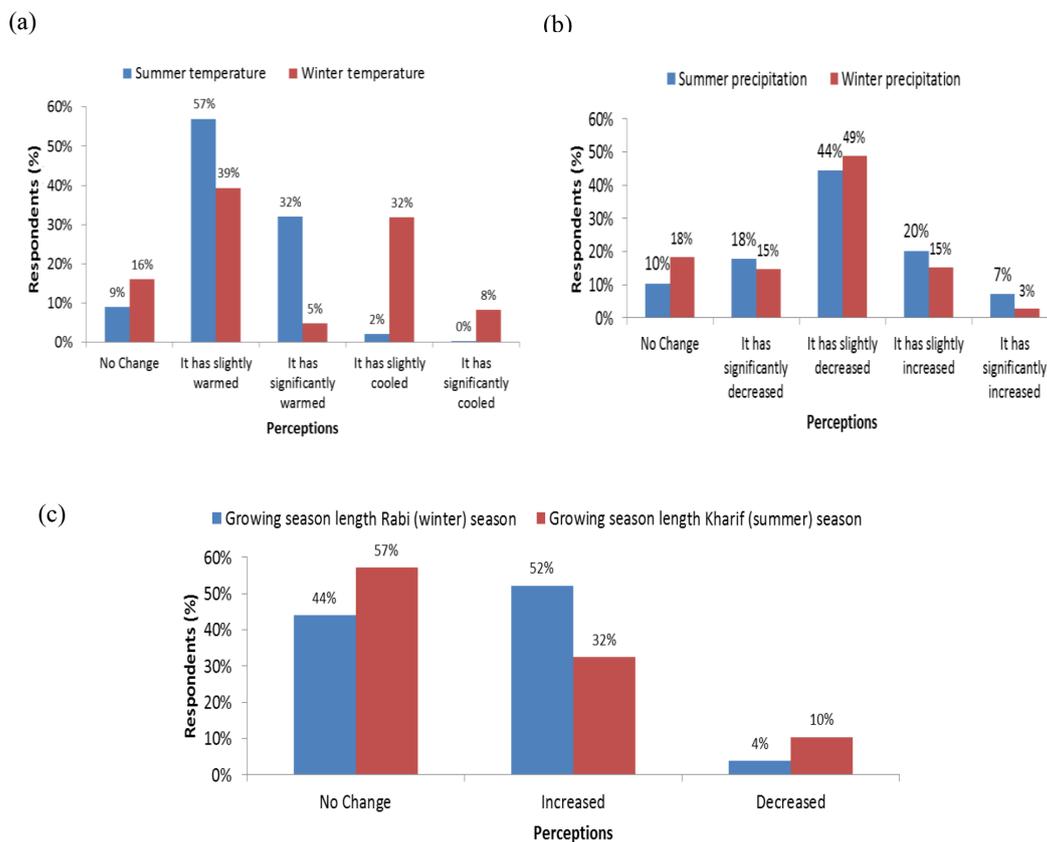


Figure 2. (a–c) Farmers' perceptions of climate change in study area of Punjab province, Pakistan.

3.3 Farm-level adaptation strategies and constraints

Farmers who observed variability in the climate over the period of 10 to 20 years were further asked to describe the farm-level adaptation measures undertaken in response to climate change. The results of the study demonstrated that farm households applied a wide range of adaptation measures in response to the changes in climate. As shown in Fig. 5, the most common adaptation measures were changing crop va-

rieties (32.20%), changing planting dates (28.40%), planting shade trees (25.30%) and changing fertilizers (18.70%) followed by changing crop types (10.20%), increasing irrigation (9.80%), soil conservation (9%), crop diversification (7.56%), migration to urban areas (3%) and renting out land (2.20%). Greater use of changing crop varieties and changing planting dates as adaptation measures could be associated with ease of access and low cost of adaptation method by farmers. The lesser use of renting out of land and migration

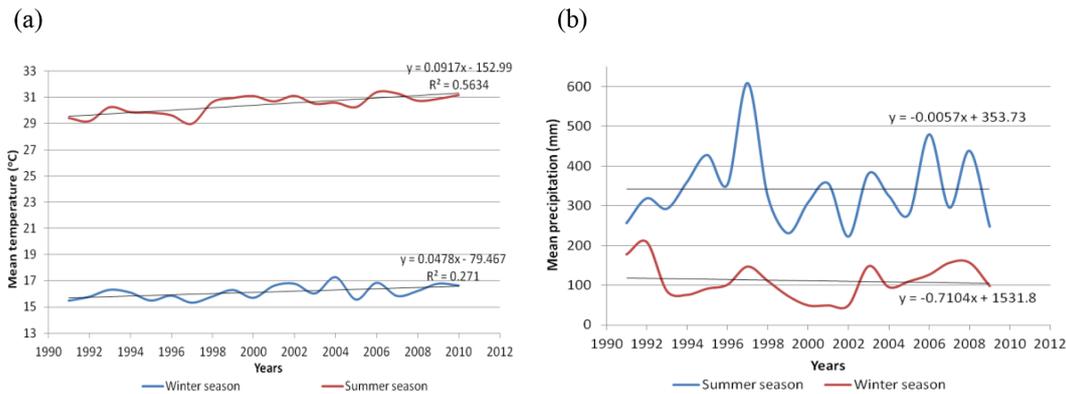


Figure 3. Mean temperature (a) and precipitation (b) trends in study area over the period of 1990–2010.

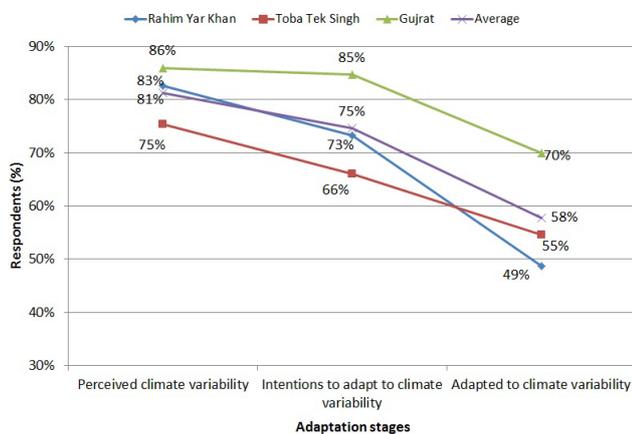


Figure 4. Perceptions, intentions and adaptation to climate change across different study districts.

to urban areas may be attributed to the fewer opportunities in urban areas or other sectors for unskilled farmers.

Implementation of adaptation measures by farm households varied across the three study districts (Fig. 5). In the Gujrat district, major adaptation measures adopted by farmers included the use of different crop varieties (39%), changing planting dates (36.70%), planting shade trees (31.30%) and changing fertilizers (24%). The main reason for changing crop variety, planting dates and shade trees may be due to more dependence of farming on rain and groundwater for cultivation of crops in the Gujrat district. That is why farmers need to modify their farming behaviors according to the variability in climate. In Toba Tek Singh district, changing crop variety (36%), changing planting dates (17.30%) and planting shade trees (17.30%) were the primary adaptation measures. In Rahim Yar Khan, farmers mainly used changing planting dates (31.30%), planting shade trees (27.30%), changing crop variety (22%), changing fertilizer (20%) and changing crop types (18%) as the adaptation measures in a changing climate (Fig. 5).

Moreover, we identified a number of constraints faced by the farmers who perceived long-term changes in climate and intended to adapt their farming in the second stage of the adaptation process, but did not adapt their farming in the third stage of the adaptation process. The major constraints identified by the majority of the respondents (Fig. 6) were lack of information (44%) and lack of money (22%) followed by resource constraints (17%), shortage of irrigation water (14%) and other constraints (2%). Lack of information deals with less information access by the farmers either from private or public sources about how to modify their agriculture in the case of extreme weather events, including high rainfall, water stress at sowing stage, extreme high or low temperatures which are frequently mentioned as indicators of climate change. Farmers showed their intention to adopt particular adaptation measure in the case of extreme weather events but did not manage to adapt due to improper information either about the adaptation method or usefulness of certain adaptation for their crops.

Lack of money is identified by responding farmers as another key constraint for adaptation, even if they plan to adapt to climate variability. Use of farm credit in the study sites is limited, despite access to microcredit facilities available at the town level. High credit interest rates are one of the reasons for minimal attraction of farmers to credit institutions. Less access to or availability of resources at farm-level constrains the capability of adapting to climate change. Physical resources may include farm inputs (improved seed, fertilizers), farm implements (tools for soil conservation, cultivators, harvesters etc.) and institutional resources (water and soil testing laboratories).

Further, we asked farmers to identify best measures to enhance effective adaptation to climate variability. Respondent farmers identified the provision of subsidies on farm inputs, updated farm information services and sufficient irrigation water supply as necessary means to enhance the adaptation of agriculture to climate variability in the study area.

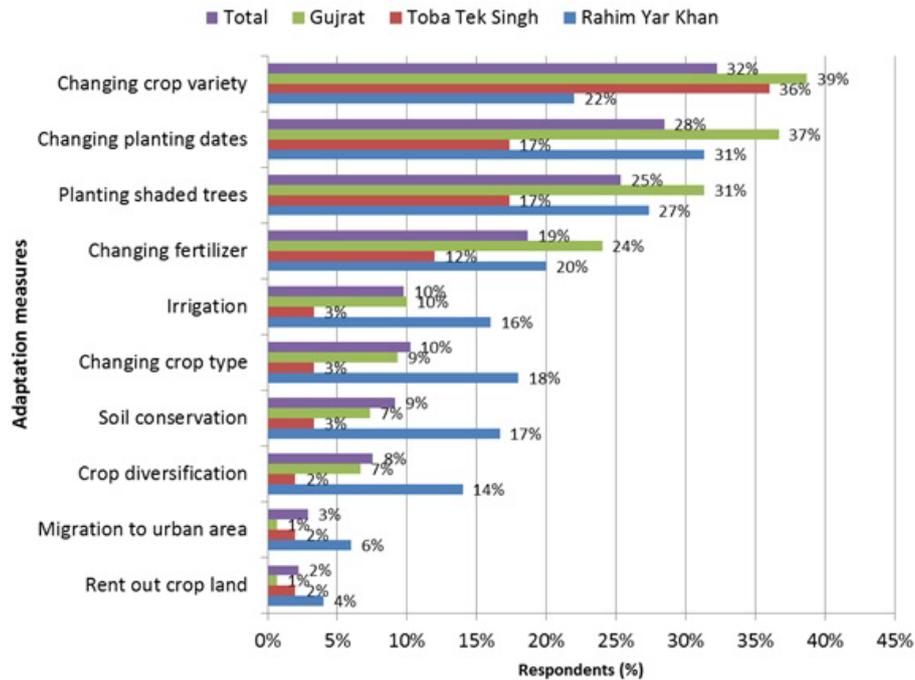


Figure 5. Adaptation measures adopted by farmers across three study areas in Punjab, Pakistan.

3.4 Adaptation to climate variability across regions and different farm characteristics

From the results of the adaptation process explained above in Sect. 3.2 and Fig. 9, we can observe that farm-level adaptation processes (perceptions, intentions and adaptation) are influenced by various factors. These adaptation measures can be further explored based on different characteristics of farm households or their location. Hence, we assume that perceptions, intentions and final decisions of adapting to climate change all differ in terms of extent to choose different adaptation measures. To analyze this variation, we categorize the farm households on the basis of education and farming experience. On the basis of education, we divided farmers into three categories: illiterate farmers without formal education; farmers with 1 to 10 years of schooling; and farmers with more than 10 years of schooling (Fig. 7). In terms of farming experience, we again divided farmers into three categories, i.e., farmers with less than 10 years of experience in farming; farmers with 10–20 years of farming experience, and farmers with more than 20 years of experience.

From the results shown in Fig. 7, it can be observed that moving from a lower to higher education level leads to an increase in the perception, intentions to adapt and final adaptation to climate change in all study districts. Overall, farmers with more than 10 years of schooling were more likely (44.2%) to perceive changes in climate over the past 10–20 years than farmers with less than 10 years of schooling (25.8%) or no education (11.3%). In the case of intentions to adapt, farmers with less than 10 years of schooling (23.6%)

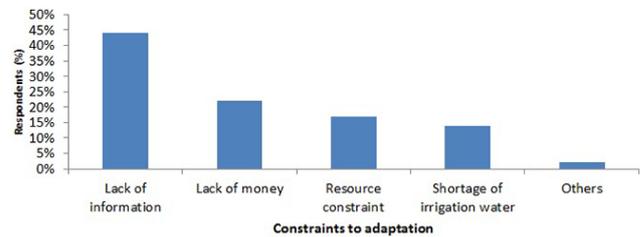


Figure 6. Constraints to adaptation to climate change in the study area.

or no education (10.9%) were less willing to adapt compared to farmers with more than 10 years of schooling (40.2%). The same was found true in the case of adaptation to climate change where more than 31% of the farmers who adapted to climate change had more than 10 years of schooling, and 18.2% of the farmers had education between 1 and 10 years. Adaptation was the lowest in the case of illiterate farmers who were the only 8.4% of the total sampled farmers who adapted to climate change. The same trend can be observed for all three study districts with little variation (Fig. 7).

The analysis of adaptation measures across different categories of farmers based on farming experience is explained in Fig. 8. Farmers with more than 20 years of experience were more likely (40.9%) to perceive variability in climate than farmers with experience between 10 and 20 years (28.2%) or farmers with less than 10 years of experience (12.2%). Similar results were obtained for both intentions to adapt and final adaptation to climate change. Overall, farmers with more

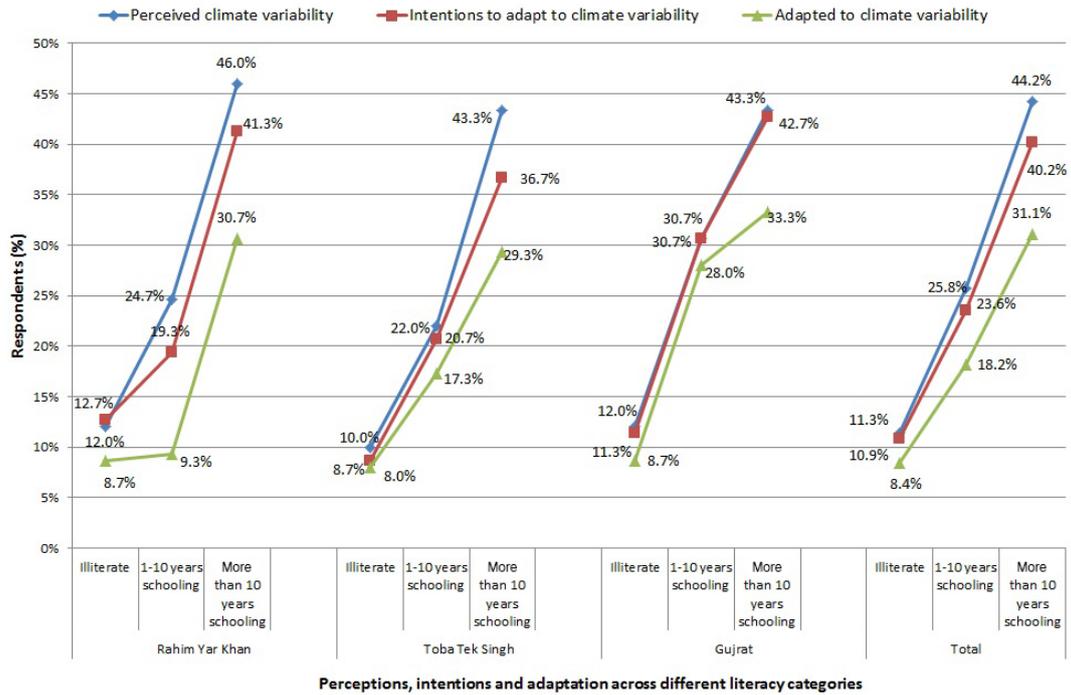


Figure 7. Adaptation to climate variability across different categories of farmers based on education level.

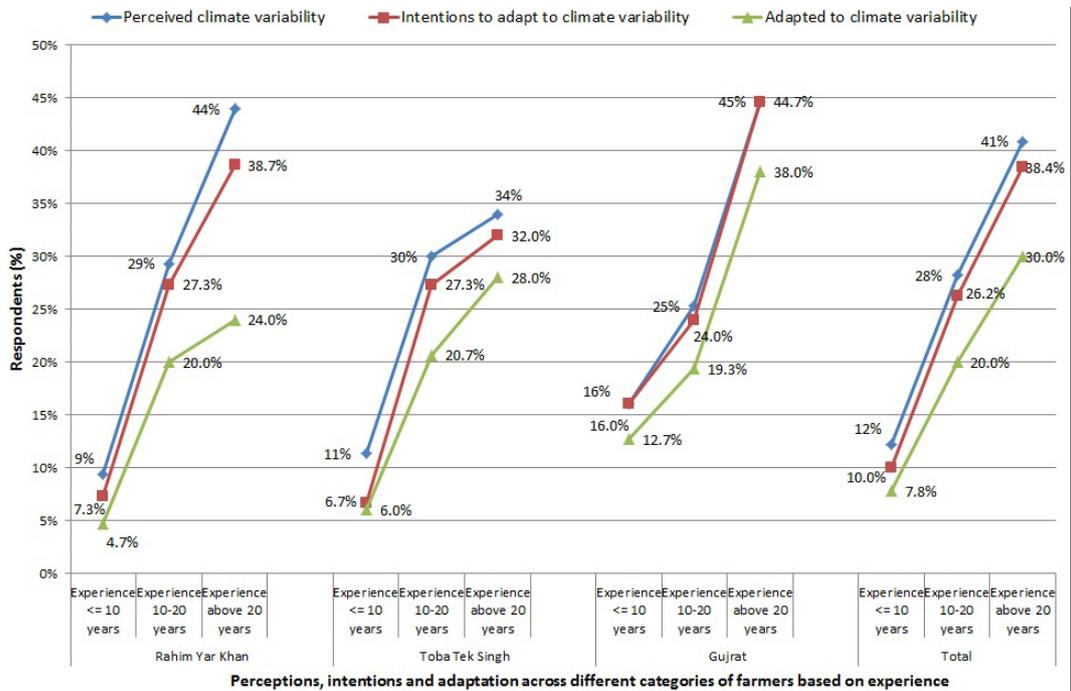


Figure 8. Perceptions, intentions and adaptation to climate change across different categories of farmers on farming experience in Punjab.

than 20 years of farming experience (38.4 %) have greater intentions to adapt compared to the farmers in the other two groups, i.e., farmers with experience between 10 and 20 years (26.2 %) and farmers with less than 10 years of experience (10 %). Farmers with more than 20 years of farming experi-

ence were the 30 % of the total farmers who adapted to climate change, while farmers with experience between 10 and 20 years (20 %) and farmers with less than 10 years of experience (7.8 %) adapted less. Figure 8 shows the same pattern for all districts. In summary, the higher the level or education

and farming experience for a given household, the higher its probability of adaptation to climate change.

3.5 Factors affecting adaptation measures

To quantify the impact of various explanatory factors affecting farmers' choice of adaptation methods, we used logistic regression models for all adaptation measures. The coefficients of logistic regression that tell us about the direction of effect of independent variables are presented in Table 4 and the marginal effects that explain the effect of a unit change in explanatory variables on the dependent variable are shown in Table 5. Finally partial elasticity calculations to elaborate the percentage impact of various factors on the probability of different adaptation measures are described in Table 6. For continuous variables, we described the results in marginal form from Table 5, while for the binary variables, we used the elasticities for interpretation of results from Table 6. In the following sub-sections, we describe the impact of various explanatory variables on the probabilities of adopting different adaptation measures in response to variability in climate.

3.5.1 Years of experience in farming

The coefficient of years of experience in farming has a positive sign for most of the adaptation measures, indicating a positive relation between farming experience and possibility of adapting to climate change. According to results in Table 4, years of farming experience significantly increases the probability of choosing changing crop varieties, changing planting dates and changing fertilizer as adaptation measures. Elasticity calculations in Table 6 show that a 1 % increase in the years of experience increases the probability of adopting changing crop variety (0.14 %), changing planting dates (0.15 %) and changing fertilizer (0.11 %) as adaptation measures. The results of the study are in accordance with those from Maddison (2007) and Nhemachena and Hassan (2007) which also found a positive relationship between farming experience and adaptation to climate change. Hence, it can be concluded that farmers with greater farming experience are likely to be more aware of past climate events and better judge how to adapt their farming to extreme weather events.

3.5.2 Education

Education is assumed to be an important factor in accessing advanced information on new improved agricultural technologies and increased agricultural productivity (Norris and Batie, 1987; Elahi et al., 2015). In our study, the highly significant coefficient of education of the household head shows that the probability of adapting to changes in climate increases with an increase in the years of schooling (Table 4). The elasticities in Table 6 show that 1 % increase in the years of schooling of household head would lead to an increase

in the probability of changing crop type (0.08 %), changing crop variety (0.09 %), changing planting dates (0.17 %), planting shade trees (0.08 %), soil conservation (0.08 %), changing fertilizer (0.15 %) and irrigation (0.09 %) as adaptation measures to climate variability. Various studies (Bryan et al., 2013; Deressa et al., 2009; Maddison, 2007) also found a significant positive relationship between education of household head and adaptation to climate change that supports the finding of this study. Hence, it can be concluded that farmers with more years of schooling are more likely to adapt to changes in climate compared to the farmers with little or no education.

3.5.3 Household size

A positive coefficient of household size indicates a positive relationship between household size and probability of adaptation (Table 4). For instance, an increase by one individual in the average household would lead to a 0.25 % increase in the likelihood of planting shade trees and 0.47 % increase in choice of soil conservation as adaptation measure (Table 5). Findings of the studies of Croppenstedt et al. (2003) and Deressa et al. (2009) also support our findings of a positive relationship between household size and adoption of agricultural technology or adaptation to climate change.

3.5.4 Land area

Land area represents the total land area held by a farm household and may be taken as a proxy for farm household wealth. The results in Table 4 indicate that the land area has positive and significant impacts on changing crop varieties and crop types. A 1 % increase in the land area increases these probabilities of changing crop type and changing crop varieties by 0.01 and 0.06 %, respectively (Table 6).

3.5.5 Tenancy status

Tenancy status indicates farmers' land tenure status as owner or tenant. In this study, tenancy status has a negative sign for most of the adaptation measures which indicate that tenants are more likely to adapt their farming to perceived climate change compared to the self-operating farmers (owners). This can be observed from marginal effects presented in Table 5 that if the farmer is the owner, it reduces the probability of changing crop type (9.29 %), changing planting dates (7.64 %) and changing fertilizers (9.77 %). Increased likelihood of adaptation for tenants may be due to the reason that tenants are more conscious about their farm income compared to owners as the former also has to pay the rent of land hence they will adapt more to climate change to keep their gross revenue above total cost as compared to owners.

Table 4. Parameter estimates of the logistic regression models of farm-level adaptation measures.

Explanatory variables	Changing crop type	Changing crop variety	Changing planting dates	Planting shade trees	Soil conservation	Changing fertilizer	Irrigation	Crop diversification
Intercept	-5.0048*	-1.2789**	-3.1395*	-4.9009*	-6.9262*	-4.845*	-5.587*	-3.826*
Farm experience (years)	0.0065	0.0316*	0.0350*	-0.0029	0.0217	3.314*	0.018	0.002
Years of education	0.1336*	0.0618**	0.1229*	0.0641**	0.1395*	1.397*	0.142*	0.038
Household size	0.0316	-0.0365	0.0141	0.1102*	0.0644**	2.469	-0.002	-0.007
Land area (acres)	0.0093**	0.0200*	0.0026	-0.0048	-0.0020	-1.679	0.003	0.006
Tenancy status owner (base tenant)	-1.2338*	-0.4066	-0.6840*	-0.0057	-0.5095	-7.371**	-0.565	-0.322
Tube well ownership	0.9512**	-0.1819	0.0511	0.2835	0.4408	7.316**	0.405	0.213
Distance from the local market	-0.0773**	-0.0156	-0.0104	0.0163	-0.0378	-6.844	-0.051	-0.063
Access to farm credit	-0.1793	0.0876	-0.0924	-0.4597	-0.0478	-1.736	0.247	-0.192
Access to information on water delivery	-0.7165	0.5820	0.6729**	-0.1998	0.2123	5.549	-0.210	0.158
Information on weather forecasting	1.5052**	-0.2564	0.8692**	2.5448*	2.2544**	1.279**	2.207**	1.255**
Agricultural extension services provided for crop and livestock production	-0.8448**	0.6958**	0.2537	0.2829	-0.3809	-1.976	-0.536	-0.642
Access to market information	1.1377**	0.1153	-0.0616	0.0088	0.1759	9.942	0.161	0.165
Mixed crop zone (base rain-fed zone)	-0.7351	-0.5965**	-1.4044*	-0.7664**	-0.6644	-1.008**	-0.696	-0.954
Cotton zone (base rain-fed zone)	1.0392**	-1.5353*	-0.5562**	-0.1057	0.9810**	-3.330	0.901**	1.058**
N	450	450	450	450	450	450	450	450

*, ** Significant at 1 and 5 % probability levels, respectively

Table 5. Marginal effects from the binary logistic models of farm-level adaptation measures.

Explanatory variables	Changing crop type	Changing crop variety	Changing planting dates	Planting shade trees	Soil conservation	Changing fertilizer	Irrigation	Crop diversification
Farm experience (years)	0.0005	0.0059	0.0061	-0.0005	0.0016	0.0044	0.0014	0.0001
Years of education	0.0101	0.0116	0.0214	0.0104	0.0101	0.0185	0.0112	0.0025
Household size (individuals)	0.0024	-0.0069	0.0025	0.0179	0.0047	0.0033	-0.0001	-0.0004
Land area (acres)	0.0007	0.0038	0.0005	-0.0008	0.0001	0.0000	0.0002	0.0004
Tenancy status owner (base tenant)	-0.0929	-0.0764	-0.1192	-0.0009	-0.0369	-0.0977	-0.0448	-0.0210
Tube well ownership	0.0716	-0.0342	0.0089	0.0460	0.0319	0.0969	0.0321	0.0139
Distance from the local market	-0.0058	-0.0029	-0.0018	0.0026	-0.0027	-0.0009	-0.0041	-0.0041
Access to farm credit	-0.0135	0.0165	-0.0161	-0.0747	-0.0035	-0.0230	0.0196	-0.0125
Access to information on water delivery	-0.0539	0.1093	0.1173	-0.0324	0.0154	0.0735	-0.0166	0.0103
Information on weather forecasting	0.1133	-0.0482	0.1515	0.4133	0.1633	0.1695	0.1750	0.0817
Agricultural extension services provided for crop and livestock production	-0.0636	0.1307	0.0442	0.0459	-0.0276	-0.0262	-0.0425	-0.0418
Access to market information	0.0856	0.0217	-0.0107	0.0014	0.0127	0.0132	0.0128	0.0108
Irrigated plains mixed crop zone (base rain-fed zone)	-0.0553	-0.1121	-0.2447	-0.1245	-0.0481	-0.1335	-0.0552	-0.0621
Irrigated plains cotton zone (base rain-fed zone)	0.0782	-0.2885	-0.0969	-0.0172	0.0710	-0.0441	0.0715	0.0689
N	450	450	450	450	450	450	450	450

3.5.6 Tube well ownership

Tube well ownership indicates adequate supply of ground water for crops in time of need. The ownership of a tube well is positively associated with the majority of the adaptation measures, even though the coefficients are insignificant (Table 4). Moreover, ownership of a tube well leads to 7.16 % increase in the likelihood of adopting changing crop type and 9.69 % increase in the probability of changing fertilizer (Table 5). Hence, it can be concluded that farmers with a tube well are more likely to adapt their agriculture to climate change as they have the assurance of sufficient water supply to make any adjustment at the farm level in response to variability in climate.

3.5.7 Distance from the local market

Proximity to market may serve as a means of sharing and exchanging information with farmers and other service providers (Maddison, 2007). In this study for most of the adaptation measures, the coefficient of distance from the local market is negative which indicates that farmers located

near to the local market have more chances to adapt to climate change compared to farmers who are far away from the market (Table 4). A 1 % increase in the distance of the farm from nearest local market results in a decrease of 0.05 % in the probability of the changing crop type (Table 6).

3.5.8 Access to farm credit

Access to farm credit has an insignificant effect on the adaptation to climate change. Access to farm credit is positively related to changing crop variety and increased irrigation and negatively related to the changing crop type, changing planting dates, planting shade trees, soil conservation, changing fertilizer and crop diversification, although not significantly (Table 4).

3.5.9 Access to information on water delivery

Access to information on water delivery has a positive but insignificant impact on most of the adaptation measures except changing planting dates (Table 4). The access to information on water delivery increases the likelihood of changing plant-

Table 6. Elasticity calculations of the binary logistic models of farm-level adaptation measures.

Explanatory variables	Changing crop type	Changing crop variety	Changing planting dates	Planting shade trees	Soil conservation	Changing fertilizer	Irrigation	Crop diversification
Farm experience (years)	0.0119	0.1445	0.1487	-0.0114	0.0383	0.1070	0.0348	0.0026
Years of education	0.0817	0.0942	0.1739	0.0845	0.0821	0.1503	0.0911	0.0203
Household size (individuals)	0.0230	-0.0662	0.0238	0.1729	0.0450	0.0316	-0.0014	-0.0041
Land area (acres)	0.0113	0.0604	0.0074	-0.0124	0.0023	0.0000	0.0032	0.0062
Tenancy status owner (base tenant)	-0.0752	-0.0619	-0.0965	-0.0008	-0.0299	-0.0791	-0.0363	-0.0170
Tube well ownership	0.0451	-0.0215	0.0056	0.0290	0.0201	0.0611	0.0202	0.0088
Distance from local market	-0.0529	-0.0267	-0.0164	0.0241	-0.0249	-0.0082	-0.0371	-0.0374
Access to farm credit	-0.0043	0.0053	-0.0052	-0.0239	-0.0011	-0.0074	0.0063	-0.0040
Access to information on water delivery	-0.0421	0.0853	0.0915	-0.0253	0.0120	0.0574	-0.0130	0.0080
Information on weather forecasting	0.0952	-0.0405	0.1272	0.3472	0.1371	0.1424	0.1470	0.0687
Agricultural extension services provided for crop and livestock production	-0.0273	0.0562	0.0190	0.0198	-0.0119	-0.0113	-0.0183	-0.0180
Access to market information	0.0651	0.0165	-0.0082	0.0011	0.0097	0.0100	0.0097	0.0082
Irrigated plains mixed crop zone (base rain-fed zone)	-0.0183	-0.0370	-0.0808	-0.0411	-0.0159	-0.0441	-0.0182	-0.0205
Irrigated plains cotton zone (base rain-fed zone)	0.0258	-0.0952	-0.0320	-0.0057	0.0234	-0.0146	0.0236	0.0227

ing dates by 11.73 % (Table 5). We can conclude that farmers who have more access to information on water delivery are more likely to adjust the planting dates according to water availability.

3.5.10 Information on weather forecasting

Information on seasonal and daily weather forecasting (i.e., temperature and rainfall) has a positive and significant effect on the probability of changing crop types, changing planting dates, planting shade trees, soil conservation, changing fertilizer, irrigation and crop diversification as adaptation methods (Table 4). The results in Table 5 show that access to information on seasonal and daily weather increases the probability of planting shade trees (41.33 %), increased irrigation (17.50 %), changing fertilizers (16.95 %), soil conservation (16.33 %), changing planting dates (15.15 %), changing crop type (11.33 %) and crop diversification (8.17 %). In summary, the information on weather forecasting increases the likelihood of adaptation to climate change.

3.5.11 Agricultural extension services provided for crop and livestock production

The provision of agricultural extension services is an ongoing process and can be defined as a systematic tool of dissemination of useful and practical information related to agriculture, including improved farm inputs, farming techniques and skills to farmers or rural communities with the objective of improving their farm production and income (Syngenta, 2014; Swanson and Claar, 1984).

The results in Table 4 indicate that provision of extension services for crop production is significantly and positively related to changing crop variety. On the other hand, it is significantly and negatively related to the probability of changing crop type which may be due to the reason that farmers get poor information on crop production and adaptation to climate change, or the information from the extension services is outdated. The results of the marginal effect in Table 5 show that access to extension services leads to 13.07 %

increase in the likelihood of changing crop variety and decrease of 6.36 % in the likelihood of changing crop type as an adaptation method. For all other adaptation measures, no significant relationship is found between extension and adaptation measures. These results support the farmers' complaints about the lack of updated information on adaptation to climate change from the agricultural extension department.

3.5.12 Access to market information

The results of logistic regression show a positive association between access to market information and the adaptation to climate change though most of the coefficients are insignificant (Table 4). The probability of changing crop type increases by 8.56 % if farmers have access to market information (Table 5).

3.5.13 Irrigated plains mixed crop zone (base rain-fed zone)

Farmers living in different agroecological zones used different adaptation measures. For example, farming in mixed crop zones leads to an increase in the likelihood of changing crop variety (11.21 %), changing planting dates (24.47 %), planting shade trees (12.45 %) and changing fertilizers (13.35 %) compared to the farming in the cotton zone or rain-fed zone (Table 5). From the results, we can conclude that farmers in different crop zones adapt differently based on crop patterns and needs.

3.5.14 Irrigated plains cotton zone (base rain-fed zone)

Likelihood of changing crop type (7.82 %), soil conservation (7.10 %), irrigation (7.15 %) and crop diversification (6.89 %) increases in the case of farming in the cotton zone (Rahim Yar Khan) compared to the farming in other zones. Moreover, farming in the cotton zone reduces the probability of changing crop varieties and changing planting dates as adaptation methods by 28.85 and 9.69 %, respectively, compared to the farming in other zones (Table 5).

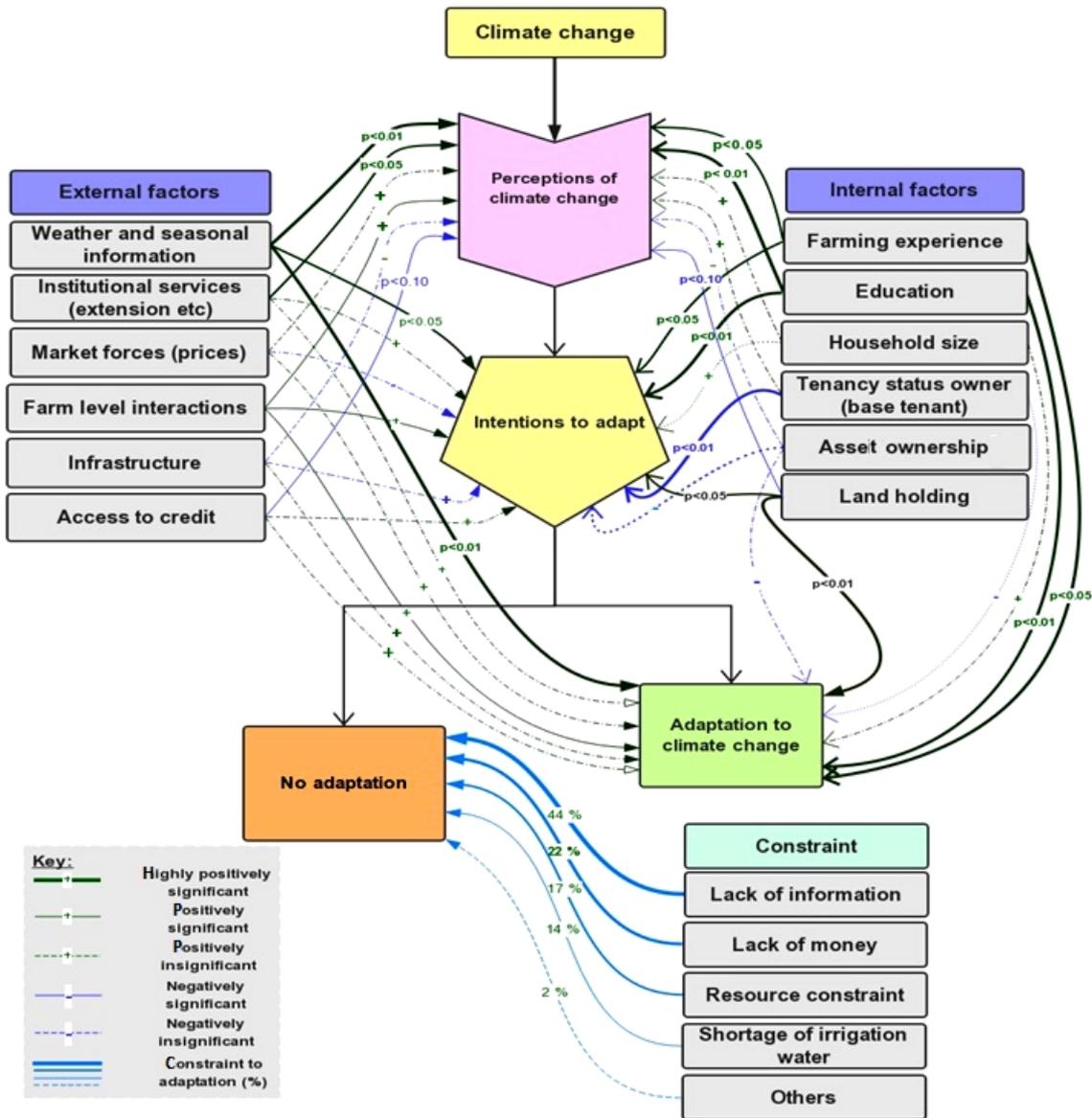


Figure 9. Schematic framework of farmers' adaptation process in Pakistan (own illustration).

3.6 Schematic framework of farmers' adaptation process

A schematic framework of the farmers' adaptation process was developed based on field data analysis to summarize the adaptation process at the farm level (Fig. 9). In this framework, we described the farmers' adaptation process as a three-step procedure. In the first step, farm households perceive climate change and its adverse impacts on their agricultural production. These perceptions can be defined through various internal (socioeconomic) and external (e.g., environmental or institutional) factors. In the second stage, farmers showed their intentions to adopt certain measures to adapt to climate change that again can be described or influenced by internal and external factors mentioned in Sect. 2.1. In the

last and third stage, farmers decide either to adapt or not to perceived changes in climate. Farmers' adoption of particular adaptation measures again may be subject to various internal and external factors (Table 4), while the farmers' decision to not adapt to climate variability may be explained by various constraints elaborated by the farmers, including those who did not adapt even with intentions (Fig. 2). In this framework, the width of connection lines shows the significance or insignificance of individual variables on the perceptions, intentions or adaptations. Green and blue lines represent positive and negative relations between interdependent variables (perceptions, intentions or adaptations), respectively, while dotted lines represent a weak link, and solid lines show a significant relationship.

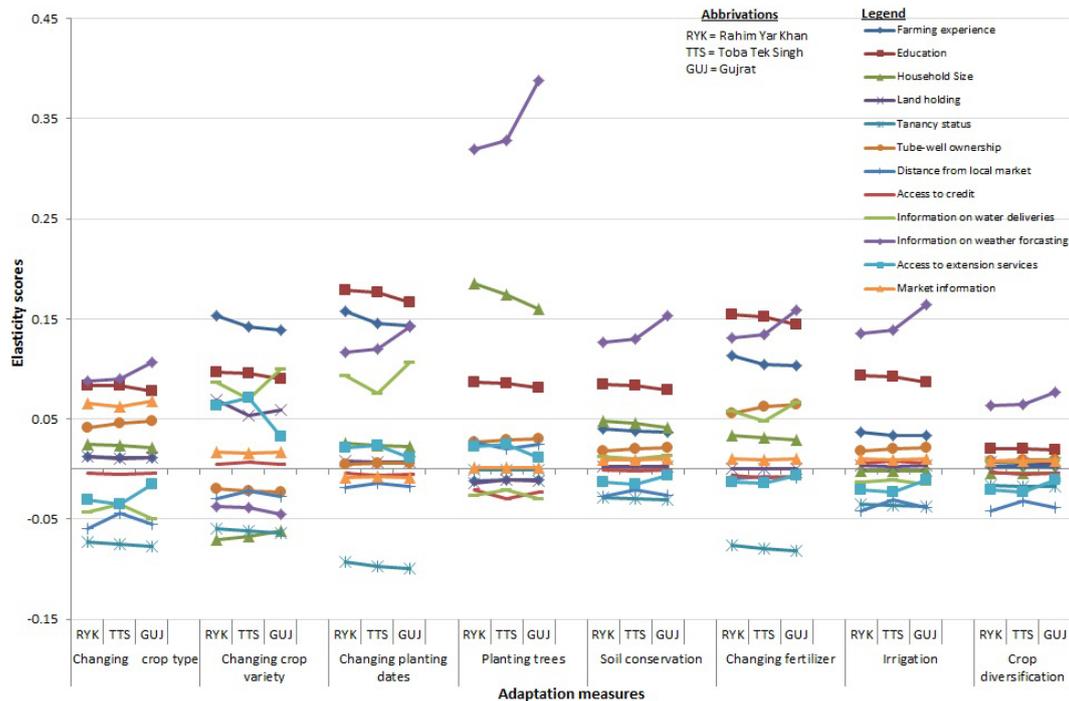


Figure 10. Partial elasticity calculations across three study districts of Punjab province.

3.7 Partial elasticity comparisons across regions

We further analyzed and compared the partial elasticities of explanatory variables for all adaptation methods across three study districts (Fig. 10). From the results, it can be observed that elasticity scores range from -0.01 to 0.20 except for the elasticity scores of the weather information variable (0.30 – 0.40) of the planting shade trees model. Elasticity of farming experiences is higher for farmers in the Rahim Yar Khan district for most of the adaptation methods followed by farmers in Toba Tek Singh district and Gujrat. The highest elasticity for farming experience was observed in the case of adaptation measures changing crop varieties (0.15) and changing planting dates (0.16) in Rahim Yar Khan, which indicates that farming experience increases the chances of adaptation to climate change in Rahim Yar Khan more compared to the districts of Toba Tek Singh and Gujrat. The same trend was found for elasticity of education where the highest score (0.18) was obtained for changing planting dates in Rahim Yar Khan and the lowest elasticity score was found for crop diversification (0.02) in Gujrat. It can be concluded that education has more significant effects on adaptation to climate change in the Rahim Yar Khan district.

Elasticity calculations for household size show the highest elasticity in the case of planting shade trees in Rahim Yar Khan (0.19) while the lowest elasticity of household size (but insignificant) was observed for changing crop variety (-0.07) for the Rahim Yar Khan district. Elasticities of household size were close to zero for the irrigation and

crop diversification method of adaptation. In the case of the variable of total landholding, the highest coefficient was observed for changing crop variety in Rahim Yar Khan district (0.07) while for adaptation methods soil conservation, changing fertilizer, irrigation and crop diversification, the coefficient was close to zero, which indicates little or no effect of landholding on adoption of these measures. Elasticity coefficients for the tenancy status variable were the highest for Rahim Yar Khan district followed by Toba Tek Singh and Gujrat.

4 Conclusions and policy suggestions

Climate change is a reality which is expected to have significant impacts on Pakistan's economy with an increase in the frequency of extreme events including floods and droughts and changing rainfall patterns (Asif, 2013). Being severely dependent on natural water resources, agriculture in Pakistan is particularly vulnerable to further climate change. Hence, suitable adaptation measures to climate change are important. This study uses novel farm-level data from three distinct agroecological zones in Pakistan to analyze farmers' awareness and their adaptive capacities and measures to changes in climate.

This study reveals real and perceived constraints for farm-level adaptation to climate change. Most constraints are institutional in nature and can be covered with improving the institutional services in terms of access, use and viability for climate adaptation. Furthermore, this study shows the impor-

tance of different types of institutional services such as easy access to information on weather forecasting and improved agricultural technologies; easy access to resources and financial services for the enhancement of farm-level adaptation. However, the services currently provided at the farm level are not sufficient to support an effective adaptation process. Hence there is dire need for collaboration at different levels of the adaptation process. This could consist of public–private partnerships or integration at horizontal and vertical levels across public and private organizations. This study also shows that farmers in different agroecological zones prefer different adaptation measures. This diversity confirms the need for research at local levels, i.e., in different agroecological zones, to develop efficient and effective adaptation strategies for the agriculture sector.

The study also shows that historical adaptation measures at the farm level do generally not include advanced management technologies but are limited to simple measures, particularly changing crops or crop varieties. Very few farmers adopted advanced adaptation measures. As we already mentioned, the reason behind not using advanced measures lies in lack of knowledge and support from local institutions. Hence, future policies need to address barriers for the adoption of advanced adaptation measures at the farm level such as providing information and support, introducing climate smart varieties, promoting soil conservation and new adaptation measures based on different agroecological zones. Despite the need for locally specific adaptation of agriculture to climate change, investment and research are also needed at the macro level. In particular, commodity prices, resource endowments, and environmental impacts depend on regional and international developments but interact with local adaptation measures.

Appendix A: Marginal effect and elasticity calculations

Assume a logit function (in terms of observed variable Y_{ij}) already explained in Eq. (3) in Sect. 2:

$$\Pr(Y_{ij} = 1) = Y_{ij} = G(X_k\beta), \tag{A1}$$

where $G(\cdot)$ takes the specific binomial distribution (Fernihough, 2011).

If we take the partial derivative of Eq. (3) with respect to explanatory variable X_k , by applying chain rule (Dawkins, 2005), it will give us the marginal effect as follows:

$$\begin{aligned} \frac{\partial Y_{ij}}{\partial X_k} &= \frac{\partial G(X_k\beta)}{\partial X_k} = \frac{\partial G(X_k\beta)}{\partial X_k\beta} \cdot \frac{\partial X_k\beta}{\partial X_k} \\ &= G'(X_k\beta) \cdot \beta_k = g(X_k\beta)\beta_k. \end{aligned} \tag{A2}$$

As we know that

$$G(X_k\beta) = \frac{e^{X_k\beta}}{1 + e^{X_k\beta}},$$

the derivative of $G(X_k\beta)$ with respect to $X_k\beta$ by applying the quotient rule (Dawkins, 2005) will be as follows:

$$\begin{aligned} g(X_k\beta) &= \frac{(1 + e^{X_k\beta}) \cdot e^{X_k\beta} - e^{X_k\beta} \cdot e^{X_k\beta}}{(1 + e^{X_k\beta})^2} \\ &= \frac{e^{(X_k\beta)}}{(1 + e^{X_k\beta})^2}. \end{aligned} \tag{A3}$$

If we put the value of $g(X_k\beta)$ from Eq. (A3) into Eq. (A2) then it becomes

$$\frac{\partial Y_{ij}}{\partial X_k} = \frac{e^{(X_k\beta)}}{(1 + e^{X_k\beta})^2} \cdot \beta_k. \tag{A4}$$

Usually marginal effects are calculated at mean of explanatory variables (\bar{X}_k) so we may replace X_k with mean value of \bar{X}_k (Schmidheiny, 2013):

$$\begin{aligned} y'_{ij} &= \frac{e^{(\bar{X}_k\beta)}}{1 + e^{(\bar{X}_k\beta)}} \cdot \frac{1}{1 + e^{(\bar{X}_k\beta)}} \cdot \beta_k, \\ &= \Pr(Y_{ij} = 1) \cdot \left(1 - \frac{e^{(\bar{X}_k\beta)}}{1 + e^{(\bar{X}_k\beta)}}\right) \cdot \beta_k, \\ &= \Pr(Y_{ij} = 1) \cdot (1 - \Pr(Y_{ij} = 1)) \cdot \beta_k. \end{aligned}$$

Partial elasticity can be easily calculated from marginal effects. As we already know, elasticity is the responsiveness of the dependent variable in percentage given a percentage change in the independent variable. However, the elasticity measure for logistic regression is different from other normal elasticity measures because, in the case of logistic regression, the dependent variable is a unitless number and takes values between 0 and 1 (Curran, 2010). Hence partial elasticity (η_Y) for logistic regression may be defined as

$$\eta_Y(X_k) = X_k \cdot \frac{\partial G(X_k\beta)}{\partial X_k}. \tag{A5}$$

As $\frac{\partial G(X_k\beta)}{\partial X_k}$ is simply the marginal effect of logistic regression (see Eq. A4) so we may write Eq. (A5) as

$$\eta_Y(X_k) = X_k \cdot \Pr(Y_{ij} = 1) \cdot (1 - \Pr(Y_{ij} = 1)) \beta_k. \tag{A6}$$

Moreover, we can conclude that partial elasticity is equal to X_k times the marginal effect (y'_{ij}) (Rahji and Fakayode, 2009).

In a similar way of calculating marginal effects, partial elasticities are also calculated at mean of explanatory variables (\bar{X}_k), and thus we may write Eq. (A6) as

$$\eta_Y(\bar{X}_k) = \beta_k \bar{X}_k \Pr(Y_{ij} = 1) (1 - \Pr(Y_{ij} = 1)), \tag{A7}$$

where

$$\Pr(Y_{ij} = 1) = \frac{e^{(\bar{X}_k\beta)}}{1 + e^{(\bar{X}_k\beta)}}.$$

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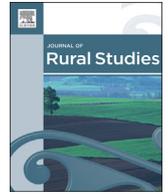
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4 Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan

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Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan



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ABSTRACT

Evaluation of the ongoing efforts for farm level adaptation to climate change is crucial to understand their effectiveness and to suggest further actions at the policy level. The current study explores the adaptation of wheat farmers to climate change, its determinants and its impact on food productivity and crop income in rural Pakistan. This study is based on a primary dataset of 442 wheat farmers conducted through face-to-face structured interviews from 65 villages across three agro-ecological zones of Punjab Province, Pakistan. The study employs logistic regression analysis to find adaptation determinants and uses the propensity score matching technique to estimate the causal impact of adaptation on food productivity and crop income. The results of the study suggest that wheat farmers were well aware of climate change, but for various reasons did not adapt accordingly. The major adaptation strategies implemented by wheat farmers include changing planting dates, crop varieties and fertilizer types. Moreover, education, farming experience, access to agricultural extension, weather forecasting and marketing information were the factors that significantly affected farmers' adaptation decisions. Adapting wheat crops to climate change significantly and positively affects wheat productivity and net crop income and hence indirectly improves the farmers' wellbeing and local food security. More benefits were achieved by farmers who used a combination of different adaptation strategies. The study suggests to focus on farmers' education, easy access to farm advisory services and information on new adaptation methods for sustainable food production and local food security.

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1. Introduction

Projected changes in climate and increasing climatic risks over the 21st century pose serious challenges to agricultural development in developing countries (IPCC, 2014). Pakistan is one of the countries most affected by climate change due to its low adaptive capacity and poor infrastructure (Stocker et al., 2013). Projections suggest a 2–3° increase in temperature and a significant variation

in the distribution of rainfall in Pakistan by 2050 (Gorst et al., 2015). The Global Climate Risk Index (GCRI) ranked Pakistan number 8 in a list of countries most affected by climate change and extreme weather events over the period 1995–2014 (Kreft et al., 2016). Due to extreme events and climate variability, rural livelihoods and the productivity of major crops such as wheat, cotton, rice and sugarcane have been greatly affected over the last two decades (Abid et al., 2015). The historic floods during 2010–2014 and severe droughts lasting from 1999 to 2003 indicate the vulnerability of rural households in Pakistan to climate change (Abid et al., 2015).

The resilience of the agricultural sector to climate change is one of the most important concerns for economic development in Pakistan as more than two-thirds of the country's population lives in rural areas and relies on the agricultural sector for their subsistence and livelihood (Abid et al., 2011; WB, 2014). Further, through adverse impacts on cereal productivity and food prices,

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climate change could have serious implications for local food security in Pakistan, which mainly depends on cereal crops. Wheat alone, which was grown on 8.66 million hectares in 2013, supplies 37% of the total daily calories in Pakistan (Prikhodko and Zrilyi, 2013). However, the current national average wheat yield (2797 kg/ha in 2013) is much lower than the global mean (3268 kg/ha in 2013) (FAO, 2015). According to a recent study, farmers in Pakistan only realize 32% of the potential crop yield (Prikhodko and Zrilyi, 2013). The huge gap between actual and potential crop yields is one of the major factors contributing to the insufficient supply of cereals in the country. For instance, Zulfiqar and Hussain (2014) reported an increasing gap between per-capita wheat demand and supply in Pakistan for the period of 2013–2050 (for details on wheat caloric demand-supply gaps, see Table A.1 in Appendix A). Unsteady agricultural growth coupled with a steadily increasing population may lead to serious consequences for local food security and livelihoods (Sheikh et al., 2012). Climate change may aggravate the situation if not managed adequately and in a timely manner.

To ensure food security and to protect rural livelihoods from the adverse impacts of climate change, effective adaptation at farm level is required (Abid et al., 2015). However, a major challenge at the local level is that farmers, as the key stakeholders, will have to face most of the adaptation burden themselves. Under perfect market conditions, farmers still may be better off and may get compensation for the increased cost of production in term of higher prices. However, this is not always true in the case of developing countries like Pakistan, where prices are mainly controlled by non-market forces (imperfect conditions) and farmers may suffer from increased production cost and lower returns. Hence, there is dire need for public adaptation policy that keeps in mind farmers' intentions and their adaptive capacities. Therefore, it is crucial from a policy perspective to understand the factors that drive farmers' adaptation decisions and the impact of their actions on farm production, which may vary across regions and scales (Niles et al., 2015). Also, it would be worthwhile to investigate the dynamics of gains from ongoing private adaptation measures to climate change. For example, if there are substantial short-term adaptation benefits, it could motivate policy makers to put in more effort to support farmers in the adaptation process by providing access to farm advisory services and technical support (Gorst et al., 2015).

Over the last decade, the literature on climate change and agriculture has evolved from mitigation studies (e.g. McCarl and Schneider, 2001; Metz et al., 2007) to impact assessments (e.g. Schlenker and Lobell, 2010; Seo and Mendelsohn, 2008) and adaptation studies (e.g. Alam et al., 2012; Bryan et al., 2013; Deressa et al., 2011; Mugi-Ngenga et al., 2016). Most of the literature on climate change adaptation in the agricultural sector is either focused on developed countries or developing countries in Africa. However, the adaptation literature showing the perspective of South Asian countries, especially Pakistan, is rare and only a few studies (e.g. Abid et al., 2015; Esham and Garforth, 2013) have analyzed agricultural adaptation to climate change from the farmers' perspective. Most studies of adaptation have highlighted farmers' experiences with changing climatic conditions, their adaptation strategies and determinants and identified relevant constraints for different regions and socio-economic settings. Empirical estimates of the effectiveness of adaptation efforts are scarce and only a few studies (e.g. Bastakoti et al., 2014; Bradshaw et al., 2004) have addressed this aspect at the

farm or local level. Thus, more studies focusing on the economic assessment of ongoing adaptation processes may indicate the extent of benefits and suggest policies for actions required to accelerate local adaptation (Abid et al., 2015).

Given this knowledge gap, this study takes the case of wheat farmers and investigates their adaptation to climate change and its impact on food productivity and crop income. Specifically, this study addresses four research questions. First, how do wheat farmers adapt to climate change? Second, how does adaptation vary across various types of farmers? Third, which factors influence wheat farmers' adaptation decisions in response to a changing climate? And fourth, how does adaptation to climate change affect food productivity and net crop income?

The paper is divided into four sections. After the introduction, Section 2 describes the conceptual framework, empirical modeling and methodology. Section 3 presents the results. Finally, Section 4 outlines the conclusion and implications of the results.

2. Material and methods

2.1. Study area and data collection

This study focuses on the Punjab province due to its significance for Pakistan's cereal production (74%) and agricultural gross domestic product (GDP) (53%) (Abid et al., 2015). Punjab is mainly divided into four agro-ecological zones: Irrigated plains, Barani (rain-fed) region, Thal region and Marginal land. In this study, we selected only three regions and excluded Thal region due to budget constraints. All three selected agro-ecological zones have a distinct climate, environment and geography and hence are subject to different kinds of environmental and socio-economic constraints. Fig. 1 shows the map of study areas located in Punjab province.

Further, we focus on wheat farming for two main reasons. First, wheat is the primary source of food in rural Pakistan and accounts for about 50% of the daily per-capita caloric intake in rural areas (Malik et al., 2014). Second, it accounts for about 46% of the total cropland and around 75% of the total area being used for cereals (Farooq et al., 2007). This widespread cultivation allows us to study wheat farmers across different regions to analyze the differences in adaptation strategies and to see how regional characteristics influence the choice of adaptation strategies and associated benefits.

Initially, we interviewed 450 farmers from three agro-ecological zones of Punjab province selected through a multi-sampling technique. Afterwards, we dropped the cases where farmers do not grow wheat crop. The final remaining sample was 442 farmers. The sampling procedure consisted of seven steps. In the first stage, Punjab was selected as the main study area. In the second stage, three agro-ecological zones were selected out of four and in the third stage we randomly selected three representative districts from the three agro-ecological zones; irrigated plains (Toba Tek Singh), marginal land (Rahim Yar Khan) and Barani (rain-fed) zone (Gujrat). Some parts of the Rahim Yar Khan also lie in irrigated plains. In the fourth stage, two sub-district divisions (*tehsils*) were randomly selected from each district. The fifth stage involved the selection of a certain number of rural union councils (UCs) from each sub-district division (*Tehsil*) using stratified random sampling and keeping in view the cropping patterns and distance of the UC to the city and to other UCs. In the sixth stage, a certain number of villages were selected from each UC using simple random sampling. In total, we surveyed 65

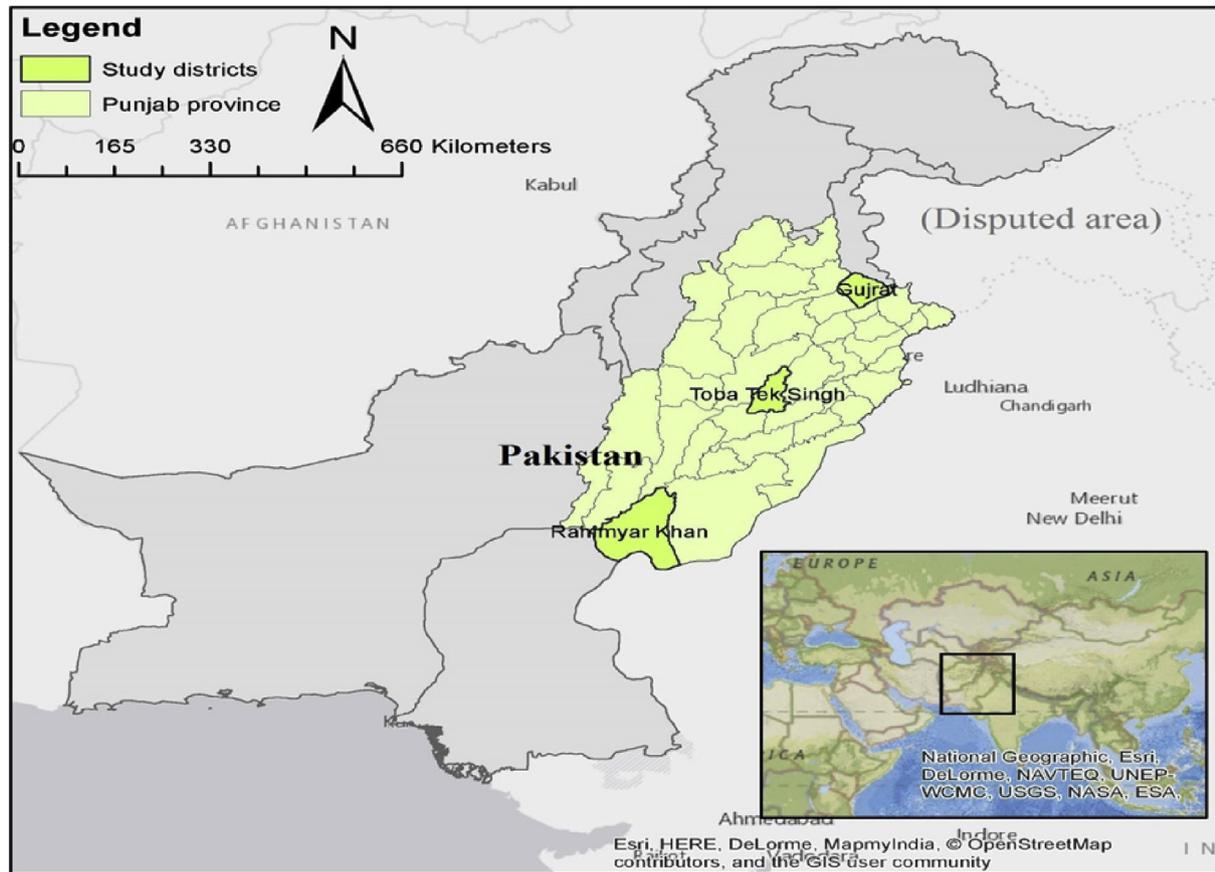


Fig. 1. Map of study districts in Punjab, Pakistan.

villages across the three regions. In the seventh stage, farmers were randomly selected from each village from a list of farmers collected from the revenue department. A pre-tested structured questionnaire was used for face-to-face interviews to collect information on the farmers' socio-economic characteristics, adaptation strategies, access to different institutional services and cropping technologies. The enumerators were trained prior to the survey about the study objectives and data collection tools.

2.2. Conceptual framework

The conceptual framework of this study is based on a top-down approach starting with climate change vulnerability at farm level and ending with implications for farm income and local food security (Fig. 2). As shown in Fig. 2, the study framework consists of three components; climate change vulnerability (left vertical box), adaptation processes (upper horizontal box) and farmers' wellbeing (lower horizontal box). Dotted and straight lines represent the interactions between the three components of the framework. Specifically, the dotted lines show adverse effects such as reduced productivity or farmers' wellbeing while straight lines show positive effects such as improved crop productivity or farm welfare through improved access to food. In this study (as shown in the first vertical box of Fig. 2), we defined climate change as perceived or observed changes in the local environment over the last ten to twenty years or more in terms of occurrence of extreme climatic events such as extreme temperature events, uncertain rains, floods or droughts (Bryan et al., 2013).

Climate change could affect farmers' wellbeing negatively (dotted line) directly or indirectly by affecting food productivity

and net crop income through reduced per hectare crop yields (Abid et al., 2015; Antwi-Agyei et al., 2014). Here, food productivity mainly refers to wheat productivity as wheat is the primary staple food in Pakistan. The adverse impact of climate change on food productivity may have direct implications for local food security by limiting the production of wheat grains. However, farmers could reduce losses from climate change by timely management of their crops accordingly. The adoption of certain measures at farm level may not only help farmers to reduce potential losses due to climate change, but it may also have positive impacts on crop productivity and net income. The improved crop productivity and revenue may ultimately improve food security at household level and hence improve farmers' wellbeing. In contrast, the no-adaptation pathway could potentially adversely affect crop productivity and farmers' wellbeing.

2.3. Analytical framework

2.3.1. Adaptation decisions

In this study, we defined adaptation to climate change as a measure to avoid losses due to changes in climatic indicators, temperature and precipitation. A farmer will be considered as an adapter if he implements certain wheat management measures and as a non-adapter if he does not. Following Kato et al. (2011), we use a random utility framework to model adaptation decisions of wheat farmers. We assume that the i th farmer will choose to adapt the wheat crop to climate change only if the expected net benefits from adaptation are positive (Abid et al., 2015). The adaptation benefits may include reduced crop losses or improved farmers' wellbeing. This difference in net benefits may be expressed in form of a latent

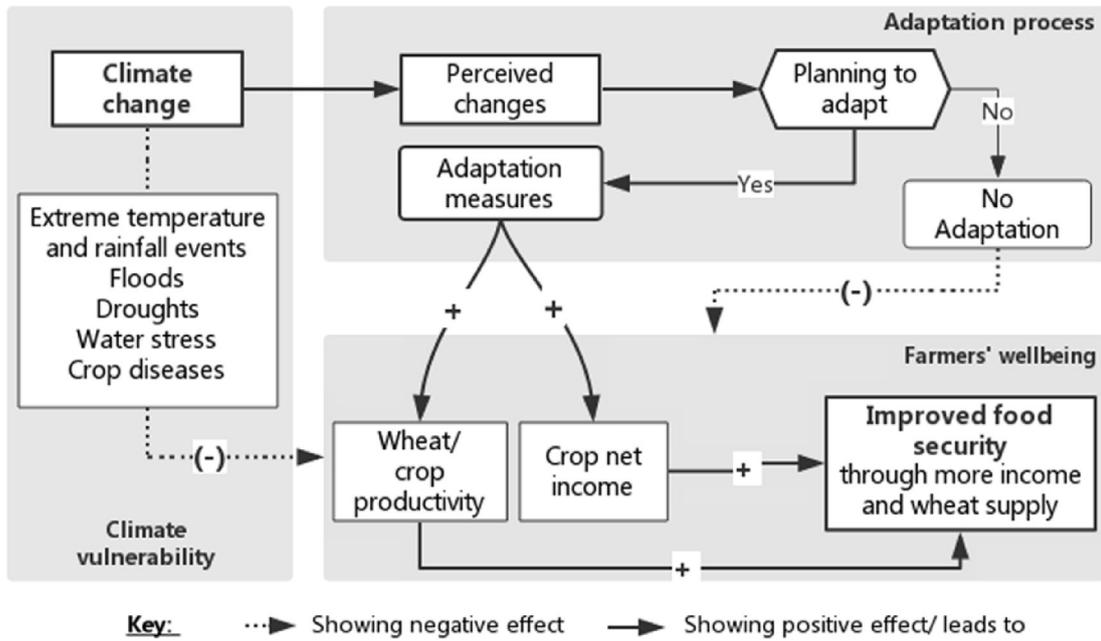


Fig. 2. Conceptual framework of the study showing interactions among climate change, adaptation and farmers' wellbeing.

variable (U_i^*):

$$U_i^* = \beta X_{ik} + \mu_i \tag{1}$$

where X_{ik} is the vector of k explanatory variables, β is the vector of logistic regression coefficients and μ_i is the error term. As the latent variable (U_i^*) is unobservable, we have only:

$$U_i = \begin{cases} 1 & \text{if } U_i^* > 0 \\ 0 & \text{if } U_i^* \leq 0 \end{cases} \tag{2}$$

where U_i indicates that the i th farmer will adapt his wheat cultivation to climate change ($U_i = 1$) only if the net benefits from adaptation are positive ($U_i^* > 0$). In contrast, the i th farmer will not adapt to climate change ($U_i = 0$) if the net benefits are non-positive ($U_i^* \leq 0$).

Efficient adaptation to climate change could help increase crop productivity and net income and hence could improve farm welfare. However, it might be difficult to differentiate between welfare of adapters and non-adapters. In cases where experimental data are collected through randomization and information on the counterfactual situation is recorded, it would be easy to distinguish the differences between adapters and non-adapters (Ali and Abdulai, 2010). For cross-sectional data, as is the case in this study, when no counterfactual information is available, the direct effect of adaptation could be calculated by looking at the differences in outcomes of adapters and non-adapters. However, these estimates may be misleading and biased.

To measure the net impact of adaptation on wheat productivity and net crop income, the issue of self-selection bias is crucial. To show the importance of self-selection bias, let us assume a reduced-form ordinary least square (OLS) equation that demonstrates the relationship between adaptation and outcome variables:

$$Y_{ij} = \lambda X_{ik} + \Psi U_i + \varepsilon_i \tag{3}$$

where Y_{ij} is the vector of outcome variables such as wheat productivity and net crop income for the i th farmer and ε_i is the error term. Similar to Eq. (1), X_{ik} represents the vector of explanatory variables and λ and Ψ are the regression coefficients. It might be possible that the decision to adapt (U_i), which is assumed to be independent in the above Eq. (3), may be influenced by some unobservable factors e.g. farmer's knowledge, perceptions or managerial skills which are already part of the error term (ε_i) of Eq. (3) (Ali and Abdulai, 2010). In other words, the error term (ε_i) of Eq. (3) may be correlated with the error term (μ_i) of Eq. (1) and the resulting selection bias may yield biased estimates (Kassie et al., 2011; Thoemmes, 2012). The literature shows various methods to address this selection bias. Some studies have adopted the Heckman two-step method that assumes a normal distribution of unobserved variables. Another method employs instrumental variables (IV). This approach usually requires at least one variable in the treatment equation to serve as an instrument for the specification of the outcome equation. Finding valid instruments is a challenge for many empirical analyses (Heckman et al., 1998). Moreover, both OLS and IV procedures restrict the model to take a linear functional form, implying that the coefficients on the control variables are similar for treatment and control groups (Ali and Abdulai, 2010).

2.3.2. Propensity score matching

Another widely used method to deal with the problem of selection bias is propensity score matching (PSM), which is also employed in this study. The PSM technique pairs the treatment (adapters) and control (non-adapters) groups based on the similarity of observable characteristics (Dehejia and Wahba, 2002). In contrast to the OLS and IV techniques, the PSM technique relaxes the assumptions of functional form, normal distribution of unobserved covariates and finding instrumental variables for the

specification of the outcome equation. It only requires a set of observable covariates for matching and to determine causal effects of treatment on the outcome variable (Heckman and Vytlacil, 2007). One limitation of PSM is that it does not account for the unobservable variables directly; rather it assumes that selection is based on observable variables. PSM can be a better choice when instruments are weak or not available (Ali and Abdulai, 2010).

Following Rosenbaum and Rubin (1983), we defined PSM as the conditional probability that a farmer adapts to climate change, given the pre-adaptation characteristics. Employing the conditional independence assumption for a randomized experiment, the PSM constructs a statistical comparison group by matching adapters and non-adapters based on the similarity of their predicted probabilities of adapting to climate change (p-score) (Kassie et al., 2011; Thoemmes, 2012). Once this assumption is set or X_{ik} is controlled for all unobserved factors, this implies that adaptation to climate change is random and uncorrelated with outcome variables. The PSM can be represented as:

$$p(X_{ik}) = Pr[U_i = 1 | X_{ik}] \quad (4)$$

where p shows the propensity scores of pre-adaptation characteristics (X_{ik}), Pr is the probability and U_i indicates the adaptation to climate change. The conditional distribution of X_{ik} is similar to both adapters and non-adapters (Thoemmes, 2012).

In summary, we can divide PSM into five steps. In the first step, a set of pre-test covariates is selected based on theoretical assumptions. The second step involves the estimation of propensity scores (p-value) using a logistic regression where outcome variables are regressed over the selected covariates (Kassie et al., 2011). In the third step, a matching procedure is conducted using the nearest neighbor method (NNM) for matching (Ali and Abdulai, 2010). In the fourth step, causal effects of adaptation on outcome variables are calculated. In the fifth and last step, a sensitivity analysis for matched data is employed to check the adequacy of the results (for more detail on the steps of PSM, please see Figure B.1 in Appendix B). In this study, the whole empirical analysis was conducted using the SPSS and R statistical packages.

2.3.3. Causal effect of adaptation to climate change

The effect of adaptation to climate change on outcome variables may be represented in terms of average treatment effect (ATE) or average treatment effect on the treated (ATT), where treatment refers to adaptation to climate change. The term ATE represents the overall impact of adaptation on the outcome variables considering all respondents, while the term ATT measures the impact of adaptation on the outcome variables only for the treated respondents (i.e. matched adapters and non-adapters). Following Ali and Abdulai (2010), the effect of adaptation on the outcome variables may be expressed as:

$$\tau_{U_i=1} = E(\tau | U_i = 1) = E(Y_1 | U_i = 1) - E(Y_0 | U_i = 0) \quad (5)$$

where τ is the average treatment effect (ATE) for all respondents (in our case treatment is the adaptation to climate change) and Y_1 and Y_0 shows the values of the outcome variables for adapters and non-adapters respectively. As discussed above, we do not observe $E(\tau | U_i = 1)$ directly, although we can estimate the difference [$\tau^e = E(Y_1 | U_i = 1) - E(Y_0 | U_i = 0)$] which is a bias estimator. To account for this selection or hidden bias, we can employ the propensity score model (PSM) (Dehejia and Wahba, 2002).

As we are more interested in the average treatment effects on

the treated (ATT), so it can be computed after estimating the propensity scores as:

$$\begin{aligned} T &= E\{Y_1 - Y_0 | U_i = 1\} = E[E\{Y_1 - Y_0 | U_i = 1, p(X)\}] \\ &= E[E\{Y_1 | U_i = 1, p(X)\} - E\{Y_0 | U_i = 0, p(X)\} | U_i = 0] \end{aligned} \quad (6)$$

where T indicates the ATT and $p(X)$ indicates the propensity scores as explained in Equation (4). As discussed above, we here employed the NNM method which involves selecting individual cases (wheat farmers) from both groups of adapters and non-adapters as matching partners based on their closeness to each other. The closeness is measured by using propensity scores. The NNM method matches the adapters and non-adapters and excludes the unmatched cases from both groups (Smith and Todd, 2005). In other words, we could say that ATT is acquired after subtracting the effect of selection bias (the inherent differences between the adapters and non-adapters) from the ATE.

2.3.4. Sensitivity analysis

The key purpose of the PSM is to stabilize the estimated distribution of covariates across the groups of adapters and non-adapters (Lee, 2013). If there are some unobserved factors that simultaneously affect the adaptation decision and outcome variables, a hidden bias problem might arise and matching estimates will not be robust (Rosenbaum, 2002). Hence, after matching, we perform a series of model adequacy tests to ensure that there are no systematic differences in the distribution of the covariates between groups of adapters and non-adapters (Ali and Abdulai, 2010). Available indicators include pseudo R^2 , F-statistics, the Hosmer and Lemeshow test and standardized mean differences before and after matching. Further, we also use the Rosenbaum (2002) bound test to check the sensitivity of the estimated average adaptation effects (ATT) to hidden bias by calculating the Wilcoxon signed rank. The p-value of the Wilcoxon signed rank test tells us how significant the treatment effect is (Keele, 2010; Rosenbaum, 2007). If the p-value is less than the usual 0.05 threshold, we reject the null hypothesis of no treatment (adaptation) effect.

3. Results and discussion

3.1. Farm and household descriptive statistics

Table 1 presents the description and summary statistics of the variables used in the study. The differences in characteristics of adapters and non-adapters show how important these factors are to understand local adaptation to climate change. The table shows that wheat yield, net crop and farm income were found to be slightly higher in the case of adapters than of non-adapters. Likewise, adapters had more farming experience, education and more land under cultivation compared to non-adapters. These results are in line with the findings of other studies (e.g. Abid et al., 2015; Antwi-Agyei et al., 2014; Bastakoti et al., 2014), which found that educated and experienced farmers adapted more compared to less educated and less experienced farmers. It might be possible that educated and experienced farmers were more observant and better informed than less educated and less experienced ones about the ongoing changes in the environment and ultimately adapted more. Likewise, adapters had larger-scale farms and more access to institutional services (e.g. extension, credit and market information, weather forecasting) than non-adapters. These findings confirm that access to institutional services may have a positive

Table 1
Description, units and statistics of variables used in the study.^b

	Adapters	Non-adapters	Difference ^a
Wheat yield (tons/hectare)	4.08	4.05	0.03
Wheat net returns (thousand PKR/hectare)	75 (\$743)	74 (\$733)	1 (\$9.9)
Total returns from wheat crop (thousand PKR)	278 (\$2752)	276 (\$2736)	2 (\$17)
Total farm income (thousand PKR)	1050 (\$10,395)	1041 (\$10,308)	8.8 (\$87)
Farming experience (years)	26.55	23.31	3.25
Education (years of schooling)	9.62	7.95	1.68
Household (HH) size (numbers)	9.91	9.58	0.33
Household head (1 if farmer is HH's head, zero otherwise)	0.76	0.77	−0.01
Agricultural source of income (1 if agriculture is the main income source, 0 otherwise)	0.62	0.63	−0.01
Wheat area (hectares)	9.34	5.18	4.16
Tenancy (1 if farmers is owner-cultivator, zero otherwise)	0.73	0.85	−0.11
Tube well (1 if farmer owned a tube well, zero otherwise)	0.68	0.61	0.07
Soil fertility (1 if soil is fertile, zero otherwise)	0.56	0.67	−0.10
Credit services (1 if farmer had access, zero otherwise)	0.10	0.09	0.01
Extension services (1 if farmer had access, zero otherwise)	0.27	0.25	0.02
Market information (1 if farmer had access, zero otherwise)	0.70	0.65	0.05
Weather forecasting information (1 if farmer had access, zero otherwise)	0.92	0.79	0.13
Rahim Yar Khan (1 if farmer belonged to the district, zero otherwise)	0.35	0.31	0.04
Toba Tek Singh (1 if farmer belonged to the district, zero otherwise)	0.21	0.40	−0.19
Observations	149	293	

^a The difference is calculated by subtracting averages of non-adapters from averages of adapters.

^b Here we used the average exchange rate for year 2013 (1 \$ = 101.01 PKR), when the survey was actually carried out.

impact on the farmers' adaptation decision. These results agree with the results of Bastakoti et al. (2014) and Bryan et al. (2013). However, non-adapters were found to have a larger household size and greater dependence on agricultural income. This implies that higher dependency of a household on agriculture may restrict farmers from adapting to climate change.

3.2. Farm level perceptions of and adaptation to climate change

To investigate the farmers' current understanding of climate change and farm level adaptation processes, we jointly assessed the perceptions of farmers along with planned and actual adaptation measures to perceived changes in climate across three study districts (Fig. 3). Results show a substantial reduction in farm-level responses moving from perception to planning and adaptation. On average, 80% of the farmers perceived changes in climate over

the past 10–20 years. Still 75% of farmers planned some adaptive measures to observed changes but only 37% of the farmers actually implemented adaptation measures for wheat cultivation. The same trend can be seen in all three study districts. The difference between perceptions, planning and actual adaptation may be due to some internal or external constraints that limit adaptation to climate change in the study districts.

Farmers adopted various measures to adapt their wheat crop to climate change across the three study districts (Fig. 4). Overall, the major strategies were changing planting dates, changing crop variety and changing fertilizer types such as urea, diammonium phosphate, nitrophos and single superphosphate. Modified planting dates include both early and delayed sowing depending on weather conditions. As discussed earlier, the majority of the adapters use weather forecasting information from different sources to adjust management options, particularly the wheat planting

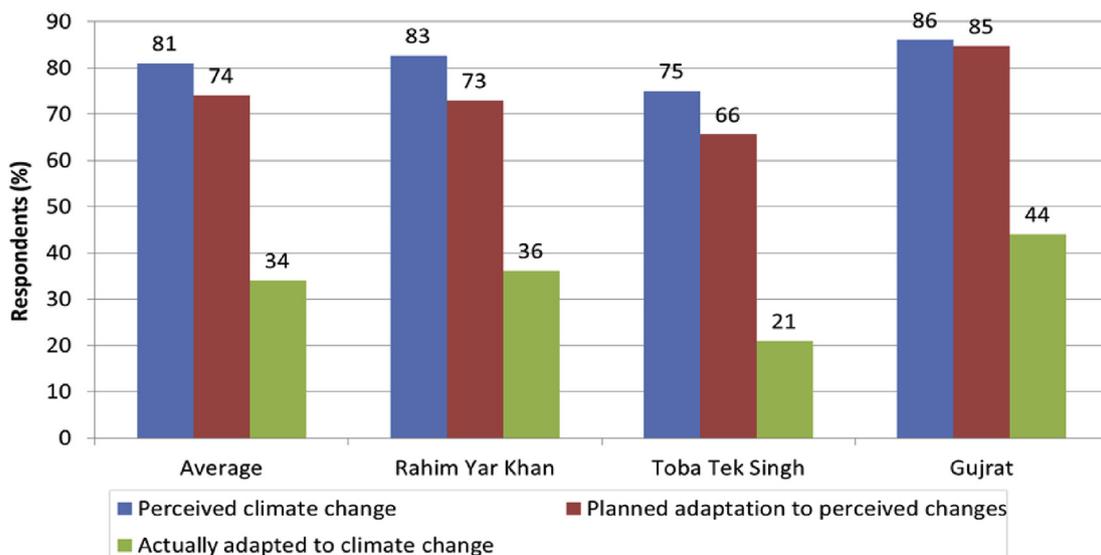


Fig. 3. Average difference between perceptions, planning and actual adaptation to climate change.

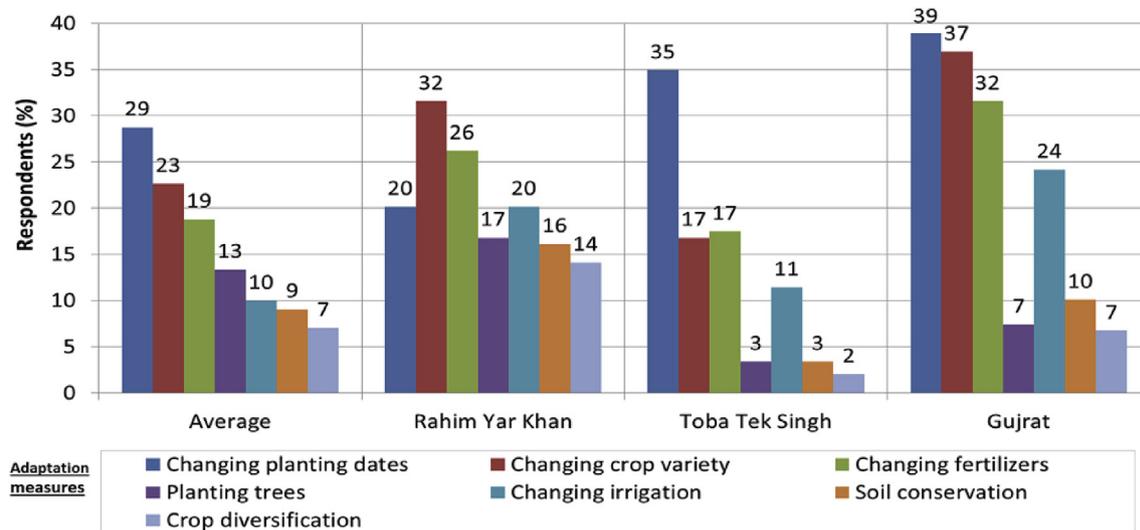


Fig. 4. Adaptation measures used by wheat farmers in three study districts of Punjab. Note: The sum is greater than 100 because some adaptation measures can be selected simultaneously.

dates. For instance, farmers in the *Barani* (rain-fed) region used this technique more often due to their higher dependence on rainfall for wheat sowing. Further, crop variety adaptation includes switching from traditional wheat varieties to heat and drought-tolerant varieties to protect the crop from increasing temperature and water shortage. The implementation of adaptation measures by farmers in the three study regions differs according to regionally relevant crop needs and environmental problems. For instance, in Rahim Yar Khan, changing crop variety was the primary adaptation measure adopted by farmers while changing planting dates was the major adaptation measure adopted by farmers in Gujrat and Toba Tek Singh. These findings may be supported by the findings of other studies (e.g. Asif, 2013; Bukhari and Sayal, 2011), which reported an increasing water shortage in rain-fed (including Gujrat) and semi-arid regions (including Toba Tek Singh) due to ongoing climate change. Similarly, Ahmad et al. (2013) also reported a shift in planting dates in rain-fed regions due to climate change. Interestingly, most of the adaptation measures implemented by wheat

farmers were of short-term nature. Long-term measures such as crop diversification and soil conservation were the measures adopted least often by farmers across all three study regions. This may imply that either farmers do not have sufficient funds to implement advanced measures or they do not have proper knowledge about advanced measures. Several other studies (e.g. Bryan et al., 2013; Deressa et al., 2009; Gbetibouo, 2009) have identified the existence of various resource and financial constraints that restrict farmers to effectively adapt their crops to climate change.

Further, we analyzed the farm level adaptation measures across different categories of farmers, i.e. the size of their land holdings and their educational level (see Fig. 5 (a, b)). Concerning farm size, farmers were divided into three categories: 1) small-scale farmers, who owned up to 2 ha of land; 2) medium-scale farmers, who owned 2–5 ha of land; and 3) large-scale farmers, who owned more than 5 ha of land. Regarding their educational level, farmers were divided into two categories: 1) illiterate or less educated

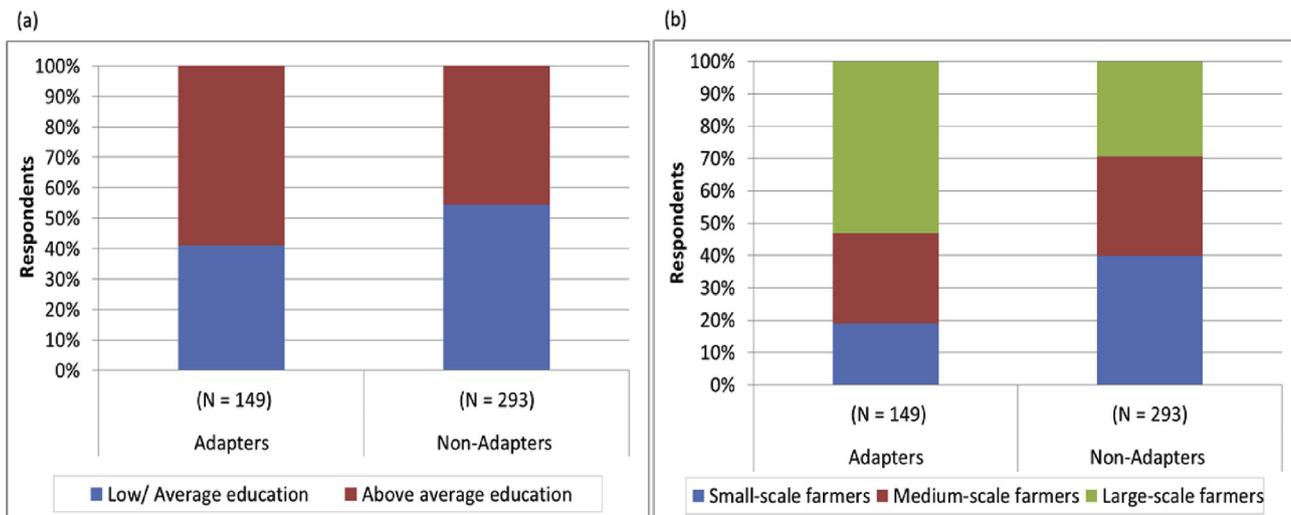


Fig. 5. (a)–(b) Distribution of adapters and non-adapters with respect to their education and size of land holding (% of group sample).

farmers with less than eight years of schooling and 2) educated farmers with eight or more years of schooling.

The results in Fig. 5a show a positive association of adaptation decisions with education level. About 39% of the farmers with above-average education adapted to climate change, while of the farmers with below-average education, only 27% adapted to climate change. Similar positive associations of adaptive behavior with education were reported by Wood et al. (2014) and Bryan et al. (2013). Furthermore, Fig. 5a shows a higher rate of adaptation for large-scale farmers compared to the small-scale farmers. The share of large-scale farmers was 53% among adapters but only 29% among non-adapters. The proportion of medium-scale farmers was similar for adapters and non-adapters. Small-scale farmers, on the other hand, comprised only 19% of the adapters but 40% of the non-adapters. This suggests that large-scale farmers faced fewer restrictions to adapt to climate change. These results are in line with findings of Sahu and Mishra (2013) who reported a positive relationship between land holding and adaptation to climate change. These results are in line with the findings of previous studies on farm level adaptation (e.g. Bryan et al., 2013; Silvestri et al., 2012), which indicated a positive relationship between education and adaptation to climate change.

3.3. Empirical results

3.3.1. Results of propensity score matching

As described above, the matching process starts with the estimation of propensity scores for the treatment variable. For this purpose, we used a logistic regression model, where the probability of adapting to climate change was regressed to a number of covariates. The results of estimation of the propensity score are reported in Table 2.

The results indicate that many of the households and farm-specific variables influence the probability of climate change adaptation. In particular, farming experience, education, an agricultural source of income, market information and weather forecasting information have positive coefficients and tend to expedite adaptation to climate change. These findings confirm our expectations from before the survey and also agree with the findings of other studies (e.g. Bryan et al., 2013; Deressa et al., 2009; Hassan and Nhemachena, 2008; Nabikolo et al., 2012).

Table 2
Estimation of propensity scores through logistic regression.

	Estimate	Standard error	z-value
Farming experience (years)	0.04	0.01	3.46***
Education (years)	0.13	0.03	4.16***
Household size (numbers)	0.02	0.02	0.94
Household head (dummy)	-0.15	0.29	-0.54
Agricultural income source (dummy)	0.56	0.29	1.94**
Area under wheat crop (hectares)	0.00	0.01	-0.09
Tenancy status (dummy)	-0.84	0.28	-3.00***
Tube well (dummy)	0.29	0.24	1.18
Soil fertility (dummy)	-0.33	0.25	-1.32
Farm credit (dummy)	-0.12	0.40	-0.29
Agricultural extension (dummy)	0.11	0.29	0.36
Market information (dummy)	0.65	0.27	2.39**
Weather information (dummy)	0.86	0.36	2.38**
District R.Y. Khan (dummy)	-0.77	0.37	-2.08**
District T.T. Singh (dummy)	-1.61	0.38	-4.24***
(Intercept)	-2.88	0.70	-4.11***
Number of observations		442	
Hosmer p-value		0.33	
Pseudo R-squared		0.23	

***, ** and * show the significance at 1%, 5% and 10% probability levels, respectively.

On the other hand, tenancy status (if the farmer is the owner-cultivator), soil fertility, farm credit and location of the farmer in either Rahim Yar Khan or Toba Tek Singh have negative coefficients. Unlike the findings of some studies (e.g. Fosu-Mensah et al., 2012; Iheke and Agodiike, 2016) mainly conducted in Africa, a negative coefficient of tenancy status in this study implies that owner-cultivators were less likely to adapt to climate change compared to the tenants or sharecroppers. The differences in adaptation intentions between tenants and owner-operators may be due to the differences in their educational status, household dependency and resource access. For instance, here in this study the tenants were found to be more educated and have larger households than the owner-operators, which may be the cause of their higher adaptation intentions. Another potential reason may be the tenants' plan to maximize their profit to offset the land rents and to sustain a larger household. Similar to our findings, Javed et al. (2015) and Nabikolo et al. (2012) also reported a negative association of land tenancy and adaptation behavior. According to Javed et al. (2015), higher dependency on farm income and payment of land rents may be the main reasons behind tenants' adaptation intentions (Javed et al., 2015). The negative coefficients for regional dummies imply that farmers in both districts (Rahim Yar Khan and Toba Tek Singh) were less likely to adapt to climate change compared to the farmers located in Gujrat district. This may be due to the fact that farmers in Gujrat were more concerned about climate change as their farming is more dependent on climatic factors, particularly rainfall.

3.3.2. Farm level adaptation impacts on food productivity and crop income

After calculating the propensity scores, the nearest neighbor matching (NNM) method was employed to match the control group of individuals (non-adapters) to the treated group (adapters) based on similar propensity scores. During the matching process, the NNM discards the unmatched non-adapters and hence, it leads to the reduction in sample size from 442 to 298 for the post-matching impact analysis (Figure B.2 in Appendix B show the distribution of propensity scores of matched and unmatched individuals in both groups). In the next step, we calculated the average adaptation effects on the wheat productivity (t/ha) and per hectare net crop income before matching (ATE) and after matching (ATT) (Table 3).

The post-matching results reveal that adaptation tends to positively and significantly affect wheat productivity and crop income. The values of ATT illustrate that adapters produced 0.14 t/ha more wheat than non-adapters. Further, adaptation generates PKR 5142 (\$51) per hectare more returns for adapters. However, the ATE values depict larger yield gains (0.23 t/ha) and higher crop income improvements (PKR 7370 (\$73) per hectare) compared to the ATT estimates. Mainly, the difference between the ATT and ATE values is due to the selection bias that comes from the effect of other observable factors and was removed using the propensity score matching technique. If the matching procedure was not performed before the estimation of adaptation impacts, the results might be biased and misleading.

Higher productivity and higher crop income for adapters also implies a positive impact of adaptation on overall farmers' wellbeing. In addition, the higher yield impacts of adaptation (0.14 t/ha) may lead to the supply of extra 457,800 kcal per hectare which could indirectly improve the local food security situation to some extent by reducing the gap between supply and demand of food calories. These results are generally in line with the findings by Gorst et al. (2015) for different regions of Pakistan, where adaptation shows a positive impact on wheat, cotton and rice yields.

Table 3
Impact of adaptation on wheat productivity and net crop income.

	Wheat yield (tons/ha)	Net crop income (PKR/ha)
Number treated (Adapters)	149	149
Number control (Non-adapters)	149	149
ATE	0.23 (0.002)*	7370 (1.86)*
ATT	0.14 (0.003)*	5142 (1.37)*
Wilcoxon signed rank (WSR) P-value	0.04	0.02
Confidence interval for treatment effect (C.I.)	1.05–1.10	1.10–1.15

* shows the significance at 10% probability level.

Table 4
Indicators of covariate balancing before and after matching.

Indicators of covariates balancing	Before matching	After matching
Pseudo R2	0.23	0.05
p-value of Likelihood ratio	0.00	0.72
F-stat value	81.42 (0.00)	11.40 (0.29)
Hosmer and Lemeshow test values	11.14 (0.33)	9.18 (0.19)
Mean standardized difference	0.18	0.07
Total% bias reduction	–	61

Values in parenthesis show the significance level (p-value).

As discussed earlier, different measures were used to ensure the adequacy of the results. Table 4 demonstrates the indicators of the matching quality from the matching model. The results indicate a decline in the model goodness of fit (pseudo-R2) after matching, which implies that after matching there is no systemic difference in the distribution of covariates between adapters and non-adapters and therefore any difference in the outcomes of both groups would only be due to the adaptation. Further, the significance level (p-value) for the likelihood ratios shows a shift from a highly significant model to a highly insignificant model after matching, which depicts that the covariates are no more associated with adaptation decisions after matching. The F-value of models also demonstrates the overall insignificance of the model after matching and the same applies for the Hosmer and

Lemeshow test which shows a decline in model estimation power after matching. The mean standardized difference for distance has also declined, and matching shows overall 61% reductions in selection bias. All results reveal that substantial reduction in bias was obtained through matching and the model is no more dependent on observable factors as it was before matching.

The results of the Rosenblum's sensitivity analysis for the presence of hidden bias are shown in Table 3. Generally, the results agree with findings from other studies (e.g. Faltermeier and Abdulai, 2009; Kassie et al., 2011). For instance, for the impact of adaptation to climate change on wheat yield, the sensitivity analysis recommends that at confidence interval (CI) = 1, the mean difference in the per hectare wheat yields between adapters and non-adapters is 0.14 t/ha if there is no selection bias. Furthermore, at CI = 1.15, the causal inference of the significant treatment (adaptation) effect needs to be critically observed, which implies that the significance of the treatment effect on wheat yield may be questionable if individuals (farmers) differ in their odds of adapting to climate change by a factor of 15%. The critical value of CI for the adaptation impact on wheat net crop income is 1.10, which implies that the treatment (adaptation) effect may change if the covariates differ by 10% from current values. Hence, based on the results of the sensitivity analysis, we can reject the null hypothesis of no treatment

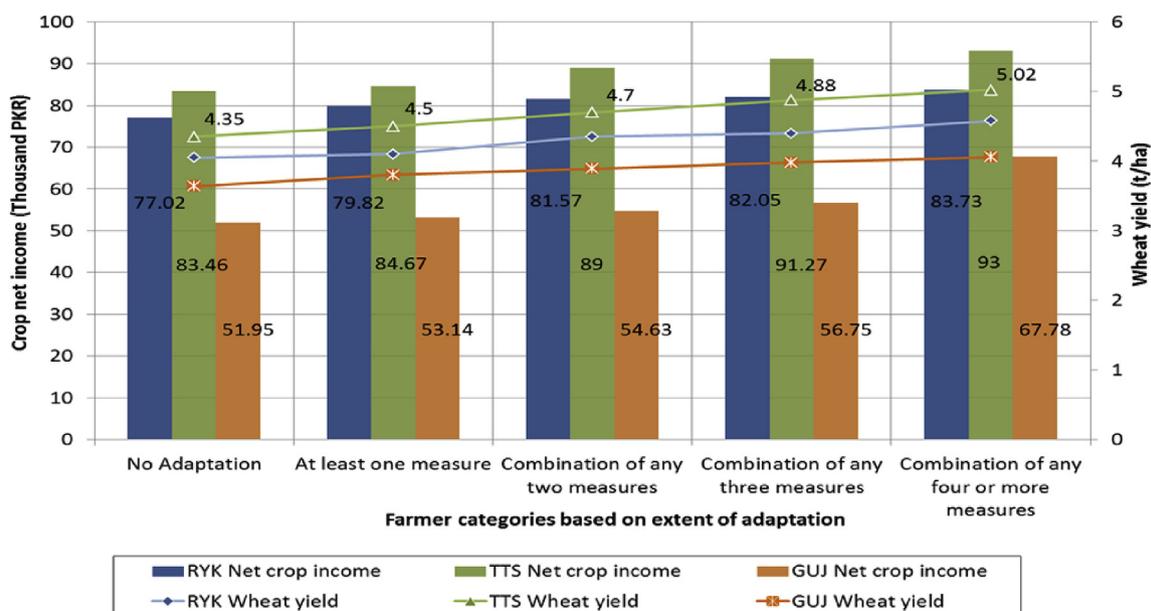


Fig. 6. Wheat productivity and net crop income among farmers' categories based on the extent of adaptation. * here RYK, TTS and GUJ stand for Rahim Yar Khan, Toba Tek Singh and Gujrat respectively.

(adaptation) effect on outcome variables. We can conclude that adaptation has a significant positive impact on crop yield and net crop income.

Furthermore, we compared the wheat productivity and net crop income of different categories of farmers based on their extent of adaptation or number of adaptation measures (Fig. 6). The results indicate that wheat yield and crop income increases with the increase in the extent of adaptation. This implies that farmers who adopted more adaptation measures achieved higher wheat yields (t/ha) and net income levels (PKR/ha) than non-adapters or farmers who took fewer adaptation measures. These findings are in line with the findings of other studies (e.g. Ahmed et al., 2015; Gorst et al., 2015) conducted in a similar context.

4. Conclusions and policy implications

Climate change is expected to adversely affect agricultural productivity and rural livelihoods in Pakistan. Thus, timely adaptation is desirable to reduce potential losses at the farm level. This case study analyzes wheat farmers from rural Pakistan and provides insights into their adaptation to climate change, their determinants and impacts of adaptation on food productivity and crop income.

The study reveals the extent to which farmers perceive climate change and adapt their wheat crop accordingly. While relatively many farmers recognize climate change as a real and ongoing development, we find a substantial reduction in farm-level responses moving from perception to planning and adaptation given the existence of various information, resources and financial constraints. Farmers adapt their wheat crop to climate change ranging from short-term to long-term measures. The key adaptation measures across all three regions include changing planting dates, crop varieties, fertilizer types and planting trees. However, adaptation decisions are significantly affected by various internal and external factors. In particular, education, farming experience, access to agricultural extension, weather forecasting, marketing information and agricultural income source were the important factors influencing the farmers' adaptation decision. In addition, the study also reveals that large-scale farmers adapt more than small-scale farmers adapt, which also shows the importance of access to resources for adaptation to climate change.

Moreover, the empirical findings of the study confirm that adaptation tends to increase wheat productivity and net income at the farm level. These gains show the effectiveness of adaptation at farm level and its contribution to overall caloric supply to a household. Current adaptation is found to be dominated by short-term and less costly measures and shows room for improvement if proper support and information is provided at the farm level. In addition, the study also finds that adaptation benefits increase with the use of more combinations of different

adaptation measures compared to single measures. This also shows that utilizing the full adaptation potential may not only help farmers to enhance their livelihoods but it may also support local food security. To fully utilize the benefits of adaptation, region-specific policies need to be designed, keeping in mind climate-related risks and farmers' needs in the particular area.

Overall, the study confirms and quantifies the claim that farm-level adaptation provides substantial benefits to farmers through improved incomes and to society through improved food security. However, farmers are yet unable to enjoy all the advantages of adaptation due to various constraints and lack of information on improved adaptation options. Here, the government, private sector organizations and non-governmental organizations may play a major role in addressing these constraints through active collaboration for the capacity building and education of farmers, easy access to climate-specific information and awareness on improved adaptation measures. Further, agricultural policies need to be updated based on on-the-ground research and attention should also be given to resource-constrained and small-scale farmers, who account for more than two-thirds of the total farming population in Pakistan. All these implications may lead to better adaptation of food crops to climate change and may be able to support farmers to improve their crop yields and ensure local food security.

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Appendix A. Gaps between supply and demand of energy calories from wheat grains in Pakistan

Table A.1
Supply and demand of per capita wheat calories in Pakistan.

Year	Population (in thousands)	Annual wheat supply and demand (thousand tons)		Annual per capita wheat calories (Kcal)		
		Total production	Net consumption	Supply	Demand	Gap
2010	184,405	23,311	20,980	372,030	405,480	33,450
2011	187,343	25,214	22,693	396,091	405,480	9,389
2012	190,291	23,473	21,126	363,028	405,480	42,452
2013	193,239	24,211	21,790	368,730	405,480	36,750
2014	196,174	25,286	22,757	379,340	405,480	26,140

Source: (own calculations based on FAO, 2015).

Caption: Annual per capita wheat calories are calculated at rate of 3270 thousand kcal per ton of wheat grain. The supply of per capita wheat calories is derived from net consumption available to the households while the caloric demand is calculated at the annual per capita requirement of 0.125 ton of wheat grains in Pakistan.

Appendix B. Propensity score matching procedure

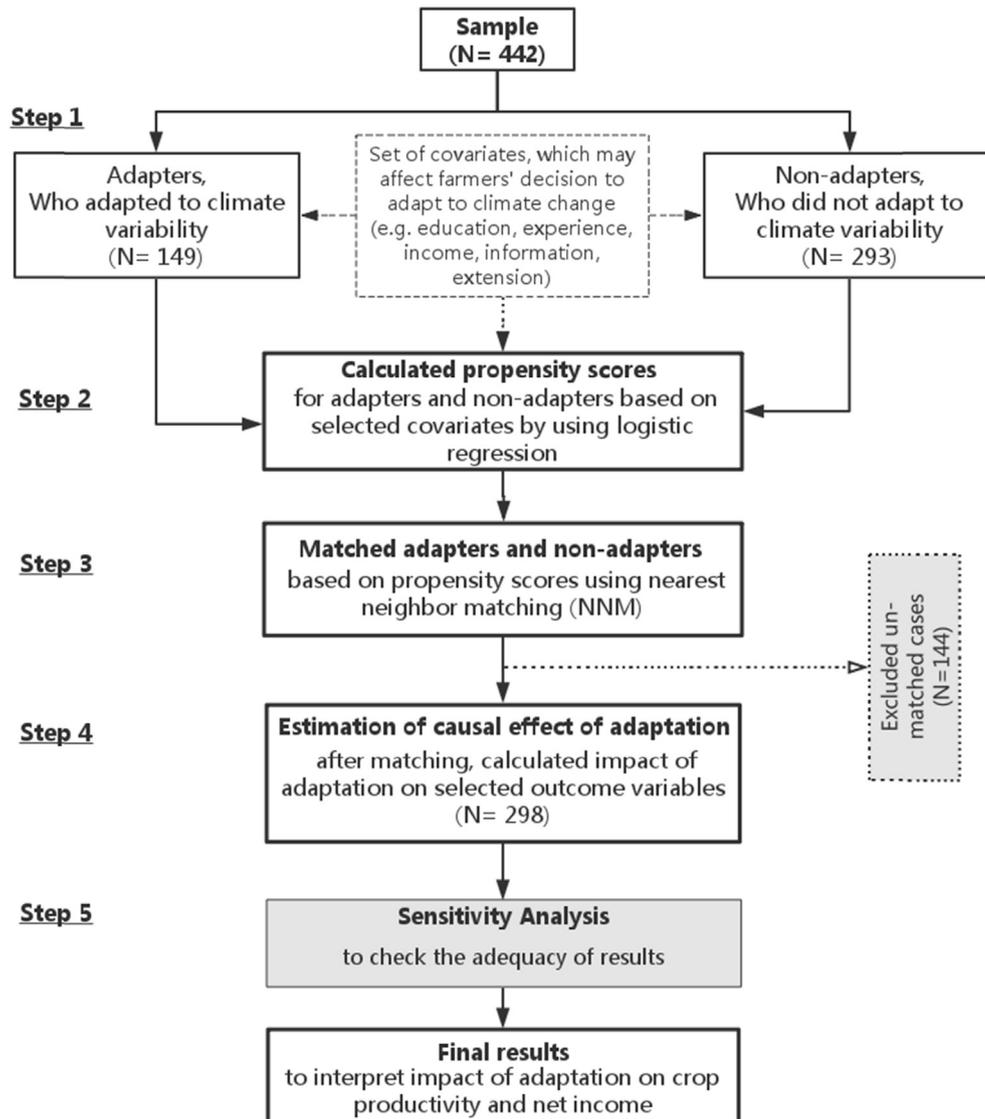


Fig. B.1. Steps involved in performing propensity score matching (PSM).

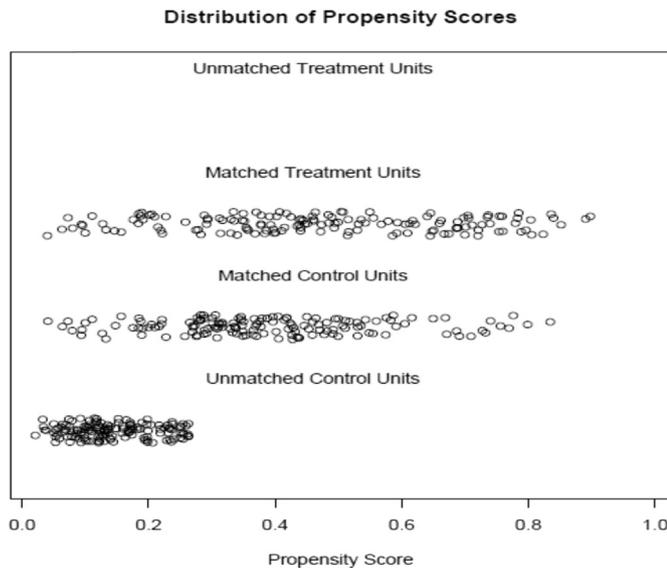


Fig. B.2. Distribution of propensity scores.

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5 Farmers' decision-making of agricultural land use under climate change and policy scenarios: a multi-farm model for Pakistan

5.1 Introduction

Projected changes in climate pose a serious threat to food production and local livelihoods worldwide (Wood *et al.*, 2014). Particularly, changes in temperature, rainfall and frequency of extreme events such as droughts and floods threaten the ability of current farming systems to meet regional goals for food security and economic growth. The negative effects of climate change on crop yields are likely to be stronger in warmer regions where increases in temperature will have large impacts (Funk and Brown, 2009; Lobell *et al.*, 2011; Gourdjji *et al.*, 2013). Unfortunately, most of the warmer regions include poorer countries, where populations mainly live in rural areas and rely on climate-sensitive agriculture (Schlenker and Lobell, 2010; Wood *et al.*, 2014). Thus the impacts of climate change are likely to be fall disproportionately on poorer nations and rural households within those nations (Gourdjji *et al.*, 2013; Wood *et al.*, 2014).

To reduce the negative effects of climate change on agriculture, current farming systems and related land management decisions need to be adapted (Jarvis *et al.*, 2011). In this regards, understanding and awareness among farming communities is very important as they are the key decision makers of land management choices at farm level. These decisions further determine the land use and cover changes (LUCC) at local and regional scale (Rindfuss *et al.*, 2004). However, Farmers' decision-making of land use is a complex process and depends on several internal as well as external factors (Deressa *et al.*, 2011). Internal factors are the factors that are inherent to farmers from their local environment, socio-economic and personal settings. These factors include family composition, farm type, size of land holding, farming activities and own beliefs (Gbetibouo, 2009; Deressa *et al.*, 2011; Esham and Garforth, 2013). External factors relate to the socio-economic and biophysical context (Deressa *et al.*, 2011) and include climate conditions, commodity market structure, resource constraints, access to technologies, and exposure to policies (Bryant *et al.*, 2000; Bryan *et al.*, 2011; Abid *et al.*, 2016b). Internal factors mainly determine the willingness and ability of a farmer or decision maker to take certain decision, while external factors influence the range of farmers' options (Lambin *et al.*, 2001; Lambin *et al.*, 2003).

Understanding farmers' land management decision-making is of interest to policy makers and scientific communities in the developing countries such as Pakistan where agriculture, a key source of livelihood for population, is exposed to extreme climatic and environmental risks (Nguyen *et al.*, 2016). Such research is important to understand the interactions between farmers' decision-making, socio-economic and environmental settings and their impact on farmers' wellbeing (Schilling *et al.*, 2013). A greater volume of research on farmers' decision-making of land use and land cover changes and related aspects is available from both developed and least developed countries (Lambin *et al.*, 2003; Hageback *et al.*, 2005). However, the literature specifically focusing on climate change and its effects on farmers' decision-making and welfare is still growing in developing countries. The same applies to Pakistan, where much of the research on climate change and agriculture at regional or national scales using statistical methods has provided insights into impacts (e.g. Hussain and Mudasser, 2007; Hanif *et al.*, 2010b; Ashfaq *et al.*, 2011; Nomman and Schmitz, 2011) but has been unable to address the associated household level dynamics and changes in the decision-making and their impacts on farm welfare (Abid *et al.*, 2016b).

Keeping in view the existing research gaps, this study establishes a multi-farm model for Pakistan to investigate the effect of climate change and policy scenarios at farm level land use decision-making and welfare. Specifically, this study has three objectives: 1) to examine the effect of different socio-economic and policy settings on farmers' land use decision-making and welfare, 2) to determine the effect of climate-related factors and changes on farm level decision-making of land use and welfare and 3) to assess the impact of adaptation strategies on the farm level welfare.

5.2 Model design and structure

5.2.1 Model Framework

The multi-farm model is based on a simplified mathematical structure of the Agricultural Sector and Mitigation of Greenhouse Gas Model (ASMGHG), a partial equilibrium model linking agricultural commodity markets to regionalized cropping systems, developed by (Schneider *et al.*, 2007). This model focus on farmers using farm level data of crop and livestock management collected from different agro-ecological regions in order to calculate

the welfare changes aggregate level. The narrowing down from regional to farm level gives more accurate picture of use of resources and technologies and their impact on welfare at farm level.

This model has a dynamic characteristic as it takes into consideration the different external factors that may affect the farmers' welfare and decision-making over time. These factors include environmental factors such as climate change and farm-specific characteristics and market factors such as market prices that may affect farmers' willingness or ability towards endowment of resources and choice of specific crop.

5.2.2 Model structure

The multi-farm model maximizes the net farm revenue using three study regions, several products, products, farms and resources. Crop management activities are the main decision variables. The multi-farm model is constructed to emulate the decision-making process of heterogeneous farmers by maximizing their total net revenues subject to different resource endowment, production, land management and crop mix constraints (Table 5.1). These constraining equations are formed to represent physical, technical and other restrictions faced by farmers. Also, we assess the impact of different external factors on farm level welfare in different regions. Currently, the model is static but may be further extended to different time horizon as it is indexed over time. Prices are exogenously determined for various regions for Pakistan. The current model is established only for three study regions in Punjab but may be extended to the whole province and then to the national scale. The model covers eight crops, wheat, sugarcane, rice, sorghum, millet, berseem, winter and summer maize and four livestock species i.e. buffalo, cow, goat, and bull. Berseem and sorghum were mainly introduced as the fodder crop and used as input for feed processing. All crop production activities include both rain-fed and irrigated agriculture. For irrigated agriculture, the model considers further four management options such as irrigated canal, irrigated groundwater, and mixed irrigation while for rainfed regions only rainfall and groundwater irrigation options are considered. Further, livestock management includes semi-controlled and open-shed.

Solving the optimization model requires finding an optimal level for all endogenous variables subject to compliance with all constraints. The optimal solution of decision variables

maximizes the total net revenue over all included farms. In this model, the economic surplus is computed as the sum of producer revenue minus the variable cost of production and cost of land use change. The multi-farm model is based on farm household data collected from three sample regions through face-to-face interviews with 450 farm households (for further details on sampling and data collection procedure please refer to Chapter 1 of this thesis).

Table 5.1. Model equations and variables

Feature	Item	Description
Objective equation	Farmer welfare	The sum of producer revenue minus all specific and unspecific production cost; feed processing cost and cost of land use change.
Equations	Resource endowment	This equation depicts the use of each production factor or resource for agricultural and livestock production
	Production equation	This equations limits production and processing activities under crop and livestock management
	Crop mix equation	This equation is related to farmers' decision-making of crop choices which are restricted to a linear combination of historical cropping pattern. Cropping activities are restricted to a linear combination of historically observed choices.
	Land use equation	This equation limits the area allocated to major land use to not exceed the initial area for this category plus the area added from leasing in from other farmers located in the same region.
	Land use maximum equation	This constraint limits the endowment of land in each region in each year to the given endowments.
Decision variables	The cultivated area of each crop	Cultivated area for wheat, sugarcane, rice, millet, berseem, sorghum, summer and autumn maize

Before giving the detailed description of the equations used in the model, we provide a brief overview of variables and parameters used in the equations. The level of economic activities such as production or consumption is represented by endogenous variables written in capital letters. For instance, W stands for farmer net welfare in millions Pakistani Rupees (PKR), A depicts the amount of area (acres) allocated to different cropping activities; S represents the sale of agricultural products and livestock products (PKR), L represents the livestock (animals numbers), P depicts the process variable to prepare feed for livestock, M stands for crop mixes, H stands for home use consumption and LUC shows the land use change

variable. The parameters given to the model are the data inputs and represented by coefficients of the variables (right-hand side values of the equation) with a description of the type of data given in superscripts. For example, Ω stands for feed processing data for livestock feed, δ indicates the price of agricultural products [PKR/unit], λ depicts the crop data including information on crop yields, resources and resource costs, γ appears for resource limit, χ stands for crop mixes, η shows the production minimum data, ω represents resource data including exogenous resources and limit on resource use, φ stands for land use data, η shows the livestock yields and resources, ρ represent the agricultural products and Θ represents home consumption data.

The equations described below actually depict set of equations that are reproduced using indices shown in subscripts. Specifically, f represents the farmers, fm farmer map, r regions, j different management options, c crops, a livestock, pr products, s season and u indicates resources.

Equation (5.1) represents the endowment of resources to differentt production activities.

$$\sum_{c,j} (\lambda_{r,f,j,t,s,c,u}^{cropdata} \cdot A_{r,f,j,t,s,c}) + \sum_{a,lj} (\eta_{r,f,lj,t,s,a,u}^{livedata} \cdot La_{r,f,lj,t,a}) - \omega_{r,f,t,u,i}^{resdata} = \omega_{r,f,t,u,i}^{reslim} \quad \forall r, f, j, t, u, i \quad (5.1)$$

Equation (5.2) indicates the production and processing activities under differnet management options while equation (5.3) established constraints on minimum production activity.

$$\begin{aligned} & - \sum_{f,j,s,c} (\lambda_{r,f,j,t,s,c,pr}^{cropdata} \cdot A_{r,f,j,t,s,c}) - \sum_{f,lj,s,a} (\eta_{r,f,lj,t,a,pr}^{livedata} \cdot La_{r,f,lj,t,a}) \\ & + \sum_s S_{r,t,s,pr} - \sum_{f,s,pf} (\Omega_{r,f,t,s,pf,pr}^{feedproces} \cdot P_{r,f,t,s,pf}) \\ & + \sum_{fm,s} (\theta_{r,f,t,s,pr}^{homedata} \cdot H_{r,f,t,s,pr}) < 0 \quad \forall r, t, pr \end{aligned} \quad (5.2)$$

$$\begin{aligned} & + \sum_{f,s,j,c} (\lambda_{r,f,j,t,s,c,pr}^{cropdata} \cdot A_{r,f,j,t,s,c}) + \sum_{f,lj,s,a} (\eta_{r,f,lj,t,a,pr}^{livedata} \cdot La_{r,f,lj,t,a}) \\ & + \sum_{f,s,pf} (\Omega_{r,f,t,s,pf,pr}^{feedproces} \cdot P_{r,f,t,s,pf}) \\ & > \rho_{r,t,s,pr,i}^{proddata} \quad \forall r, t, pr \end{aligned} \quad (5.3)$$

Equation (5.4) relates to farmers' decision-making of crop choices which are restricted to a linear combination of historically observed cropping patterns.

$$-\sum_{\tilde{t}} (\chi_{r,f,\tilde{t},s,c}^{cropmix} \cdot M_{r,f,\tilde{t},s}) + \sum_{cj} A_{r,f,j,t,s,c} = 0 \quad \forall r, f, t, s, c \quad (5.4)$$

Equation (5.5) limits the area allocated to major land use to not exceed the initial area for this category plus the area added from leasing in from other farmers located in the same region.

Equation (5.6) maintains the maximum land use in the specific region.

$$\left[\begin{array}{c} -\sum_{f^o} LUC_{r,f^o,f,t} \\ +\sum_{f^n} LUC_{r,f,f^o,t} \end{array} \right] + \left[\begin{array}{c} +\sum_{c,j} A_{r,f,j,t,s,c} \\ -\sum_{c,j} A_{r,f,j,t-1,s,c} \end{array} \right] < \lambda_{r,f,j,t,s,c,ar}^{cropdata} \quad \forall r, f, t, s \quad (5.5)$$

$$\sum_{f^n} LUC_{r,f^o,f,t} + < \varphi_{r,f,t,rent}^{landusedata} \quad \forall r, f, t \quad (5.6)$$

Finally equation (5.7) represents the objective function, which maximizes the sum of farmer net benefits by subtracting from the gross revenues the cost of resources (area underneath inverse resource supply function), the cost of production, cost of feed processing and land use changes.

$$Max \ W = \left[\begin{array}{l} \sum_{r,t,s,pr} (\delta_{r,t,s,pr}^{price} \cdot S_{r,t,s,pr}) \\ - \sum_{r,f,j,t,s,c} (\lambda_{r,f,j,t,s,c,i}^{cropdata} \cdot A_{r,f,j,t,s,c}) \\ - \sum_{fm,j,t,s,c,u} (\omega_{r,f,t,u,i}^{resrdata} \cdot \lambda_{r,f,j,t,s,c,u}^{cropdata} \cdot A_{r,f,j,t,s,c}) \\ - \sum_{r,f,pf,t,s} (\Omega_{r,f,t,s,pf,i}^{feedproces} \cdot P_{r,f,t,s,pf}) \\ - \sum_{fm,f^n,t} (\varphi_{r,f,t,s,i}^{landusedata} \cdot LUC_{r,f,f^o,t}) \end{array} \right] \quad (5.7)$$

5.2.3 Calibration and scenario development

After establishing equations, the model is calibrated to correct data misspecification and to

adjust model solutions with observed trends. For this purpose, reference values for different parameters are used.

After calibration, different scenarios are established to analyze welfare and land use decision-making under different scenarios. We develop three primary scenario categories and eighteen individual combinations. Three main scenario categories include adaptation, cooperation and policy access scenarios. In the next step, each scenario is further divided into different sub-scenarios.

Adaptation scenarios imply the adoption of different adaptation measures by farmers in response to changing environmental conditions. Adaptation measures may include changing cropping types, varieties, planting dates, plantation of trees, input mixes, livelihood diversification, soil or water conservation or migration to urban areas. Here, we categorize adaptation scenarios into further three scenarios, no adaptation, low adaptation and high adaptation. No adaptation scenario implies that farmers do not adopt any measure even if there is climate change. Low adaptation means farmers implement only up to two measures and high adaptation implies the use of a combination of five or more than five adaptation measures.

Cooperation scenarios are developed based on farmers' interaction with other farmers which may be either positively or negatively directed. Here, we divide cooperation scenario into further two scenarios, cooperation, and conflict. Cooperation implies that farmers positively interact with other farmers to exchange information on crops, weather or market, exchange of resources such as water, fertilizer or farm implements or exchange of outputs and assumption is that this kind of interaction may lead to improvements in crop productivities and farm wellbeing. On the other hand, the conflict scenario is negatively driven and implies that farmers negatively interact with other farmers and have conflict or dispute over different issues such as water or land allocation or other social issues. We assume that conflict might have an adverse impact on farm wellbeing as it may affect farmers' access to common pool resources.

In the end, we develop policy access scenario based on farmers' access to eight different institutional services such as extension, credit, marketing information, weather forecasting, marketing services, water delivery information, post-harvest services and access to agricultural machinery and farm implements. Further, we categorize policy access scenarios

into 1) low policy access, 2) medium policy access and, 3) high policy access. Further, we develop a criterion for each policy scenario. Low policy access means farmers have access to up to only two of the institutional services mentioned above. Medium policy access means farmers' access to more than 2 and up to 4 services, while in high access scenario; farmers may have access to a combination of five or more than five institutional services.

In next step, percentage impact of different combinations of scenarios is assessed using propensity score matching technique (PSM), which is used to remove the impact of other observable factor before calculating the casual impact of policy scenarios. The details on the PSM procedures see Chapter 4 of this thesis.

5.3 Results

5.3.1 Descriptive statistics

The cropping pattern in winter and summer seasons is shown in Figure 5.1. Wheat, cotton, maize are major crops grown in all three regions. Wheat accounts for 60% share in total area under cultivation in the rain-fed region, Gujrat and more than 40% in irrigated regions (Rahim Yar Khan and Toba Tek Singh). Sugarcane, a perennial crop is mainly grown in Rahim Yar Khan, where it occupies more than 40% of the total area. Winter maize, mustard, and berseem are minor crops grown in all three regions. In the summer season, farmers in Rahim Yar Khan mainly grow cotton and rice, while in Toba Tek Singh, cotton and maize are major crops. Millet, maize, and rice are major crops in Gujrat.

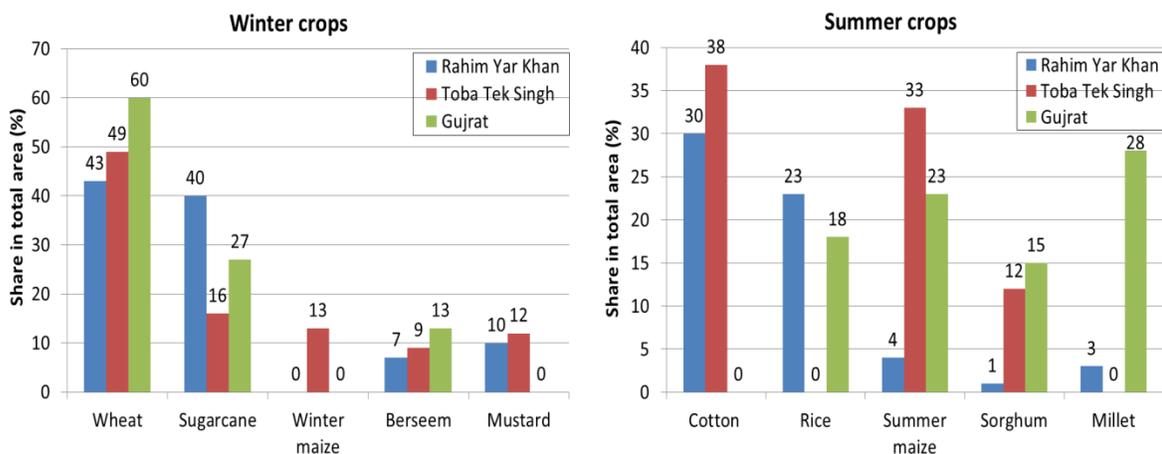


Figure 5.1. Cropping patterns in summer and winter season

The overview of crop yields across study regions is provided in Figure 5.2. Crop yields in

irrigated regions (Rahim Yar Khan and Toba Tek Singh) are always higher than of rain-fed regions. However, there are mixed yield differences within the irrigated regions. The average yield of wheat is found almost similar in Rahim Yar Khan and Toba Tek Singh but quite lower in the rain-fed region, Gujrat. In the case of sugarcane and sorghum, farmers in Rahim Yar Khan are getting higher yields than farmers in the other two regions. However, winter maize, mustard, cotton, and berseem have higher yields in Toba Tek Singh. Appendix B provides the overview of input use under different crops.

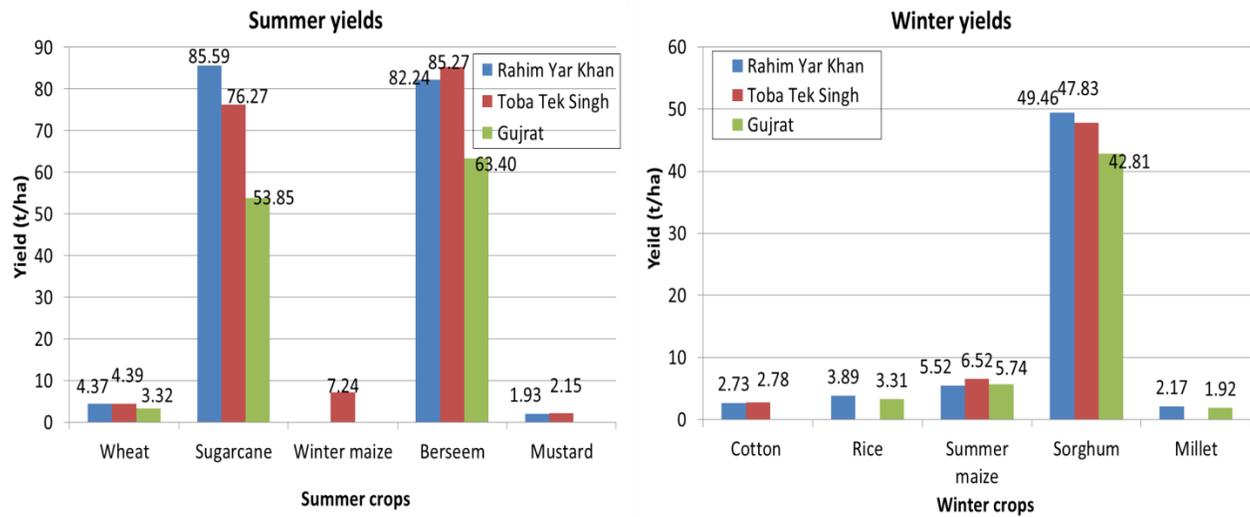


Figure 5.2. Crop yield differences across study regions

5.3.2 Scenario impacts on overall welfare

First, we analyse the impact of different scenarios on farmers' net revenue and associated land use patterns. Figure 5.3 shows the impact of different combinations of adaptation, cooperation and policy access scenarios on farm net revenue in million Pakistan rupees. The findings of the study confirm that under scenarios which combine no adaptation, conflict, and low policy access, farm income is roughly 1700 million PKR less than the best-case scenario, when high adaptation is combined with high policy access and cooperation scenarios. This implies that when farmers are provided with ample access to resources and technologies, and they work in harmony, then they are more productive and generate more revenue and income. Under the cooperation scenario, income increases by 10% and 20% while moving from no adaptation to low and high adaptation. On the other hand, under conflict scenario, welfare increases only by 5% and 10% under low and high adaptation scenarios

respectively. Similarly welfare increases with moving from low policy access to medium and high policy access but at very low rate (approximately between 2 and 5%) compared to adaptation scenarios (5%-20%). However, the net revenue value always remains more in cooperation scenarios than conflict scenarios. Interestingly, total welfare drastically decreases by 30% under low policy, no adaptation and conflict scenarios compared to medium policy, no adaptation and conflict.

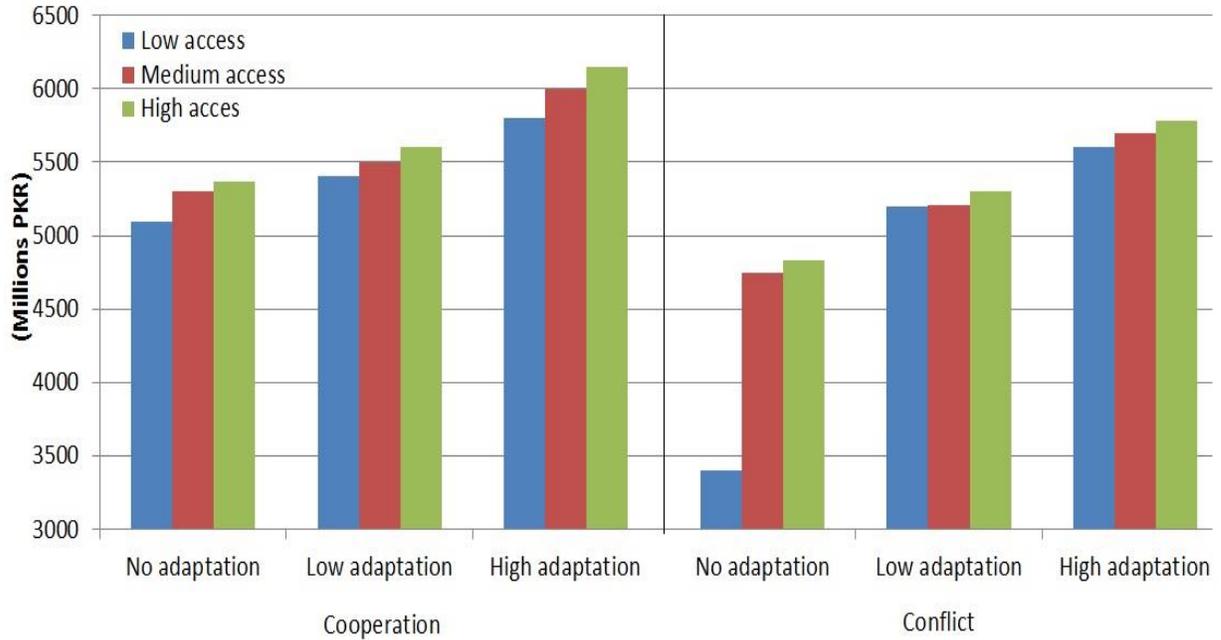


Figure 5.3. Welfare impacts of different scenarios

5.3.3 Scenario impacts on regional welfare

In the next step we conduct a farm welfare (overall net revenue) analysis at district level under different combinations of adaptation, cooperation and policy access scenarios Figure 5.4a-c. Under low policy access, welfare increases with increase in adaptation and cooperation among farmers across three regions.

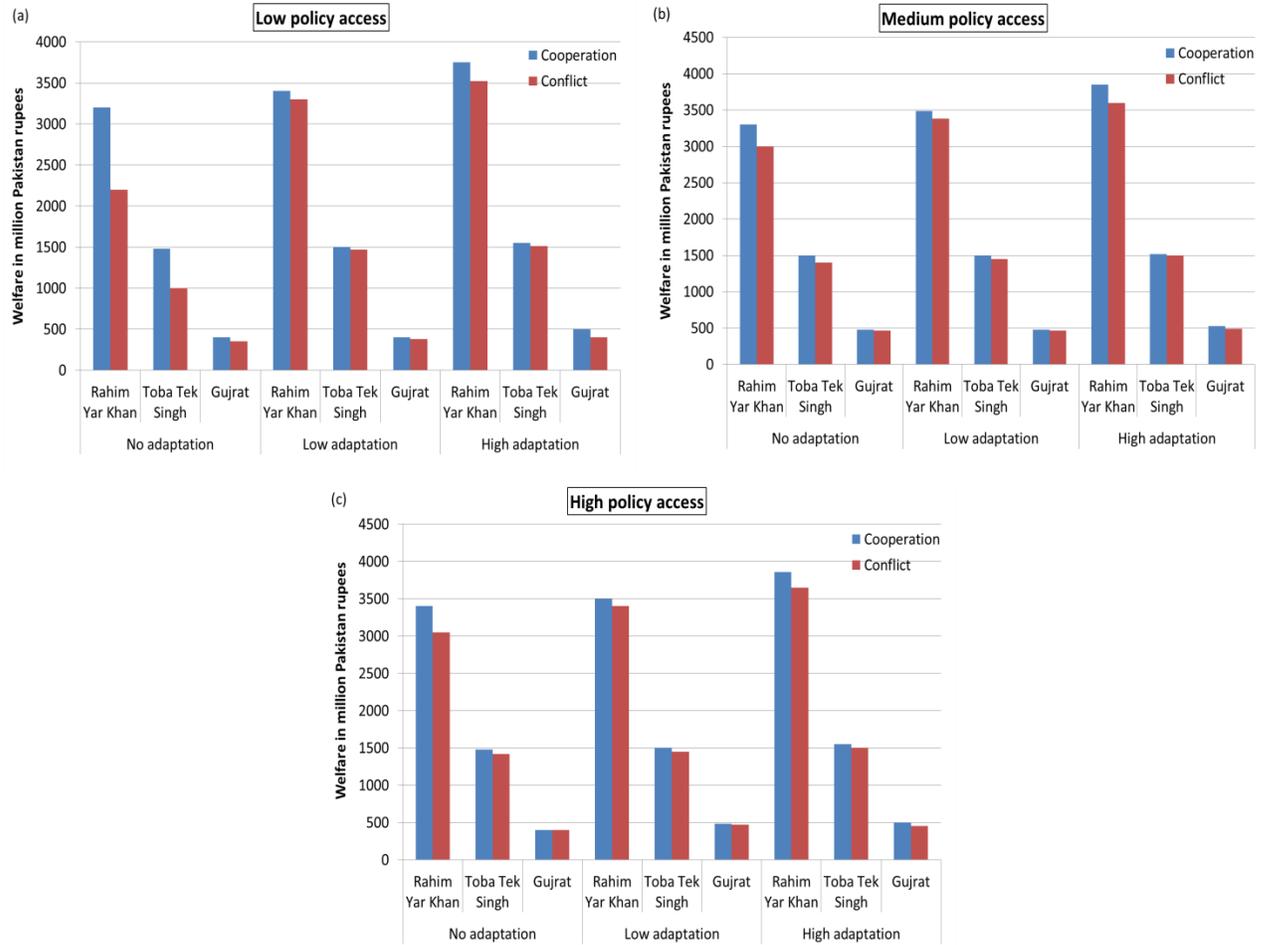


Figure 5.4 (a)-(c). Scenario impacts on welfare across study regions

Conflict plays a major role in reducing welfare in Rahim Yar Khan under the worst-case scenario when there is no adaptation and farmers have low access to institutional and policy services. Specifically, the net revenue declines by 36% in the conflict case compared to cooperation scenario under no adaptation and low policy access in Rahim Yar Khan. Similar patterns may be observed in other two policy scenarios, which also show (little) increase between 2 and 5% in welfare along with improvements in adaptation and farmer interactions. Furthermore, we analyze the impact of the combination of different scenarios on land use decision-making. Study findings given in Figure 5.5a-c show that under the worst-case scenario with low policy access, no adaptation and conflict, farmers allocate 10% to 30% more land to subsistence or fodder crops such as maize, berseem, and sorghum compared to the cooperation scenario under the same adaptation and policy settings. However, in the case of the cooperation scenario, farmers tend to increase the area under major crops such as

wheat (36%), cotton (40%) and sugarcane (20%). This implies that under the worst condition, farmers tend to rely more on livestock animals and therefore allocate more area to fodder crops. While farmers prefer to grow resource-intensive crops when there is cooperation, which implies that farmers may get help from other co-farmers through exchanging resources particularly, labor, water, and inputs.

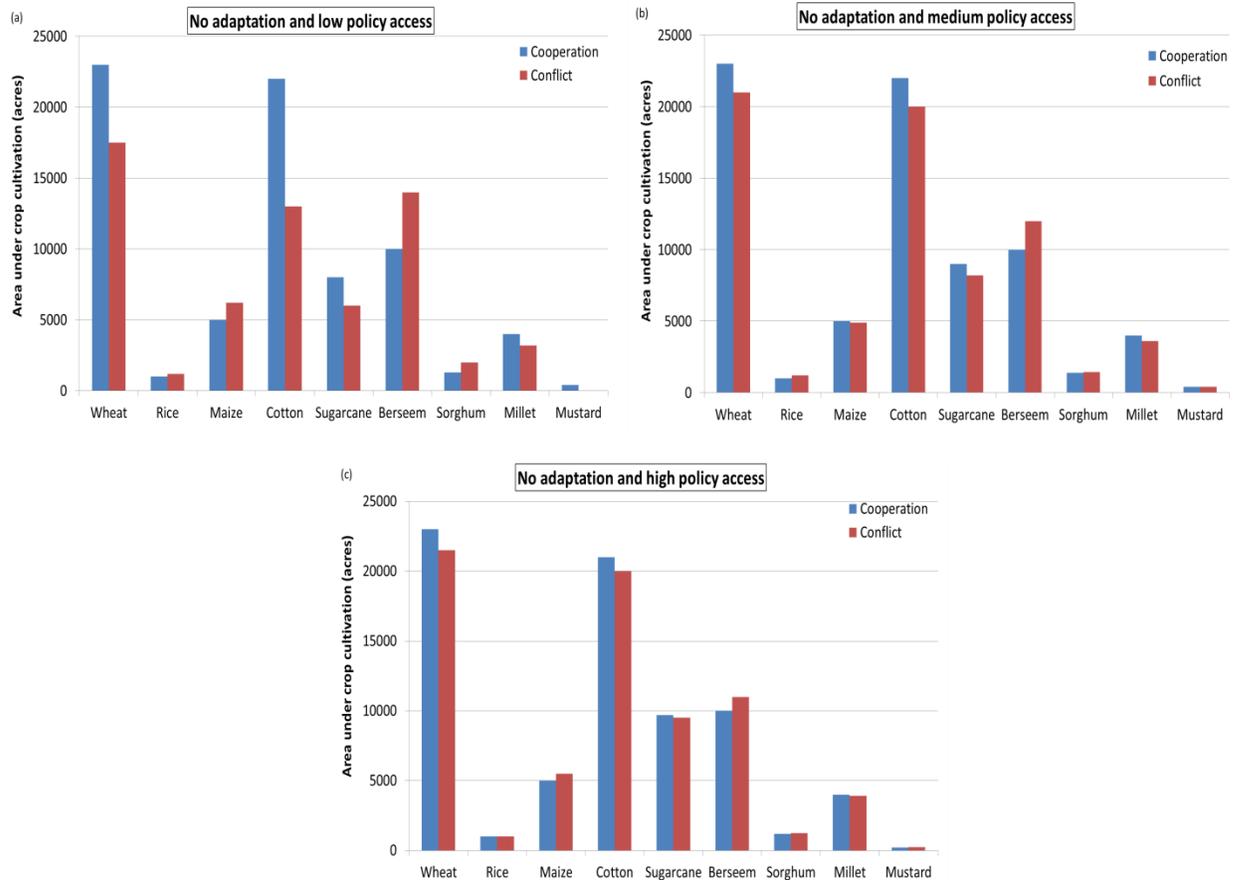


Figure 5.5(a)-(c). Crop area under no adaptation, all policy and cooperation scenarios

Under medium and high policy access combined with no adaptation, there are minor differences between crop area of cooperation and conflict scenarios. With low adaptation, there are not many changes in crop areas under all policy access and cooperation scenarios except some changes in wheat i.e. increase in case of cooperation (5%) and decrease in case of conflict (7%) and while berseem areas decrease by 5% moving from cooperation scenario to conflict scenario (Figure 5.6). With high adaptation scenarios and all policy scenarios, areas under wheat crop increase while moving from cooperation to conflict scenario (2-5%),

while the area under fodder crops decreases moving from cooperation to conflict by 3 to 5%. All other crops do not show much variation. All this implies that the adaptation scenarios significantly change cropping patterns in combination with low access and conflict. Wheat and berseem are major responsive crops that change area in all scenarios while cotton area changes in case of no adaptation scenarios and remains unchanged in other adaptation scenarios.

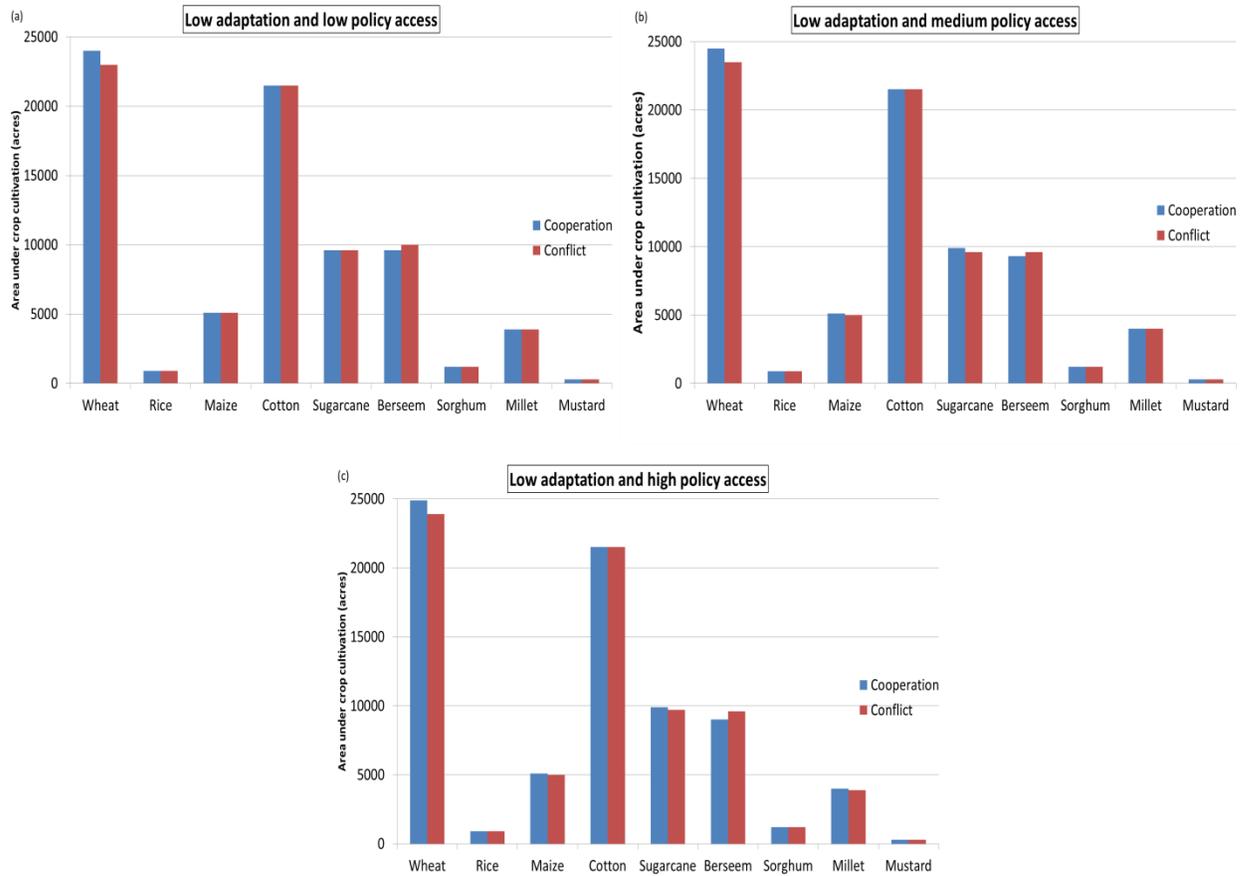


Figure 5.6(a)-(c). Crop area under low adaptation, all policy and cooperation scenarios

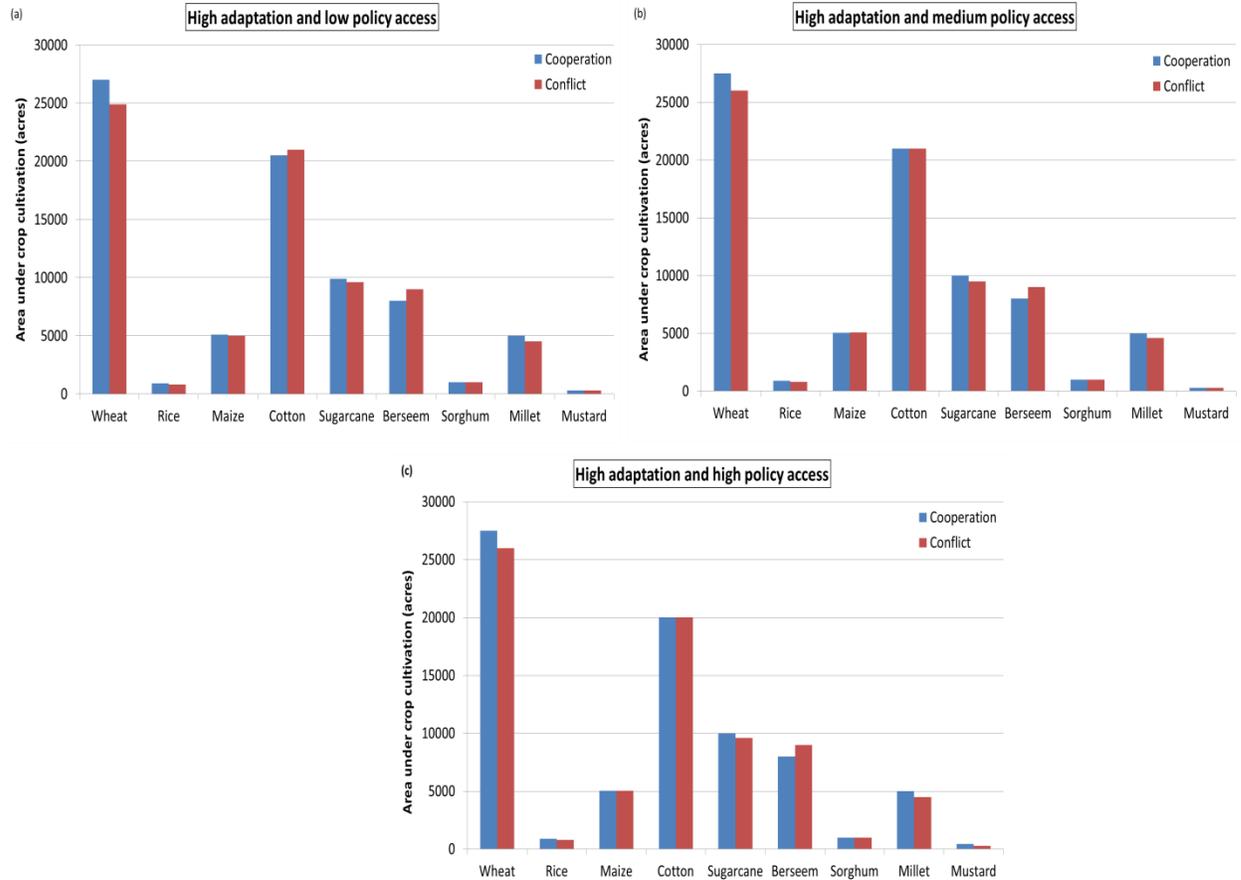


Figure 5.7(a)-(c). Crop area under high adaptation, all policy and cooperation scenarios

5.4 Discussion

Farmers in Pakistan are highly vulnerable to climate change and are adapting to climate change by implementing several measures. Wheat, sugarcane, and cotton are major crops in the Rahim Yar Khan District. In Toba Tek Singh, wheat, maize, and cotton are major crops, while farmers in Gujrat mainly grow wheat, millet and maize. Average crop yields are higher in irrigated areas of Rahim Yar Khan and Toba Tek Singh than farmers in Gujrat. In line with our findings, Wani *et al.* (2009) also reported significant differences in irrigated and rain-fed yields. The higher yields in irrigated areas possibly may be due to sufficient access to resources particularly water, which is relatively scarce in Gujrat. This might be one of the reasons that sugarcane and rice that are water consuming crops are grown more in Rahim Yar Khan than other two regions (see Appendix B for details on water use under different crops across three study regions). Similar trends can be observed in other input uses for different

crops. However, the average crop yields are far less than potential crop yields. According to an estimate, farmers in Pakistan can produce only 30% of the potential crop yields (Abid *et al.*, 2016b).

Adapting current farming practices to climate change may not only protect farmers' livelihoods, but it may also have positive impacts on their wellbeing. The study findings reveal that farmers implement several adaptation measures to climate change. However, adaptation is limited in the study region due to lack of institutional support and informational gaps. Farmers, particularly in the rain-fed region lack access to different institutional services such as credit, marketing services, extension and post-harvest services. If farmers are provided with better access to institutional services, then it may have a positive impact on their wellbeing and crop productivities. Similarly, positive interaction among farmers could also result in more welfare in study regions. To test these assumptions, we develop a multi-farm model for Pakistan and assess the impact of different adaptation, cooperation and policy access scenarios on farm wellbeing and land use decision-making using GAMs.

The results of the scenario analysis show that if farmers do not adapt to climate change and also do not have access to policy services or have a conflict with other farmers at the same time then their welfare will be lowest. On the other hand, in opposite scenario, adaptation to climate change along with sufficient access to policy services and cooperation improve overall welfare in the study area. Various other studies (e.g. Deressa *et al.*, 2005; Van Aalst *et al.*, 2008; Khan and Damalas, 2015) also reported the positive impact of adaptation, improved access to institutional services and cooperative environment on the welfare of farmers. Further, regional welfare also differs across different regions under different scenarios. Welfare found highest in Rahim Yar Khan followed by Toba Tek Singh and Gujrat. Further, cooperation scenarios have more impact under no adaptation scenarios in all three regions, particularly in Rahim Yar Khan. This implies that when there is conflict and farmers are also not adopting then, it could lead to negative impact on overall welfare. This could be due to the reasons that with conflict there will be a low level of cooperation and in those case, farmers will not exchange crop-related information or updates. Hence, it may lower crop yields and ultimately will adversely affect the individual as well as regional welfare. The impact of conflict and no adaptation seems more due to the reason that farmers in that region grow crops that are resource intensive like sugarcane and cotton. And at many

occasions, farmers require help from other farmers in term of exchanging farm inputs such as labor, water. In the case of conflict, the productivity of major crops will be negatively affected due to less access to productive resources.

Further, the impact of scenario analysis on land allocation for different crops shows that all crops change their area under all cooperation and policy scenario. However, while moving from no adaptation to low and high adaptation, crop area changes slowly except wheat, sugarcane, and berseem which show more response to a change in adaptation scenario and policy access. Again here the role of cooperation is important like in previous cases, as in the case of conflict farmers tend to increase the area under fodder crops or the crops that require fewer resources such as berseem, maize, and sorghum. The increase in fodder crop area implies that in the case of conflict and no adaptation scenarios farmers tend to keep more livestock to sustain their livelihoods while in case of opposite cooperation scenario, they prefer to grow cash crops such as cotton and sugarcane.

5.5 Conclusion

The main purpose of the study is to develop an agricultural sector model for Pakistan and to estimate farm welfare under different adaptation, policy and cooperation scenarios. The multi-farm model is developed in GAMs using partial equilibrium optimization technique. The data for model analysis comes from farm household survey collected in three representative districts in three agro-ecological zones.

The study findings reveal that wheat, sugarcane, cotton, and maize are major crops cultivated in the study area. Overall crop yields significantly differ between irrigated and rain-fed regions, which were mainly due to access to water resources and institutional access. More than half of the farmers in study regions perceived and adapted to climate change through implementing different adaptation measures. They key measures include changing cropping varieties, crop types, planting dates, planting shade trees and changing input mixes. Further, the study farmers in Rahim Yar Khan were wealthier than farmers in the other two regions. More welfare in case of Rahim Yar Khan is due to higher crop yields and more access to resources particularly water and institutional services. Further, findings of the scenario analysis show significant changes in overall welfare and land use patterns under different adaptation scenarios. Adaptation to climate change, access to policy and institutions and

positive interaction within farming communities improves farm wellbeing. Similar trends are also observed at the regional level. Further, conflict scenario plays a major role in affecting the welfare and land use patterns under no adaptation scenarios.

The study findings suggest putting more efforts to enhance local adaptive capacities through providing farmers more access to adaptation information, new cropping techniques, and institutional access. Further, farmers' interactions and cooperation need to be enhanced as it will significantly influence farmers' access to common resources and information on different new measures and techniques. For this purpose, local institutions may help farmers to create informal social groups to exchange information and ideas to improve crop yields and solution to farm-related issues.

5.6 Next step

In next step, we will work to transform the model into the agricultural sector model by adding endogenous product prices through demand and supply functions and adding more data to represent whole regions and time periods. Further, model will include climate change scenarios to assess its impact on overall welfare and land use patterns.

6 Accuracy of perceptions and adaptation to climate change under different land tenure and land holding setting: Insights from farming communities in Pakistan

6.1 Introduction

Adverse impacts of climate change on natural and human systems are more common than its positive impacts (IPCC, 2014a). Particularly, agricultural production and livelihoods in the developing regions are likely to be largely affected due to their low adaptive capacity and high exposure to climatic events such as floods and droughts and increases in plant pests and diseases induced by climate change (Adger, 2003). According to an estimate, the net cereal production in South Asia is projected to decline between 4% and 10% by the end of 21st century under the most conservative climate change scenario (Lal, 2011). Similarly in Pakistan, productivity of main staple crops, wheat and rice is likely to be reduced by 6-8% and 16-19% under B2 and A2 climate change scenarios respectively (IPCC, 2014a).

Because agricultural production remains the key source of livelihood for more than half of the population in South Asia, adaptation is necessary to enhance the resilience and adaptive capacity at farm level and to sustain the rural livelihoods (e.g. Gbetibouo, 2009; Bastakoti *et al.*, 2014; Keshavarz *et al.*, 2014; Roco *et al.*, 2014; Zampaligré *et al.*, 2014). For effective adaptation of agricultural systems, efforts are required at national level in developing heat and drought resistant varieties, irrigation and soil conservations and crop insurance schemes, and at local level in disseminating information among farmers and training them to deal with extreme events (Howden *et al.*, 2007). Further, it also requires farm households to adjust their current farming practices ranging from planting date adjustments to changing crop types and varieties.

Enhancing the farmers' adaptive capacity requires a better understanding of current adaptation patterns and its key drivers along with barriers to adaptation. A growing body of research on adaptation (e.g. Semenza *et al.*, 2008; Gbetibouo, 2009; Mertz *et al.*, 2009; Deressa *et al.*, 2011), mainly available from African countries, suggest a widespread awareness about climate change and adoption of different measures to avoid climate vulnerabilities at farm level. Various studies (e.g. Gbetibouo, 2009; Deressa *et al.*, 2011; Le

Dang *et al.*, 2014; Comoé and Siegrist, 2015) also identified a number of barriers to adaptation of agricultural systems in African countries ranging from financial to physical constraints. Despite a vast body of available data from both developed and least-developed countries, however this kind of literature is very limited in South Asia (Abid *et al.*, 2016a). Particularly, in Pakistan, most of the existing studies on climate change and agriculture focus on impacts (e.g. Hanif *et al.*, 2010b; Rasul *et al.*, 2012; Zhu *et al.*, 2013) and little on adaptation (e.g. Abid *et al.*, 2015; Gorst *et al.*, 2015a).

More in-depth research on the dynamics of farm level perceptions and adaptation processes at the grass roots level as well as at regional level is required for the development of new and effective adaptation policies. Further, it is also useful to understand the process of adaptation at farm level and the role of different socio-economic, agro-ecological and institutional settings in developing climate change (Abid *et al.*, 2016a). This first-of-its-kind study addresses the social dimensions of agricultural adaptation to climate change in Pakistan and explores the farm adaptation process starting with the climate change perceptions and looking into factors affecting the accuracy of farmers' perceptions and adaptation intentions. Specifically, this study has four research objectives: 1) to quantify the correlation of farmers' perceptions of climate change with actual climatic developments; 2) to determine links between different stages of adaptation: perception, intention, and implementation; 3) to evaluate the factors driving the three adaptation stages; and 4) to explore how the accuracy of perceptions and the implementation of different adaptation measures differ across farming groups.

6.2 Conceptual framework

Climate change is adversely affecting the agricultural productivity and farm wellbeing in Pakistan through its direct and indirect effects. Farmers could avoid losses at farm level by timely perceiving and adjusting their farming practices to climate change. Here for this study we consider adaptation to be a linearly connected three-step process (from left to right), where the first stage is the perception of changes in various indicators of climate change such as changes in seasonal temperature and rainfall. Being the first step in the adaptation process, timely and accurate perceptions are important determinants for farmers' intentions and the choice of adaptation methods (Deressa *et al.*, 2011) (Figure 6.1). However, the development

of these perceptions may depend on various socio-economic factors, access to institutional resources and agro-ecological settings. Underestimated or no perceptions may lead to maladaptation and may increase farmers' exposure to climate change impacts while the accurate perceptions may positively influence the adaptation process at farm level (Le Dang *et al.*, 2014). The second stage is the intention stage, where farmers consider and plan the adoption of different measures to mitigate direct or indirect effects of climate change. These intentions may be influenced by the accuracy of farmers' perceptions along with various internal and external factors. In the last and third stage, farmers actually adapt to climate change by implementing different measures subject to the availability of and access to resources required for preferred adaptation measures. The implementation of planned adaptation measures may be interrupted or stopped due to physical, financial and institutional restrictions.

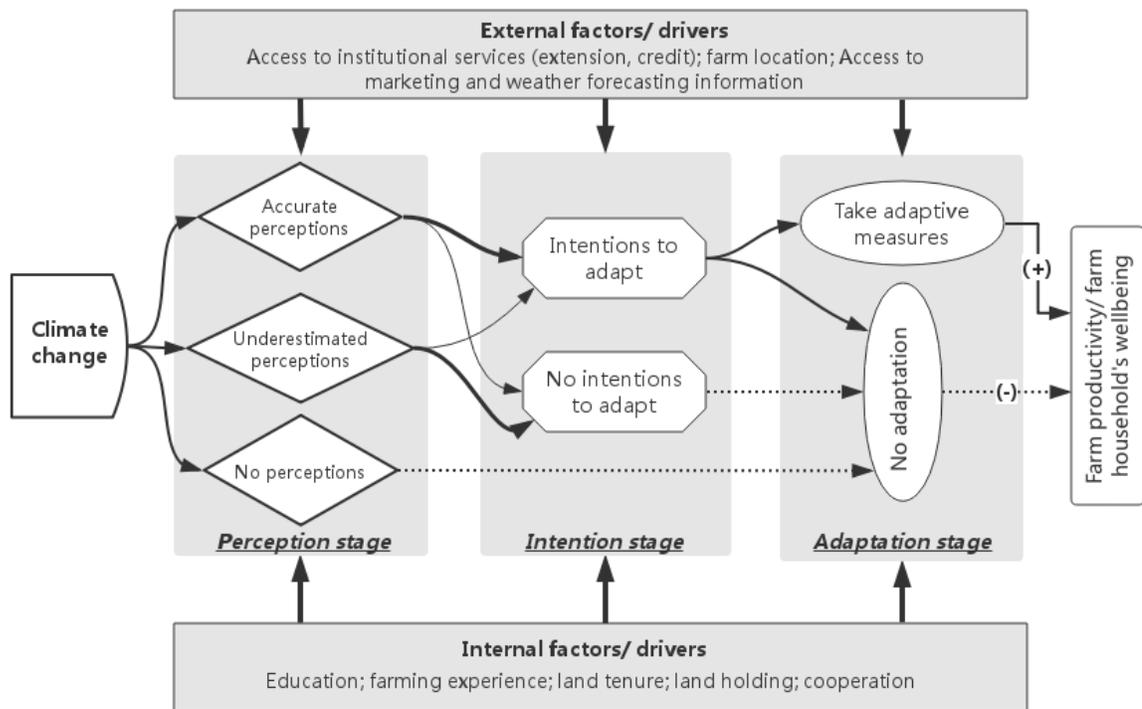


Figure 6.1 Conceptual framework of the study

The adaptation process is shown as a three step process (one directional causal chain) where one stage leads to the other. Several external and internal factors may influence the three stages of adaptation (shown by one sided arrows). The strength of connecting lines shows the

potential assumed influence of factors on the respective adaptation stage, while the dotted lines show the possible adverse impact of no perceptions or non-adaptation on farm level wellbeing.

In order to explore farmers’ understanding of climate change and role of accuracy of perceptions in the adaptation process, here we establish two assumptions: 1) More accurate perceptions lead to stronger adaptation intentions and 2) underestimated or low perceptions leads to weaker adaptation intentions. To test these assumptions and factors affecting the three adaptation stages, a multivariate probit modeling technique described in the method section. To assess the determinants of adaptation stages, we first create four dependent variables for three stages (Table 6.1). For the perception stage, we develop two dependent binary variables of accurate perceptions and underestimated perceptions, while for each adaptation and intentions stages a binary variable is developed (Table 6.1).

Table 6.1 Description of variables for all three stages of adaptation

	Variables	Description
Dependent variables (binary; A_{ij})		
	Accurate perceptions (A_{i1})	It takes value 1 if a farmer accurately perceives changes in all climate indicators and zero otherwise
	Underestimated perceptions (A_{i2})	It takes value 1 if farmer underestimates climate change by perceiving some of climate indicators and zero otherwise
	Adaptation intentions (A_{i3})	It takes value 1, if a farmer has intention to adapt
	Adaptation to climate change (A_{i4})	It takes value 1, if a farmer actually adapts to climate change
Independent variables		
	Education	Years of schooling
	Farming experience	Years of farming experience
Internal factors	Farmer-to-farmer cooperation	A binary variable takes value 1, if farmer cooperates with other farmers and zero otherwise
	Land tenure	It takes value 1, if farmer is owner-cultivator and zero otherwise
	Land holding	It takes value 1, if farmer owns less than 2 ha of land (small landholder) and zero otherwise
External factors	Extension services	It takes value 1, if farmer has access & zero otherwise
	Weather information	It takes value 1, if farmer has access & zero otherwise
	Marketing information	It takes value 1, if farmer has access & zero otherwise
	Location in AEZ (Rahim Yar Khan)	It takes value 1, if farmer belongs to Rahim Yar Khan and zero otherwise
	Location in AEZ (Toba Tek Singh)	It takes value 1, if farmer belongs to Toba Tek Singh and zero otherwise

The explanatory variables used in this study include both internal as well as external factors. Internal factors are the farmer-specific socio-economic characteristics and include education, farming experience, farmer-to-farmer cooperation, land tenure and land holding status, while external factors capture the societal and natural environment to which a farmer belongs and include access to extension services, weather information, marketing information and location of farm (Mertz *et al.*, 2009; Deressa *et al.*, 2011; Hisali *et al.*, 2011; Bryan *et al.*, 2013). Variables of education and farming experience are continuous variables measured in years, while all other variables are binary and take values of zero and one. The cooperation variable is based on farmers' interaction with other farmers to trade inputs or outputs or to exchange information on crops, weather and prices. The dummies for location in agro-ecological zones are used as a proxy for the difference in climatic conditions, cropping pattern and other unobservable differences across three agro-ecological zones. Table 6.1 provides the definitions and descriptive statistics of the variables used in this study.

6.2.1 Data collection

This study uses cross sectional farm level data and historical climate data from selected meteorological stations situated close to our study locations. The procedure of sampling and data collection for primary dataset is already described in chapter 1. Monthly time series data of rainfall and temperature for three relevant meteorological (met) stations is obtained from Pakistan meteorology department (PMD). The data covers the period from January 1980 to December 2013. For Rahim Yar Khan, Toba Tek Singh and Gujrat, we use nearby met stations i.e. Khanpur, Faisalabad and Jhelum respectively. Met station Khanpur is located exactly in the same study district Rahim Yar Khan while the other two stations Faisalabad and Jhelum are located 30-40 km away from the study districts Toba Tek Singh and Gujrat respectively. The location of the study districts and met stations can be observed from the study area map in Figure 1.2. From the collected monthly time series records of rainfall and temperature, we calculate seasonal mean temperature and seasonal rainfall for the respective years. Here, we define winter or *rabi* season as November–April and summer or *kharif* season as May– October.

6.2.2 Statistical Analysis

To compare farmers' perception of climate change with observed meteorological trends, we first analyze how observed data from meteorological stations evolve (variability and trends) and how farmers perceive long-term changes and trends in the climate indicators. While for climatic trends, we consider only seasonal temperature and rainfall due to the non-availability of data on other parameters. In the next step we perform statistical tests for linear trends in seasonal means of temperature, and seasonal rainfall and compare those trends with farmers' perceptions in all three regions. For comparison we consider only farmers having at least 10 years of experience in agriculture in order to get real insights of their understanding. Hence, the final sample size used for the analysis is reduced to 417 from 450. The findings are further supported by the descriptive statistics to provide insights into farmers' perceptions of climate change.

Next, a multivariate probit model (MVP) is used to analyze the factors driving the different adaptation stages. With the MVP technique we also test the existence of concurrent relationships between adaptation stages (dependent variables) (Raguindin and de Vera, 2012; Kassie *et al.*, 2013). A multivariate probit model can be written as follows:

$$A_{ij} = X'_{ij} \beta_j + \varepsilon_{ij} \quad (6.1)$$

where $A_{ij}(j=1, \dots, m)$ represents a latent variable underlying three adaptation stages (j) faced by the i th farmer ($i=1, \dots, n$), X_i is a vector of explanatory variables that may influence the three adaptation stages, β_j shows the vector of unknown parameters that are to be estimated and ε_{ij} depicts the unobserved error term. We cannot measure the latent variables (A_{ij}^*) directly, however, we can write equation (1) for all observed outcomes (which are the adaptation stages) as:

$$\begin{aligned} A_{i1} &= \alpha_1 + X_{i1}\beta_1 + \varepsilon_{i1} \\ A_{i2} &= \alpha_2 + X_{i2}\beta_2 + \varepsilon_{i2} \\ A_{i3} &= \alpha_3 + X_{i3}\beta_3 + \varepsilon_{i3} \\ A_{i4} &= \alpha_4 + X_{i4}\beta_4 + \varepsilon_{i4} \end{aligned} \quad \text{where } \begin{cases} A_{ij} = 1 \text{ if } A_{ij}^* > 0 \\ A_{ij} = 0 \text{ if } A_{ij}^* < 0 \end{cases} \quad (6.2)$$

where A_{i1} , A_{i2} , A_{i3} and A_{i4} are four observed variables showing three adaptation stages and take value 1, only if the respective latent variables have values above zero and vice versa.

Adaptation to climate change is a chain process where all three stages do not occur

simultaneously and one stage leads to the other, hence it is assumed that three stages are not correlated. This assumption is tested by the Likelihood Ratio and Wald Chi-square tests. Under the assumption of multivariate normality, the unknown parameters in equation (1) are estimated using simulated maximum likelihood (SML). SML uses the Geweke-Hajivassiliour-Keane (GHK) simulator to estimate the multivariate normal distribution (Zulfiqar et al., 2016).

6.3 Results and discussion

6.3.1 Perceived and recorded changes in temperature and rainfall

Farmer perceptions of climate change are a precondition to plan for subsequent adaptation measures. Therefore, the exact knowledge of farm level perceptions of climate change and its evolution is important to understand to design effective adaptation policies. As the first step, we analyze the farmer perceptions of climate change. The findings show that farmers in all three study districts are aware of climate change and perceive changes in temperature and rainfall. Generally for changes in the seasonal temperature, an increase in summer temperature is more strongly perceived by the farmers across three study regions than changes in the winter temperature. Specifically, more than three-fourth of the farmers perceive the summer temperature to increase in all three study districts (Figure 6.2a-b). For the changes in winter temperature, farmers across all three districts respond differently. For instance, more than two-fifth of the farmers across the three study districts perceive an increase in winter temperature. However, around one-third of the farmers in Rahim Yar Khan and Gujrat and more than one-fourth in Toba Tek Singh notice the contrary, a decrease in the winter temperature. Notably, more than one-fourth of the farmers in Rahim Yar Khan do not perceive any change in the winter temperature.

Regarding the perceptions of rainfall patterns, generally, farmers in all three study districts perceive a decrease in the rainfall intensity in winter as well as in summer season (Figure 6.2 c-d). Specifically, about two-third of the farmers in Gujrat, half of the farmers in Toba Tek Singh and more than two-fifth in Rahim Yar Khan perceive a decrease in the summer rainfall. Interestingly, more than two-fifth of the farmers in Rahim Yar Khan and more than one-fourth of the farmers in Toba Tek Singh and Gujrat perceive an increase in the

summer rainfall. For changes in winter rainfall patterns, almost half of the farmers in all three study districts perceive a decrease in the winter rainfall and about one-third of the farmers in Toba Tek Singh and Gujrat perceive the contrary, an increase in the winter rainfall. In addition, more than one-fourth of the farmers in Rahim Yar Khan perceive no change in the winter rainfall pattern.

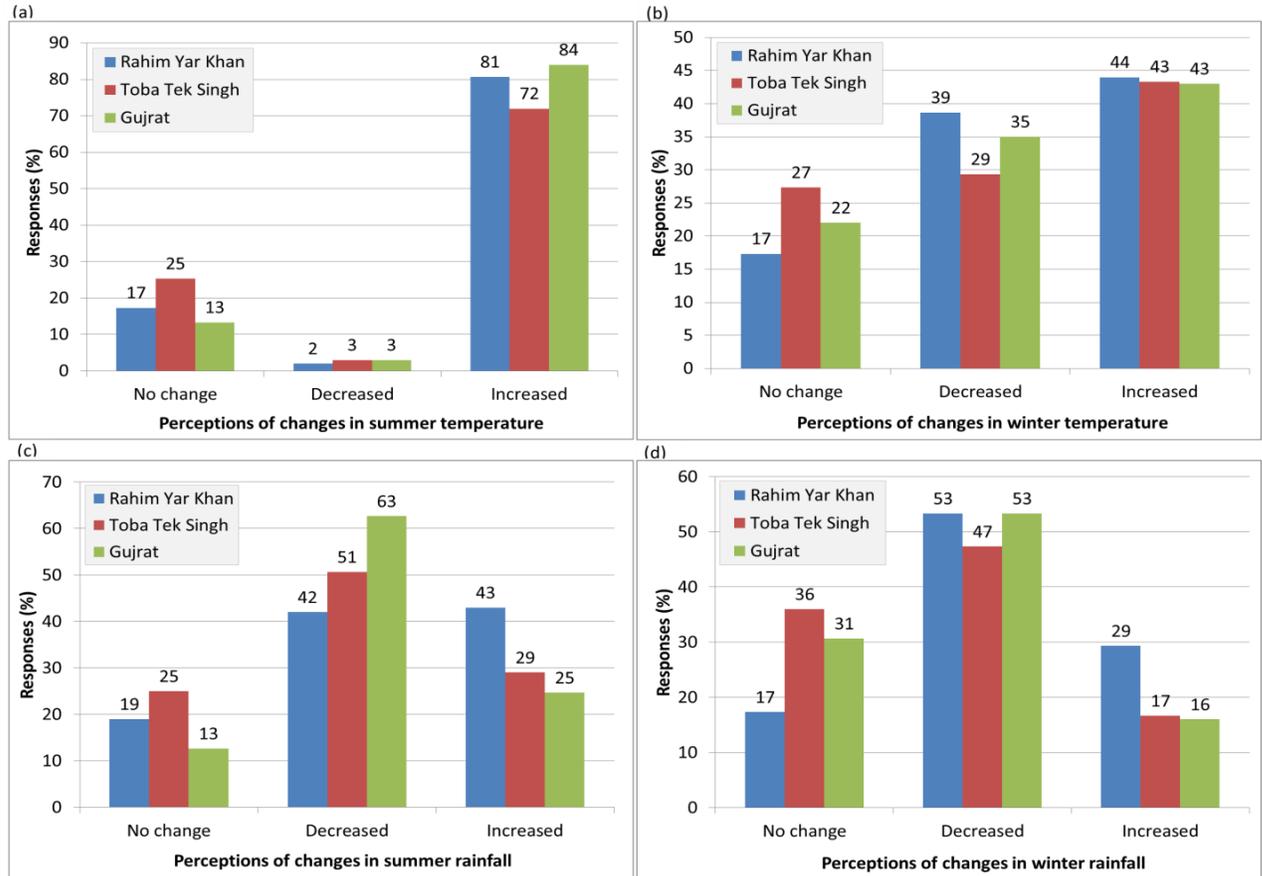


Figure 6.2(a)-(d). Farmers' perception of changes in seasonal temperature and rainfall during the last 20 years

In this study, to understand the extent of the farmers' perceptions of climate change, a comparison with local climate data (1980-2013) is undertaken. The results show an overall significant increase ($p < 5\%$) in the summer and winter temperature (Figure 6.3a-b). The highest increase in temperature is observed for Khanpur station where summer and winter temperature shows an average increase of $0.10\text{ }^{\circ}\text{C}$ and $0.13\text{ }^{\circ}\text{C}$ respectively while the lowest increase in temperature ($0.03\text{-}0.04\text{ }^{\circ}\text{C}$) is found in the case of Jhelum station. In contrast to the temperature trends, the rainfall trends differ between zones and show higher fluctuations

(Figure 6.3c-d and Table 6.2). In Rahim Yar Khan district, the amount of rainfall is slightly increasing in both summer and winter seasons over the period 1980-2013, whereas it decrease significantly in Gujrat (in both seasons) and slightly in Toba Tek Singh (only in winter season). However, summer rainfall in Toba Tek Singh shows increasing but insignificant trends. The historical records of summer rainfall from all three stations show a huge fluctuation across all three study regions.

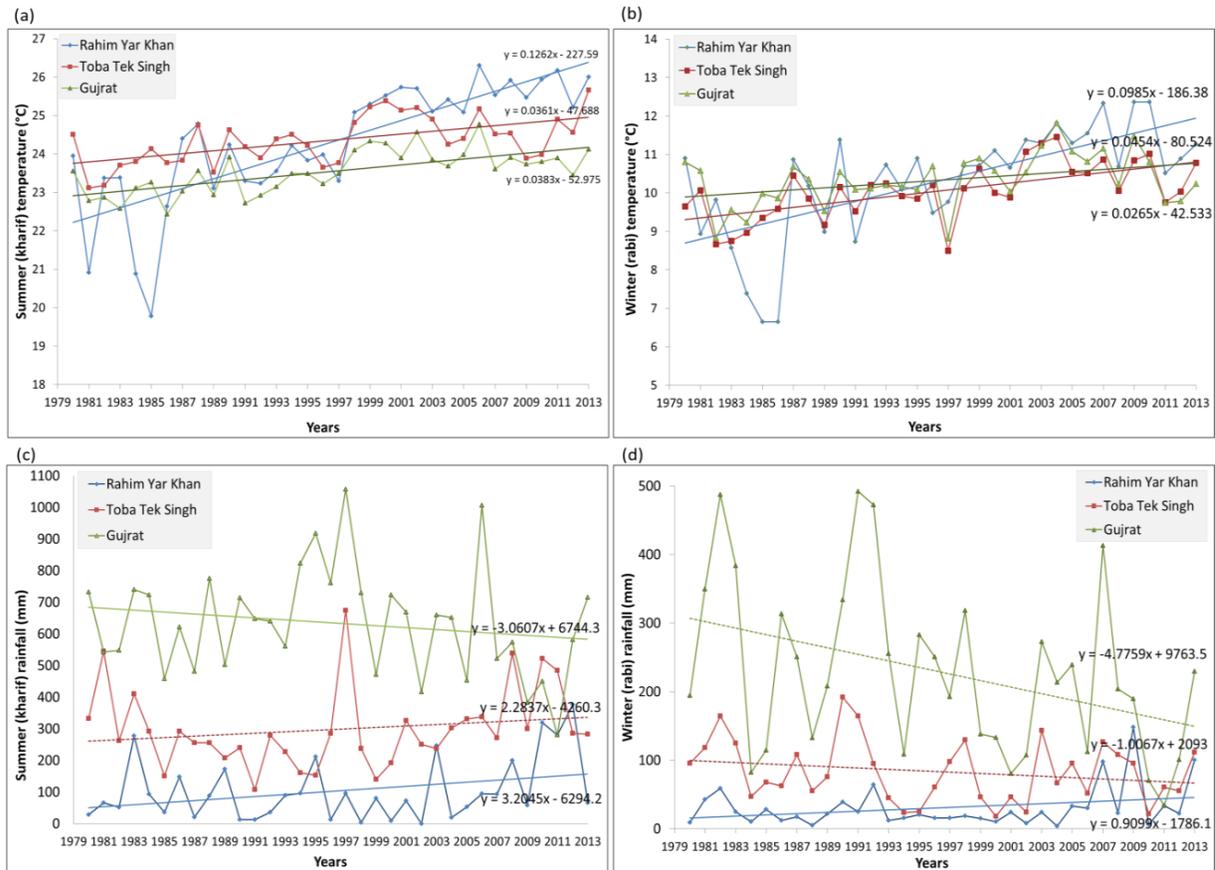


Figure 6.3(a)-(d). Observed changes in seasonal temperature and rainfall in the study areas (Data source: Pakistan Meteorological Department)

Comparison of the farmers' perceptions with local climate data confirms that most of the perceptions of change in both summer and winter temperatures match with climate records. These findings are in line with the findings of the other studies (e.g. Hageback *et al.*, 2005; Maddison, 2007; Gbetibouo, 2009; Zampaligré *et al.*, 2014) with similar contexts. However, a discrepancy between farmer perceptions and rainfall records is found in some cases. For instance, there is only one instance where more than half of the farmers perceive changes in both summer and winter rainfall correctly and that is in the case of Gujrat where more than

half of the farmers perceive a decrease in seasonal rainfall. The correct perceptions of rainfall changes in Gujrat are evidence of the fact that farmers belonging to rain-fed regions, where farming mainly relies on rainfall, generally have a good understanding of ongoing changes in the rainfall. In the case of Rahim Yar Khan, only two-fifth of the farmers accurately perceived an increase in summer rainfall while the same number of farmers in Rahim Yar Khan perceives in contrary a decrease in summer rainfall. One possible reason for this large number of disagreements could be the consecutive dry spells during 1996-2002 and low rainfall during 2009 and 2013 in Rahim Yar Khan. In Toba Tek Singh, the majority of the farmers perceive a decrease in summer rainfall in contrast to an increasing observed trend. One possible reason for this disagreement may be the continuous decline in rainfall since 2011 in Toba Tek Singh.

Table 6.2 Linear regression results for long-term changes in temperature and rainfall

Study districts	Temperature				Rainfall			
	Winter season (<i>rabi</i>)		Summer season (<i>kharif</i>)		Winter season (<i>rabi</i>)		Summer season (<i>kharif</i>)	
	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat	coeff.	t-stat
Rahim Yar Khan	0.10***	5.15	0.13** *	7.36	2.98**	2.27	8.64**	2.15
Toba Tek Singh	0.05***	4.43	0.04** *	3.92	-1.01	-1.29	8.10	1.55
Gujrat	0.03**	2.36	0.04** *	5.09	-3.01	-0.80	-19.1***	-2.74

*** and ** indicate significance at $p < 0.01$ and $p < 0.05$. Here, coeff. represent the climate parameter's coefficient and t-stat shows the t statistics which is commonly used to determine whether the population mean significantly differs from a specific value (a hypothesized mean).

For winter rainfall changes, perceptions of more than half of the farmers in Rahim Yar Khan are incorrect while only about 29% of the farmers in Rahim Yar Khan correctly perceive a decrease in the winter rainfall. These incorrect perceptions may be due to continuous low rainfall between 1992 and 1995 and 2009 and 2013 in Rahim Yar Khan. In the case of Toba Tek Singh, about half of the farmers perceive correctly a decrease in winter rainfall. However, there are still a large number of farmers ($> 30\%$) in Toba Tek Singh and Gujrat who perceive no change in the winter rainfall. In line with the findings of the other studies like Gbetibouo, (2009) and Zampaligré *et al.*, (2014), most farmers in this study perceive

long-term rainfall evolution more negative than testified by meteorological records. These findings also show that farmers do not just perceive climate change as a single process, but that they are aware of some components of climate change more than others.

The comparison of farmers' perceptions with the mean deviation in seasonal temperature and rainfall (Figure 6.4) also shows that in most of the cases, farmers perceived climate change more in those regions where there is a higher deviation in seasonal temperature and rainfall. This implies that higher deviation in climate indicators increases the chances that farmers will notice the changes in climate more compared to the farmers belonging to other regions with less variability in temperature and rainfall. For instance, temperature changes are more accurately perceived by farmers in Rahim Yar Khan, where climate data shows more deviation from mean temperature. While rainfall changes are perceived more by farmers in Gujrat district where climate data shows higher deviation in seasonal rainfall from their mean.

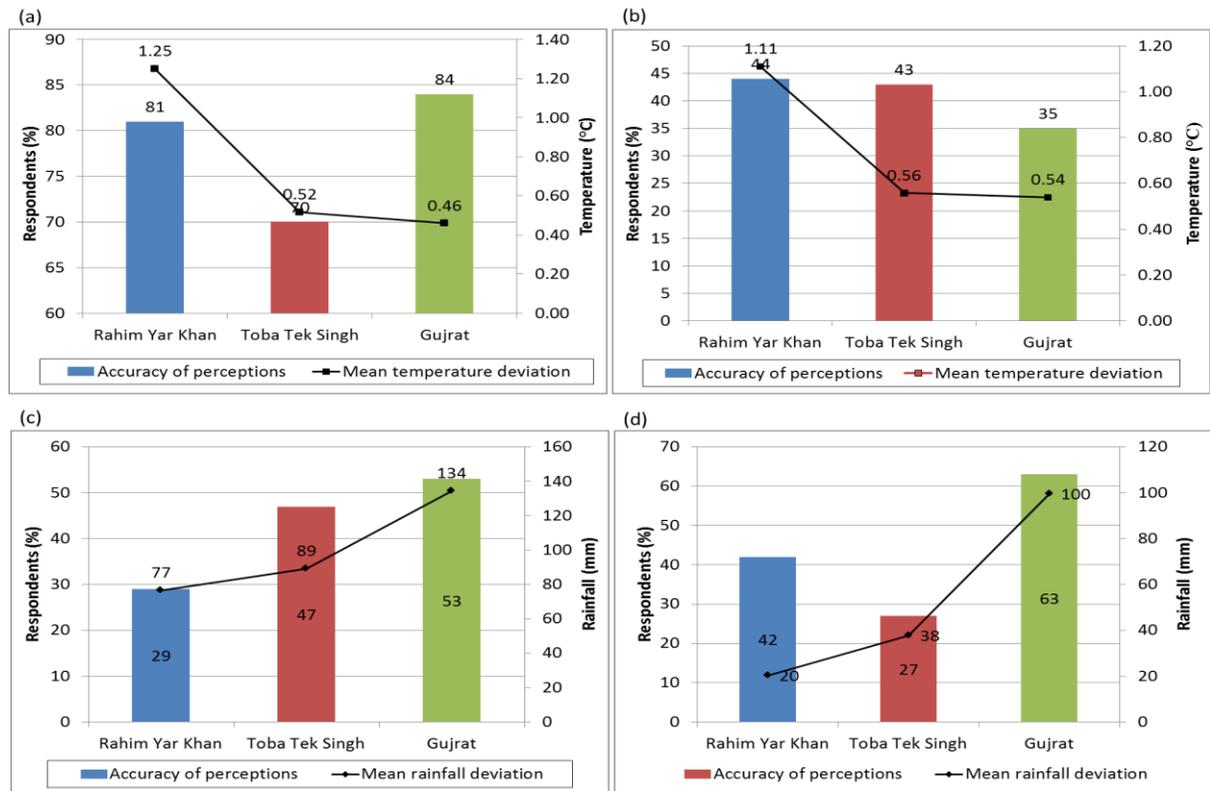


Figure 6.4 Mean deviation in seasonal climate indicators and local perceptions. Here the mean deviation of specific climate parameters is measured by calculating the mean of the distances of each value from their mean. The accuracy of perceptions is measured by comparing farmers perceptions of changes in climate with historical observed climatic trends (1980-2013).

6.3.2 Empirical findings

The correlation coefficients of the three adaptation stages estimated through the multivariate probit model show a positive and significant association or link among all stages (Table 6.3). The positive and significant coefficient of correlation between accurate perceptions and adaptation intentions (Rho31) shows that accurate perceptions of climate change does have a significant influence on adaptation intentions of farmers. While an insignificant coefficient of correlation between underestimated perceptions and adaptation intentions (Rho32) shows a positive but insignificant relationship and implies that underestimated perceptions may not guarantee that farmers will adapt to climate change. Both findings justify our assumption that more accurate perceptions lead to stronger adaptation intentions and underestimated or low perceptions leads to weaker adaptation intentions. Furthermore, accurate perceptions do also have a direct association with adaptation intentions implying that positive intentions lead towards actual adaptation. All these findings also support our assumption of causal chain linkages among the three stages of adaptation, where one stage leads to the other. Further, it also justifies the use of the multivariate probit model instead of using separate probit models for each stage (Howden *et al.*, 2007). The likelihood ratio (LR) and Wald χ^2 tests also reject the hypothesis of conjoint nullity of ρ_{kj} and supports the use of the multivariate probit model (Table 6.3).

Table 6.3 Multivariate probit results showing correlation among adaptation stages

	Coefficient	Standard error
Rho31= Adaptation intentions and accurate perceptions	0.537***	0.166
Rho32= Adaptation intentions and underestimated perceptions	0.0837	0.104
Rho43= Adaptation to climate change and adaptation intentions	0.866***	0.121
Log likelihood value	-562.42	
Wald χ^2 (30)	253.81***	
LR test of $\rho_{kj}(H_o=\rho_{kj}=0)$	66.40***	
Total observations	417	

***, ** and * show the significance level at less than 1%, 5% and 10% p-level respectively

The results of the multivariate probit model for all three stages of adaptation are presented in Table 6.4 and Figure 6.5. In Figure 6.5, green and red lines show the significant positive and negative relationship among the explanatory and dependent variables respectively, while the

blue lines show insignificant relationship. The study findings indicate variation in the influence of different factors on all three adaptation stages. The education level of the farmers is found to be statistically significant for the perception accuracy and underestimated perceptions and insignificant for the other two models. The positive coefficient implies that educated farmers are more likely to observe the changes in climate accurately compared to the farmers with no or less education. This may be due to the fact that educated farmers are more likely to use advanced means of communication and record keeping that assist them to memorize the changes in the past. The negative and significant coefficient for the second perception model shows that education increases the likelihood that farmers will not underestimate climate change. These results are in line with the findings of other studies (e.g. Deressa *et al.*, 2009; Deressa *et al.*, 2011).

Table 6.4 Determinants of different adaptation stages (N=417)

Variables	Perceptions (base farmers who do not perceive any climate change)		Adaptation intentions	Adaptation to climate change
	Accurate perceptions	Under-estimated perceptions		
Education	0.111*** (0.0210)	-0.0572*** (0.0145)	0.00143 (0.0186)	-0.00362 (0.0166)
Farming experience	0.00561 (0.00789)	0.00780 (0.00610)	0.000170 (0.00772)	0.0121* (0.00706)
Land tenure	0.816*** (0.228)	-0.272* (0.164)	0.603*** (0.200)	0.784*** (0.174)
Land holding	-0.842*** (0.257)	0.179 (0.167)	-0.583*** (0.190)	-0.506*** (0.181)
Marketing information	-0.0982 (0.228)	-0.210 (0.162)	0.279 (0.195)	0.316* (0.182)
Weather forecasting information	0.175 (0.328)	-0.0185 (0.198)	1.054*** (0.214)	0.572** (0.232)
Extension services	0.191 (0.173)	0.150 (0.136)	0.118 (0.174)	0.283* (0.151)
Cooperation	0.785*** (0.251)	-0.0990 (0.152)	0.777*** (0.171)	1.175*** (0.173)
Location in AEZ (Toba Tek Singh)	-1.615*** (0.265)	0.223 (0.167)	0.225 (0.250)	-0.346* (0.194)
Location in AEZ (Rahim Yar Khan)	0.0908 (0.187)	0.762*** (0.169)	-0.560*** (0.214)	-0.0182 (0.187)
Constant	-2.645*** (0.449)	0.0458 (0.295)	-0.794** (0.357)	-2.032*** (0.395)

***, **, * show the significance level at less than 1%, 5% and 10% p-level respectively while the values in parenthesis show the standard error.

Further, farming experience does have positive but insignificant coefficients for perception and intention stages but has a positive and significant association with adaptation. This implies that more experience in farming increases the chances that farmers will adapt to climate change. This also shows the confidence and expertise to take new decisions, which may be lacking in less experienced farmers. Similar to our findings, Deressa *et al.* (2011) also found a positive association between farming experience and adaptation decision making. The variable for land tenure is found to be highly significant and positive for all stages of adaptation except for under-estimated perceptions. The positive coefficient of land tenure implies that owner-cultivators are more likely to accurately perceive changes in climate and thus have more intentions and adaptation preferences compared to tenants or sharecroppers. Similarly, the negative coefficient for under-estimated perceptions implies that owner-cultivators are less likely to underestimate climate change. This may be due to the reason that owner-cultivators are supposed to live in the area for a long time and hence they may have a good understanding of current and past climate compared to tenants or sharecroppers.

In contrast to land tenure, land holding variables show a significant but negative association with all three adaptation stages except an insignificant underestimated coefficient. This implies that small land holdings do not only negatively affect the accuracy of perceptions but also restrict farmers to plan measures to adapt to climate change. The low perception accuracy and adaptation intentions may be linked to the limited access to the resources and services in case of small farmers. On the other hand, large landholders, which enjoy unrestricted access to resources and information, perceive correctly and also adapt more. These findings are in line with the findings by (Bryan *et al.*, 2013). A significant and positive coefficient of access to marketing information in case of adaptation intentions and adaptation implies that more access to marketing information enables farmers to make proper adaptation plans keeping in view the available information and resources from nearest possible sources (Bryan *et al.*, 2013).

Access to weather forecasting information is positively but insignificantly associated with accuracy of perceptions and significantly relate to adaptation intentions and adaptation to climate change. This implies that access to weather information does not guarantee that farmers will perceive changes accurately. However, access to weather information may

enhance farmers' intentions and actual adaptation decision making by enabling them to use this information to adjust their short term day-to-day crop management decisions such as watering crops, harvesting, fertilization according to weather changes. Similar results are found by the studies (e.g. Maddison, 2007; Semenza *et al.*, 2008; Mertz *et al.*, 2009; Deressa *et al.*, 2011) conducted in Africa with similar background and problems.

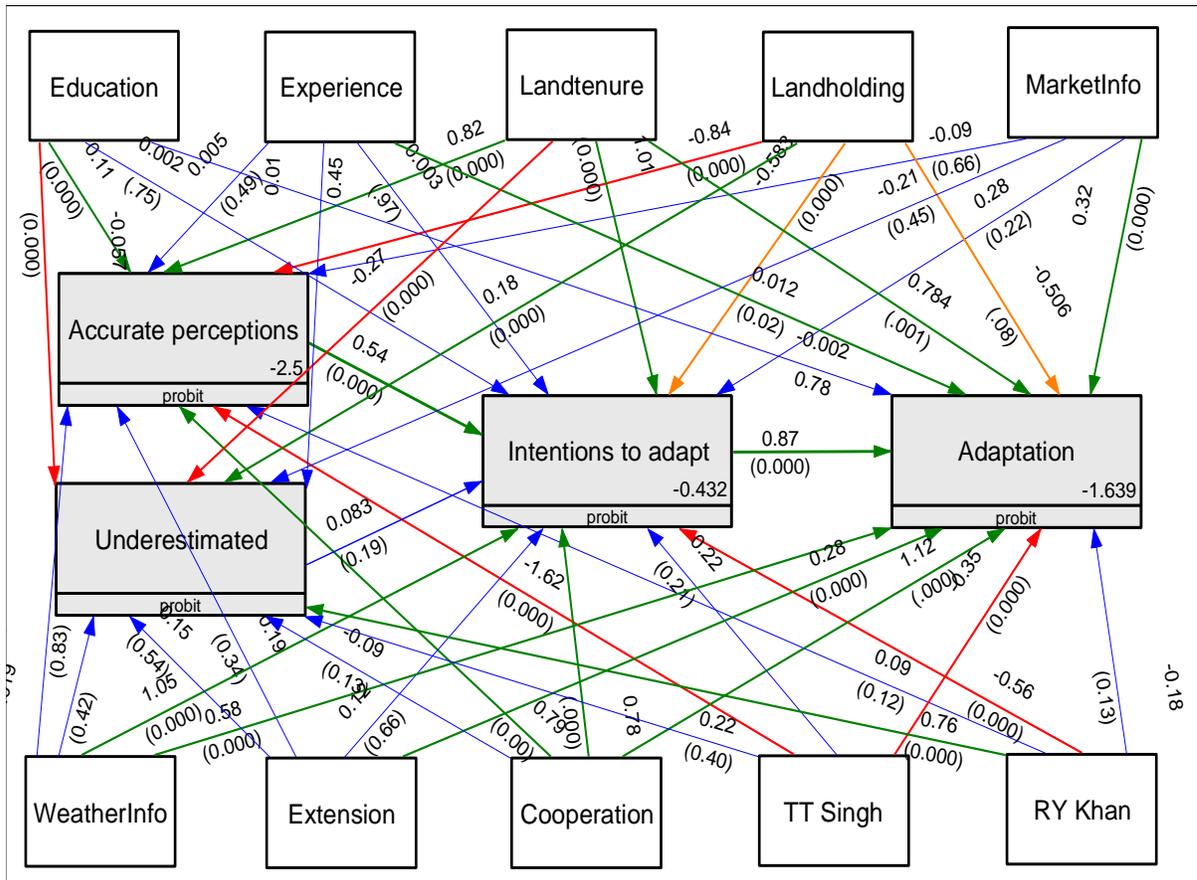


Figure 6.5 Multivariate probit estimates for three adaptation stages. Here, the green (positive) and yellow (negative) lines show significant effect of the variables on different adaptation stages, while blue lines show insignificant effects and values in parentheses show the respective p-values.

Moreover, the study finds that access to farm advisory services increases the chances that farmers will adapt to climate change. This indicates that farmers, who are continuously in touch with extension workers to get information on new cropping technologies or instructions about weather or pests, adapt more compared to farmers having little or no access to extension services. These findings are in agreement with other studies (e.g. Brondizio and Moran, 2008; Campos *et al.*, 2014). On the other hand, insignificant

coefficients of extension services for perception accuracy and adaptation intentions shows the limited role of advisory services in shaping farmers perceptions of climate change and adaptation planning. This is true in the sense that the advisory services in Pakistan focus mainly on the dissemination of information on cropping technologies to farmers without any climate-context. However, the access to extension services still has a positive impact on the choice of adaptation strategies to climate change.

Farmers cooperate and interact with other co-farmers to trade inputs and crop products or to exchange information. These kinds of interactions are very important to shape farmers' understanding and decision-making at the farm level. In this study, we found a positive association between farmer-to-farmer cooperation and accurate perception, intention and adaptation stages. These findings suggest that cooperation with other farmers enables farmer to perceive changes in climate accurately and adapt more than the farmers with less or no interactions. It is quite possible that farmers who interact with other farmers may exchange their experiences about ongoing changes in the climate and information on new cropping methods, which ultimately improve their understanding and perceptions of climate change. In line with our findings, other studies (e.g. Reid and Huq, 2007; Van Aalst *et al.*, 2008) reported the positive impact of farmers' interactions in understanding and managing climate-related risks.

Location of farmers in the agro-ecological zone significantly affects the adaptation stages. The negative coefficient of Toba Tek Singh for perception accuracy and adaptation implies that locating in Toba Tek Singh decreases the probability that farmers perceive changes in climate correctly and adaptation likelihood. These findings are in accordance with our previous findings in section (3.1) where we found that changes in climate are less observed in Toba Tek Singh compared to the other two districts. Further the negative coefficient for Rahim Yar Khan depicts that farmers located in Rahim Yar Khan are likely to adapt less compared to farmers in Gujrat. This implies that farmers in the rainfed region, who are more observant of and dependent on climate, are more likely to adapt to climate change compared to farmers in irrigated regions.

6.3.3 Accuracy of perceptions and adaptation across different farming categories

Further, we also investigate the accuracy of perceptions and adaptation under various

categories of farmers based on land tenure and size of land holdings (Figure 6.6). In terms of land tenure, we divided farmers into owner-cultivator, owner-cum-tenants and tenants/sharecroppers. Here owner-cultivators are the farmers, who own certain units of land, while the tenants are those, who do not own any land but hire land from others and sharecroppers are tenant farmers who give (or receive) a part of each crop as rent (payment). With respect to land holdings, farmers were divided into small (< 2 ha), medium (2-5 ha) and large landholders (>5 ha).

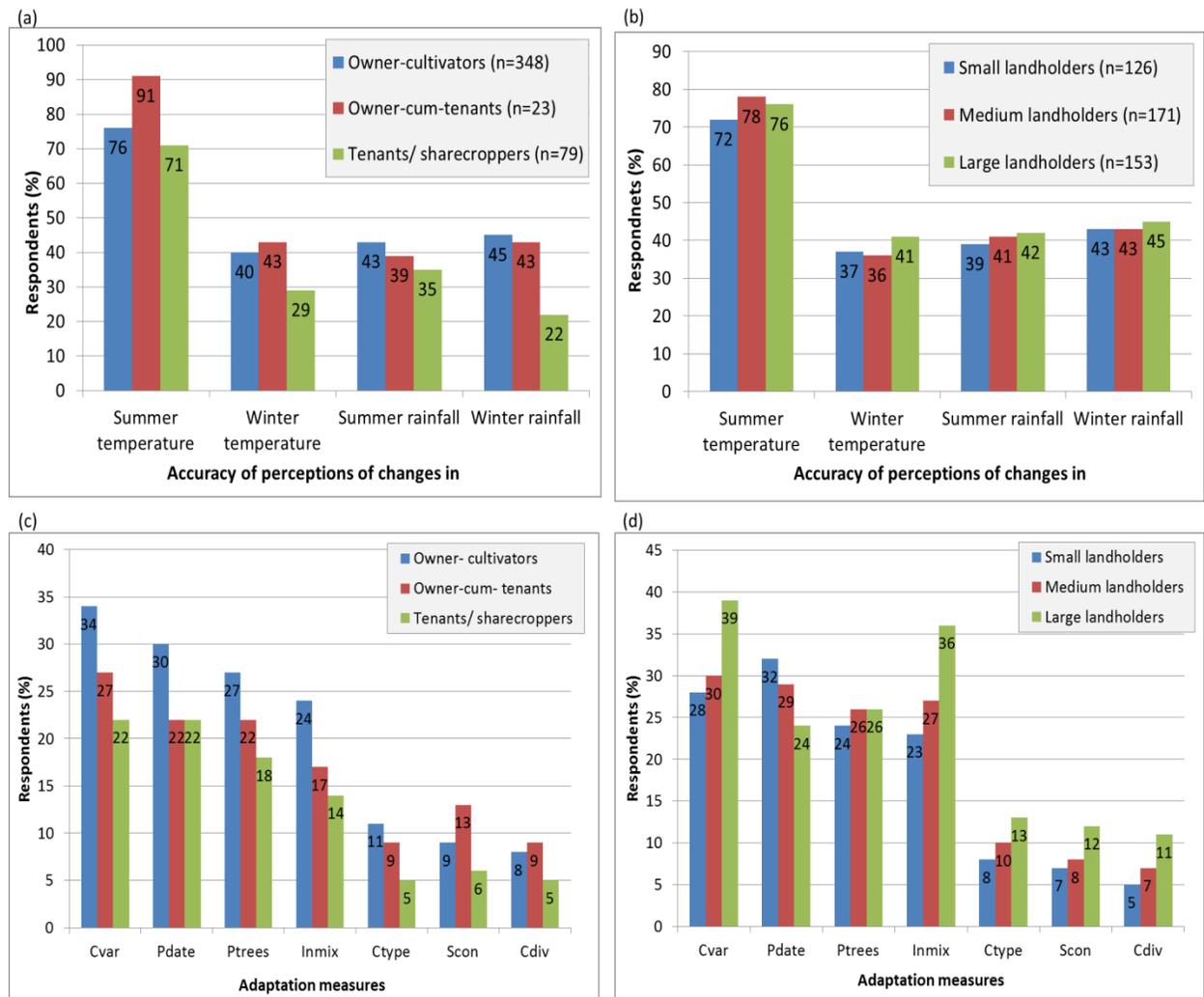


Figure 6.6 Accuracy of perceptions and adaptation under different categories farmers. Here Cvar= crop varieties, Pdate= planting dates, Ptrees= planting trees, Inmix= Input mixes, Scon= Soil conservation and Cdiv= Crop diversification

The findings of the study presented in Figure 6.6 show that changes in seasonal temperature and rainfall are correctly perceived by either owner-cultivators or owner-cum-tenants and

farmers with large or medium landholdings. The lower perceptions by tenants and smallholders could be due to their little access to resources particularly to the modern telecommunication sources from where they can get information about daily or seasonal weather changes. These findings are consistent with the study by Brondizio and Moran (2008) which also shows the resource constraints as a major barrier for small landholders to perceive and adapt to climate change. Likewise, the findings of adaptation measures adopted by different categories of farmers also show similar trends. In most of the cases, adaptation strategies are adopted by owner-cultivators and large landholders followed by owner-cum-tenants and medium landholders respectively. Interestingly, smallholders and tenants prefer low-cost adaptation measures (changing cropping varieties, planting dates) over high-cost adaptation measures (soil conservation, crop type and diversification). These findings are also consistent with the idea that adaptation has certain costs, which may not be bearable by small farmers. Further, it may also show little access to physical and informational resources required for implementing adaptation measures. In line with our findings, Maddison (2007) also reported that tenants or sharecroppers are less likely to adapt to climate change possibly due to the presence of a number of resources and financial constraints. Further, Jianjun *et al.* (2015) also reported that large landholders adapt more to climate change due to more access to resources.

6.4 Conclusion

This study analyzes perceptions of climate change by farmers and their agreement with observed changes in temperature and rainfall and explores the key determinants of and links between three distinct stages of adaptation (perceptions, intention, and implementation). In addition, we investigate the accuracy of perceptions and adoption of different measures with respect to different farming categories.

The study emphasizes the importance of understanding local perceptions of climate change in order to design effective adaptive measures at the farm level. The results reveal that farmers do not perceive climate change as a single process, but differentiate different components of the climate system, which may change differently. Generally, farmers perceive an increase in seasonal temperature and a decrease in seasonal rainfall, with an exception in the case of Rahim Yar Khan District, where a small majority of the farmers perceive an increase in the

summer rainfall. Farmers' perceptions of an increase in seasonal temperature match fairly well with the local temperature records. However, a discrepancy is found in some cases between farmer perceptions of rainfall changes and local climate records. Generally, the seasonal rainfall changes are perceived more accurately by farmers belonging to the rain-fed region (Gujrat district). The study also confirms that a higher deviation from the mean climate leads to a higher awareness of climate change.

Further, using a multivariate probit model, the study reveals a positive chain association between three stages of adaptation, where perceptions lead to adaptation intentions and in turn intentions lead to the implementation of adaptation measures to climate change. The influence of internal and external factors varies across different stages of adaptation. Land tenure, land holdings, cooperation and location of a farm significantly affect all three stages. While education significantly improves the understanding of farmers to accurately perceived changes in climate, while access to marketing information influences intentions and adaptation decisions of farmers due to better access to resources and information. Farming experience and extension positively influence farmers' adaptive behavior through better access to new techniques and expertise required to adapt to climate change. A positive interaction and cooperation within the farming community is necessary to improve the local understanding and effective adaptation of agriculture to climate change. These findings show the importance of education and internal communication and access to resources for adaptation.

This study finds that changes in climate are perceived accurately by owner-cultivators and large landholders and the same is found true in case of adaptation to climate change. Adaptation strategies adopted at farm level particularly by small farmers and tenants, were more of short-term nature. The main adaptation measures implemented by farmers include changing cropping varieties, planting dates, input mixes and planting trees. The preference of short-term and low cost measures is mainly due to limited access to informational, physical and financial resources at farm level, particularly in case of tenants and small landholders. Consequently, the employment of medium- and long-term adaptation measures needs to be focused more while designing national as well as regional policies in order to provide efficient technical and financial assistance to vulnerable groups in case of climate change events. Furthermore, development and implementation of adaptation strategies aiming at

reducing adverse climate change effects must be site-specific keeping in view the high variability of natural resources as well as land tenure and small landholders in different regions.

7 The role of social networks in agricultural adaptation to climate change: implications for sustainable agriculture in Pakistan

7.1 Introduction

Projected changes in climate and increasing frequency of extreme events over the 21st century pose serious threats to agricultural development in developing countries (Abid *et al.*, 2016b). Over the last two decades, Pakistan has become highly vulnerable to climate change events like floods, droughts, extreme temperature and uncertain rainfalls (IUCN, 2009; Kreft and Eckstein, 2013; Abid *et al.*, 2015). The agricultural sector which is a source of livelihood for more than half of the population in Pakistan, has particularly been the most affected sector by climate change due to lack of infrastructure and adaptive capacity (IPCC, 2011). For instance, the floods in 2010 damaged two million hectares of standing crops and caused a 4.1 billion USD loss only to the agricultural sector (GOP, 2011).

Adaptation of current farming systems is one of the ways to avoid the risks of climate change and to protect the livelihoods and local food security (Abid *et al.*, 2015). However, the type and extent of adaptation strategies vary across regions and change socio-economic and agro-ecological settings. A lot of studies (e.g. Bryant *et al.*, 2000; Adger *et al.*, 2003; Bryan *et al.*, 2011; Deressa *et al.*, 2011; Bryan *et al.*, 2013; Abid *et al.*, 2015) show the effectiveness of local and farm level adaptation efforts towards improved adaptive capacity and protection against climatic risks. Since climate change adaptation is largely local, its effectiveness highly depends on the functioning of local actors and institutions (public, private and civic) that interact to provide institutional support and incentives to farmers and locals (Agrawal, 2010). In particular, the role of local government interactions is crucial to ensure sustainable adaptation among poor and smallholding farmers, who are also more vulnerable in most of the cases (Smit and Wandel, 2006; Stringer *et al.*, 2009). These institutional arrangements and collaborations at the local level may be more effective than individual efforts to enhance the adaptive capacity and resilience in the agricultural sector to climate change (Agrawal, 2010; Kiragu, 2010).

Over the last decade, research on climate change and agriculture has evolved from mitigation (e.g. McCarl and Schneider, 2001; Metz *et al.*, 2007) and impact studies (e.g. Seo and Mendelsohn, 2008; Schlenker and Lobell, 2010) to adaptation and resilience studies (e.g.

Deressa et al., 2011; Alam et al., 2012; Bryan et al., 2013; Mugi-Ngenga et al., 2016). There is an increasing recognition on the role of social capital in the adaptation literature (e.g. Carlson and McCormick, 2015; Jordan, 2015; Kithiia, 2015; Lei *et al.*, 2016; Paul *et al.*, 2016) where it is considered to be an important part of support systems at the rural level (Alam *et al.*, 2016). Various studies (e.g. Deressa *et al.*, 2009; Wolf *et al.*, 2010; Chen *et al.*, 2014; Alam *et al.*, 2016) reported the significant role of access to different institutions in shaping adaptation decision making and improving farmer wellbeing. Such kinds of literature mainly come from either developed countries or developing African countries. However, studies from South Asia hardly explore institutional aspects of adaptation. A growing literature from South Asian countries including Pakistan mainly focuses on incremental impacts of climate change on different crops (Jeswani *et al.*, 2008; Hanif *et al.*, 2010a; Yasin, 2011b; Siddiqui *et al.*, 2012; Abbas, 2013) and rather little on adaptation perspectives (Ahmad *et al.*, 2013; Abid *et al.*, 2015; Gorst *et al.*, 2015b).

The role of social networks has particular importance in developing countries like Pakistan where access to institutions is limited (Abid *et al.*, 2016a). Particularly, the small landholders are often deprived of access to institutional services that are biased towards landlords or influential farmers (Amjad and Hasnu, 2007; Abid *et al.*, 2015). Given the limited knowledge and information on climate change adaptation in Pakistan, the institutional aspect of adaptation is yet to be explored. There is dire need of studies focusing on the current linkages and interactions among different stakeholders and their role in the local adaptation process. Such kind of knowledge will be helpful to assess the potential of social capital and its use as an effective tool to improve farm households' resilience and adaptation to climate change.

Keeping in view the current knowledge gap, this is the first study of its kind in South Asia that particularly focuses on social capital and the role of social networks in farm level adaptation to climate change. Specifically, this study responds to four research questions: 1) What is the current status of social networks at farm level in term of source and type of services? 2) What are the structural gaps in current institutional support to climate adaptation? 3) Is current local institutional setup enough to support climate change adaptation? 4) What interventions are required at institutional level to enhance farmers' adaptive capacity to climate change?

7.2 Methodology

7.2.1 Social network analysis

There is growing recognition in the literature to use social network analysis in resource governance and adaptation studies at various scales ranging from regional to local (Bodin and Prell, 2011; Ngaruiya *et al.*, 2015). A social network is mainly consisting of interdependent actors that interact with each other to establish the flow of resources or information. These interactions may be either one-directional or two-directional. Grounded in systematic empirical data, social networks analysis is primarily motivated by identifying the structural ties linking interdependent social actors and uses graphic imagery and computational models to uncover patterns that might otherwise go undetected (Freeman, 2004; Prell *et al.*, 2010). Unlike the standard social science research that heavily focuses on attributes of individual actors, social network analysis focuses on the characteristics and linkages of social actors to uncover the hidden theoretical motivations behind the social relationships that shape environmental outcomes and individual decision-making (Wasserman and Faust, 1994). Studying the role of social networks in adaptation and governance can reveal deficiencies in the existing farmer support management that can be useful to enhance the local adaptive capacities and resilience to climate change. Based on network theory, this study selected two measures (structural holes and density) of the social network to analyze patterns of interrelationship and to understand the level of synergy among local stakeholders in agriculture and adaptation implementation.

7.2.2 Structural holes

This study is mainly interested in understanding how social networks facilitate identification of stakeholder positions in a network and how these actors link various parts of the system together (Prell *et al.*, 2010; Ngaruiya *et al.*, 2015; Ngaruiya, 2016). Further, through social network analysis, the study also explores the structural holes among different actors. Structural holes represents the empty spaces in social structures that exist between two actors when they are not connected even having some common or mutual goals. There are various ways to measure structural holes including bridge counts, hierarchy, constraint values, and ego betweenness.

Several mathematical indices are used to define the significance of an individual unit or actor within the network domain. Equation (7.1) describes the betweenness centrality index that counts the number of network pathways passing through an actor and is used to measure how much potential control an actor has in sharing relevant information across the social network.

$$B_C(j) = \sum_{i \neq j \neq k} \frac{\partial_{ijk}}{\partial_{ik}} \quad (7.1)$$

where $B_C(j)$ represents the betweenness centrality of actor j , ∂_{ijk} shows the number of paths linking actors i and k that pass through actor j , and ∂_{ik} is the number of paths connecting actor i and k . This definition works under the assumption that interactions between two nonadjacent actors might depend on other actors, particularly the actors who lie on the path between two (Wasserman and Faust, 1994). In other words, we can say that the actors, who rest between many others, may act as “broker” to disseminate adaptation information to other actors. Through information sharing with other actors, they are not only able to positively affect the individual decision making of others, but they will also influence the level of collective knowledge in the community to resolve common resource problems. For instance, if a community has well-equipped brokers or well-connected actors then the overall adaptive capacity of the community will increase and it may reduce the damages from climate change and related risks. On the other hand, unconnected or weakly equipped brokers may negatively affect the adaptive capacity of the community and may increase its exposure to climate change and its adverse impacts (Ngaruiya, 2016).

7.2.3 Density

Network density represents the average strength of connection between actors (Ngaruiya *et al.*, 2015) and indicates how actors are linked together (Prell *et al.*, 2010). The density (d_i) in equation (7.2) calculates the proportion of ties existing in a network and explores the community behavior, attitudes, and performance.

$$d_i = \frac{L}{n(n-1)/2} \quad (7.2)$$

where n depicts the number of actors connected to actor i and L is the number of lines between the actors. Density scores represent the cohesion levels among actors, where higher density indicate shows the higher number of ties between actors based on the assumption of close communication in the community. For instance, poor adaptation at farm level may be

due to fragmentation or missing links in the community that may be identified through social network analysis and may be improved accordingly.

7.2.4 Data collection and analysis

Field work was conducted in March–April 2014. A multi-stage sampling technique has been used to select the study districts and 450 farm households. Details on the sampling method are described in section 1.2 of chapter 1. A structured questionnaire is used to collect relational (social network) data of actor linkages, their socio-economic attributes, and adaptation to climate change. Before the final data collection, the questionnaire is pre-tested in the field to avoid missing any important information. Data collection is done with the help of three enumerators hired from the local agricultural university located in Faisalabad, Pakistan. Enumerators are trained for the questionnaire terminologies and data collection techniques. After data collection, surveys are carefully entered into excel database and cleaned using Stata software.

After that, the social network data is converted into an actor matrix and analyzed for brokerage using the algorithm for betweenness centrality that finds the geodesics in the network and then computes potential connections of every actor in the community. The output data is then visualized as a sociograph using NetDraw™ that efficiently illustrates the actual situation at the grassroots (Borgatti et al., 2002).

To simplify our understanding of the networks at local level, we divide the data sets into two main categories, climate adaptation access (CA_Access) and financial support (Fin_Support). Climate adaptation access deals with activities directly related to climate change and adaptation and include extension services, weather information and water delivery. While, financial support (Fin_Support) deals with activities that increase the adaptive capacity of farmers through increase in agricultural output or income for the farmers and includes agricultural credit, marketing information, post-harvest processing and marketing of produce, farm machinery. Appendix D describes the acronyms representing the nodes in both networks.

7.3 Results and discussion

7.3.1 Institutions providing on-farm services

Three types of institutional governance systems are active in rural Pakistan. Table 7.1 provides the overview of different institutions, their type, location and kinds of on-farm services. Public institutions are present from regional to local scales due to their vast public infrastructure and top-down hierarchy in the allocation of staff and offices. However, the quality and outreach of public institutional services at farm level is questionable due to low human and financial resources. On the other hand, private sector organizations have sufficient budget to launch self-promoting and well-managed services for farmers. However, these services may be biased and sometimes provided with the motive to sell their produce. Some public institutions such as irrigation and meteorology departments do not have any direct or formal links to deliver services to farmers. But they maintain and update information online, which is freely available to anybody.

Table 7.1. Institutions that provide on-farm services to farmers

Institutions	Location	Type	Services
Agricultural Extension	Regional/ village level	Public	Advisory services regarding crop and livestock production
On Farm Water Management	District	Public	Watercourse improvement and subsidized farm implements including water saving technologies
Pest Warning & Quality Control of Pesticides	Sub-district level	Public	Pest scouting, farmer training
Punjab Seed Corporation	Sub-district level	Public	Seed sales, farm advisory services, seed quality testing
Soil and Water Testing Laboratories	District	Public	Soil and water testing services to farmers
Directorate General Agriculture (Field)	District	Public	Land levelling, soil and water conservation and water resource development
Directorate of Agriculture (Economics & Marketing)	Provincial/ Sub-district level	Public	Online agriculture marketing information service, capacity building at farm level
Pakistan Agricultural Storage and Services Corporation (PASSCO)	Sub-district level	Public	Marketing of cereal grains

Pakistan Meteorology Department	National/ provincial	Public	Weather forecasting information
Irrigation Department	Sub-district	Public	Irrigation water services
Zarai Taraqati Bank Limited (ZTBL)	Provincial/ sub-district	Public	Credit
Micro Credit institutions	Sub-district	Private	Credit
Input producing and distribution companies	Sub-district/ Village level	Private	Input sales and distribution, agricultural information services
Friends and colleagues	Village level	Community	Informal credits, farm implement, weather and marketing information,
Telecommunication sources (TV/ Radio/ Internet)	Online/ Local	Private	Extension, weather and marketing information

The connections and linkages between different institutions that have the potential to provide on-farm services to farmers are presented in Figure 7.1. The color and strength of the lines show the level of linkages between different institutions. The dark lines show the active connection between two institutions while the light blue lines show the inactive linkage. Further, more dense lines show more ties between institutions and vice versa. Similarly, the size of the node representing each institution is set according to its number of connections with other institutions. The findings of the study show the presence of many inactive connections between actors implying that most of the institutions are not well connected and normally work in isolation from other neighboring institutions. However, only the extension department is somehow connected to other institutions such as on-farm water management (OFWM), irrigation department, pest warning department, agricultural field and some private companies that are providing extension and information services to farmers. In some occasions these institutions work jointly with the extension department to provide on-farm services to farmers such as information on water saving technologies, farming practices, new fertilizers and pesticides. In line with our findings, various studies (Jan *et al.*, 2008; Shahbaz *et al.*, 2008; Saqib and Tachibana, 2014) also stated the weak linkages and coordination between allied state and non-state institutions related to agriculture in Pakistan. This lack of coordination could lead to the inefficient use of the public resources allocated to agriculture and may also be one of the reasons behind the poor performance of most of the public institutions in providing services to farmers. It is quite possible that through joint collective

actions, these institutions could provide services to a large number of farmers using fewer resources. However, such kind of horizontal integration and collective actions require proper policies.



Figure 7.1. Network showing connections between different institutions

7.3.2 Institutional support, agricultural productivity and climate adaptation

The study results reveal that 89% of those surveyed, have access to any of the 24 categories of institutions and eight main types of services that are offered to farmers, while the remaining respondents do not participate in the services offered by various institutions. However, not all the farmers have complete access to all services which depends on farmers' socio-economic status and resources.

Private, public and community institutions offer the community information related to weather conditions and also ways to adapt their agricultural livelihoods. The services provided to farmers can be classified into two categories, namely; access to financial services and access to climate adaptation services. Results from the study show that only 28% and 13% of the respondents do not have access to any financial services and climate adaptation

knowledge respectively.

Access to financial services is provided through agricultural credit services, affordable farm equipment (lease/buy options), marketing farm produce, post-harvest services and general marketing information. These services enhance the farmers' ability to increase their capacity to buy more seeds, equipment to plough larger parcels of land, avenues to market their produce or learn new agricultural skills or plants with higher profits and increase the value of their harvested produce before selling for more profits. This is the business-as-usual scenario for most agricultural sectors.

However, in addition to increasing agricultural productivity, there are institutions that offer services related to climate-related matters and new knowledge in smart agriculture to increase livelihood output despite changing climatic conditions. The access to climate adaptation knowledge services includes agricultural extension services, provision of weather information and delivery of water to villages. The study revealed that respondents have 32%, 96% and 82% access to extension services, weather information and water delivery services respectively in the climate adaptation knowledge area.

7.3.3 The institutional services-farmers network

The social network data is analyzed to assess the network density, structural holes, and suitable brokers. The study network with the density of 0.013 emanating from the 2,938 ties between the actors confirms the little linkages between stakeholders involved in the agricultural sector (See Appendix C). Figure 7.2 and Figure 7.3 show the adaptation access and financial support networks, where we divide farmers into three groups based on districts and see how farmers in each district are connected to different institutional actors in the networks. In these networks, the density of lines is set according to the relationship and strength of ties between different actors. For instance, high density linkages are represented using thick and bold lines between actors while the low density linkages are shown using thin and faint lines between actors. The type of line becomes an indication of how strong or weak the linkage is in the network. Similarly, the size of the actors' symbols is set according to their degree of betweenness. The actor with more connections with other actors appears bigger compared to actors with fewer connections in the network. Figure 7.2 shows that in the adaptation network, farmers in all three districts are well connected to weather

information from private sources (WeathPrv) followed by water delivery information from public (WatPub) and community sources (WatCom). Private sources through which farmers acquire weather forecasting information include modern telecommunication means such as the internet, radio and television that are easily available even in rural areas. The higher dependence on private sources of weather forecasting information shows their lack of access to public information sources as shown in the network where farmers in all three regions are loosely connected with public actors. This lack of access is mainly due to lack of awareness as there are various public entities at federal (meteorology department) and provincial (agriculture department) levels who use their web portals to disseminate information on daily and seasonal weather forecasting and issue alerts especially for farmers.

Further, water delivery information comes to farmers mainly from the irrigation department and community sources including friends, relatives and co-farmers. In rural areas, it is common to have contacts with lower-rank irrigation staff to acquire water-related information particularly during crop sowing and early growth stages. These findings are in line with other studies conducted in parts of Punjab province of Pakistan showing the role of local connections in acquiring water and agriculture-related information. Agricultural extension, an important factor in the network that is supposed to be an essential component of agricultural development, is found to be loosely connected in the network compared to the other two actors. Farmers rely mainly on community source actors to acquire extension and agricultural information followed by public and private extension sources. In line with our findings, Yaseen *et al.* (2016) also reported that about half of the farmers in Punjab rely on community while very low percentage of farmers actually have access to public or private extension sources. Similarly, findings of other studies (e.g. Davidson *et al.*, 2001; Luqman *et al.*, 2014; Rahman *et al.*, 2014) also confirm the notion of the limited role of public institutions in the provision of various on-farm services to farmers in Pakistan. In light of current changes in climate and the frequency of extreme events and their adverse impacts on the agricultural sector, the role of public and private extension services is very crucial (Abid *et al.*, 2016a). However, the shortage of human resources and lack of infrastructure are some of the main challenges faced by public extension in Punjab where each extension actor is responsible to serve hundreds of farmers. Another reason for low access to farmers may be the biased provision of extension services at the local level as reported by many studies in

Pakistan.

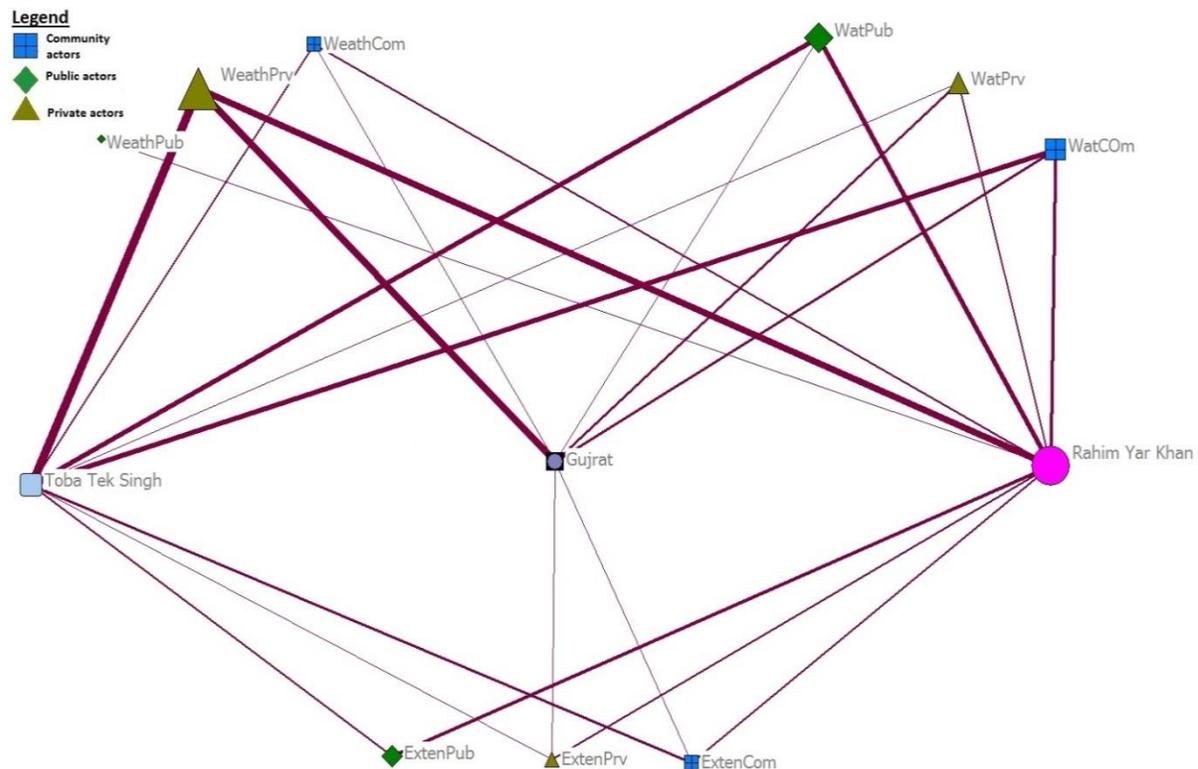


Figure 7.2. Climate change adaptation support network. The social network showing linkages from farmers to climate adaptation knowledge sources, whereby, thick and bold links represent higher link densities between actors, while actor size is an indication of the number of linkages an actor has in the network.

In the financial support network shown in Figure 7.3, marketing information (InfoCom) and farm equipment (MachCom) from community sources and marketing information from private sources (InfoPrv) are the highly connected factors among farmers in all regions. However, the connections within the financial network vary across regions. For instance, the size of symbol and the number of connections suggests that farmers in Rahim Yar Khan are more connected to institutions and farmers in Gujrat are loosely connected. Further, the role of public institutions in providing financial support to farmers is not impressive. For financial services, farmers mainly rely on the community sources such as friends and co-farmers and private sources like input dealers and sellers. The loosely connected public marketing information (InfoPub) is mainly due to the lack of its recognition as a product among public institutions (Yaseen *et al.*, 2016). For farm equipment, farmers again rely mostly on the

community and less on private and public sources. Here it is important to mention that the agriculture department in Punjab has recently launched a project to provide farm equipment such as laser guided land leveler, and water saving technologies at a subsidized cost through its on-farm water management departments which are operative at sub-district level (GOP, 2016). Unfortunately, not all the farmers have access to those services due to lack of awareness and capacity to pay the starting cost (initial investment) of the equipment.

In the financial support network, agricultural credit, marketing of agricultural products and post-harvest services are the most loosely connected factors. Agricultural credit that could provide support to farmers in case of climate shocks and other disasters is the weakest factor in the network. Farmers in all three regions do not have access to public credit sources. The situation is worse in the case of Gujrat and Toba Tek Singh, where farmers rely totally on community for financial support. These findings are in line with the results of the study which reported that only 15% of farmers in Pakistan have access to the public source of credit. However, this ratio further decreased to 6.5% when it comes to poor farmers (Hussain and Thapa, 2012). Further, high interest rate, lack of collateral or guarantee and lengthy processing may be some of the other reasons behind this little credit access at the farm level. Further, loosely connected marketing of produce and post-harvest services implies that farmers in Punjab are most likely to get unfair prices of their produce due to non-availability of marketing services. Here the role of a middleman is very important to discuss. Due to the lack of marketing infrastructure and access to local and regional markets, small farmers are forced to sell their produce to the middleman at lower prices which is one of the many reasons of low income at farm level. Further, non-availability of postharvest services at local level shows farmers inability to add value to their crops by the use of advanced technologies such as cold storage and selling products at higher prices. All these findings imply that limited access to financial support services may have an adverse impact on the adaptive capacity, and the anticipated climatic changes may lead to more vulnerability at the farm level in the absence of proper support infrastructure.

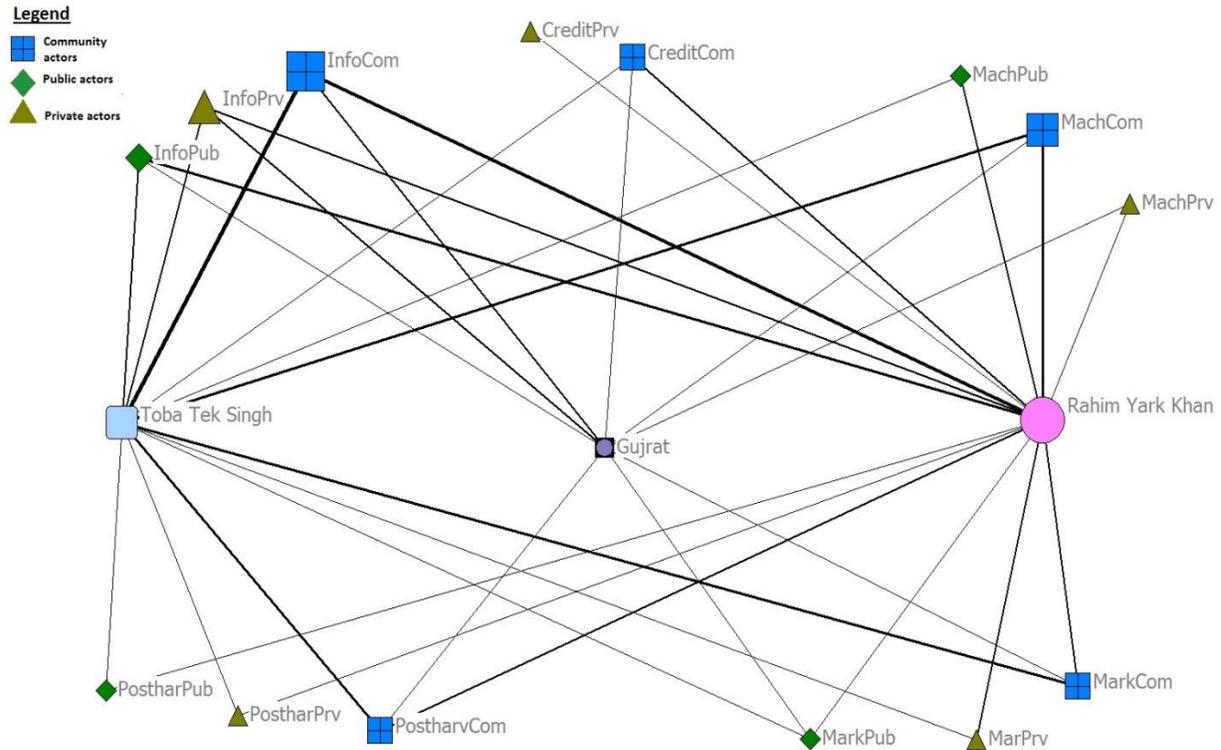


Figure 7.3. Financial support network. The social network shows linkages from farmers to financial services sources, whereby, thick and bold links represent higher link densities between actors, while actor size is an indication of the number of linkages an actor has in the network.

7.3.4 Structural gaps in current institutional support

Given an ego-network representing the set of nodes (factors) with direct ties to the focal nodes (farmers in different regions), a structural hole represents the absence of a tie among a pair of nodes in the ego network (Burt, 1992; Borgatti *et al.*, 2009). The lack of structural holes around a node means that the node is well bounded with other nodes to communicate and provide financial or adaptation knowledge services to farmers (focal nodes) (Borgatti *et al.*, 2009). Here in this study, we tried to explore the structural holes and gaps in the current institutional support to farmers using betweenness, brokerage and degree measures. The factors having more values in all three aspects may represent better connected or bounded with farmers in providing different financial and adaptation services to farmers and vice versa.

The structural holes (betweenness, brokage) and degree of actors in both financial support and adaptation networks are shown in Figure 7.4. Figure 7.4a shows that most of the adaptation

factors are loosely connected to farmers and provide little support to farmers especially in extension services for better crop production and information on new cropping technologies. The highest responsive services (betweenness) is weather forecasting information from private sources (WeathPrv) with 60,256 ties and 330 degree, while the lowest response is found in case of weather information from public (WeathPub) and private extension (ExtenPrv) with 87 and 85 ties and 7 and 18 degrees respectively. Similarly, Figure 7.4b shows that except for marketing information and farm machinery, all other services are loosely connected to farmers in the financial network. The highest response is found in case of marketing information from public sources (InfoPub) with 30,718 ties and 167 degrees; while the lowest connection is found in case of credit from public sources (CreditPub) with zero ties and degree. All these results show that farmers in both networks have limited access to institutional services. Thus, institutions need to extend their support in terms of all services so that farmers may benefit from them and enhance their adaptation and adaptive capacities.

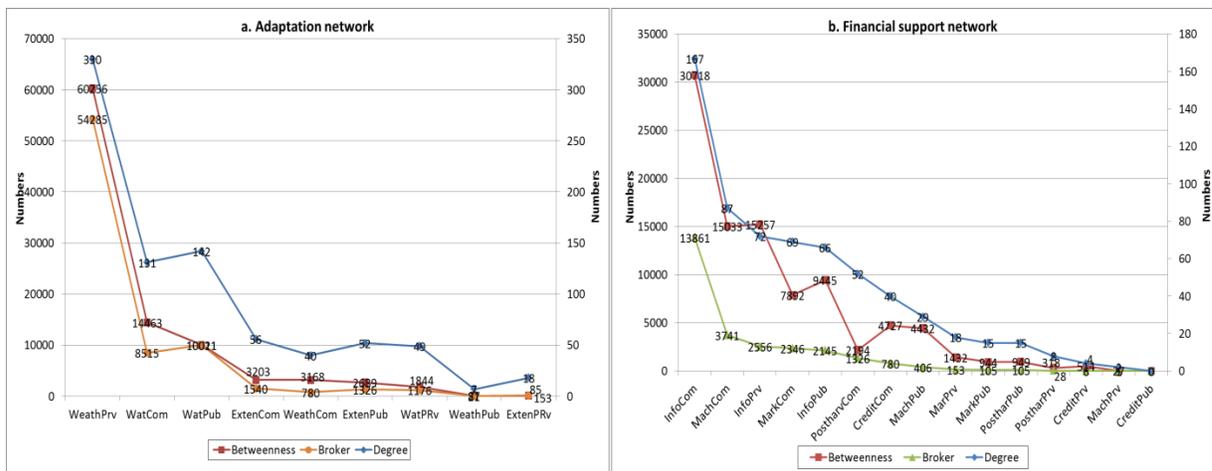


Figure 7.4 (a)-(b). Structural gaps in current institutional support to climate adaptation. The red lines shows the betweenness between farmers and different institutional factors that counts the number of network pathways passing through an actor, the green lines show the broker linkages which indicate how much potential control an actor has in spreading information or providing services in a social network and the blue lines (on secondary vertical axis) indicates the degree of different factors showing the absolute number of connections of each factors with farmers from all regions.

7.3.5 Enhancing the role of local stakeholders in adaptation to climate change

Following our previous results and based on a framework from Meinzen-Dick *et al.* (2013), the study explores the interaction of three main stakeholders for an effective adaptation by looking into four key areas namely information sharing, innovation and investment, capacity

building and insurance. Figure 7.5a describes the current situation of interaction between the major actors in the study area. The arrow signs show the direction of particular service from one actor to the other, which may be either one-directional or two-directional. The dotted line(s) shows the weak or missing links while the straight lines show the significance of the interaction between actors. Our study findings reveal that public institutions are more active in providing information services and investing at rural or community level to provide different on-farm services while the private sector is involved more in information delivery, capacity building of farmers and innovation and investment. However, one thing is common in the work of public and private sector organizations that most of their services are supply-driven (one directional) and do not incorporate backward linkages with farming communities (Davidson *et al.*, 2001).

For instance, various public and private sector institutions are investing and providing small or medium scale agricultural loans to farmers, but they do not care for which purpose farmers are using that credit. Similarly, the provision of advisory services to farmers is one-directional where public or private extension workers are supposed to provide advice to a certain number of farmers and to meet their targets (Abid *et al.*, 2016). They even do not care about actual needs of farmers. Here, public institutions have the advantage of their presence at the local level through its top-down hierarchy, but they are unable to deliver services adequately due to lack of physical and human resources. On the other hand, private institutions have sufficient financial viability, but their outreach is limited in terms of area and scope. Further, capacity building is completely missed in the framework without some exceptions in the case of private sector organizations that have designed their limited ability building programs and training for farmers. Further, linkages between private and public institutions are very weak and no single instance is found in the study area where both kinds of institutions interact together to provide joint services to farmers.

To enhance the effectiveness of existing institutional setup and to prepare it for effective adaptation to climate change, we propose an improved framework as shown in Figure 7.5b. This framework involves filling missing links and suggests focusing on partnerships and collaborative work at the different levels to provide better services to farmers so that they may effectively adapt to climate change. The basic stimuli for such collaborative actions arise from the limitations in term of function, capacity and scope of institutions within the

public, private and community domains. Each institution has some limits and may not have all required expertise. Hence, through active cooperation and collaboration, different stakeholders may benefit from each other's expertise to fulfill their common goal of agricultural sustainability and improving farmers' wellbeing.

Increasing adaptive capacity is dependent on the acquisition of information and technologies at farm level; hence any increase in the coverage by on-farm services in the study area will enhance adaptive capacity (Smit and Wandel, 2006). Therefore through this study, we proposed an integrated framework to improve the support to farmers so that they may be able to adapt better to climate change. This framework given in Figure 7.5 suggests four types of partnerships, i.e. public-private, private-social, public-social and community-community. For collective actions and collaboration, the role of central government is critical and may act in this framework as a connecting body to facilitate and connect all stakeholders. Now we will discuss all these partnerships one by one.

Public-private partnership: Public-private partnerships (PPPs) by involving the private sector as a partner in recognizing and adapting to climate change in developing economies are essential for multiple reasons. PPPs may play a key role in mobilizing financial resource, enhancing technical capacity, engaging communities and developing climate services and adaptation technologies (Glendenning *et al.*, 2010). Public and private sector organizations may use each other's expertise and may serve better than individually. The public sector may dominate in providing startup infrastructure and physical resources required to initiate joint adaptation efforts. Private entities may provide their expertise in infrastructure investments and agricultural research to develop more drought-resistant varieties, water management infrastructure and technologies, capacity building of government officials and service providers. It is observed that most of the public institutions are related to agricultural work in sole isolation from their sister institutions. Therefore, public-private-partnership will not only help to connect public and private entities, but it will also join all public institutions to work together for climate change adaptation in the agricultural sector. Further, these partnerships may also be helpful in designing effective dissemination and training models to provide adaptation services and training to farmers such as joint farmer field days, discussion groups, exchange visits (Hoang *et al.*, 2006). The local adaptive capacity may also be improved through public-private collaborations where the private sector may be engaged to

develop financial assistance services to farmers exposed to climatic risks and disasters such as floods, extreme temperature events and droughts (Biagini and Miller, 2013).

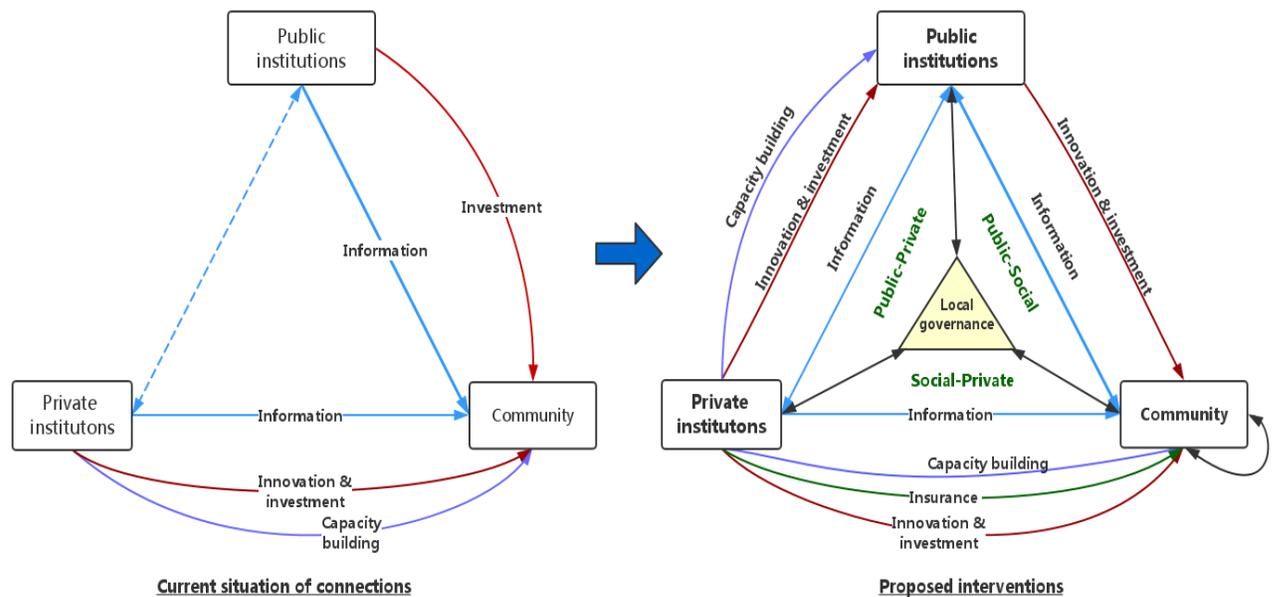


Figure 7.5 (a)-(b). Current and enhanced interactions for local adaptation to climate change

Social-private partnership: Social-private partnership is mainly suggested to improve communication between communities and private sector organizations working in rural areas. Various private sector bodies are providing advisory and technical services to farmers to improve their crop productivities. Private sector institutions may involve communities to get their feedback about provided services and may enhance their services according to farmers’ needs (Nelson, 2009). Private sector organizations in cooperation with public entities and communities may design schemes to provide farm level access to advance on-farm services such as water and soil testing laboratories; need-based farm advisory services and climate-smart loans. However, active monitoring and checks may be required to ensure the effective use of climate-smart loans.

Another component of climate change adaptation is the insurance to climatic risk, which is completely ignored in the agricultural sector in Pakistan. The private sector may take advantage of this gap and may develop some insurance schemes to protect farmers from climatic shocks. Risk is always recognized as a constraint to the adoption of new practices and technologies (Binswanger, 1981). Providing farmers with risk insurance will enable them

to take more risk to generate more profit. Initially, risk insurance schemes may be tested on the small scale for single crops before it is extended to a larger area and multiple crops.

Public-community partnerships: Public-community collaboration is essential to transform supply-driven services towards need-based services. Most of the on-farm services including extension and on-farm management do not consider current needs of farmers (Meinzen-Dick *et al.*, 2011). Through public-community partnerships, public entities may be able to collect information from farmers on their needs and issues to improve their service delivery, introducing need-based services and solutions to farmers. Here, the collaboration of public-private partnership may also play a useful role in this transformation.

Another important aspect of these collaborations may be to use already established networks and farmer groups. For instance, in Punjab under the new irrigation reforms, farmer organizations are established at canal circle level manage irrigation water and to collect water charges (Senanayake *et al.*, 2015). These organizations do have their elected members and public offices and have connections at grass root level. So public entities may use these established organizations to improve their service delivery and extend their scope including climate change adaptation services.

Community-Community collaborations: Another perspective of social networking may be to enhance community-to-community and farmer-to-farmer interactions to enhance local adaptive capacity and service provision. Various studies (e.g. Abid *et al.*, 2016a; Abid *et al.*, 2016c) identified the potential role of such cooperation in enhancing local adaptation decision making. Further farmer organizations may also play a significant role to increase such kinds of networking among farmers through community meetings. Public and private institutions may collaborate with each other to arrange capacity building training for farmers to highlight the importance of collective work and to teach methodologies to increase resilience to climate change.

7.4 Conclusion

Social networks can play a major role to enhance the adaptive capacity of farming communities to climate change. Using a cross-sectional dataset of 450 farm households, this study examines social networks at the local level and their role in the adaptation process and also investigates the structural gaps in the current institutional support at the farm level.

The study reveals that the majority of the farmers have access to different kinds of institutional services. However, still there were some respondents who do not participate in any services provided by various institutions. Private, public and community sources provide different types of climate change adaptation and financial support services to farmers. However, the findings of social network analysis indicate that the network has very low density showing various loosely connected factors in the system. Results from both networks show that District 3 (Gujrat) has the lowest response to activities across the study area and also within the three categories (Figure 7.3). In the climate change adaptation network, farmers are strongly connected to private sources to acquire weather forecasting information and are loosely attached to a public source of weather forecasting information. Weather forecasting information from public sources is completely missing in case of Gujrat and Toba Tek Singh and only a few farmers in Rahim Yar Khan have access to the public source of weather forecasting, which could be due to the presence of the weather station in Khanpur. Weather stations in the other two locations are far away from the respective cities. Particularly agricultural extension, an important source of information for farmers to improve farm productivity, is found to be very weak in the Gujrat district. This could be due to several factors: it has the highest null (limited) response rate of 31% because the area is characterized by high subsistence agriculture, low education and low availability of surface water. Similarly, in the financial support network, farmers were mainly connected to marketing information from community sources and marketing information from private sources. This implies that how loosely farmers are linked to public sources of services and how positively community sources are serving farmers to improve their resilience and adaptation to climate change. Social network analysis also reveals that farmers in Gujrat district are least connected compared to farmers in the other two districts.

The study further analyze the current institutions (public, private and community) at the local level in term of four key areas (information, innovation and investment, capacity building and insurance) and found that public and private institutions are not linked together at local level. Further, most of the services provided by public and private institutions are one-directional and miss the backward linkages with communities and farmers. Public and private organizations also fail in the insurance part of the framework. Based on study findings and review of the literature, this study suggests an improved integrated framework to enhance the

networking between different stakeholders. This framework mainly focuses on the four kinds of partnerships between the various ties of the local network such as public-private, private-social, public-social and community-community linkages. Such collaborations at the local level could improve financial viability and adaptive capacity of farmers and may help them to improve their crop productivity and livelihoods.

8 Internal migration and changing environmental conditions: A farmers' perspective from rural Pakistan

8.1 Introduction

It is well recognized that climate change through an increase in mean temperature, variability in rainfall distribution and rising sea level poses serious threats to the ecosystems and human wellbeing, especially in developing countries (IPCC, 2014a). The projected changes in climate and increase in the frequency and severity of environmental hazards are expected to alter the migration patterns throughout the developing world (Raleigh *et al.*, 2008). Pakistan is one of the developing countries supposed to be highly vulnerable to climate change and involuntary displacement (Mueller *et al.*, 2014). Alone in 2010, floods in Pakistan affected 25 million people, destroying two million hectares of crops and temporarily displacing roughly 14 million people across the country (Mueller *et al.*, 2014; Khan *et al.*, 2016). Further, high temperatures and droughts also affect population wellbeing in Pakistan by lowering agricultural productivities. Extreme weather events and the resulting decline in agricultural incomes are expected to alter the rural-urban migration patterns in Pakistan (Mueller *et al.*, 2014).

The susceptibility of a system to changing climate and environmental conditions depends on its sensitivity and adaptive capacity i.e. the ability of a system to respond to adverse impacts of environmental change (Adger, 2006; Smit and Wandel, 2006). A system would be vulnerable if it is more sensitive to climate-related risks and has limited adaptive capacity at the same time (Fellmann, 2012). In Pakistan, livelihoods are highly vulnerable to climate change due to their heavy dependence on climate-sensitive agriculture and low adaptive capacity (Abid *et al.*, 2015). The low adaptive capacity of rural communities and food producing systems is due to the lack of adaptation infrastructure and less availability of required institutional services (Schilling *et al.*, 2013). Further, exposure and sensitivity at local and household level depend on various other non-climatic factors, including household characteristics, access to resources and support, risk perceptions, intentions and capability to adopt coping measures.

Cost-efficient and timely livelihood diversifications that enhance the coping capacity of households may reduce the household vulnerability to extreme events (Gioli *et al.*, 2014a;

Gioli *et al.*, 2014b). However, adaptation at the local level mostly depends on the willingness and ability of a household to adopt certain measures. Adaptation could be seen as a three step process starting with perceptions followed by adaptation intentions and adoption of coping strategies. Perceiving risk due to changing environmental and climatic conditions is the first step in the recognition of need for adaptation and may be influenced by direct exposure to extreme events, socio-economic characteristics, own beliefs, access to resources and means of information (Adger, 1999; Smit and Wandel, 2006; Mertz *et al.*, 2009; Tambo and Abdoulaye, 2013; Abid *et al.*, 2015; Abid *et al.*, 2016a). Secondly, in response to the observed and perceived changes, the households may intend to take certain measures to protect their livelihoods from adverse impacts of climatic and environmental change (Adger *et al.*, 2005; Tambo and Abdoulaye, 2013). At this stage, various constraints like lack of physical, financial or informational resources may jeopardize the coping and adaptation plans.

At local and rural level, household adaptation options may range from changing crop management options to changing livelihoods (Gbetibouo, 2009; Deressa *et al.*, 2011). Changing Management options may include new crop types, varieties, planting dates and input mixes, while livelihood options may include diversification of income sources through investing in other businesses or switching businesses. Labor migration may be another option that farm households may consider as an income-diversification strategy to cope with livelihood losses due to environmental shocks (see e.g. (Bardsley and Hugo, 2010; Banerjee *et al.*, 2012; Warner *et al.*, 2012). In other words, circular labour migration can be seen as an integral part of the communities' strategy to cope with and (to a lesser extent) adapt to economic and environmental shocks (Goulden *et al.*, 2013). Despite the evolution of literature on climate change and agriculture, including studies on mitigation (e.g. McCarl and Schneider, 2001; Metz *et al.*, 2007), impact assessments (e.g. Seo and Mendelsohn, 2008; Schlenker and Lobell, 2010) and adaptation (e.g. Deressa *et al.*, 2011; Alam *et al.*, 2012; Bryan *et al.*, 2013; Mugi-Ngenga *et al.*, 2016), research in developing countries like Pakistan has focused more on the vulnerability of ecosystems to climate change, and less on adaptation. Research on adaptation is important in the sense that it helps providing suitable and sustainable pathways in the mid and long run (Mimura, 2007; Mortreux and Barnett, 2009).

In Pakistan, there has been very little consideration of the adaptive capacity of social systems, constraints and barriers that limit adaptation. Similarly, literature on migration in Pakistan mainly has focused on internal rural-urban migration (e.g. Irfan, 1986; Khan *et al.*, 2000; Arif, 2005; Farooq *et al.*, 2005; Haq *et al.*, 2015) and very little in the context of (global) environmental change and adaptation (e.g. Gioli *et al.*, 2014a; Gioli *et al.*, 2014b; Mueller *et al.*, 2014; Saeed *et al.*, 2016). Still there is insufficient evidence to draw a conclusion about the likelihood of migration as an adaptation strategy in Pakistan. More field-based studies are needed to understand the actual situation on the ground at the local level considering household risk perceptions and intentions to migrate and its connections to climate change.

Given the existing knowledge gap, this study explores the link between the farmers' perceptions of environmental and climatic changes and their willingness to undertake internal labor migration as an adaptation strategy to climate change. Overall this study has three key research questions, 1) What kinds of environmental or climatic risks are perceived by most by farm households heads? 2) How do perceived climatic risks (and other socioeconomic or institutional factors), interlink with the willingness of undertaking labour migration as a livelihood option 3) Is there any change in the land borrowing trend in the study area, given the changes in environmental conditions, and what are the possible reasons of any observed trends.

8.2 Material and methods

8.2.1 Conceptual framework

Climatic and environmental changes are expected to affect rural communities and their livelihoods adversely and, in extreme cases such as flood or drought, they may result in distress migration or displacement (Bardsley and Hugo, 2010; Warner *et al.*, 2012). On the other hand, it can also be labour migration as an income-diversification strategy undertaken by a household in response to environmental shocks, as well as to cope with a long-term decline in livelihoods due to those shocks (Warner *et al.*, 2012). This is true especially in the case of rural communities that rely heavily on the agricultural sector and hence are highly sensitive to climatic risks and other environmental shocks (Schilling *et al.*, 2013).

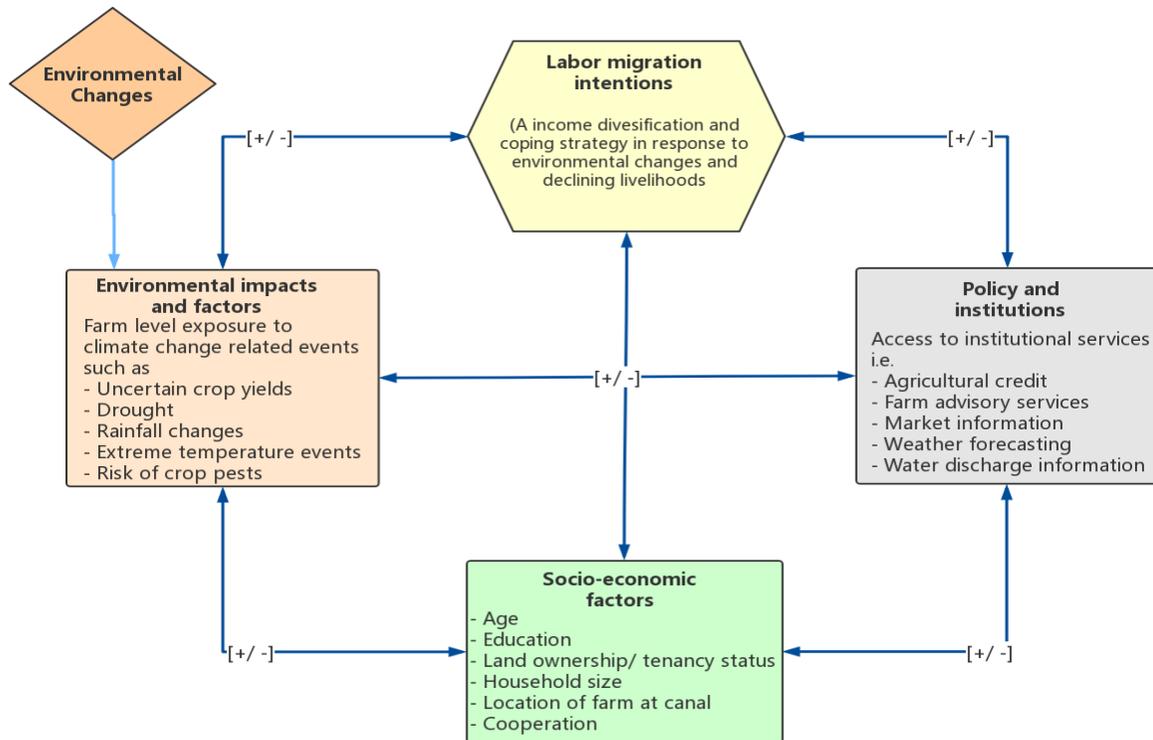


Figure 8.1. Conceptual framework of the study. Here (+) and (-) signs show the positive and negative association between different factors.

However, vulnerability to (global) environmental change is socially constructed (Shearer, 2012; Christmann *et al.*, 2014; Gautier *et al.*, 2014) and individual and collective perceptions affect hazard-related behaviour. Sometime social structural factors, access to resources and institutional services play an important role in defining susceptibility, perceptions and responses to environmental extreme events (Hewitt, 2014). These social and institutional settings also determine how environmental shocks are perceived and responded by local communities. For instance, a community or household with enough access to resources and livelihood options could be considered less vulnerable to environmental extremes which cause damages to other communities or households that depend on natural resources and have limited resource access (Adger, 2006; Smit and Wandel, 2006). As we discussed earlier, in response to anticipated climatic shocks and long-term decline in livelihood options, farm households may consider labour migration as a strategy to diversify their income sources and to avoid further livelihoods shocks (Figure 8.1).

8.2.2 Analytical framework

In our assessment of livelihoods, we consider the household as the main decision-making unit. Hence we have restricted our interviews to the head of the household. This study does not cover important intra-household dynamics. Under this criterion, the sample size of the study is reduced from 450 to 344.

In the next step, we employ both correlation and logistic regression analysis to assess the interaction of environmental, socioeconomic and institutional factors with the willingness (or not) of undertaking migration as a livelihood strategy. Following Kato *et al.* (2011), a latent form of binary logistic regression model for migration intentions may be represented as:

$$M_i^* = \beta X_{ik} + \mu_i \quad (8.1)$$

where X_{ik} represents the vector of k explanatory variables of household i , β is the vector of logistic regression coefficients and μ_i shows the error term. As the latent variable (M_i^*) is unobservable, we have only:

$$M_i = \begin{cases} 1 & \text{if } M_i^* > 0 \\ 0 & \text{if } M_i^* \leq 0 \end{cases} \quad (8.2)$$

where M_i indicates that the i th household will intend to migrate ($M_i = 1$) only if the household anticipated benefits from migration are positive ($M_i^* > 0$). In contrast, the i th household will not intend to migrate ($M_i = 0$) if the net benefits are non-positive ($M_i^* \leq 0$).

8.2.3 Dependent variable

The dependent variable used in the study is migration intentions. Household heads are asked about their intentions to migrate from rural to urban areas for labor purposes in near future in the form of 'yes' or 'no'. The households who intended to migrate were assigned value 1 and zero otherwise. Further, we also asked household about their past migration behavior.

8.2.4 Explanatory variables

The explanatory variables used in the study include climatic and environmental factors such as perceived risks to drought, changes in rainfall, extreme temperature events and risks to crop pests; institutional and policy factors like access to credit, farm extension services, marketing information services, weather forecasting information and information on water discharge and household internal socio-economic factors. We categorize households based

on their internal socioeconomic characteristics such as age, education, household size, land holding, tenancy status, the location of farm at the water channel and cooperation with other farmers to explore their role in the migration decision process. We classify household heads into three age groups i.e. young with less than 30 years, medium-aged of 30-50 years and old aged above 50 years. We also stratify the sample according to the education level: less educated (with primary or lower education) and above average educated (with elementary or above education). Also, income plays an important role in the migration decision making process and has been used as a proxy for non-labor income because with more landholding, there will be more non-labor income of the family.

Here we use landholding as a proxy for income status of households, where more landholding may be referred to more income because large landholders are supposed to have more access to productive resources and services than smallholders (Zahoor *et al.*, 2013). We also group farm households into small (with less than 2 hectares), medium (between 2-5 hectares of land) and large landholders (with land more than 5 hectares). Moreover, farm households are categorized based on their family size into small (up to three members), medium (3-5 members) and large households (with 6 or more members). Larger households may be more inclined towards labour migration, as they have more human capital. Further, tenancy status and location of the farm along the watercourse could also play an important role in shaping the migration decision process, as they are both indicators of a differential access to certain resources and information. Farm households are categorized as owner-cultivators and tenants, and according to their location along the water channel, downstream and upstream. The location of a farm along the water channel determines a farmer's access to water, which is relatively scarce in Pakistan and sometimes becomes the cause of dispute among downstream and upstream farmers. Further, we explore the role of cooperation in the decision making process, by dividing the farmers into two groups: 1) households who interact or cooperate with other groups (i.e. exchange of labour, water and trading products, as well as information sharing on cropping technologies and inputs); and 2) households who do not interact with other farmers and/or have a conflict with other farmers. Moreover, we analyse migration intentions with respect to households' access to different institutional factors. It might be possible that the access to certain institutional services may change households' intentions to migrate. For instance, access to credit could provide financial

support and guarantee to farmers at the time of need or in the case of natural hazards. Through this financial support, they may be able to invest in different advanced adaptation measures to avoid losses due to natural hazards. Similarly, access to extension services and marketing information may enable farmers about new farming techniques and cropping technologies and farmers may be less intended to migrate.

8.2.5 Linking land borrowing trends and migration

Population movement from rural to urban areas is not a new phenomenon, and climate change may foster this process by affecting the rural livelihoods and lowering agricultural yields. Besides household intentions to migrate in the near future, there may be a number of households who have already moved to urban areas due to various reasons. Since it was not possible to conduct interviews with absentee landlords or absentee members of the household, hence we assess the situation by testing some hypotheses with the interviewees:

- *Hypothesis 1): Given the changes in environmental conditions, there may be an increasing land-borrowing trend (both in number of farmers and volume of land) by existing farmers,*
- *Hypothesis 2): The increasing borrowing pattern may be associated with reduced crop productivities and livelihood losses due to climatic factors.*

Hence, to test these hypotheses, we ask farmers to share their history of land borrowing-in and out during the last five years (2009-13). In addition, we ask farmers to describe the reasons for increasing borrowing trends only if there is any significant increase in the borrowing of land in the specified period.

8.3 Results and discussion

8.3.1 Descriptive statistics

The descriptive statistics of the variables used in the study are presented in Table 8.1. In most of the cases, the values represent percentages. The findings show that household heads perceive changes in the rainfall distribution (93%), extreme temperatures (47%), increase in the incidents of crop pests (25%) and uncertainty and reduction in crop yields (18%) as major climatic risks to their farming. In line with our findings, various studies report an increase in the extreme temperature events (Zahid and Rasul, 2011; Kreft and Eckstein, 2013) and

incidents of crop pests and disease (Yasin, 2011a; Younas *et al.*, 2012) due to changing weather conditions. Further, studies also predict the changes in the rainfall distribution in Punjab over the last few decades and negative impacts on crop yields due to the increased frequency of extreme events (Zahid and Rasul, 2011; Kreft and Eckstein, 2013).

Table 8.1. Descriptive statistics

Variables	Mean	Standard deviation
Migration intentions	0.22	0.41
Climatic and environmental risks		
Extreme temperatures	0.47	0.50
Changes in rainfall distribution	0.93	0.26
Crop pests and diseases	0.25	0.43
Drought	0.18	0.39
Uncertain or reduced crop yields	0.22	0.41
Socioeconomic factors		
Level of education (years)	8.63	4.25
Land holdings (hectares)	6.47	11.33
Household size (numbers)	9.90	5.05
Age (years)	47.46	12.44
Tenancy status (owner-cultivator) %	0.80	0.40
Location of watercourse (Downstream) %	0.59	0.49
Cooperation or interaction with other farmers	0.55	0.46
Institutional factors (%)		
Credit use	0.08	0.27
Marketing information	0.64	0.48
Water delivery information	0.68	0.47
Agricultural extension services	0.21	0.41

The intentions to migrate in the next 5 to 10 years came up significantly among the respondents. About 22% of the farm households consider internal labour migration (from rural to urban areas) as a desirable livelihood option. Household heads in the study area have an average age of 47 years, which is similar to findings of other studies conducted in rural Punjab (e.g. Abid *et al.*, 2011; Durr-e-Nayab, 2015). More than 90% of the household heads are males. Female-headed households could not be considered to for the survey given the difficulties in approaching and interviewing women. Household heads attain on average eight years of schooling. The average household size in the study area is of 9 members, which is above the provincial average of 6.6 members (Durr-e-Nayab, 2015). While, the dependency

ratio per working household member is 5. A household in the study area cultivates around 6 hectares of land. About 80% of the farm households are owner-cultivators, while the rest are either tenants or sharecroppers. About 59% of the farm household heads have their lands downstream of the water channel. More than 55% of the farmers cooperate or interact with other farmers to exchange information or products while the rest report to have a conflict with other farmers on the issues related to allocation of resources such as water and land or social issues like the caste system and marriage disputes.

8.3.2 Association between climate-related events and internal migration intentions

The bivariate association between migration intentions and explanatory variables is shown in Table 8.2. The findings here indicate that the household heads who perceive more climatic risks, have more intentions to migrate. This implies that risk perceptions play an important role in the migration decision process at the household level (Abu *et al.*, 2014). Concerning other explanatory variables, education, household size, age, the location of the farm on a watercourse, cooperation, extension services and agricultural credit services are statistically associated with migration intentions, while landholdings, household size, marketing information and tenancy status were statistically insignificant.

Table 8.2. Percentage distribution of climatic, socioeconomic and institutional factors by intentions to migrate (N = 77)

Variables	Variables description	Percentage
Climatic and environmental risks	Crop pests and diseases	58.33
	Drought	83.33*
	Changes in rainfall distribution	100*
	Extreme temperatures	52.08
	Uncertain or reduced crop yields	77.08***
Socioeconomic factors		
Education	Primary or below	14.58*
	Elementary or above	85.42
Land holdings	Small landholders (<2ha)	28.11
	Medium landholders (2-5ha)	31.79
	Large landholders (>5ha)	40.10
Household size	Small household (≤ 3 members)	22.61
	Medium household (4-5 members)	38.23
	Large household (≥ 6 members)	39.16
Age	Young (≤ 30 years)	20.83*
	Medium aged (31-50 years)	64.58

	Old aged (>50 years)	14.58
	Tenancy status (Owner-cultivator)	25.43
Location	Gujrat	39.51***
	Rahim Yar Khan	31.10
	Toba Tek Singh	29.39
	Location of watercourse	50.01**
	Institutional factors	Agricultural credit
	Marketing information	70.83
	Water delivery information	70.83
	Agricultural extension services	24.43*

Turning to multivariate analyses, the results shown in Table 8.3 indicate that climatic factors along with socio-economic and institutional factors only explain 33% of the variation in the intentions to migrate in the study area. Household heads who perceive uncertainty or reduction in crop yields, changes in rainfall distribution and drought are more inclined towards resorting to labor migration. These findings are in line with the findings of other studies (e.g. De Jong, 2000; Abu *et al.*, 2014).

Further age, education, location of the farm on water channel are the key socioeconomic factors influencing the household head intentions to migrate. Particularly, the age of the household head may determine the security of entire households in time of crisis. In our study, we find that young and medium aged household heads intend more to migrate than old aged household heads (Yang, 2000). It is mostly just because migration requires strength and younger people are more likely to do it. On the other hand, older people favour their traditional practices and are interested to stay at their ancestral place. Often, younger household heads prefer to rent out land to other farmers and migrate permanently with the entire household. Education is another important factor influencing decision making at the household level, and correlates significantly with the willingness to migrate. Household heads with primary education or below are less willing to migrate compared to those with elementary or higher education. It might be possible that highly educated household heads are more aware of environmental changes and related consequences. In addition they may also have more alternative opportunities in case they migrate to urban areas (Abu *et al.*, 2014). The location of a farm along the water channel may also be used as a proxy for farmers' access to resources, especially surface water and land. In Pakistan as well as in Punjab, the agriculture is mainly irrigated and depends much on surface water during the

different crop growth stages. Due to this scarcity, the distribution of surface water has become a source of conflict among upstream and downstream farmers. Most of the times, upstream farmers, who are either large landholders or influential farmers have ample access to water compared to downstream farmers to grow crops and to sustain their livelihoods, and they are less willing to resort to migration. On the other hand, downstream farmers have poor access to water resources and always have issues of water blockage and theft by upstream farmers.

Table 8.3. Determinants for internal migration derived from logistic regression

Variables	B	SE
Climatic and environmental risks		
Crop pests and diseases	0.368	0.386
Drought	0.654*	0.407
Changes in rainfall distribution	1.262*	0.737
Extreme temperatures	0.227	0.350
Uncertain and reduced crop yields	2.865***	0.381
Socioeconomic factors		
<i>Education (base elementary or higher)</i>		
Primary or below	-0.861*	0.487
<i>Land holdings (base large landholders (>5ha))</i>		
Small landholders (<2ha)	-0.270	0.438
Medium landholders (2-5ha)	-0.213	0.415
<i>Household (HH) size (base large HH)</i>		
Small HH (≤ 3 members)	0.710	0.716
Medium HH (4-5 members)	-0.493	0.483
<i>Age (base old aged, >50 years)</i>		
Young (≤ 30 years)	2.493***	0.604
Medium aged (31-50 years)	1.355***	0.432
Tenancy status (base Owner-cultivator)	-0.199	0.443
Location of watercourse	-0.966***	0.368
Institutional factors		
Agricultural credit	-0.325	0.623
Marketing information	0.398	0.497
Water delivery information	-0.024	0.567
Agricultural extension services	-0.689*	0.431
Nagelkerke R2	33	
N	344	

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Among the institutional factors, access to credit and extension services significantly influences household head intentions to migrate. This could imply that access to institutional services improves adaptive capacity of households and their capacity to overcome unfavourable conditions and that is why they have fewer intentions to migrate. Specifically, a better access to financial services enables farmers to invest more on other coping strategies to protect their livelihoods. Similarly, access to advisory services at farm level makes farmers more aware of environmental changes, different adaptation measures and cropping technologies. Using this information, farmers may be able to enhance their farm productivity and avoid potential losses due to environmental changes. Other studies (Smith and Pilifosova, 2003) also reported the effectiveness of credit and extension access in enhancing farmers' adaptive capacities and use of different adaptation measures in response to climate change.

8.3.3 Land tenancy and borrowing trends

Further, we explore farm level land borrowing trends among existing farmers and explained possible reasons of borrowing trends. To test our hypothesis about land borrowing trends, we ask farmers to share their history of land borrowing-in and out during the last five years (2009-13) and reasons for land borrowing by absent or migrated farmers. The findings of the study presented in Figure 8.2(a)-(b) confirm our hypothesis and indicate an increase in the number of farmers who hired land from other farmers, from 80 in 2009 to 100 in 2013, while there is an observable increase (25%) in the total borrowed land from 1200 acres in 2009 to 1500 acres in 2013. This trend implies that there is an upward borrowing-in trend in the study area which may be due to the increase in the number of absentee farmers who left or reduced agricultural lands as an option to diversify their income sources.. The trends are more significant in Rahim Yar Khan and less significant in Toba Tek Singh and unchanged in Gujrat. The unchanged land borrowing pattern in Gujrat may be due to the little dependence of farm households on agriculture in that region. Interestingly the rented-out trend among the existing farmers is very small.

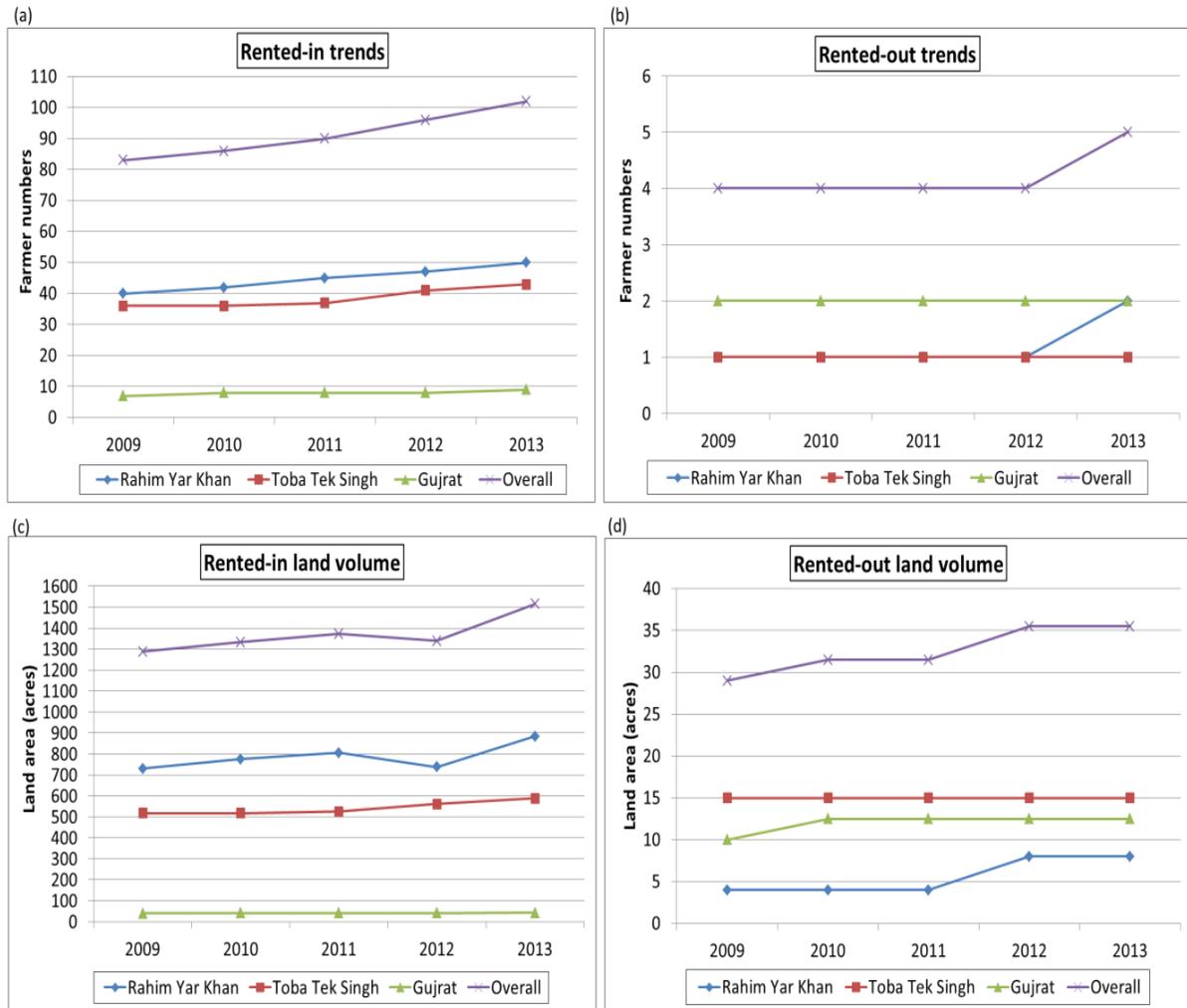


Figure 8.2 (a)-(b). Land borrowing trends in the study area during 2009-2013

Several factors ranging from socio-economic to environmental factors may influence land borrowing trends in the study area. Therefore, we further probe farmers about the possible reasons for this increasing trend in their area (Figure 8.3). According to the farm household heads, the primary causes of this behaviour include fewer returns from agriculture due to climatic factors, lack of resources and socio-economic reasons (Figure 8.3). These findings further support our hypothesis of linkage between land borrowing and environmental changes.

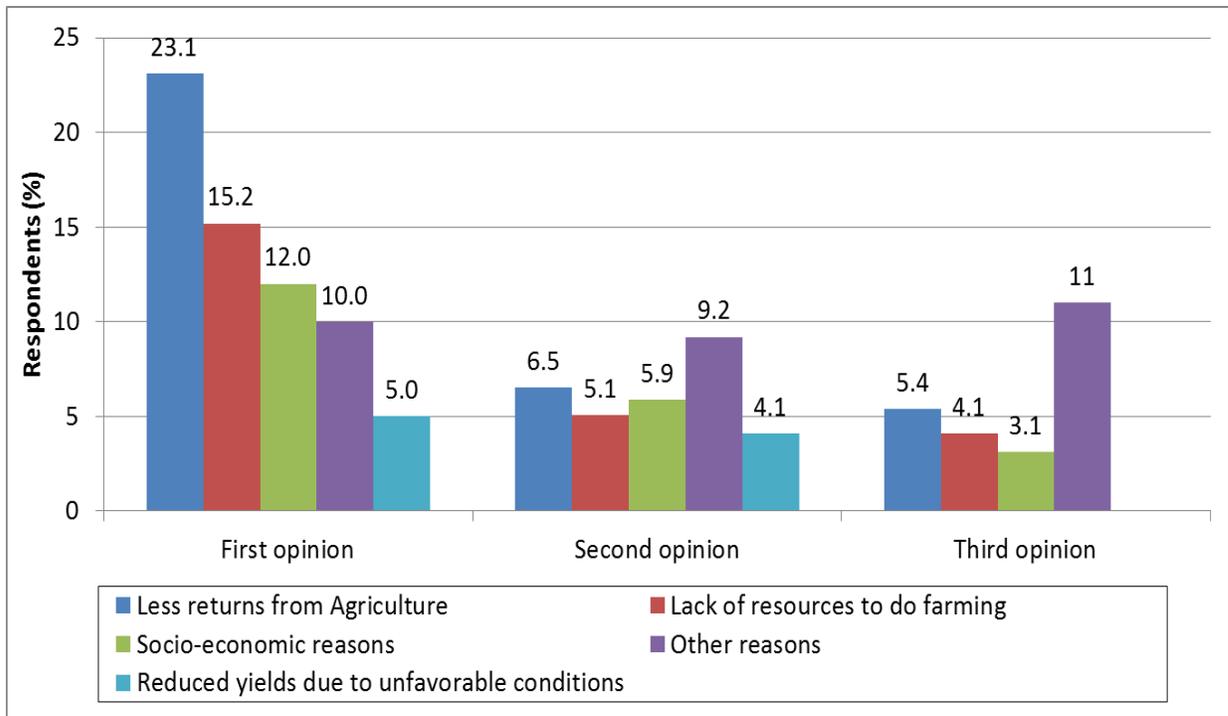


Figure 8.3. Farmer responses regarding agricultural trends among farmers

8.4 Conclusion

Climate change is expected to affect rural livelihoods adversely in Pakistan. Farmers are adopting several measures to cope with climatic risks ranging from short-term to long-term options. In response to declining livelihoods, farm households may resort to labour migration to diversify their incomes.

This study takes the household heads in the case of Punjab, Pakistan to examine the exposure of households to climate change, their perception of labour migration as a livelihood diversification strategy, and its interrelations with environmental, socioeconomic and institutional factors.

The findings of the study reveal that changes in rainfall distribution, uncertainty and reduction in crop yields, extreme temperatures, risks to drought and crops pests are the key climatic risks perceived by farm household heads. Further, the study findings reveal that a better understanding of environmental and climatic risks affect the propensity of resorting to labour migration, as farm household heads who perceive more climatic risks are more inclined to migrate. Mostly the willingness to migrate is significantly associated with

uncertainty and reduction in crop yields, changes in rainfall distribution and risks to drought. The uncertainty and reduction in the crop yields directly affect the rural livelihood, while the other two affect the sources of livelihoods such as affecting soil and water resources that may adversely affect the crop productivity and farm income. Further, the willingness to migrate varies across different categories of farmers based on socioeconomic settings. For instance, young and educated farm household heads have stronger intentions to migrate compared to old-aged and less educated household heads. However, the findings of the study show no differences in migration intentions of farm household heads based on land holding and household size, as both show similar trends across different classes. There are not so many differences in the intentions of tenants and owner-cultivators to migrate as well. However, downstream farmers are more willing to migrate possibly due to the lack of access to resources, particularly irrigation water. Migration intentions are also influenced by access to credit and extension services. Through credit access, farm households may be able to invest in new technologies or ways to avoid losses due to natural hazards. Similarly, the extension provides farmers access to information on new crop varieties, input mixes and technologies through which they can get higher productivities and can reduce losses. The findings of the study show a 28% increase in the borrowing land trends in the study area over the period 2009-13. This implies that there are a number of farmers who left agriculture due to several reasons. Farmers report less returns from agriculture, lack of resources to do farming and socio-economic factors such as better health and education facilities and diversified income options as the key determinants of the increasing borrowing trend in the respective regions.

The study findings indicate that uncertainty and reduced yields are major concerns for farmers in the study regions as these directly affect the sustainability of rural livelihoods and compel farmers to find new ways to cope with these losses. Among many other options, farm households may undertake labour migration as a strategy to diversify their income and cope with the risks that are threatening their livelihoods. The study findings also show that farmers have very little access to institutions and resources that could be one of the reasons behind low adaptive capacities of farmers in the study region. Therefore, additional efforts are required to enhance the adaptive capacity of farmers through access to resources and new technologies. For this purpose, the existing institutional setup needs to be reformed to provide farmers a better access to resources and on-farm services, including new improved

verities, cropping technologies and marketing facilities. Further, private sector organizations may also collaborate with public institutions to improve local adaptive capacities. Through these efforts, farmers could not only cope with climatic risks, but they may also be able to attain higher yields and fill the potential yield gaps.

9 Synthesis

This chapter summarizes the main findings of the previous chapters to explore the study objectives and to answer the associated research questions of the thesis (9.1). Further, conclusions are drawn, and recommendations are provided to inform policy and further research (9.2).

9.1 Summary

Given the adverse impacts of climate change on agricultural development and rural livelihoods in developing countries such as Pakistan, adaptation of the current farming and livelihood systems is a means to mitigate damages. However, effective adaptation requires adequate information on risks and vulnerabilities and current adaptation capacities. This information should be used to design appropriate adaptation policies and to build additional local adaptive capacity if necessary. I have addressed the overall objective of this thesis, to assess the climate change impacts and adaptation in the agricultural sector of Pakistan considering its socioeconomic and geographical dimensions.

The research on climate change impacts, vulnerabilities, and adaptation aspects is still limited in developing countries, compared to the abundant research in developed countries. However, such assessments are crucial for the countries such as Pakistan where livelihoods and economic development rely heavily on the climate-sensitive agricultural sector. Researching the social dimensions of climate change in local contexts is useful to understand the current level of vulnerabilities and adaptive capacities in agricultural communities and to find possible adaptation options.

Farmers have reported different types of climatic risks such as extreme temperature events, animal diseases, crop pests and soil problems to their farming and livelihoods. Farmers take into consideration uncertainty and changes in crop and livestock yields, changes in current cropping calendars and water shortage due to the observed climate change and related risks. This study also shows variations in results across different regions depending on their sensitivity to climate change. For instance, uncertainty in crop and livestock yields and changes in cropping calendars are reported more in the rain-fed region (Gujrat) where farming is more sensitive to climate change. Challenges of decreasing water availability,

poverty and the weakness of local institutions in the process of adaptation make farm households more susceptible to climate-related risks. The quality of irrigation water is found declining in most of the regions while poverty is found higher in the rain-fed region. Farmers adopted various measures to adapt their farming to climate change such as changing cropping practices, changing farm management options and advanced land use management measures. However, adaptation can be limited due to lack of resources, financial restrictions or insufficient access to institutional services. The study found an active role of cooperation in farmer interactions and the negative role of conflict (mainly water and land) in the adaptation decision making (Chapter 2).

Further, in Chapter 3 the study identified a substantial reduction in farm level responses moving from perception to planning and adaptation given the existence of various types of information, resources, and financial constraints. Moreover, using logistic regression analysis, the role of different household-specific internal factors and access to institutional services in the choice of adaptation measures to climate change is explored. The study also found that traditional adaptation strategies at farm level do not include advanced management technologies but are limited to simple measures, particularly changing crops or crop varieties. Very few farmers have adopted advanced adaptation measures. Lack of knowledge and support from local institutions are the primary reasons behind this low adoption rate. Further, adaptation also varied across regions and different farming groups based on education and farming experience. For instance, educated and experienced farmers have taken more adaptation measures compared to farmers with less education and experience.

The next part of the thesis (Chapter 4) explored the adaptation of wheat farmers to climate change, its determinants and impact on food productivity and crop income in rural Pakistan. The findings of the study suggest that wheat farmers are well aware of climate change but for various reasons did not adapt accordingly. Changing planting dates, crop varieties and input mixes especially fertilizer types are the key measures adopted by wheat farmers. Moreover, education, farming experience, access to agricultural extension, weather forecasting and marketing information are the factors that significantly affected farmers' adaptation decisions. Adapting wheat crops to climate change significantly and positively affects wheat productivity and crop income and hence indirectly improves the farmers' wellbeing and local

food security. However, more benefits are achieved by farmers who used a combination of different adaptation strategies.

Chapter 5 details the development and application of a multi-farm model for the studied regions in Pakistan. The model is used to assess farm welfare and land use decision making under different adaptation, policy and cooperation scenarios. Compare to cooperation scenario, welfare decreases by 35% under conflict scenario when where there is no adaptation and farmers and low access to institutional services. While high adaptation coupled with better access to policy and interactions with farmers leads toward higher welfare (10-20%) and farm wellbeing in the study area. Further, farmers allocate more area to fodder crops in case of conflict and no adaptation scenarios (worst case) and grow cash crops when there is a positive interaction within farmer groups and higher adaptation and access to policy services.

In Chapter 6, the study examine farmers' perceptions of changes in climate and how these perceptions agree with observed climatic trends. Perceptions of temperature change match fairly well with the locally recorded climate data; however, a bias is found in some cases between farmer perceptions of rainfall changes and local climate records. Further, a multivariate probit model is used to analyze the three adaptation stages (perceptions, intentions, and adaptation) and various internal and external factors affecting these stages. The study found a strong association between accurate perceptions, adaptation intentions and actual adaptation, which implies a positive role of accurate understanding in the adaptation process. Moreover, owner-cultivators and farmers with large landholdings are found to be more accurately perceiving and adapting to climate change compared to tenants and farmers with small landholdings.

Further findings of the study Chapter 7 focus on social networks in the agricultural sector to assess the institutional support surrounding farmers for climate change adaptation and existing structural gaps in the current institutional setup. The findings of the social network analysis show that most of the support and on-farm services come to farmers either from the community or from private sources. The current role of public institutions is found to be limited in providing on-farm services to farmers. The weather forecasting service from private sources is the only well-connected actor in the climate adaptation network while marketing information from the community and private sources and farm equipment from

community sources are the key players in the financial support network. However, extension services in the climate adaptation network and agricultural credit and marketing of produce in the financial support network are weakly connected actors. The rain-fed region receive the lowest support from all stakeholders due to their subsistence agriculture and limited infrastructure.

Chapter 8 examines the exposure of households to climate change, their perception of labor migration as a livelihood diversification strategy, and its determinants. Further, this chapter investigates land borrowing trends in the context of climatic and environmental stressors. Farmers perceive changes in rainfall, temperature and drought as major climatic risks to their crops and livelihood. Many farm household heads saw labor migration as a desirable option. Younger and educated farmers are more inclined towards migration, as compared to older and less educated ones. For downstream located farmers, migration is more desirable in the context of low productivities and lack of water resources. Further, access to different institutional services reduces households' migration intentions that might be due to sufficient access to other livelihood options and adaptation measures, given the support from different institutions. An increasing land borrowing trend is observed in the study area during 2009-13. The increasing trend is mainly due to low returns from agriculture, lack of resources to do farming, and socioeconomic reasons such as education, better livelihood, and living opportunities.

Finally, the last chapter provides the synthesis of all study findings and provides policy recommendations. Further, this chapter sheds light on the outlook and ideas for future research.

9.2 Conclusions

Several conclusions can be drawn from the findings of this thesis and the summary given above. First, farm households are exposed to various climatic risks, and their sensitivity and adaptive capacity highly depend on the access to resources, institutional settings, and geographical locations. Second, the understanding of climate change is widespread across the study regions, and in most of the cases, farmers' perceptions are matched well with locally recorded climate data except for some biases in the perception of rainfall changes. Third, adaptation to climate change in the study regions is limited, and farmers consider only low-

cost and short-term measures such as changing cropping types, varieties and planting dates. Adaptation faces various informational and resource constraints and advanced adaptation measures are only implemented by large or educated farmers. Fourth, climate change perception and adaptation are highly influenced by socioeconomic factors (education, farming experience, land holdings) and access to institutional services (extension, marketing information). More importantly, cooperation and interactions with farming communities do play a significant role in shaping adaptation decision-making at the farm level. Fifth, adaptation to climate change substantially improves local food security through increased food productivity and increased farm income. However, these benefits can be extended by enhancing local adaptive capacities. Sixth, the role of the social network is imperative in adapting local agricultural systems to climate change. The current institutions are not sufficiently supporting farmers in adapting to climate change and observe many structural gaps in the current institutional setting that need to be eliminated. However, the services of community and informal farming groups for the local adaptation at farm level are promising and need to be encouraged through more support from public and private sector institutions. An increasing trend in migration intentions among existing farmers and land borrowing in rural areas due to indirect effects of climate change on rural livelihoods draw attention to develop effective adaptation plans and policies at different scales.

Seventh, policy recommendations span different scales including the international, national and regional level. At the international level, efforts are desirable to reduce emissions of greenhouse gasses to reduce adverse climate change effects. It is promising to extend the support to developing and poorer countries to mitigate and adapt to climate change vulnerabilities.

At national level, consensus is needed to develop mitigation and adaptation strategies for different sectors including agriculture to adapt to climate change. Notably, adaptation policies in the agricultural sector need to be designed based on the sensitivity of local farming and livelihoods to climate change in different regions, differences in socio-economic, farming types and agro-ecological settings. For instance, adaptation strategies and plans developed for irrigated agriculture may not fit well to rain-fed agriculture. Further, understanding of changes in climate and adaptive capacity at farm level need to be enhanced through improved resource access and institutional support. Here, existing extension and

credit services need to be revised to include climate change and adaptation as their integral part. In this regards, partnerships and collaborations between public and private institutions and communities may be useful to enhance local level adaptation and resilience to climate change. Failure to implement appropriate adaptation plans in agriculture may increase the farm households' vulnerability to climate change and may affect the agricultural growth and food security at local and national level.

Based on the findings of this thesis I suggest the following key areas for further research: 1) how to enhance local adaptive capacities and farmers' access to advanced adaptation measures given the socioeconomic and institutional constraints, 2) how could local institutions be transformed to provided better services to farmers aiming enhancing farm level adaptation to climate change, 3) how may the existing policies be modified based on on-ground research to meet current needs and challenges, 4) how can the social capital be utilized to improve farmers access to on-farm services and to enhance agricultural product ivies given the changing environmental conditions, 5) what cost-efficient adaptation options could be developed keeping in view the small scale and resource constraint farming communities.

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Appendices

Appendix A: Field research questionnaire used for data collection in Pakistan

Climate change and agriculture; A farmers' prospective

موسمیاتی تبدیلی اور زراعت؛ کسانوں کی نظر میں

Farm household Level Survey Punjab Pakistan
Baseline Survey, March- April 2014 v final

سوال نامہ کسان سطح؛ پنجاب پاکستان

بنیادی سروے مارچ- اپریل 2014

To be asked from farmers in the selected district in Punjab Pakistan

1. BASIC INFORMATION									
S.N	Question	سوال	Response and Code				جواب اور کوڈ	Go to	
1.1.	District	ضلع	① R.Y. Khan	② T.T. Singh	③ Gujrat				
1.2.	City (Tehsil)	تحصیل	_____						
1.3.	Branch Canal	برانچ کینال	_____						
1.4.	Distributary	راجبہ	_____						
1.5.	Watercourse No.	کھال کا نمبر	_____						
1.6.	Village ID	گاؤں کا نام	_____						
1.7.	Respondent ID	جواب دہندہ کا شناخت نمبر	_____						
1.8.	Respondent Name	جواب دہندہ کا نام	_____						
1.9.	Respondent Mobile #	جواب دہندہ کا موبائل نمبر	_____						
1.10.	Date of Survey	سروے کی تاریخ	_____						
1.11.	Enumerator Name	نام سروے کنندہ	_____						
2. FARMER'S HOUSEHOLD INFORMATION									
کسان کی گھریلو معلومات									
2.1.	How long have you resided in this village?	آپ کتنے عرصے سے اس گاؤں میں رہائش پذیر ہیں؟	_____ Years						
2.2.	What is your age?	آپ کی عمر کیا ہے؟	_____ Years						
2.3.	What is your education?	آپ کی تعلیم کیا ہے؟	_____ Years						
2.4.	What is your primary occupation? ① Farming ② Public employment ③ Private employment ④ Own off business ⑤ other (specify_____)	آپ کا بنیادی پیشہ کیا ہے؟	① ② ③ ④ ⑤						
2.5.	What type of family system do your household have? ① Joint ② Nuclear ③ other (specify_____)	آپ کے گھر کا خاندانی نظام کس قسم کا ہے؟	① ② ③						
2.6.	How long is your experience in Agriculture?	زراعت میں آپ کا کتنا تجربہ ہے؟	_____ Years						
Household size and on farm and off farm employment									
2.7.	Age group	Number of members	Number in school	Full time on farm	Part time on farm	Full time off farm	Part time off farm	Status of off farm	Type of migration
	<15 years								
	15 to 65 years								
	> 65 years								
Note: ¹ include respondent as well with his spouse, children & other relatives sharing the same kitchen									
2.8.	How would you split your annual income sources for 2013(for the entire household): Splitting of income sources آپ 2011 میں ہونے والی سالانہ آمدن کو مندرجہ آمدنی کے ذرائع (بشمول تمام گھرانے کے) میں کیسے تقسیم کریں گے؟	a. From farm or on-farm work _____% b. From livestock and poultry _____% c. From financial remittances _____% d. From non-farm work _____%				Total 100%			

2.9.	In your opinion, what is the minimum cash amount that a family of your size would normally need on a monthly basis for food, clothes and other basic needs? آپ کی رائے میں، وہ کیا کم از کم نقد رقم ہے جو کہ آپ کے جیسے خاندان کی ماہانہ دیکھ بھال (بشمول خوراک، کپڑے اور دیگر بنیادی ضروریات) کے لیے ماہانہ کافی ہو؟	_____ (PKR) روپے
2.10.	Assuming all the basic needs of your family as 100%, to what extent do you think they are satisfied today? فرض کریں اگر آپ کی ضروریات ۱۰۰ فیصد ہوں تو موجودہ طور پر آپ کی رائے میں کتنے فیصد یہ پوری ہو رہی ہیں؟	_____ %

A. AGRICULTURAL INFORMATION

3. LAND HOLDING AND RELATED CHARACTERISTICS

S.N.	Question	Codes and Responses	Go to
3.1.	What kind of ownership does your household have on the majority of your land? 1. Owned 2. Share cropping 3. Tenant 4. Leased land 5. other (specify)	① ② ③ ④ ⑤	
3.2.	What is your total Landholding Size within this <u>canal circle</u> ? کل رقبہ کتنا ہے؟	_____ acre(s)	
3.3.	What is your operational Landholding Size within this <u>canal circle</u> ? قابل کاشت رقبہ کتنا ہے؟	_____ acre(s)	
3.4.	What is the location of your farm at the <u>watercourse</u> ? [① Head, ② Middle, ③ Tail]	① ② ③	
3.5.	What is the location of your watercourse at the canal? [① Head, ② Middle, ③ Tail]	① ② ③	
3.6.	What is your operational Landholding in any other canal circle?	_____ acre(s)	
3.7.	What type of soil your lands have? 1=Sand, 2=Loam, 3=Light Loam, 4=Heavy Clay, 5=Gravel, 6=Laterite, 7=Other (____)	① ② ③ ④ ⑤ ⑥ ⑦	
3.8.	How do you assess the soil fertility of your cropland? زمین کی زرخیزی؟ 1= Very High, b 2= High, 3=Average, 4= Low, 5= Very low	① ② ③ ④ ⑤	
3.9.	How do you assess the soil salinity at your farm? [① Nil ② average ③ High]	① ② ③	
3.10.	How much is the average land rent per acre in your village at present?	_____ PKR per year	
3.11.	How much was the land rent in year 2009 in your village?	_____ PKR per year	
3.12.	In your opinion, what is the status of land renting out in your area since 2009? ① No change ② Increased ③ Decreased Don't Know	① ② ③	
3.13.	Do you know, How many farmers on average each year left the agriculture and migrated to city from your village	_____ (Numbers) Don't Know	
3.14.	Do you know, In total how many farmer left agriculture or rented out land in last 5 years since 2009	_____ (Numbers)	
3.15.	In your opinion, What are the important factors that lead to land renting out trend in your area?	1. _____ 2. _____ 3. _____ 4. _____	
3.16.	What are the main factors, do you consider while deciding for..? 1. Soil fertility 2. Past and current climate 3. Resource availability	Farming strategy	
3.17.	(water, other inputs), 4. Traditional customs 5. Associated risk with crop 6. Expected gross margin 7. Follow trend in village 8. Formal	Crop mix	

3.18.	advice/ intention 9. Informal advice 10. Own perception and expectations 11. Crop need, 12. Other (specify)	Specific Input use				
3.19.	What is your main objective as farmer? 1. To maximize profit 2. To sustain family livelihood 3. Both1 and 2, 4. other(specify)		① ② ③ ④			
3.20.	Do you consider impacts of your management decisions on land/soil fertility?		①Yes, ②No			
3.21.	Do you and your neighboring farmers cooperate with each other?		①Yes, ②No			
3.22.	If yes, then what type of cooperation does exist between you and your neighboring farmers?		① ② ③ ④ ⑤ ⑥			
	1. Exchange of labour, 2. Exchange of inputs 3. Exchange of water 4. exchange of output 5. Exchange of information 6. other(specify)					
3.23.	If no, then what kind of conflict does exist between you and your neighboring farmers?		① ② ③ ④ ⑤ ⑥			
	1. water conflicts 2. land conflicts 3. output conflicts 4. 5. 6.					
3.24.	Do you have livestock animals?		①Yes, ②No			
3.25.	If yes, what are the numbers of livestock do you have in 2012-13?		Buffalo	Cow	Bull	Goat and sheep
		No. of animals				
3.26.		Value of by products				
		Associated costs				
3.27.	Reasons of variation in cropland area in last 5 years since 2009					
	Year(s)	2009	2010	2011	2012	2013
	Total area under cultivation					
	Reason for cropland expansion ^{\$}					
	Reason for cropland reduction*					
	Reason for no change in cropland [€]					
	*Codes for cropland expansion			*Codes for cropland reduction		
	1. decrease in land rent زمین کرائے میں کمی			1. less net returns last year Due to گزشتہ سال --- کی وجہ سے کم منافع		
	2. more net returns/ profit last year			1a. decrease in prices of final produce زرعی اجناس کی قیمتوں میں کمی		
	2a. increase in prices of final produce			1b. decreased crop yield due to pest attack کیڑوں کے حملے سے فصل کی پیداوار میں کمی		
	2b. increase in crop yield			1c. decreased yield due to more or uncertain rains غیر یقین بارشوں کی وجہ پیداوار میں کمی		
	2c. availability of access canal water			1d. less availability of canal water نہری پانی کی کمی		
	2d. more rains at required time last yea			1e. crop loss due to high temperature		
	3. higher expectations from future			1f: less crop yield due to land degradation and water logging		
	4. to grow cash crops (specify reason)			2. Increase in land rent		3. decreased household labour (off farm job)
5. co-farmer suggest to expand crop land			4. lower expectations from future		5. growth of urban area	
6. Governemt subsidy on inputs or sale price			6. neighbor farmer/ other relative suggested to rent out crop land			
7. other (specify__)			7. Diminishing ground water due to less rains			
			8. increasing soil salinity		9. other (specify_____)	
Codes for No change in cropland[€] 1. traditional pattern of farming; 2. No change in returns 3. Donot have sufficient investment 4. Donot want to expand due to own preferences 5. Donnot want to rent in land 6. other(sepecify)						

Crop rotation and Land use pattern in Rabi and Kharif season since last 5 years

گزشتہ 5 سال سے ربیع اور خریف کے موسم میں زرعی گردش اور زمین کا استعمال

Parcel No.	Season موسم	2009		2010		Reason for change in crop rotation زرعی گردش میں تبدیلی کی وجہ	Reason for change in crop mix فصل مرکب میں تبدیلی کی وجہ	2011		Reason for change in crop rotation زرعی گردش میں تبدیلی کی وجہ	Reason for change in crop mix فصل مرکب میں تبدیلی کی وجہ	2012		Reason for change in crop rotation زرعی گردش میں تبدیلی کی وجہ	Reason for change in crop mix فصل مرکب میں تبدیلی کی وجہ	2013		Reason for change in crop rotation زرعی گردش میں تبدیلی کی وجہ	Reason for change in crop mix فصل مرکب میں تبدیلی کی وجہ
		Crop فصل	Area رقبہ	Crop فصل	Area رقبہ			Crop فصل	Area رقبہ			Crop فصل	Area رقبہ			Crop فصل	Area رقبہ		
1	Rabi																		
	Kharif																		
2	Rabi																		
	Kharif																		
3	Rabi																		
	Kharif																		
4	Rabi																		
	Kharif																		
5	Rabi																		
	Kharif																		
Reason for change in crop mix 1. Yield of previous crop was reduced due to climatic induced factors i.e. flood/ uncertain rainfalls/ increased temperature/ drought/ less rainfall/ growing season length 2. left crop was subject to severe pest attach (reason_____) 3. Un-sufficient water for left crop; 4. Own intention to grow new crop 5. expected more returns from new crop 6. neighbor Have the same/ suggested 7. Less financial resources to meet the needs of previous crop 8. don't find good seed for left crop 9. government provide subsidy on seeds of new crop 10. government announce sale price of new crop at sowing time											Ask if he change the rotation of crop in Rabi or Kharif season Reason for change crop order or pattern Reasons for change in crop rotation 1. it was necessary for better crop production 2. Ag. Ext. recommended this crop rotation 3. Follow the neighbor farmer doing the same 4. traditional setup/ ancestors do the same 5. used own experience and knowledge that it is better to rotate crop 6. it was by chance, there was no motive to change 7. other (specify____)								

Input use in crop production RABI and Kharif seasons 2012-13

		Units یونٹس	Rabi ربیع کے موسم کی فصلیں				Kharif خریف کے موسم کی فصلیں				
			Crop 1	Crop 2	Crop 3	Crop4	Crop 1	Crop 2	Crop 3	Crop4	
		Crop code *									
Crop growth	Seed quantity بیج کی مقدار	Kg/acre									
	Seed Cost بیج کی لاگت	PKR/ kg or bag									
	Variety	1. Local, 2. Hybrid, 3. Registered, 4. non-reg									
	source	1. Home, 2. Local market, 3. Private 4. Govt									
	Sowing date بوائی کی تاریخ										
Fertilization	1 st fertilization* پہلی	Use below code									
	Date تاریخ	date									
	Quantity مقدار	kg/ acre									
	Cost/ of 1 st fertilization لاگت	PKR/bag or kg									
	2 nd fertilization* دوسری	Use below code									
	Date تاریخ	date									
	Quantity مقدار	kg/ acre									
	Cost/ unit لاگت	PKR/bag or kg									
	3 rd fertilization* تیسری	Use below code									
	Date تاریخ	date									
	Quantity مقدار	kg/ acre									
	Cost/ unit لاگت	PKR/bag or kg									
Irrigation	Irrigation source [£] ابپاشی کا ذریعہ	Use below code									
	Irrigation method [¥] ابپاشی کا طریقہ	Use below code									
Canal irrigation	Allocated time فی ایکڑ مختص وقت	Minutes/acre									
	No. of canal irrigations per season	Numbers/ acre									
	Average length of one irrigation	Minutes/acre									
	Canal water charges per season	PKR/ acre									
	Depth of canal water applied	Inches/ acre									
TW	Total number of TW irrigations	Number/ acre									
	Average length of each irrigation	Minutes/ acre									
Crop code* : 1=Wheat, 2= Sugarcane, 3=Cotton, 4=Rice, 5=Other grain crop (Specify name) 6=Berseem, 7=Lucern, 8=Millet, 9=Sorghum, 10=Other fodder (Specify name),11=Fruit (Name), 12=vegetable (Name), 13=other crop (specify name)			Irrigation source (code)[£] : Canal, Tube well, Mixed, rainfed\ Irrigation method (code)[¥] : 1= Basin, 2= Flood, 3=Furrow, 4=Other(specify)				Fertilizer code : 1= Urea, 2=DAP, 3=SSP, 4=NP compounds, 5=NPK, 6=Other(specify_____)				

Input use in crop production RABI and Kharif seasons 2012-13

	Units یونٹس	Rabi <u>ربیع کے موسم کی فصلیں</u>				Kharif <u>خریف کے موسم کی فصلیں</u>			
		Crop 1	Crop 2	Crop 3	Crop4	Crop 1	Crop 2	Crop 3	Crop4
TW	Purchased TW hours	Hours/ acre							
	Cost of purchased TW hrs/season	PKR/acre							
	Depth applied	Inches/ acre							
Mixed	No of mixed irrigation applied	Numbers/acre							
	Average length of each irrigation	Minutes/acre							
	Share of canal water in mix irrigation	Percentage (%)							
Rainfall	Frequency of rainfall	No./ season							
	Was rainfall	Yes/ No							
	If not, how much loss to crop	kg/ acre							
Different farming operation and associated labour and mechanical cost	Family labour for Sowing <small>بوانی</small>	Hours/acre							
	Hired labour for sowing <small>کرایہ کی مزدوری</small>	Hours/acre							
	Ploughing	Numbers/acre							
	Mechanical cost Ploughing	PKR/plough							
	Family labour Ploughing <small>گھریلو مزدوری</small>	Hours/ plough							
	Hired labour Ploughing <small>کرایہ کی مزدوری</small>	Hours/ plough							
	Rotavator	Numbers/acre							
	Rotavator cost	PKR / operation							
	Hoeing	Numbers/acre							
	Family labour Hoeing <small>گھریلو مزدوری</small>	Hours/ hoeing							
	Hired labour Hoeing <small>کرایہ کی مزدوری</small>	Hours/ hoeing							
	Weeding <small>نلانی</small>	Numbers/acre							
	Family labour Weeding <small>گھریلو مزدوری</small>	Hours/ weeding							
	Hired labour weeding <small>کرایہ کی مزدوری</small>	Hours/ plough							
	Family labour used in Fertilization	Hours/ fert.							

Laobur and machinery use in crop production RABI and Kharif seasons 2012- 13

	Units یونٹس	Rabi <u>ربیع کے موسم کی فصلیں</u>				Kharif <u>خریف کے موسم کی فصلیں</u>				
		Crop 1	Crop 2	Crop 3	Crop 4	Crop 1	Crop 2	Crop 3	Crop 4	
	Hired labor Fertilizatio کرایہ کی مزدوری	Hours/ fert.								
	Irrigation family labor گھریلو مزدوری	Hours/ irri.								
	Irrigation hired labor کرایہ کی مزدوری	Hours/ irri.								
	Harvesting Family labor گھریلو مزدوری	Hours/ acre								
Pesticide	Harvesting Hired labor کرایہ کی مزدوری	Hours/acre								
	1 st pesticide پہلی کیڑے مار سپرے	Name								
	Pesticide quantity applied مقدار	Liter/ appl.								
	Cost of 1 st pesticide لاگت	PKR/ acre								
	2 nd pesticide دوسری کیڑے مار سپرے	Name								
	Pesticide quantity applied مقدار	Liter/ appl.								
	Cost of 2 rd pesticide لاگت	PKR/ acre								
	3 rd pesticide تیسری کیڑے مار سپرے	Name								
	Pesticide quantity applied مقدار	Liter/ appl.								
	Cost of 3 rd pesticide لاگت	PKR/ acre								
	4 th pesticide چوتھی کیڑے مار سپرے	Name								
	Pesticide quantity applied مقدار	Liter/ appl.								
	Cost of 4 th pesticide لاگت	PKR/ acre								
	Other Pesticide qty. applied مقدار	Liter/ appl.								
	Output and marketing	Cost of all other pesticides لاگت	PKR/ acre							
		Yield per acre فی ایکڑ پیداوار	Kg/ acre							
Household consumption گھریلو کھیت		Kg								
Sale price قیمت فروخت		PKR/unit(sp ecify)								
	Subsidy from Govt. امداد	PKR/unit(sp ecify)								

B. INSTITUTIONAL DATA

4. PARTICIPATION, REPRESENTATION AND DECISION-MAKING

S.N.	Question	Codes and Responses	Go to
4.1.	What is the distance of your farm from the nearest input market? کہیت کا قریبی منڈی سے فاصلہ ؟	_____ km	
4.2.	What is the distance of your farm from the nearest output market? کہیت کا قریبی منڈی سے فاصلہ ؟	_____ km	
4.3.	What is the distance of your farm from the nearest paved road? کہیت کا قریبی سڑک سے فاصلہ ؟	_____ km	
4.4.	Is there any organization working for the betterment of farmers? کسانوں کی بہتری کے لئے کوئی تنظیم؟	①Yes, ②No	4.6
4.5.	If yes, then is this organization functional? کیا یہ تنظیم فعال ہے؟	①Yes ②No	4.7
4.6.	What type of organization it is? 1. FOs 2. NGO 3. Private cooperatives 4. Others تنظیم کی قسم ؟	①②③④	
4.7.	What kind of benefits are you getting from this organization? آپ کو اس تنظیم سے کس قسم کے فوائد ہو رہے ہیں؟	1. _____ 2. _____ 3. _____	

Access and use of different of different Institutional services in RABI and Kharif season 2012-13					
Institutional services خدمات	Do you have access to these institutional services آپ کی ان اداراتی خدمات تک رسائی ہے	Did you use the asked services کیا آپ نے ان خدمات کا استعمال کیا	What was the source of particular service رشتہ دار یا دوست Own خود Relative/friend/ fellow دوست Government agency حکومتی ادارہ Private/ NGOs حکومتی ادارہ Media(TV/Newspaper/ internet) Other دیگر	How would you rate the quality of the support services for آپ ان سپورٹ خدمات کے معیار کی کیا درجہ بندی کریں گے؟ High زیادہ Reasonable مناسب Poor غیر معیاری	For which season do you get the services موسم کے لئے کس ① Rabi ② Kharif ③ Both
Agricultural credit زرعی قرضہ	①②	①②	①②③④⑤	①②③	①②③
Machinery/Tractors مشینری مثلاً ٹریکٹر	①②	①②	①②③④⑤	①②③	①②③
Supply & repair of irrigation & farm tools آبیاشی اور کہیت کے سامان کی فراہمی و مرمت	①②	①②	①②③④⑤	①②③	①②③
Marketing of produce پیداوار کی مارکیٹنگ	①②	①②	①②③④⑤	①②③	①②③
Post-harvest processing کٹائی کے بعد پراسسنگ	①②	①②	①②③④⑤	①②③	①②③
Extension on crop and livestock زرعی مشورہ	①②	①②	①②③④⑤	①②③	①②③
Weather forecast موسم کی پیش گوئی	①②	①②	①②③④⑤	①②③	①②③
Seasonal forecast موسم کی پیش گوئی	①②	①②	①②③④⑤	①②③	①②③
Market information منڈی کی معلومات	①②	①②	①②③④⑤	①②③	①②③
Information about water deliveries معلومات پانی کی ترسیل پر	①②	①②	①②③④⑤	①②③	①②③
Crop insurance فصل بیمہ	①②	①②	①②③④⑤	①②③	①②③

C. CLIMATE CHANGE

ماحولیاتی تبدیلی

5. CLIMATE CHANGE'S PERCEPTIONS, ADAPTATION AND CONSTRAINTS

S.N.	Question	Codes and Responses	Go to																																										
5.1.	Are you concerned about climate change? آپ کو موسمیاتی تبدیلی کے بارے میں فکر مند ہیں؟	①Yes, ②No																																											
5.2.	During the last 10 years, have you observed any changes in your environment which have not occurred before? گزشتہ 10 سال کے دوران آپ نے ماحول میں کسی قسم کی تبدیلی کا مشاہدہ کیا ہے، جو اس سے پہلے نہیں ہوئی تھی؟	①Yes, ②No	If NO → 5.5.																																										
5.3.	If yes, what kind of events have you observed which had not occurred in your area before and what was their frequency? ماحول میں کسی قسم کی تبدیلی کا مشاہدہ جو اس سے پہلے نہیں ہوئی تھی؟	<table border="1"> <thead> <tr> <th>Events</th> <th>Occurrences</th> <th>Frequency</th> <th>Events</th> <th>Occurrences</th> <th>Frequency</th> </tr> <tr> <td></td> <td>①Yes, ②No</td> <td>تعداد</td> <td></td> <td>①Yes, ②No</td> <td>تعداد</td> </tr> </thead> <tbody> <tr> <td>1. Drought</td> <td>خشک سالی</td> <td></td> <td>6. Human diseases</td> <td>انسانی بیماریاں</td> <td></td> </tr> <tr> <td>2. High temperature</td> <td></td> <td></td> <td>7. Animal diseases</td> <td>حیوانی بیماریاں</td> <td></td> </tr> <tr> <td>3. Low temperature</td> <td></td> <td></td> <td>8. Insect attack</td> <td>کیڑوں کے حملے</td> <td></td> </tr> <tr> <td>4. Flood</td> <td>سیلاب</td> <td></td> <td>9. Soil problems</td> <td>مٹی کے مسائل</td> <td></td> </tr> <tr> <td>5. Severe crop pest</td> <td></td> <td></td> <td>10. new weeds</td> <td>نئی جڑی بوٹی</td> <td></td> </tr> </tbody> </table>	Events	Occurrences	Frequency	Events	Occurrences	Frequency		①Yes, ②No	تعداد		①Yes, ②No	تعداد	1. Drought	خشک سالی		6. Human diseases	انسانی بیماریاں		2. High temperature			7. Animal diseases	حیوانی بیماریاں		3. Low temperature			8. Insect attack	کیڑوں کے حملے		4. Flood	سیلاب		9. Soil problems	مٹی کے مسائل		5. Severe crop pest			10. new weeds	نئی جڑی بوٹی		
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4. Flood	سیلاب		9. Soil problems	مٹی کے مسائل																																									
5. Severe crop pest			10. new weeds	نئی جڑی بوٹی																																									
5.4.	Have you noticed any change in the rainfall patterns in summer season over the past 10-20 years? آپ گزشتہ 10 سال کے دوران موسم گرما میں بارش کے پیٹرن میں کوئی تبدیلی محسوس کیا ہے؟	① No change, کوئی تبدیلی نہیں ②It has significantly decreased نمایاں کمی واقع ہوئی ہے ③ It has slightly decreased تھوڑی کمی آئی ہے ④ it has slightly increased تھوڑا سا اضافہ ہوا ہے ⑤ it has significantly increased نمایاں طور پر اضافہ ہوا ہے ⑥Number of rainy days has increased برسات کے دنوں کی تعداد میں اضافہ ہے ⑦Number of rainy days has decreased برسات کے دنوں کی تعداد میں کمی																																											
5.5.	Have you noticed any change in the rainfall patterns in winter season over the past 10-20 years? آپ گزشتہ 10 سال کے دوران سردیوں کے موسم میں بارش کے پیٹرن میں کوئی تبدیلی محسوس کیا ہے؟	① No change, کوئی تبدیلی نہیں ②It has significantly decreased نمایاں کمی واقع ہوئی ہے ③ It has slightly decreased تھوڑی کمی آئی ہے ④ it has slightly increased تھوڑا سا اضافہ ہوا ہے ⑤ it has significantly increased نمایاں طور پر اضافہ ہوا ہے ⑥Number of rainy days has increased برسات کے دنوں کی تعداد میں اضافہ ہے ⑦Number of rainy days has decreased برسات کے دنوں کی تعداد میں کمی																																											
5.6.	Have you noticed any changes in the summer temperature over the past 10-20 years? آپ گزشتہ 10 سال کے دوران موسم گرما میں درجہ حرارت میں کسی قسم کی تبدیلی محسوس کیا ہے؟	① No change, کوئی تبدیلی نہیں ② It has slightly warmed تھوڑا سا گرم ③ It has significantly warmed نمایاں گرم ④ it has slightly cooled تھوڑا سا ٹھنڈا ⑤ it has significantly cooled نمایاں ٹھنڈا																																											

5.7.	Have you noticed any changes in the winter temperature over the past 10-20 years? آپ گزشتہ 10 سال کے دوران موسم سرما میں درجہ حرارت میں کسی قسم کی تبدیلی محسوس کی ہے؟	① No change, کوئی تبدیلی نہیں ② It has slightly warmed تھوڑا سا گرم ③ It has significantly warmed نمایاں گرم ④ it has slightly cooled تھوڑا سا ٹھنڈا ⑤ it has significantly cooled نمایاں ٹھنڈا
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5.9.	Have you observed any change in the growing season length for Rabi crops in your area over the past 10-20 years? آپ گزشتہ 10 سال کے دوران آپ کے علاقے میں ربیع کی فصلوں کے لئے بڑھتی ہوئی موسم کی لمبائی میں کسی بھی تبدیلی کا مشاہدہ کیا ہے؟	① No change کوئی تبدیلی نہیں ② Increased اضافہ ③ Decreased کمی
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5.9.	Have you observed any change in the growing season length for Kharif crops in your area over the past 10-20 years? آپ گزشتہ 10 سال کے دوران آپ کے علاقے میں خریف کی فصلوں کے لئے بڑھتی ہوئی موسم کی لمبائی میں کسی بھی تبدیلی کا مشاہدہ کیا ہے؟	① No change کوئی تبدیلی نہیں ② Increased اضافہ ③ Decreased کمی
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5.10.	Have you observed any change in vegetation cover over the last 10 years? آپ نے گزشتہ 10 سال کے دوران پودوں کا احاطہ میں کسی بھی تبدیلی کا مشاہدہ کیا ہے؟	① Yes جی ہاں ② No جی نہیں
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5.11.	Have you observed any increase in pest attack in Rabi season over the last 10 years? آپ نے گزشتہ 10 سال کے دوران ربیع کے موسم میں کیڑوں کے حملے میں کوئی اضافہ کا مشاہدہ کیا ہے؟	① No change, کوئی تبدیلی نہیں ② Increased pest attack کیڑوں کے حملے میں کمی ③ Decreased pest attack کیڑوں کے حملے میں اضافہ
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5.12.	Have you observed any increase in pest attack in Kharif season over the last 10 years? آپ نے گزشتہ 10 سال کے دوران خریف کے موسم میں کیڑوں کے حملے میں کوئی اضافہ کا مشاہدہ کیا ہے؟	① No change, کوئی تبدیلی نہیں ② Increased pest attack کیڑوں کے حملے میں کمی ③ Decreased pest attack کیڑوں کے حملے میں اضافہ
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5.13.	In your opinion, What are the impacts of this climate change on agricultural production/ farming in your area over the past 10-20 years on your farming? آپ کی رائے میں، گزشتہ 10 سال کے دوران موسمیاتی تبدیلیوں کے زرعی پیداوار پر کیا اثرات مرتب ہوئے ہیں	1. _____ 2. _____ 3. _____ 4. _____ 5. _____
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How would you rate the changes in your area since last decade?					
		Improved/ Increased	Not changed	Worse/ decreased	Don't know
5.14.	Quality of irrigation water? آب پاشی کے پانی کا معیار	€①	€③	€④	€⑤
	Land water-logging? زمین کا سیم زدہ ہونا	€①	€③	€④	€⑤
	Land/ Soil salinity? زمین / مٹی کا کھارا پن	€①	€③	€④	€⑤
	Land fertility? زمینی زرخیزی	€①	€③	€④	€⑤
	Soil erosion? زمینی کٹاؤ	€①	€③	€④	€⑤
	Ground water table? زمینی پانی کی سطح	€①	€③	€④	€⑤
	Quality of drinking water? پینے کے پانی کا معیار	€①	€③	€④	€⑤

What actions (and in what proportion) have you been taking in your agricultural activities to respond to the temperature/ rainfall variability observed? Please list below							
Actions	اقدامات	Desired/ Planned	Implemented	Constraints	بندشیں	Crop	Area
		مطلوبہ / منصوبہ بندی	نفاذ	1. lack of money, 2. lack of information, 3. shortage of labor, 4. less irrigation water 5. shortage of resources 6. No access to the service 7. Other _____]	پیسے کی کمی، معلومات کی کمی مزدوروں کی کمی آب پاشی کے لئے کم پانی وسائل کی کمی خدمت تک رسائی نہیں دیگر _____]	فصل	
1. changed crop variety	فصل کی قسم میں تبدیلی	① Yes ② No	① Yes ② No				
2. changed crop type	مختلف فصل کا انتخاب						
3. change planting dates	فصل کی بوائی کی تاریخوں میں تبدیلی						
4. planted shaded trees in field	فارم میں سایہ دار درختوں کا لگانا						
5. changed fertilizer	کھاد کی تبدیلی						
6. soil conservation	زمین کے تحفظ						
7. increased irrigation	آب پاشی میں اضافہ						
8. crop diversification (mix- multi cropping)	ایک موسم میں مختلف فصلوں کا انتخاب						
9. rented out cropland/ changed amount of land	کرایہ پر دے دی زمین						
10. migrate to urban area for off farm employment/ business	کاروبار کے لئے شہری علاقے کی طرف ہجرت						
11. Other (specify _____)	دیگر _____						
5.16.	What is your opinion on the best way to implement adaptation in your area? Please explain						

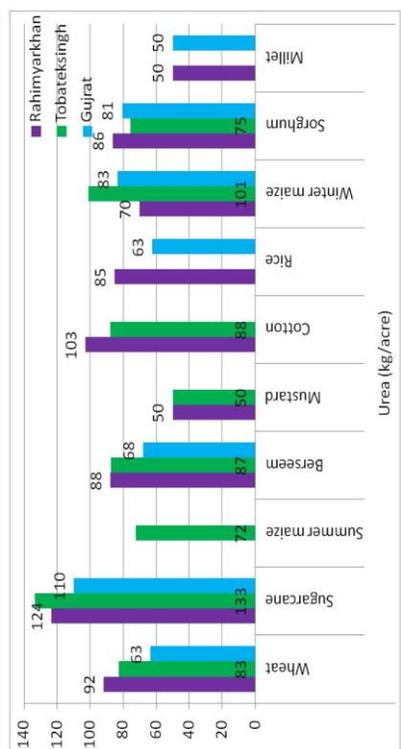
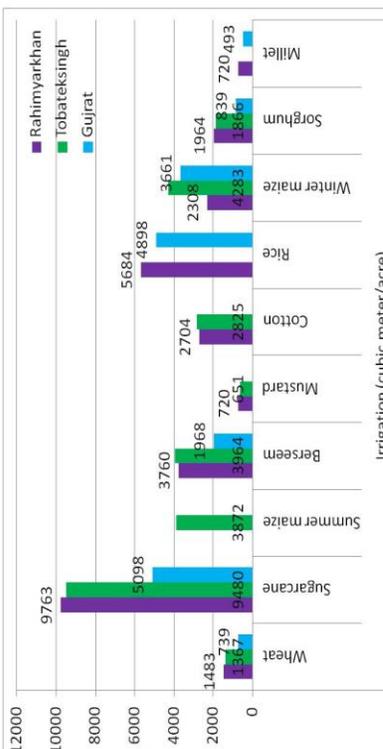
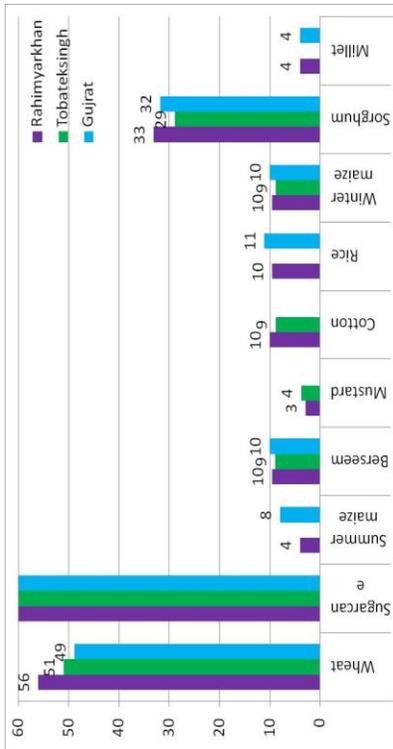
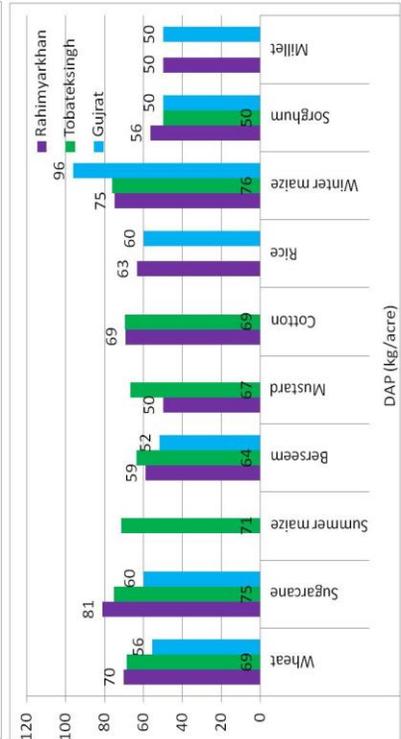
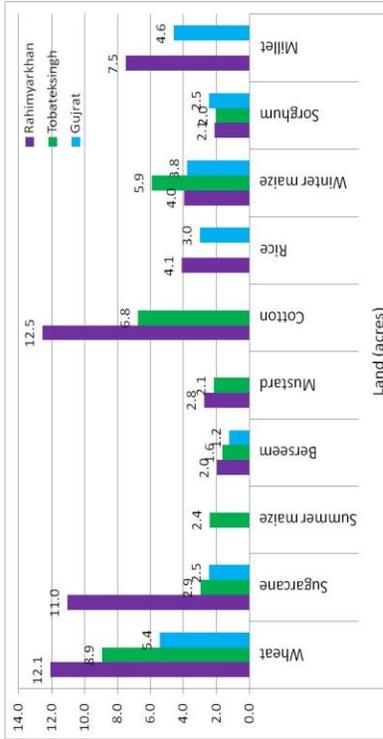
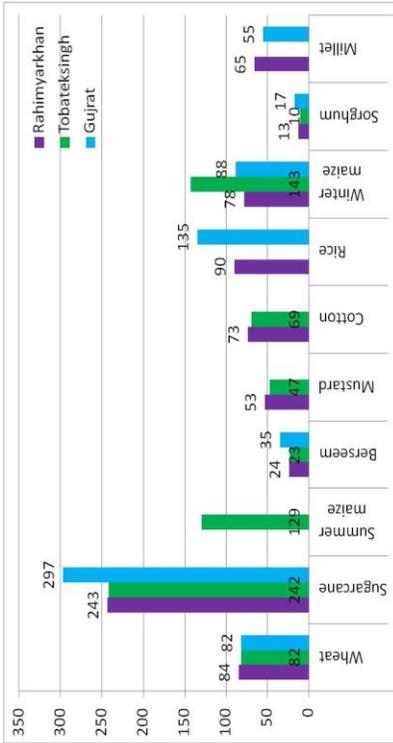
6. PRIORITIES FOR FUTURE

6.1	In your opinion, which of the following conditions are important for improving farmers wellbeing	
	1. government should provide subsidies to farmers to adapt against environmental hazards	①
	2. farmers collectively have to think about possible on farm solutions to improve their adaptation in changing climate	②
	3. there should be more extension and advisory services by government or private sector for betterment for farmers about innovative ideas and technology advancement	③

For Interviewer only:

Was the interviewee: 1. Cooperative, 2. Interested 3. Uninterested 4. Off-hand in responding	
Have the interviewer feel that he/she was getting thoughtful and realistic responses?	Yes ① No ②
Were there some of the issues raised that were not in the questionnaire? Detail:	

Appendix B: Input use in different cropping practices



Appendix C: List of variables, parameters and indices used in the model

Variables

W	Farmer net welfare [PKR]
A	Variable for crop area [acres]
S	Sale agricultural produce [kg]
L	Variable for livestock products
La	Livestock animals
P	Livestock feed processing variable
M	Variable for crop mix
C	Crop variable
LUC	Land Use Change

Parameters

$\Omega^{\text{feedprocess}}$	Feed processing data for livestock feed
δ^{price}	Sale price of products [PKR/unit]
$\lambda^{\text{cropdata}}$	Crop data (includes yield data, resource data and costs)
$\lambda^{\text{resrcost}}$	Resource cost [PKR/ acre]
γ^{reslim}	Resource limit
χ^{cropmix}	Crop mix data
η^{prodmin}	Production minimum data
$\phi^{\text{landusedata}}$	Land use data
η^{livedata}	Livestock data
ρ^{proddata}	Product data
ω^{resr}	Resource data
ω^{reslimit}	Resource limit

Indices

<i>af</i>	all farmers
<i>f</i>	farmer (indices for 450 farmers)
<i>r</i>	agro-ecological regions (Rahim Yar Khan, Toba Tek Singh and Gujrat)
<i>c</i>	crops (wheat, rice, maize, cotton, sugarcane, berseem, sorghum, millet, mustard)
<i>a</i>	livestock (buffalo, cow, bull, goat)
<i>i</i>	all items (include products, crops and resources)
<i>pr</i>	all products (wheat, rice, cotton, sugarcane, maize, wheatresidue, riceresidue, milk, milletgrain, value)
<i>lp</i>	livestock product (milk, value)
<i>cp</i>	crop product (wheat, cotton, rice, maize, sugarcane, wheatresidue, riceresidue, milletgrain)
<i>t</i>	time (2009-2030)
\tilde{t}	historical time (2009-2013)
<i>s</i>	all seasons (summer, autumn, perennial, allseasons)
<i>j</i>	all management (irrigatedcanal, rainfed, irrigatedgroundwater, irrigatedmixed, advanced, conventional, semicontrolshed, openshed)
<i>ij</i>	irrigation management (irrigatedcanal, rainfed, irrigatedgroundwater, irrigatedmixed)
<i>cj</i>	crop management (advanced, conventional)
<i>lj</i>	livestock management (semicontrolshed, openshed)
<i>ls</i>	land status (total, owned, rentin, rentout)
<i>pf</i>	process livestock feed (processfeed1*processfeed3)
<i>u</i>	resources (land, water, labor)
<i>z</i>	variable cost items (production cost, internalized external cost)

Appendix D: Acronyms representing nodes in networks

Factors in networks	Acronyms
1. Adaptation Network	CA_Access
Public extension services	ExtenPub
Private extension services	ExtenPrv
Community extension services	ExtenCom
Weather information public sources	WeathPub
Weather information private sources	WeathPrv
Weather information community sources	WeathCom
Water delivery information public sources	WatPub
Water delivery information private sources	WatPrv
Water delivery information community sources	WatCom
2. Financial support network	Fin_Support
Agricultural credit public sources	CreditPub
Agricultural credit private sources	CreditPrv
Agricultural credit community sources	CreditCom
Marketing information public sources	InfoPub
Marketing information private sources	InfoPrv
Marketing information community sources	InfoCom
Post-harvest processing public sources	PostharPub
Post-harvest processing private sources	PostharPrv
Post-harvest processing community sources	PostharCom
Marketing of agricultural products public sources	MarkPub
Marketing of agricultural products private sources	MarkPrv
Marketing of agricultural products community sources	MarkCom
Farm machinery and implements public sources	MachPub
Farm machinery and implements private sources	MachPrv
Farm machinery and implements community sources	MachCom

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